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Recent Variations in the Water Supply of the Western Great Basin

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RECENT VARIATIONS

IN THE

WATER SUPPLY

OF THE

WESTERN GREAT BASIN

By

S. T. Harding

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The material upon which the following report is based has been put into the collection of the Water Resources Center Archives, University of California, Berkeley. It is available at the Archives for the use of the interested public.

PREFACE

The following report represents the results of what has been a special interest or hobby of the writer for nearly 50 years. His first engineering work in the western Great Basin was in 1915 in the Honey Lake Valley in Lassen County, California. Work on the adjudication of the water rights on Truckee River began in 1917 and was followed by similar work on the Carson River beginning in 1928. Some work in the Mono Basin in 1922 added this area to the writer's interest.

The writer's earlier work on the water supply of this area was limited to direct activities in connection with specific engineering assignments. The deficiencies in water supply which occurred from about 1928 to 1935 stimulated interest in trying to determine the severity of drouths to which this area might be subject. The writer then began a more intensive study of the enclosed lakes in the western Great Basin seeking to determine and interpret their record over a longer period of time. Some preliminary results of this work were published in 1935.[1]

As other activities have permitted, the writer has continued his investigations on these lakes. This has been an individual effort on his part. No aid or support from any of the available research agencies was desired or sought. This was not the result of any objections to working with such agencies but their participation would have entitled them to set time limits on the completion of the results. The writer preferred to proceed at his own expense as his own time was available. This work has been a very rewarding activity to the writer which he has used to maintain his interest in this branch of engineering both during the years of his more active engineering work and since.

The retaining of this work as an individual activity rather than as a supported program does not mean that the results are limited to the writer's own observations. The publication of the 1935 articles served to identify the writer with the water supply of this area and resulted in his receiving from others many items of record and clues that might be followed. The results presented in this report would have been much less complete without such cooperation. Specific acknowledgements are made in the report. The writer is indebted to many others and gladly acknowledges their assistance.

The term "recent" in the title of this report is used to cover what may be considered to be the present historical period as distinguished from past geological time. "Historical" is, in turn, defined as matters recorded by explorers and emigrants in this area plus interpretations that can be made from the present conditions such as tree growth. It is recognized that climate has varied widely over geological time. It is equally well recognized

[1] S. T. Harding, "Changes in Lake Levels in Great Basin Area," Civil Engineering, February 1935, pp. 87--90; "Variations in Runoff of California Streams," Civil Engineering, September 1935, pp. 572--574; "Evaporation from Large Water Surfaces based on Records in California and Nevada," Transactions of the American Geophysical Union, 16th Annual Meeting, 1935, pp. 507--511.

that climate, particularly precipitation, varies irregularly from year to year. Such variations are larger in arid areas. Because the average water supply is limited in arid areas, the variations that may be expected are of particular importance in planning water projects in such areas.

This report discusses the results of an effort to extend the period of direct measurement of precipitation and stream flow over a longer period into the past. The fluctuations that have occurred over the past 300 years are a better guide to what may occur in the next 300 years than the direct record now available generally for about 100 years. While some comments are made on climate variations over longer time periods in the past, the main purpose of the work on which this report is based was the extension of present direct records to the preceding time for which present observations could be made and interpreted in terms comparable to the measured record.

A knowledge of the water supply in this area on which its development can depend is a basic need in the programming of its water projects. This report attempts to present what can be learned from the past. It also includes the writer's interpretation of this record. The factual material which is presented adds to that previously readily available although others may interpret the record differently from the conclusions of the writer.

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INTRODUCTION

The enclosed lakes of the Great Basin fluctuate with the variations in their inflow. Records of such fluctuations are available prior to the beginning of stream flow records and indirect methods can be used to define the range of fluctuations for longer periods than are covered by the direct records. An effort has been made to assemble all of the available information on each of the enclosed lakes in the western part of the Great Basin and to interpret it in terms of the water supply of their drainage areas. The results furnish a basis for estimating the variations in inflow which have occurred on some of these lakes during the past 300 years.

The results for each lake were assembled and an office report prepared in which the information which had been collected was analysed. These reports on individual lakes were lengthy for the lakes having more extensive records. It is planned that copies of these office reports on individual lakes will be filed where they may be used for reference by those who may be interested in the details which they include.

This present report brings together the essential results for the individual lakes and attempts to derive the recent water supply variations for the general area of the western Great Basin. Some less detailed results for adjacent areas are included. This aids in analysing the extent to which the western Great Basin may be a distinct climatic area.

The enclosed lakes used in the writer's work include Goose, Eagle, Pyramid, Winnemucca, Walker and Mono. Although it is not an enclosed lake, a similar study was made of Lake Tahoe. Other lakes of less usefulness include Honey, Horse, the Surprise Valley Lakes, Humboldt Sink or Lake, and several in eastern Nevada. Some of these lakes go dry at times and might be classified as playas.

Actual recorded observations began to be made on these lakes soon after definite surveys were started in this area. These were fragmentary until the value of such records came to be recognized. Records of the elevation of some of these lakes are now being secured as a part of the work of the Surface Water Branch of the U. S. Geological Survey and others.

A main purpose of the work on these lakes by the writer has been to secure and assemble information on their earlier fluctuations before it became lost. Observations were obtained on the stumps of formerly submerged trees before they had decayed and ring counts could no longer be made.

The gold rush immigrants included many individuals who kept diaries of their trip which have been preserved and published. Their accounts of streams may indicate their relative stage at the time it was forded but such a record does not disclose the character of the total runoff of the season. A description of a route followed around an enclosed lake may be interpretable in terms of the elevation of the lake. As the elevation at any time of these enclosed lakes is the composite effect of its inflow over the preceding years it represents an indication of the amount of runoff that had occurred recently. Much help was secured from such early accounts.

Beginning in the 1840's official governmental explorations and surveys began to be made. The best known of these earlier accounts were those by Fremont followed by the different explorations for railroad routes. The reports of this work include results which can be used to identify the elevations of some of these enclosed lakes at the time of these explorations. The elevations reported in the earlier surveys were mainly barometric and may not be directly convertible to the present datum.

By around 1880 development of irrigation from the tributaries of some of these lakes began to deplete their inflow. To compare the runoff of such drainage areas over a period before and after such depletion, it is necessary to make allowance for the amount of such reduction in inflow. In some cases, such as Mono Lake, this depletion has been the result of measured diversion to areas outside the drainage area so far as it can be taken into account on a definite basis. On other streams sufficient records may be available so that an estimate of the resulting consumptive use can be made.

The water supply of the area covered was generally greater during parts of the second half of the 19th century than it had been during the first half. This resulted in a rise of the enclosed lakes. Where climate and soil conditions had permitted the growth of trees adjacent to the lakes, the submergence and killing of these trees by the rise of the lake left a record of the height below which the lake had remained for a period at least as long as the age of the tree. The stumps of such submerged trees remained around some of these lakes at the time the writer began his work on their past fluctuations and ring counts and determinations of the elevation on which the trees grew were made. While the area around the majority of these lakes is too arid for tree growth, submerged trees have furnished much information on some lakes such as Eagle and Mono Lakes.

The reports on the individual lakes were completed during the years from 1960 to 1963. In each report the records available at the time of its completion were used. This resulted in variable closing dates for these records. Instead of revising these reports to a common closing date, the reports have been used as they were prepared. Where comparisons between the lakes are made, a common period has been used. The addition of the years since these reprts were prepared would not result in any essential changes in the long time means derived in this report. The records secured in the years since 1959 have generally been adequate to define the water supply for these more recent years. These later records will be preserved and their inclusion in this report is not essential.

Specifically this report brings together any documents information on the water supply of the western Great Basin with conclusions regarding the variations in this supply which have occurred during periods of varying length within the time of direct and indirect records. The previously available information is assembled with some additions based on the writer's observations. The writer's interpretation of these records is also included.

No startlingly new conclusions are reached in this report. The results are in general accord with the conditions which engineers working in this area have recognized. Added support may be supplied to the understanding of the variations to which the water supply of this area is subject and added emphasis given to the necessity of providing the water supply during the periods of deficiency which occur in this area in making the plans for its water supply projects if such projects are to meet their physical and financial obligations.

PLAN OF REPORT

This report could be made by a separate presentation of the results and conclusions relating to each lake followed by a discussion of the combined results and the general conclusions reached. Also, it could be prepared by a discussion of separate factors for all lakes followed by combining the results and conclusions.

Neither of these two methods would be entirely satisfactory. A combination method has been used. Some items needed in making use of the records on some lakes, which cannot be derived separately for such lakes, are discussed and conclusions reached before the records for the separate lakes are presented. Such an item is the evaporation from the lakes. After such a foundation has been laid, the available information on each lake is presented with the derivation of its inflow. The variations in the inflow are discussed for each lake in its general treatment. These results for individual lakes are then combined in the general discussion of the variations in the water supply of the area as a whole.

The accounts for each lake herein are an abbreviated version of the detailed office reports which were prepared on the individual lakes. These detailed reports do not justify publication as few who may be interested in the general results would care to examine all of the supporting material. For those who may desire to analyse the full record, typed copies of the detailed reports on each lake have been preserved.

Adjustments of Enclosed Lakes to Variations in Their Inflow.

Enclosed lakes are in balance with their mean annual inflow. In any time period in which the inflow exceeds the mean, the excess is stored in the lake with the lake rising by the amount required for such storage. Similarly the lake lowers in any period of below average inflow.

As the shores of these lakes are not vertical, the lakes adjust themselves to variations in their inflow. A rise of the lake increases its area and its total evaporation. The rate at which an excess inflow will be balanced by such increased evaporation varies with the rate of slope of the lake shores. On Great Salt Lake, relatively small increases in volume may result in relatively large changes in lake area and evaporation so that the fluctuations resulting from a large inflow are dampened by the increased evaporation.

Any lake whose inflow exceeds its net evaporation eventually rises until it reaches the elevation of the lowest point in its rim. The Great Lakes are examples of this condition. For at least some parts of the Great Lakes the mean annual precipitation may exceed the evaporation; for such areas the lake basin would fill until overflow occurred even if no other inflow occurred.

For the enclosed lakes of the Great Basin the mean annual precipitation on the lake surface plus their inflow can only supply the evaporation from a relatively small percentage of their total drainage area. In terms of geological time this has not always been true as Lake Bonneville rose until it overflowed to the Snake River and Lake Lahontan had an area representing a much larger percentage of its drainage area than is now occupied by its remnant lakes. The area of Lake Tahoe is the largest percentage of its drainage area of any of the present lakes and still overflows as it is located where the surface inflow and the precipitation on the lake are larger and the evaporation smaller than the similar items for the lakes in the desert portions of the Great Basin.

WATER SUPPLY CRITERIA

There are different criteria which may be used to measure the extent of the water supply of any area. The precipitation is the most widely measured climatic element relating to water supply. Precipitation records were begun before stream measurements became a general practice. In humid areas the annual variations in the precipitation are the most important element in the usefulness of the available water supply. In arid areas it is the runoff resulting from the precipitation which determines the extent of the development that can be supported.

The relationship between the precipitation and the resulting runoff involves several factors. Of these factors only the precipitation has usually been measured. The runoff in any year is affected by the amount of the precipitation in the preceding year. For precipitation in the form of rain the character of the individual storms affects the resulting runoff. For precipitation in the form of snow which accumulates on the drainage area the total amount of the precipitation may determine the snow storage and resulting runoff. For the drainage areas in the western Great Basin the larger part of their runoff occurs from April to June from the melting of the snowfall of the preceding winter.

Plotting precipitation and runoff for drainage areas for which records are available shows a relatively large amount of scattering. The longer records of precipitation can be used to derive a general estimate of the runoff for years prior to its direct measurement, but such derivations of the runoff for individual years or for short series of years are subject to relatively large probable errors. This is of particular importance for periods of deficiency as such periods determine the extent to which it may be feasible to develop these water supplies.

Another factor adding to the difficulty of deriving runoff from the precipitation is the wide variation that occurs in the precipitation over the drainage areas of the western Great Basin. Sufficient records have not been secured to enable the mean precipitation over the whole drainage areas to be defined adequately. The lower portions of some drainage areas receive precipitations of less than 10 inches per year and produce almost no runoff. Upper drainage area in the Sierras may receive 40 inches of mean annual precipitation and produce nearly all the dependable stream flow. Precipitation stations in these areas of larger runoff are generally not sufficient to define fully the variations of their precipitation.

Of the drainage areas in the western Great Basin, the one where the physical conditions and the available records are most favorable for deriving a relationship between precipitation and runoff is the area tributary to Lake Tahoe. The inflow to Lake Tahoe and the precipitation at Tahoe City are shown later in this report in Table 21 in the general discussion of Lake

Tahoe. These are plotted in Figure 1 in terms of the percentages of their annual means for the 51 years for which both results are available. Wide scattering for the individual years is shown. This scattering is too great to justify the use of statistical methods to derive the best fit for a curve indicating the mean relationship. The line of 100% percipitation and runoff has been drawn on Figure 1. For about 40 percent of the years the index of runoff exceeds the index of precipitation.

For indices of precipitation of less than 100 percent, Figure 1 indicates that the majority of the indices of runoff are less than the indices of precipitation. Some minimum amount of precipitation is required before any runoff occurs and an increasing proportion of the precipitation becomes runoff as the precipitation increases. For indices of precipitation in excess of 100 percent nearly all of the indices of runoff exceed the indices of precipitation.

The means for all points between each 20 percent variation in the index of runoff were plotted and a line drawn on Figure 1 which generally fits such means. Using this line the variation for each year was scaled. The resulting mean variation was 22 percent. This variation is an indication of the average error that would result from a derivation of annual runoff from precipitation on this drainage area.

There is some carry over effect from the precipitation of one year to the next. To see if the scatter shown in Figure 1 would be reduced by allowing for such carryover, the results were also computed on the basis of $\frac{a+2b}{3}$ for the percentages of precipitation. In this computation, 'a' was the precipitation for the preceding year and 'b' for the current year. The results are plotted in Figure 2. As no essential reduction in the scatter from the results shown in Figure 1 was shown the basis used in Figure 2 was not pursued further.

Another criterion which has been used in the study of water supply variations is the width of annual tree rings. For trees growing in areas where the water supply is the controlling element in the growth of the tree, the width of the annual ring may vary with the extent of the water supply. The use of tree ring patterns to identify the date of cutting of timber used in prehistoric structures has become a recognized procedure.

The growth of a tree is the composite result of several factors. There are time lag effects which may extend over more than one year. Later in this report an effort is made to correlate the results of tree ring measurements with the precipitation and runoff of the areas in which the tree grew. The results obtained are considered to be less useful than those derived from either precipitation or runoff.

DERIVATION OF THE INFLOW TO ENCLOSED LAKES

Where direct records of inflow to an enclosed lake are not available it may be derived if all of the other elements in the water supply balance are determinable. The inflow can be computed as the missing item in such an inflow-outflow equation.

The elements of supply are the surface stream inflow, rainfall on the

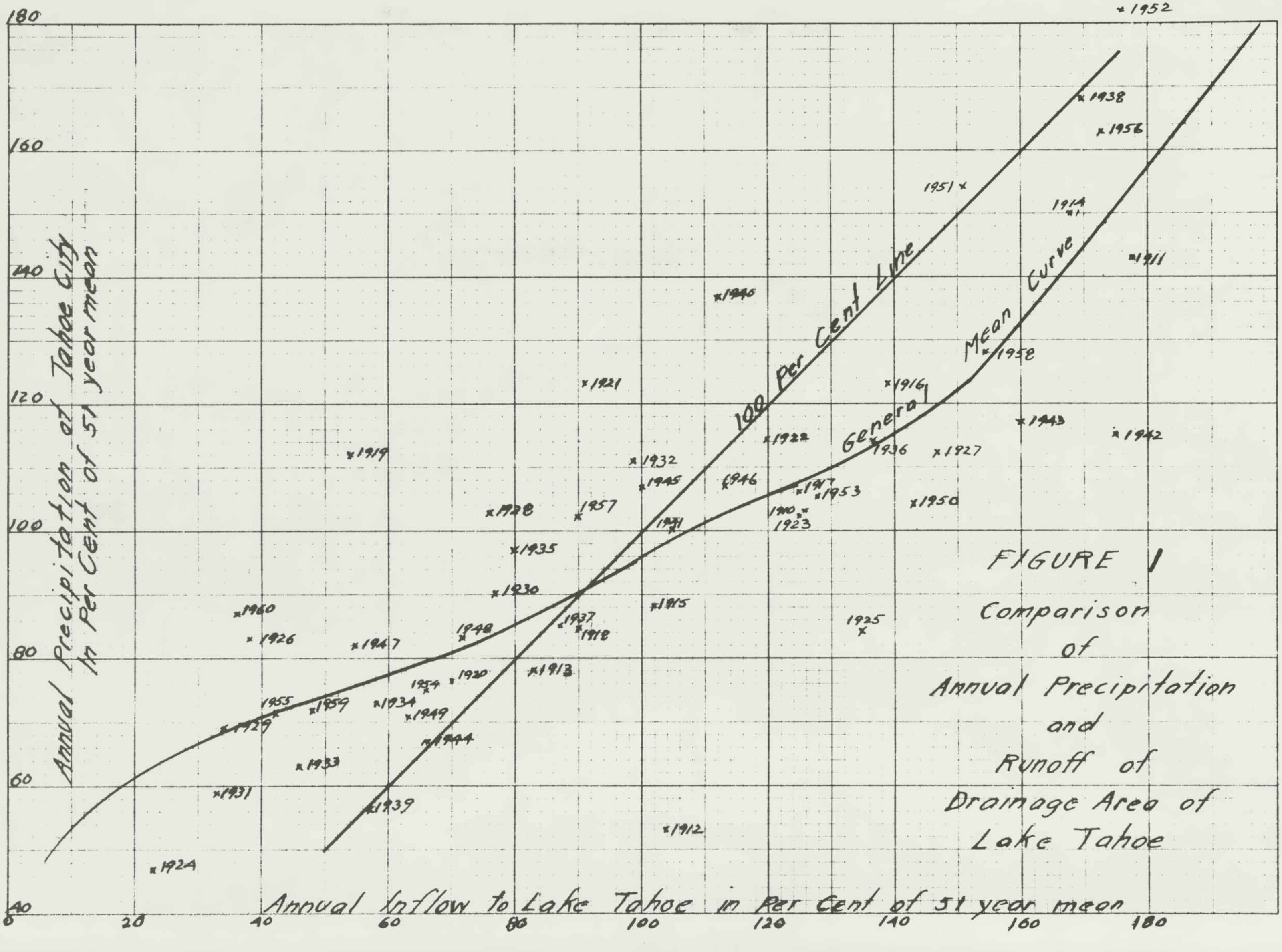

FIGURE 1

Comparison of Annual Precipitation and Runoff of Drainage Area of Lake Tahoe

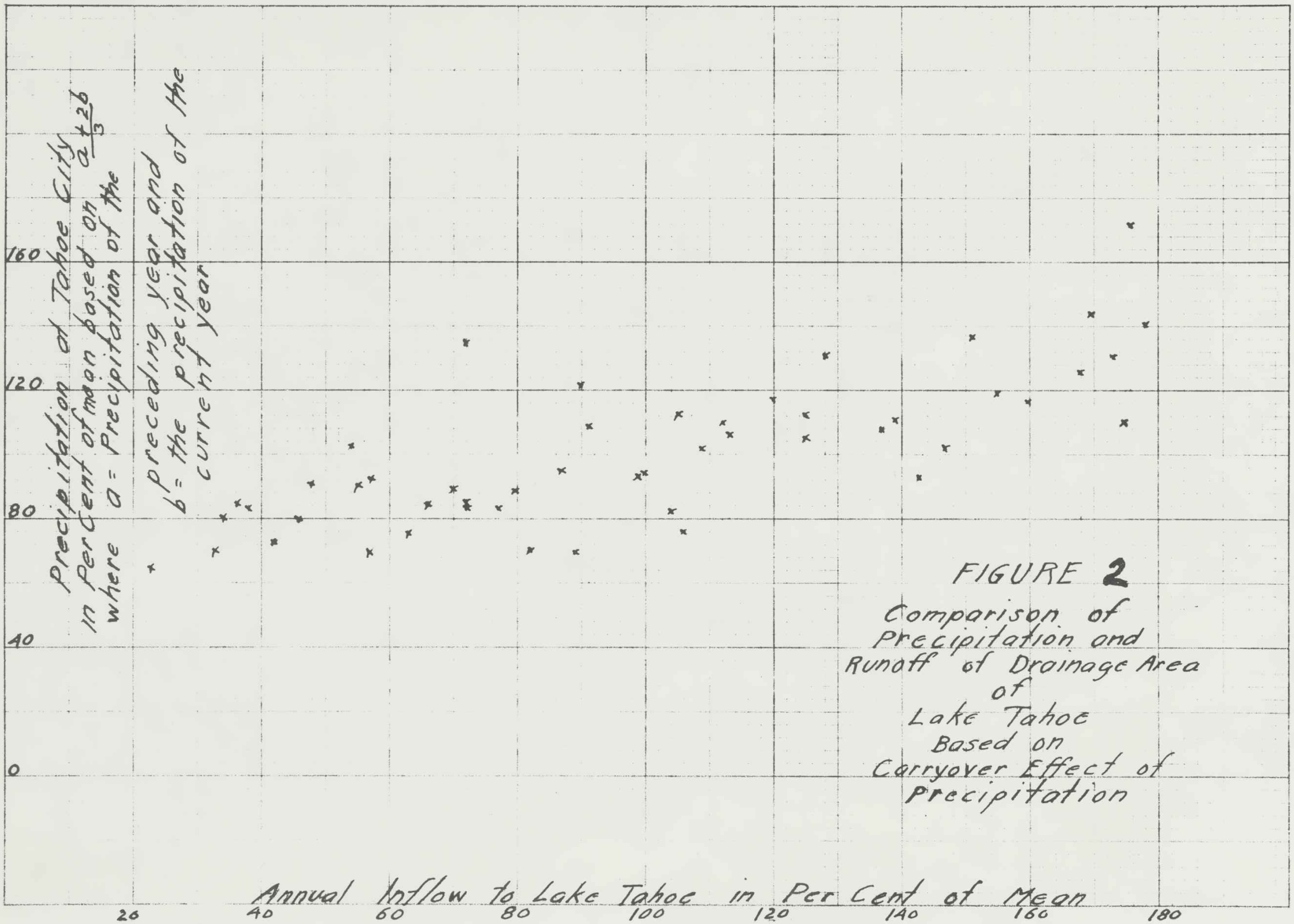

FIGURE 2

Comparison of Precipitation and Runoff of Drainage Area of Lake Tahoe Based on Carryover Effect of Precipitation lake and any ground water inflow into the lake bed. The elements of disposal are the surface outflow, the evaporation from the lake and any ground water outflow. These elements together with any change in volume of storage in the lake for the time period being considered will be in balance.

The advantage of using the records of enclosed lakes to derive their surface inflow results from the items in this balance which are either zero or small enough so that they can be neglected. Being enclosed there is no surface outflow. For the lakes that are discussed in this report there is no known outflow by ground water movement. Having received their tributary inflow, with whatever silt load it has carried, the beds of these lakes are well sealed against seepage. The impervious character of the Lahontan clay soils in the former bed of Lake Lahontan has been a major problem in their irrigation. These lakes are at the lower ends of their drainage areas and the erosion from their tributary areas is generally well ground into fine silts or clays by the time it reaches the lakes. These lakes are usually far enough from the mountainous areas which supply their main inflow so that the precipitation in their own area is too small to supply any material amounts of spring inflow in their lake areas. There are exceptions to this statements, such as in Mono Lake. For such lakes the inflow can be derived as the combined surface and sub-surface supply.

Precipitation records have generally been secured which are adequate to determine the precipitation on the lake areas. For most of these lakes the mean annual precipitation is less than one-fourth of the mean annual depth of evaporation and may be only one-eighth of the evaporation.

The largest item in the disposal of the inflow is the evaporation from the lake area. While some records of evaporation pans are available which can be used with appropriate coefficients to enable the evaporation to be estimated, records of inflow are available on some lakes from which the evaporation can be computed as the missing item in the water supply balance. On Pyramid Lake the records of the inflow from the Truckee River and the fluctuations of the lake are sufficient to enable the monthly evaporation to be computed for the full year. For some other lakes the inflow during the later summer months is so small that the lowering of the lake is a measure of its rate of evaporation. The lakes for which the evaporation can be computed are sufficient in number and in distribution to enable dependable results for the rate of evaporation to be derived for all lakes.

As the amount of the evaporation from the lake areas is the controlling item in the derivation of their inflow, the basis for the results used is described in considerable detail in a later section of this report. Additional results for each lake, where available, are included in the discussion of the individual lakes.

PRECIPITATION

A major item in the derivation of the water supply tributary to the enclosed lakes from the records of these lakes is the net evaporation from the lakes. This requires results for the gross evaporation from the lakes and for the precipitation on the lakes. The annual variations in the gross evaporation rate are less than those for other elements in the water supply, and the mean annual depth of gross evaporation can be used for individual years without large errors. The precipitation on the area of the lake is more widely variable and results for its amount for individual years are needed if annual inflows are to be derived.

While the precipitation records are inadequate in their coverage of the higher and more productive portions of the tributary drainage areas of these lakes, records from which the precipitation on the lake surfaces can be determined are generally available. Most of these lakes receive small amounts of mean annual precipitation as a result of their location away from the higher mountains and out in the desert areas. It is considered that, with one or two exceptions discussed for the individual lakes to which they apply, the amounts of precipitation on the lake surfaces which have been used are adequately supported.

Direct records of the precipitation on these lakes have been used where they have been available. Where local records have not been secured, the precipitation records at other stations considered to be representative of the precipitation on the lakes have been used.

To make the results from the different sources and for the different areas more readily comparable they have been expressed in terms of their percentage of the mean. For these annual percentages the term indices of wetness has been used in some reports. This is an appropriate description and has been used in this report.

For the climatic conditions in this area the precipitation during the year July to June determines the stream flow of the water year October to September. The precipitation results used in this report are for the July to June year. Precipitation from July to September in this area is generally negligible in amount and seldom produces surface runoff.

While such indices are useful as a guide to the probable variations from the mean, they are not a substitute for direct records. They have been used as an improvement over the use of the annual mean for all years. The use of the mean annual precipitation for each year tends to dampen the annual computed inflow that actually occurred although the mean results for longer periods would not be materially affected. To avoid such results the annual indices of precipitation have been used where applicable in periods for which no adequate direct records adjacent to each lake are available.

The first precipitation records which have been secured in northern California and maintained to date are those at San Francisco and Sacramento beginning in 1849. These stations are both outside the Great Basin but are in line with the major storm influences affecting northern California.

There are some records regarding general rainfall conditions for years prior to the beginnings of actual measurement of the precipitation and for later years. These general accounts include the following:

In Echoes of the Past (p. 67), John Bidwell describes the conditions in 1841 when he arrived in California. He states:

> "It had been one of the driest years ever known in California. The country was brown and parched and wheat, beans and everything had failed. Cattle were almost starving for grass, and the people, except perhaps a few of the best families, were without bread, and were eating chiefly meat, and that often of very poor quality."

In the 1883-84 Transactions of the State Agricultural Society (p. 192), Bidwell describes the 1840s as follows:

1841-42	Moderate
1843-44	Almost rainless
1844-45	Considerable rain
1845-46	Very wet-floods and inundations
1846-47	Copious rain-good wheat harvest
1847-48	Some early rains-open winter-good rains in March.
1848-49	Very snowy-considerable rain
1849-50	Very wet

Bidwell's account of his trip to California in 1841 is one of the best of the emigrants' diaries. He became a prominent and respected citizen at Chico, was governor of California and later a candidate for the U.S. presidency on the Prohibition ticket. His recollections of the 1840's, published in 1883-84, were probably based on notes made at that time.

In his Rainfall and Tree Growth in the Great Basin (American Geographical Society, Special Publication, November 21, 1938), Ernst Antevs reports the recollections of the character of the years which varied sufficiently from the usual so as to have been recorded or remembered. The following results have been abstracted from Antevs's account by the writer.

Year	Comment
1860	wet and severe
1862	maximum floods
1863	dry
1864	minimum conditions
1867	maximum conditions
1868	wetter than 1867
1869	severe winter
1870	unusually dry
1871	minimum
1873	dry summer
1874	snowy
1875	dry summer
1876	rainy and snowy
1877	minimum
1880	small maximum
1884	snowy
1887	dry
1888	dry
1889	dry
1890	extraordinary maximum

These results are applicable to the Humboldt-Truckee areas.

The indices of wetness for the annual precipitation which have been derived from various sources and for different areas are shown in Table 1. These all relate to the area of the western Great Basin.

In Table 1 the results in each column have been adjusted to have an average index of 100 for the years covered by that column. As the time periods covered vary in the different columns, the results for individual years are not completely comparable. The periods covered are of sufficient

Table 1 Indices of Precipitation for Western Great Basin Areas

sheet 1 of 3

Results are in Terms of the Annual Mean in Percent for the Period shown in Each Column.

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
	Precipitation of		Bulletin 5		Results of S.T. Harding				U.S.W.B for state of California				
Year	San Francisco	Sacramento	Area I Tahoe Carson	Area A Extended	Mean of Alturas and Lakeview	For Eagle Lake	For Northeast California	For Mono Lake					
1848-49													
50	147	187											
51	33	24											
52	82	91											
53	157	189											
54	106	104											
55	106	97											
56	96	71											
57	89	54											
58	97	78											
59	99	83											
1860	99	114											
61	88	84											
62	219	188											
63	61	60											
64	45	40											
65	110	117											
66	102	93											
67	155	131											
68	173	170											
69	95	86											
1870	86	70											
71	63	43											
72	137	123	123	88		140	131	144	138				
73	70	74	65	81		72	71	56	71				
74	110	119	118	77		114	106	144	113				
75	92	92	74	67		66	72	84	65				
76	139	137	124	79		136	130	144	134				
77	49	48	53	214		66	60	49	65				
78	156	130	81	91		96	97	107	95				
79	109	93	85	88		102	97	74	181				
80	119	138	125	162		130	124	123	128				
81	133	138	80	197		110	106	86	109				
82	72	86	120	131		95	100	98	94				
83	89	94	48	80		77	72	56	76				

Indices of Precipitation for Western Great Basin Areas - Cont'd

sheet 2 of 3

(1) year	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
1883-84	144	129	123	171		113	112	90			112
85	81	86	68	129		80	74	62			79
86	147	167	93	179		115	114	82			114
87	85	72	96	128		75	83	86			74
88	74	60	43	98		66	58	92			55
89	106	104	46	126		75	71	79			74
90	204	177	227	175		190	179	134			188
91	78	82	101	103		83	79	139			82
92	82	79	97	96		87	85	95			86
93	97	124	162	139		134	115	154			132
94	82	85	115	101		102	102	88			101
95	114	126	123	108		124	125	111			122
96	94	121	120	126		126	114	92			124
97	104	90	109	122		112	104	103	78		111
98	42	55	69	73		65	60	67	43		64
99	75	78	108	77		80	91	65	93		79
1900	82	105	106	101		109	112	72	82		108
01	94	105	111	110		107	114	129	97		106
02	84	90	83	92		100	90	87	100		99
03	81	87	86	83		93	91	56	85		92
04	91	97	106	128		135	137	82	125		133
05	104	115	79	87		96	103	92	89		96
06	91	124	121	107		120	720	127	159		119
07	116	125	171	142		148	137	128	134		146
08	77	64	66	79		76	71	123	77		75
09	114	114	113	110		120	121	113	173		119
10	87	58	106	83		85	91	118	69		84
11	112	162	150	122		130	129	751	121		128
12	62	50	57	70		61	58	87	92		60
13	53	42	71	87		77	66	92	104		76
14	131	106	135	133		122	120	170	128		121
15	122	90	104	67	80	92	104	108	139		91
16	121	95	121	93	98	106	104	134	144		66
17	70		84	95		85		97	68		84
18	51		67	62	61	61		92	101		60
19	114		92	75	77	83		92	88		82
20	46		64	65	76	61		77	110		60
21	103		111	117	118	112		87	107		111
22				82	69			113	119		
23				72	80			87	58		

Indices of Precipitation for Western Great Basin Areas - Cont'd

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(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Year											
1923-24				55	63			56	70		
25				93	95			77	87		
26				78	80			87	111		
27				94	122			113	114		
28				82	96			92	77		
29				67	62			56	62		
30				78	77			87	76		
31				62	54			82	100		
32				90	90			123	64		
33				51	73			77	83		
34				68	85			72	74		
35				91	116			123	91		
36				100	113			119	108		
37				66	77			134	120		
38				149	149			166	124		
39				60	67			87	65		
40				98	112			87	148		
41				108	140			144	149		
42				114	137				99		
43				107	134				99		
44				74	102				99		
45				108	122						
46				86	77						
47				73	92						
48				101	112						
49				93	103						
50				90	106						
51				96	106						
52				145	170						
53				119	132						
54				81	107						
55				66	78						
56					146						
57					129						
58					143						
59					75						
60					95						

length however so that the mean for each period does not vary essentially from a longer time mean.

San Francisco (Col. 2) and Sacramento (Col. 3) are the only precipitation stations having records extending back to 1849. These have been used in Table 1 for the years prior to 1872 and have been extended to later years to provide a period of overlap with other results. In general they are consistent with the other indices used. Years which are very dry or very wet at these two stations are usually ones of similar conditions in the other areas used. The indices for these two stations have not been extended into the more recent years when records within the drainage areas of the enclosed lakes are available.

The writer, in his work on these enclosed lakes, has also used indices of wetness for the drainage areas tributary to each lake where such results were needed to derive the annual fluctuations of the lake during periods when only infrequent records of lake elevation were available. The indices used were in some cases those derived by the California Department of Water Resources and in others were based on selected stations considered to be more directly applicable to the individual areas.

In Bulletin 5 of the California's Division of Engineering and Irrigation (1923), the state was divided into 26 areas for which the annual indices of precipitation were derived from available records for the 50 year period 1871-72 to 1920-21. Area I was the Tahoe Carson drainage areas representing the eastern slope of this portion of the Sierras. The indices were based mainly on the precipitation records at Boca and Truckee. Area A was designated as the Upper Pit-Tule Lake-Great Basin Area. It covered this portion of northeast California. Its indices in the 1870's and 1880's were based on the record at Fort Bidwell and for later years on Cedarville, Alturas, Madeline and Susanville. These stations are in or adjacent to the Great Basin. The results in Table 1 for Area I (Col. 4) are those in Bulletin 5; for Area A (Col. 5) the writer has extended the results in Bulletin 5 to 1954-55 based on the later records. The indices shown for Area A in Table 1 are those applicable to the 84 years shown and differ somewhat from those in Bulletin 5 for the years used in that Bulletin.

The results in Column 6 in Table 1 are the indices for the mean precipitation of Lakeview and Alturas which the writer derived for the years of their record for application to Goose Lake. In Table 1 these indices are shown from 1914 to 1960.

In deriving the inflow to Eagle Lake the writer used indices of wetness based on the results in Bulletin 5 adjusted more directly to be representative of the drainage area of Eagle Lake. These results are shown in Col. 7 of Table 1. These were worked out in 1934 and are shown in Table 1 from 1871-72 to 1921-22.

In his early work in this area the writer derived indices of wetness for northeastern California from 1871-72 based on the records available to 1915-16 for Summit, Truckee, Boca, Bowman's Dam, Cisco, Nevada City and Redding. All of these records were available in 1871-72 except Redding which began in 1875-76. These results are shown in Col. 8 of Table 1.

In 1934 the writer used the results in Bulletin 5 with additional stations in Nevada to derive indices of wetness which were based on a larger number of records than the indices for any single area in Bulletin 5 which were applicable to the conditions on the drainage area of Mono Lake. These results were later extended to 1940-41; they are shown in Table 1, Col. 9.

From 1897 to 1944 the U. S. Weather Bureau has published a result for the mean precipitation for each year for the entire state of California. The variations from this mean in any year may differ widely in the various parts of the state. This result is a composite of the total precipitation received in the state, and may not be applicable to separate areas. These results in terms of their percentages of the annual mean of 24.26 inches for this 48 year period have been included in Col. 10 of Table 1 for the purpose of general comparison.

The several different results which may be useful in interpolating the precipitation on individual enclosed lakes in periods when local records are lacking and also to illustrate the extent of variation that may occur in different attempts to derive such indices of wetness where only limited records may be available. Where these results have been used in the analyses for different enclosed lakes, the one considered to be the most directly applicable has been selected. Such applications are discussed later in the portions of this report relating to each lake.

None of these methods of deriving results from inadequate records can be a substitute for actual records. For some periods and areas they may represent the only available means for deriving annual results where other local records are missing. They have been used in this report where it has been thought that their use is an improvement over the use of the annual mean without variation for individual years. The extent to which they have been used is shown in the discussion of each of the enclosed lakes. Their use adds detail to the annual results without changing the mean water supply that would be derived by the use of the annual mean for all years.

STREAM INFLOW TO ENCLOSED LAKES

The conditions of stream inflow and the extent of the available records vary for each of the enclosed lakes. These are discussed in the later portions of this report dealing with each lake.

The first regular observations of stream flow in the western Great Basin began to be made in the 1890's. These early records were generally secured on the upper portions of the drainage areas above the points of proposed diversion and do not record the inflow at its entry to the lakes. The direct record of inflow to Pyramid Lake was begun in 1927 and to Walker Lake in 1913.

The available stream flow records have been used wherever they are applicable to the inflow to the enclosed lakes.

STREAM FLOW IN AREA

The California Department of Water Resources has derived indices of runoff for the various drainage areas of the state similarly to the indices of precipitation previously discussed. These results are in Bulletin 1 of the State Water Resources Board. The runoffs used were the estimated natural flow which was defined as the "Flow of a stream unaltered by diversions or storage of its waters, or by importation of water from another drainage basin." These natural flows represent the measured runoff adjusted for the estimated depletions resulting from upstream consumptive use.

These natural flows were derived for a uniform 53 year period from 1894-95 to 1946-47. Where the stream flow records did not extend over this period, the remaining years were estimated from precipitation and runoff relationships. As stream flow records were not secured on stations in the Great Basin in California over this 53 year period, much of the resulting estimates of natural flow rest largely on the derived precipitation-runoff relationship used. This prevents using the derived natural flows for the full 53 year period in the different parts of the Great Basin in California in a comparison of the annual variations in runoff in the separate drainage basins in this general area.

To see if the results for the natural flows of selected streams in the western part of the Great Basin, as derived in Bulletin 1, showed consistent annual variations, the results for 5 areas for the years 1920-21 to 1946-47 were computed in terms of their percentages of the mean for this period. This 27 year period was used instead of the 53 years used in Bulletin 1 as the results for this later period are supported by a greater extent of stream flow measurements.

Streams were selected extending from the northern to the southern portion of the western Great Basin which had relatively long direct records. The Pit River at Canby was used for the northern portion of the area although its drainage area is not in the Great Basin. Its variation should be representative of the Goose Lake-Surprise Valley area. There is essential depletion of the runoff of this drainage area before it reaches Canby and the estimate of natural runoff in Bulletin 1 is about 60% larger than the measured flow. Donner Creek was used as representative of the Truckee River as its measured flow is affected only by the variations of carryover storage in Donner Lake. This is adjusted in the results in Bulletin 1. The West Carson at Woodfords has had little change in the conditions on its drainage area. The West Walker near Coleville has a long actual record under generally undisturbed conditions. Leevining Creek represents the southern part of the western Great Basin; adjustments for differences in carryover storage have been made in Bulletin 1.

The results for these five streams are shown in Table 2.

The largest variations between the five streams shown in Table 2 is between the Pit River and the other streams. The remaining four streams show as consistent results as would be expected from the character of the records and the variations within the area. The mean annual variation from their own mean among these four stations is shown in Table 2. Only 2 years exceeded 20 per cent. These four streams extending from the Truckee River to Mono Lake appear to have been subject to the same general climatic influences during this 27 year period.

The accumulated departures from their own mean for the period covered for the four stations is also shown in Table 2. For the 11 years from 1924 to 1934 this varied from 59 per cent above to 185 per cent below the annual mean representing an accumulated deficiency of 244 per cent of the annual mean. These 11 years include the more deficient period of 7 years from 1928 to 1934 having an accumulated deficiency of 188 per cent equal to an average annual deficiency of 27 per cent.

Table 2 Natural Stream Flow in Per Cent of the Mean for the 27 years 1920-21 to 1946-47
Percentages are computed from Results in Bulletin 1 of California Water Resources Board.

Year	Pit River at Canby	Donner Creek near Truckee	West Carson at Woodfords	West Walker at Coleville	Lee-vining Creek	Mean for 4 Streams: Annual Mean	Annual Variations from Mean	Accumulated Departures from Mean	Variations of Pit from Others
1920-21	179	117	118	120	122	119	2	+19	60
22	88	137	139	142	124	135	6	+54	47
23	59	102	102	118	96	105	7	+59	46
24	38	28	38	36	52	39	7	-2	1
25	101	88	88	107	97	95	7	-7	6
26	38	63	66	68	74	68	8	-39	30
27	181	161	165	126	116	142	21	+3	39
28	121	99	102	74	86	90	10	-7	31
29	54	57	58	58	71	61	5	-46	7
30	66	89	89	71	71	80	9	-66	14
31	18	41	47	38	50	44	4	-122	26
32	113	110	117	109	111	112	3	-110	1
33	57	74	64	64	77	70	6	-140	13
34	21	62	55	51	51	55	4	-185	34
35	102	112	108	104	95	105	5	-180	3
36	124	141	127	108	111	122	12	-158	2
37	90	95	91	107	87	95	6	-163	5
38	270	179	227	249	162	204	34	-59	66
39	59	51	53	64	63	58	6	-101	1
40	97	146	108	108	133	124	16	-77	27
41	126	119	110	127	145	125	11	-52	1
42	162	132	150	140	147	142	6	-10	20
43	193	131	127	125	163	136	13	+26	57
44	70	67	66	73	92	74	8	0	4
45	123	107	108	130	120	116	9	+16	7
46	98	117	108	110	107	111	3	+27	13
47	52	75	68	73	75	73	2	0	19

The results for Pit River in Table 2 show an average variation of 22 percent from the mean of the other four stations. This variation exceeded 40 percent in 5 of the 27 years and from 30 to 40 percent in 4 additional years. While Pit River shows a similar direction of variation from the mean in individual years from the mean of the other four streams, the amount of the variation differs in many years. The drainage area of Pit River is less under the "shadow" of the Sierras than the other four streams and appears to be affected quantitatively by this condition.

EVAPORATION

The evaporation from the enclosed lakes represents the outlet for their inflow. Any seepage from enclosed lakes which occupy the lowest depression in their drainage areas would have to find its outlet by movement to some adjacent drainage areas. Topographical and geological conditions are unfavorable for any such ground water movements.

The inflow to such enclosed lakes, both surface and subsurface, is balanced by the net evaporation from the lake. Except for lakes having separate surface sources of inflow which can be measured and negligible subsurface inflow, the determination of their inflow requires the determination of the rate of the net evaporation. For any period of time the inflow is the net evaporation from the lake plus any gain in storage in the lake or minus any loss in storage.

From necessity most of the results used for the rate of evaporation from lake water surfaces have been based on observations with small evaporation pans. Such pan records are easily obtained but their application to large water surfaces involves uncertain factors. Estimates of the evaporation from the enclosed lakes could be made based on the available records with evaporation pans but the results would be subject to these uncertainties.

Fortunately, for some of the enclosed lakes, records have been secured of the inflow, precipitation on the lake and lake fluctuations from which the gross evaporation from the lake can be computed. This gives a result for evaporation which is direct and does not involve the use of any coefficients for evaporation pans. The results from the lakes for which evaporation can be derived by direct records can be interpolated for the evaporation of other lakes in this area.

Direct results for the evaporation can and have been derived for Pyramid and Winnemucca Lakes and for Walker Lake. Some results for late summer months when inflow may be negligible in amount can be derived for some other lakes such as Eagle Lake. While the inflow to Lake Tahoe occurs in too many separate streams to be measured without extensive work, the results of pan observations are available for a relatively long period and have been used to furnish an estimated rate of evaporation at the elevation of this lake.

The writer assembled the then available results from which the evaporation from these enclosed lakes could be derived in an article in the <u>Transactions of the American Geophysical Union</u>, (Sixteenth Annual Meeting, 1935). This article was entitled "Evaporation from Large Water-Surfaces based on Records in California and Nevada." Additional records have become available since this article was prepared and have been used in the present discussion. Some minor changes in the 1935 results have been made based on these longer records.

When Winnemucca Lake was approaching desiccation in the 1930's and inflow from the Truckee River had been shut off, E. P. Osgood made measurements of the elevation of the lake from which the evaporation can be derived. These records showed differences from the monthly evaporation from the deeper nearby Pyramid Lake resulting from their differences in depth and its effect on heat storage in the lake. These results were presented and discussed in a paper by the writer in the Journal of the Irrigation and Drainage Division (American Society of Civil Engineers, March 1962).

The results derived from the records for each lake for which such results can be obtained and the estimates used for other lakes are discussed in the later portions of this report relating to each lake. These results are assembled in Table 3 for comparison of the different lakes.

The results in Table 3 for the annual evaporation from Pyramid, Winnemucca and Walker Lakes are in close agreement. This would be expected as the climatic conditions and exposure of these three lakes are similar and they are at nearly the same elevation. This agreement confirms the correctness of the records used in deriving these results. The monthly results show more differences. Winnemucca Lake was generally less than 10 feet deep when the observations by Osgood were made and had little volume in which the incoming heat could be stored. Consequently, the evaporation from Winnemucca Lake during the first half of the year was about one foot greater than that from the adjacent Pyramid Lake. This difference was balanced by the excess of evaporation from Pyramid Lake over that from Winnemucca Lake in the second half of the year as the heat storage in Pyramid Lake was released and increased the evaporation from its surface.

The results shown in Table 3 for the evaporation from Lake Tahoe are those derived by the writer in 1935 from the then available pan records. The Class A, U. S. W. B. pan at the outlet of Lake Tahoe has a long record but is located where it has been subject to wind protection and some shading from the adjacent trees. Recently the California Department of Water Resources has installed evaporation pans at different points around the lake and better records will be available when these pans have been operated long enough to derive mean values. The value of the gross evaporation from the 120,000 acre area of Lake Tahoe more generally used in present water supply studies on the lake is 375,000 acre feet per year or a depth of 3.12 feet.

The results shown for Mono Lake in Table 3 are based on the lowering of the lake in late summer months extended to the other months by comparison with other lakes. These results include the uncertainty of the amount of inflow from springs in the bed of Mono Lake. Such springs exist but no means for their measurement are available. The result shown in Table 3 is consistent with the other results shown. Being at a higher elevation the evaporation from Mono Lake would be expected to be less than that from the nearby Walker Lake; being further south and at a similar elevation to Lake Tahoe, Mono Lake would be expected to have a somewhat larger evaporation than Lake Tahoe.

For Goose Lake some observations of the rate of lowering of the lake in July to September when inflow is very small have been used to derive the evaporation in these months. The other months have been computed as the same

Table 3 Evaporation from Enclosed Lakes in the Western Great Basin.

Depths of Evaporation are in Feet.

Month	Derived from Lake Records: Pyramid Lake	Winnemucca Lake	Walker Lake	Eagle Lake	Goose Lake	Estimated: Lake Tahoe	Mono Lake	Humboldt	Honey
Jan	0.24	.06	.15	.13	.05	0.10	0.11		
Feb	.23	.16	.15	.18	.14	.10	.10		
Mar	.20	.23	.20	.19	.20	.16	.18		
Apr	.22	.38	.25	.26	.33	.24	.19		
May	.25	.51	.25	.30	.45	.32	.20		
June	.32	.68	.45	.42	.58	.36	.34		
July	.39	.63	.50	.47	.51	.47	.38		
Aug	.50	.60	.50	.46	.51	.48	.55		
Sept	.52	.31	.60	.41	.36	.35	.50		
Oct	.47	.20	.45	.31	.18	.22	.35		
Nov.	.38	.14	.35	.22	.12	.15	.15		
Dec.	.30	.08	.25	.17	.07	.12	.19		
Year	4.02	3.98	4.10	3.52	3.50	3.07	3.24	4.00	4.00
Elevation of Lake	3850	3820	3900	5100	4700	6225	6400	3900	3950

percentage of the evaporation for July to September shown by the Winnemucca Lake records. The resulting 3.5 feet per year for the gross evaporation from Goose Lake is consistent with the results for Pyramid Lake when allowance is made for the difference in latitude and elevation.

The results in Table 3 for the annual evaporation from Humboldt and Honey Lakes are based on those for Pyramid and Winnemucca Lakes without attempting to assign values to the individual months. Both of these lakes are shallow and their monthly evaporation should be similar to that of Winnemucca Lake.

The results in Table 3 show a variation in the evaporation with the elevation of these lakes. In Figure 3 the gross evaporation has been plotted with the elevation. The results for these lakes show a reduction in the mean annual evaporation of about 1 foot for an increase in the elevation of 2400 feet. This result is directly applicable only to this area of the western Great Basin between elevation of about 3800 to 6200 feet.

A similar relationship for evaporation and elevation for the drainage area of the San Joaquin River in the Central Valley of California was derived in a paper by Leonard L. Longacre and Harry F. Blaney in the Journal of the Irrigation and Drainage Division, Proceedings of the American Society of Civil Engineers, June 1962, (p. 33). The relationship plotted in Fig. 6 of this paper is also shown on Fig. 3. The results for the San Joaquin River drainage area show a slightly smaller rate of decrease of evaporation with an increase in elevation than those for the western Great Basin, although the two results are generally in good agreement on the amounts of the gross evaporation.

OTHER WATER SUPPLY ITEMS

The derivation of the inflow of these enclosed lakes includes factors other than the precipitation, measured inflow and evaporation. Area-capacity curves are needed in order that the volume of storage at different elevation and the area subject to evaporation may be known. These individual factors relating to each lake are discussed in the separate accounts of each lake.

QUALITY OF WATER IN ENCLOSED LAKES

While the main purpose of the investigations on which this report is based has been the quantity of the water supply of the enclosed lakes, the results of analyses of the quality of the water by others have been assembled. Samples were also collected by the writer during his own field work.

The results of the available analyses on each lake are discussed in the account of each lake. These results for all lakes are also dicussed in a later portion of this report.

The fluctuations of the enclosed lakes in the western Great Basin over the period during which records have been secured has been sufficiently large to represent a material variation in their volume. During such changes the total soluble content of the lake water has generally varied in proportion to the volume in the lake. The total tonnage of solubles has remained generally constant as the volume of water in the lake has varied.

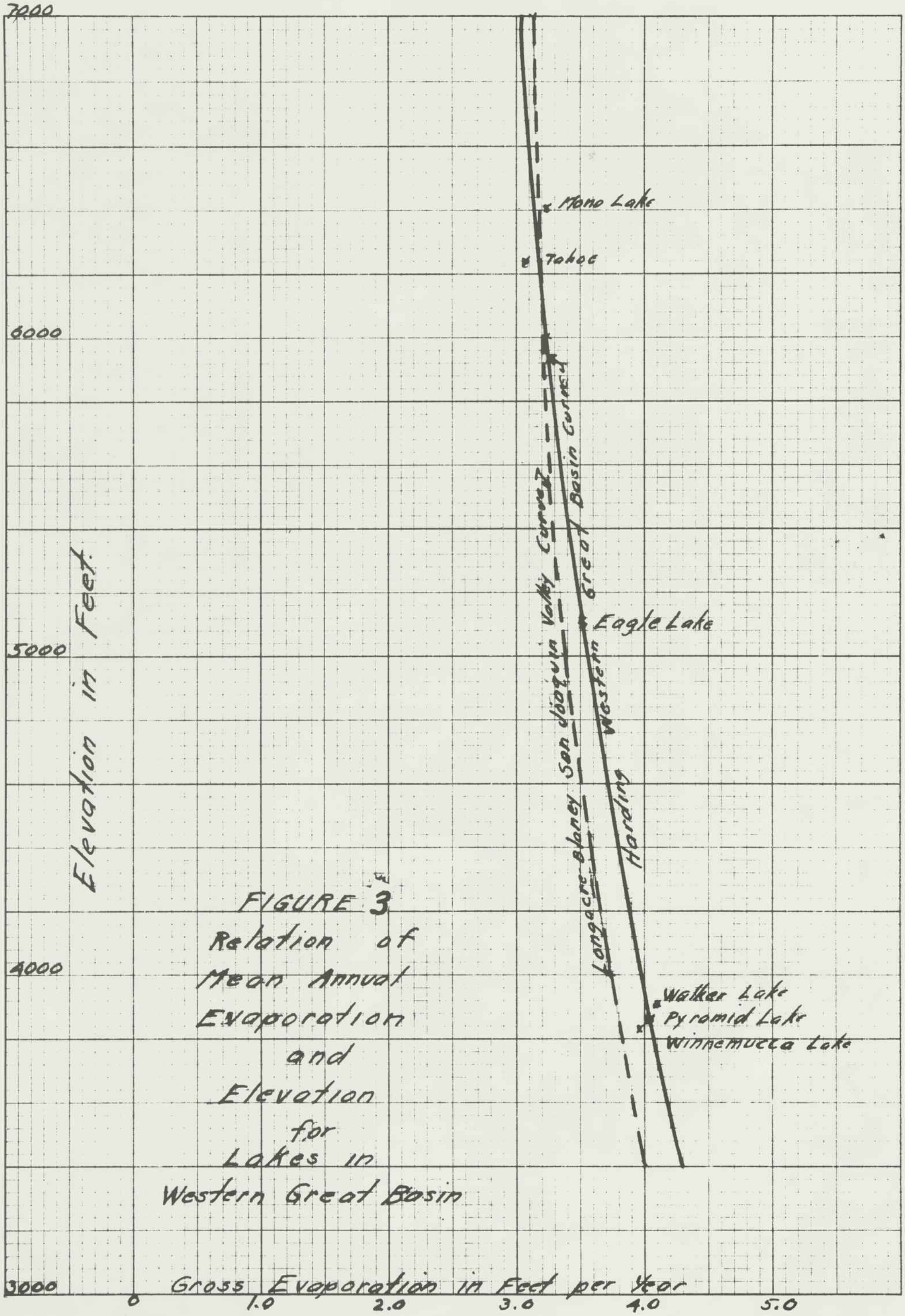


FIGURE 3
Relation of Mean Annual Evaporation and Elevation for Lakes in Western Great Basin

The quality of the water in these enclosed lakes has sufficient importance to justify its separate study. There is much conjecture regarding the disposal of the salt content of the water in Lake Lahontan as it diminished. While it is now too late to make observations relating to the water in Lake Lahontan, much might be learned regarding what probably happened from the record of its present remnant lakes.

INDIVIDUAL LAKES

The background has been laid in the preceding portion of this report for the discussion of each of the enclosed lakes of the western Great Basin. The main enclosed lakes for which the available information justifies separate discussion are, in the order from the north to the south, Goose, Eagle, Pyramid and Winnemucca together, Walker and Mono. Lake Tahoe is not an enclosed lake but its discussion adds to the overall results for the Truckee River. There are several smaller lakes which are discussed to the extent that their record contributes to the general water supply picture.

The discussion of these lakes which is included here is a shorter version of the full report which has been prepared on each lake. In order to preserve all of the material which had been secured regarding each of these lakes, accounts were prepared including and analysing all of the results. These detailed reports are too long for inclusion here. The results directly useful in developing the water supply of the western Great Basin have been included. Copies of the detailed reports have been filed for record.

GOOSE LAKE

Goose Lake is the most northern of the lakes included in the investigation on which this report is based. Geographically it is not in the Great Basin as its overflow channel leads to the upper Pit River, a tributary of the Sacramento River. As it has barely reached its overflow elevation briefly at two times in its recorded history, it is, for practical purposes, an enclosed lake.

Goose Lake is located on the California-Oregon line near the northeastern corner of California. Its bed is flat. At the elevation of its overflow it has a depth of less than 30 feet and an area of 128,000 acres. Its tributary inflow is now extensively used for irrigation and its recent fluctuations do not reflect the full variations in the runoff of its tributary drainage area.

The inflow to Goose Lake occurs in numerous local tributaries and has not been measured, although records have been secured on upper portions of some streams. The estimates of the inflow derived in this report have been based on the evaporation from the lake, the precipitation on the lake, and the changes in area and volume of the lake resulting from its fluctuations. To make the derived inflow prior to local irrigation use comparable with that since such use, the estimated depletion in inflow represented by the consumptive use of this irrigation as it has developed has been added to the inflow to the lake to give estimates of the runoff of the tributary drainage area.

There are no trees growing around the margin of Goose Lake within its range of fluctuation whose age can be used to determine the period of time when the lake has been below the elevation on which they grew. While the higher portions of its drainage area are timbered, much of the margin of the lake is too marshy for trees to grow and much is too arid. If the lake remained below its rim long enough some trees might get a start on ground below the elevation of the rim; any such trees that may have grown at any time in the past had disappeared by the time of the first reports on the lake. There are some reports that stumps around moist areas in the bed of the lake were exposed when the lake became almost dry in 1925.

The writer's work on Goose Lake began over 30 years ago as a part of his investigations of similar lakes in the western Great Basin. More detailed work was done in 1941 in connection with litigation, then current, regarding title to recession lands. Much help has been secured from local residents, from the Surface Water Branch of the U.S. Geological Survey, particularly Mr. Kenneth N. Phillips of the Portland office, and from the California Department of Water Resources. The individuals who have helped are too numerous to be listed. The writer is indebted to all who have assisted him in this work.

AREA AND CAPACITY

Soundings of Goose Lake were made in 1904 by S. G. Bennett for the then U. S. Reclamation Service. This work was done when the lake was one foot below its rim. Bennett's results were used in the 1912 report of the California State Water Commission. In 1915 O. W. Peterson used Bennett's results with some later soundings by the Goose Lake Valley Irrigation Company to derive closely similar results.

In 1959 the California Department of Water Resources made a detailed survey of the lake by sounding below its then elevation of 4704 feet; the area between elevation 4704 feet and the rim at elevation 4716 feet was not surveyed except at the elevation of overflow.

The results of these two surveys are shown in Fig. 4. The 1959 results were more detailed than Bennett's and have been used. The 1959 results show that above elevation 4696 feet from 30 to 35 per cent of the area and the volume are in Oregon with the higher percentage at the elevation of overflow of 4716 feet. At elevation 4694 about 80 per cent of the area and volume are in California and at elevation 4692.5 practically all of the remaining lake is in California.

EARLY REPORTS

Goose Lake was visited in 1832 by John Work of the Hudson Bay Co. This is the first eye witness account known to the writer. Work's account is in general terms. A reasonable interpretation of his distances between camps and their locations indicates a lake stage of about 10 to 15 feet below the rim or 4761 to 4706 feet present U. S. G. S. datum. This conclusion is also

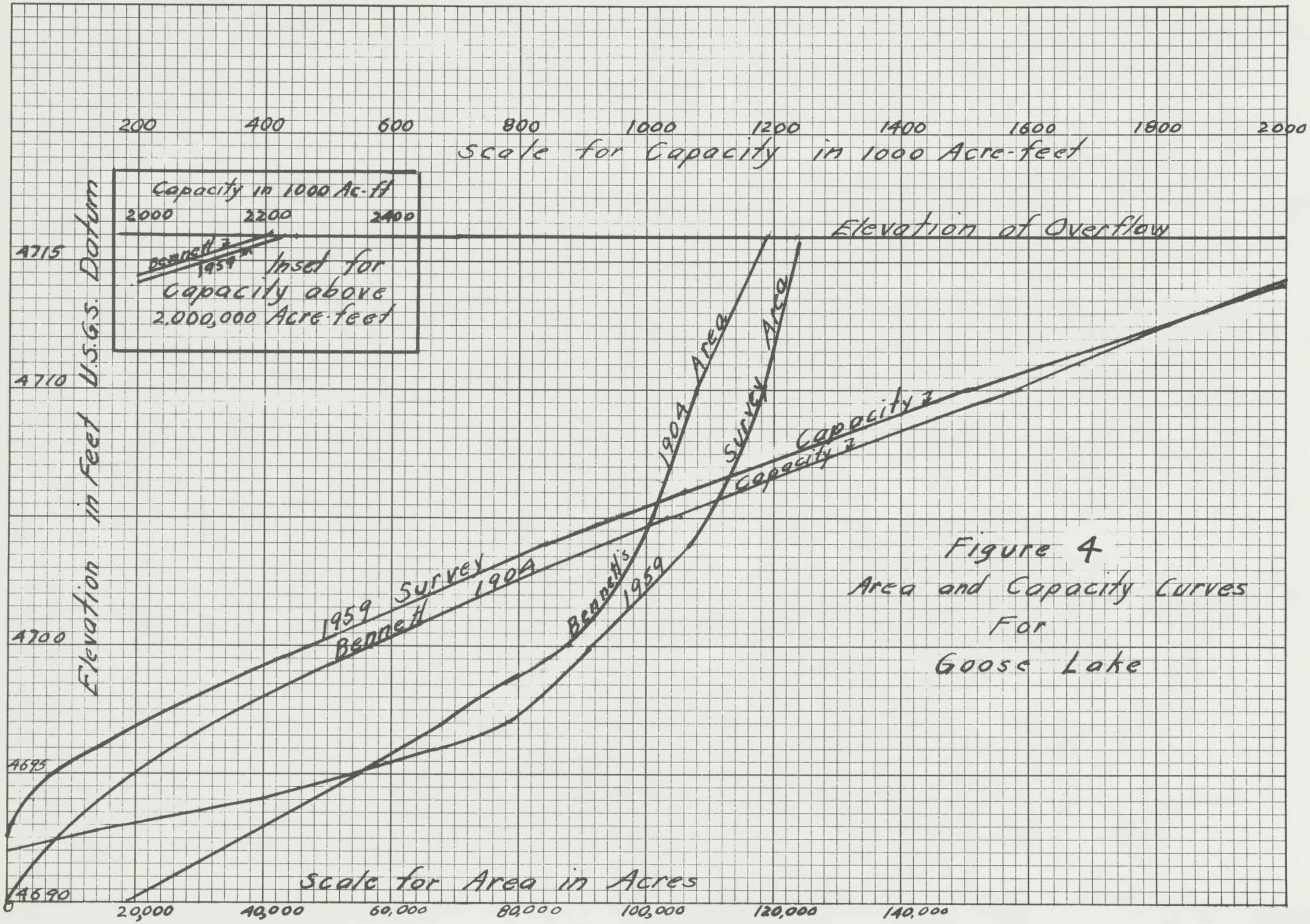


Figure 4
Area and Capacity Curves
For
Goose Lake

25

supported by Work's comment that the water was not salt but had an unpleasant taste. In recent years this comment would apply to Goose Lake when it has been at similar stages.

Charles Wilkes of the U. S. Navy describes Goose Lake in his report covering explorations from 1838 to 1842. Wilkes did not reach Goose Lake and his map and report cannot be interpreted in terms of the elevation of the lake. Wilkes' account indicates that the general location and size of Goose Lake was known by 1841.

Pierson Barton Reading passed Goose Lake in 1843 with a party of emigrants. The description in his diary has been interpreted to indicate that Goose Lake was at elevation 4699 feet at the time of his visit.

Jesse Applegate has left an account of his trip in 1846 to locate a southern emigrant route to Oregon. He crossed the southern end of the lake and went northward to cross Fandango Pass. From his account of where he travelled it has been concluded that Goose Lake was at elevation 4695 feet at the time of his trip in 1846.

Peter H. Burnett was at Goose Lake in October 1848. His account indicates a lake somewhat lower than at the time of Applegate's visit. An elevation of 4694 feet has been used by the writer.

In 1849 the Lassen Trail was in general use. It left the Humboldt River above Lovelock and crossed the Black Rock desert to Surprise Valley and over Fandango or Lassen's Pass to a route around Goose Lake. There are several descriptions of Goose Lake in the diaries of travellers over this route in 1849. There is also the report of Lt. R. S. Williamson who took command of the U. S. Army Exploration when Capt. W. H. Warner was killed by the Indians. The diaries which included comments from which the area and elevation of Goose Lake can be interpreted include those of Kimball Webster, A. Delano, Israel R. Hale, J. G. Bruff and The Foster Family. Williamson mapped the west side of Goose Lake; from this map and his report Goose Lake appears to have been at elevation 4694 or 4695 feet. The diary accounts describe the route followed on the bed of Goose Lake. From the maps now available Goose Lake would have had to be at a similar elevation to that derived from Williamson's work for these routes to have been used. From all of these results the writer has concluded that Goose Lake was at elevation 4694.5 late in the summer of 1849 when the emigrants passed Goose Lake. This is a relatively low stage of the lake and is confirmed by the emigrants' comments on the high salt content of the water in the lake.

The Lassen Trail was extensively used in 1849. Attacks by the Indians reduced its use in later years although the U. S. Army and California volunteers attempted to protect the emigrants. This route was blocked from use at times to avoid losses of life and stock. Little specific information from which the elevation of Goose Lake can be derived has been found between 1850 and 1854. In 1854 Capt. Ingalls left Col. Steptoe's party to drive horses over the Black Rock desert to Oregon. He passed Goose Lake and his description indicates a lake elevation of 4698 feet.

Stephen Powers has left an account of a trip to Goose Lake in 1874 with comments on conditions there in earlier years. Powers' account with Ingalls' report is interpreted to support the conclusion that Goose Lake remained at about its 1854 elevation until 1859 and was at about elevation 4698 feet in

1859. By 1874 the lake had risen to elevation 4713 feet.

The U. S. Land Office made meander surveys of Goose Lake in 1872, 1879 and 1880. The results of these surveys have been interpreted to indicate that Goose Lake was at or near elevation 4711 feet in each of these years.

The report on the "Geological Surveys West of the 100th Meridian" (Wheeler survey) includes a map of Goose Lake and an account by Lt. Col. Thomas W. Symons applicable to 1877. From these results it has been concluded that Goose Lake was at elevation 4708 in 1877. Symons states that Goose Lake had overflowed eight years previously which represents an elevation of 4716 feet in 1869. I. C. Russell discusses Goose Lake in the Fourth Annual Report of the U. S. Geological Survey for 1882-83. Russell stated that the lake had not overflowed since 1869 except for two hours during a gale from the north in 1881. He also states that prior to 1869 the lake was lower than it was 1882. The lake was 15 feet deep in 1882 over the former road at the south end of the lake. The lake had been slowly rising prior to 1881; to do this the lake would have to have lowered from its overflow in 1869 in order to have risen to its elevation in 1881. Russell's report indicates an elevation of Goose Lake in 1882 of 4714 feet.

Dr. George M. Kober was a physician at Fort Bidwell and has left an account of Goose Lake in 1886. This has been interpreted to represent an elevation of Goose Lake of 4713.5 feet in 1886.

EARLY WAGON ROADS IN BED OF GOOSE LAKE

When Goose Lake went dry in 1926, old wagon ruts still showed in the bed of the lake. The location of these old roads furnishes an indication of the elevation of the lake at the time they were used. On Sept. 12, 1926 pictures of these old trails were taken by M. Mark Getty of Lakeview. A reproduction of one of these pictures is shown in Figure 5. This picture was taken on the west shore of Goose Lake opposite the I. C. Everly place. These pictures furnish definite evidence that a route across Goose Lake was used at some time in the past at the location shown in these pictures. As Goose Lake had covered this route since 1862 the tracks revealed were made prior to that date. The lake would have to be below elevation 4694 for this road to have been used.

The writer in 1941 and 1955 identified the location from which Figure 5 was taken by lining a tree in the foreground with the crest of the mountains east of the lake. This was confirmed by Mr. I. C. Everly at whose request the pictures had been taken by Mr. Getty. This places the west end of the road shown in this picture on the west shore of Goose Lake about 5 miles north of McGinty Point. There is a low springy area in the lake bed north of this location which remained moist from 1926 to 1934. The early emigrants using this road probably took the most northerly route that was dry in crossing the bed of Goose Lake.

The road shown in Figure 5 is heading northeasterly across the lake from the west side. Reports of where it entered the lake bed on the east side of the lake are not definite. As the emigrants came over Fandango Pass they would not reach the lake north of Willow Creek. The road probably entered the lake bed off of Willow or Lassen Creeks and swung as far to the

Figure 5.

Marks of the old wagon road in the bed of Goose Lake exposed when the lake became dry in 1926.

Photograph by Mark Getty, Lakeview, Oregon.

south as the elevation of the lake may have required. As there are no near-by tributary streams on the west end of this road these tracks were preserved during their 70 years of submergence; on the eastern shore the road tracks in the softer deposits from Willow and Lassen Creeks were apparently obliterated in that portion of the lake. Similar tracks on the eastern shore were not reported in 1926. The road tracks in Gettys' pictures are reported to have been filled by wind action and were no longer visible by 1931.

Mr. Everly came to the Goose Lake area in 1915 and has been a close observer of the conditions there. In 1955 he told the writer that he had found traces of three roads going west from Goose Lake which were probably used to secure better feed along their routes. These roads joined about 10 miles west of the lake. In 1955 trees were growing in the lake bed about 1/4 mile off shore from Everly's place. Mr. Everly stated that there had been stumps of trees 75 to 80 years old near springs there and wet spots in the lake bed when it went dry in 1926.

In "Our Expanding and Contracting Desert" (Geographical Review, Amer. Geographical Society of New York, Jan. 1935, p. 43-61) Isaiah Bowman discusses his observations on Goose Lake in 1930 and 1932 when the lake was at a relatively low stage. He describes the old wagon roads uncovered by the lowering of the lake in 1925 and included pictures of them taken at that time by Mark Getty.

The writer has examined the files of the Lake County Examiner for the period when Goose Lake was dry or nearly dry from 1925 to 1934. The issue for July 15, 1926 contains an article by Mr. Everly. There was a sheet of water in the lake which shifted with the wind. By getting high above the lake the old trail could be seen for miles out across the lake extending in a southwest direction. Everly stated that an old Indian had told him that there had been no lake before the white man came. There had been only a small swamp in the low area with sage brush on the west. This same Indian also stated that the lake had filled in the early 1860's.

The Lake County Examiner published a four part serial on the "old South Road" by Mildred Baker in April and May 1929. This road was used as the southern trail to Oregon from 1846 to 1853 with little use after 1853 due to danger from the Indians. When the lake went dry in the 1920's the old road was visible for miles in the lake bed but did not show within one and one-half miles of the lake shore. This article described the western end of the road as being 10 miles south of the California-Oregon line which agrees with the writer's description of 5 miles north of McGinty Point.

An article in the Lake County Examiner of September 2, 1926 states that arrow heads and other evidence of Indian work were found in the bed of Goose Lake when it became dry in 1925. "Huge" willow stumps and lesser stumps of large brush had also been found.

Ingalls' report based on his work in 1854 (Report of Rufus Ingalls, Exec. Doc., House, 1st Sess, 34th Cong, 1855-56) states that the road around Goose Lake passed around the south end of the lake and "upon the west shore some eight miles." This indicates that the location of the present McGinty Point Viaduct was submerged in 1854 and that the traveller had to go around the south end of the extended road before reaching the road to the west. Ingalls' comment on the freshness of the lake water represents a fairly high stage in 1854.

Ingalls' statements agree with Powers' comments on conditions in 1854. Both indicate that the road across the bed of Goose Lake which was exposed in the 1920s had been submerged by 1854. The descriptions in the 1849 reports indicate lake crossings further to the south than the exposed road. Their results place the probable time when the more northerly location of the road was used to some part or all of the period 1850 to 1853.

From all of the information available regarding former roads in the bed of Goose Lake the writer has reached the following conclusions:

1- The Applegate route of 1846 and the trails used until 1849 crossed Goose Lake from Davis Creek to McGinty Point. The Oregon trail then went to the west through rough country to the Klamath area and the California trail went to the south to California.
2- After 1849 Goose Lake lowered so that the road did not need to swing so far to the south and the migration over Fandango Pass reaching Goose Lake at the mouth of Willow Creek could and did enter the lake bed south of any Willow Creek inflow.
3- For the lower lake stage after 1849 the road could emerge further north on the western side. Getty's pictures show that such a route was used.
4- The trail across the lake at its lowest stage would swing as far south from where it entered and left the lake bed as the lake stage at different times may have required. One controlling point appears to have been the marshy area off from the Everly place in the western part of the lake.
5- It does not appear that Goose Lake went entirely dry at any time from 1846 to 1854. The conclusions regarding the location of the different routes used in this period indicate a minimum lake elevation of 4694 feet. For this elevation Goose Lake would have had a maximum depth of 4 feet and an area of 40,000 acres.
6- The date of the minimum stage of Goose Lake during this period is later than 1849 and earlier than 1854. Ingalls' statements and general tradition make 1852 the most probable minimum year.

RESULTS AFTER 1900

In the early 1900s there was interest in a proposed project to lower the rim of Goose Lake and divert water to the Pit River. Engineering investigations were made by the U. S. Reclamation Service. Soundings of the lake were made by S. G. Bennett. As the lake was navigable, title to the land in the lake bed in each state was ceded to the United States by the legislatures of California and Oregon. Bennett's map of Goose Lake was the most tangible item resulting from this work. The lake was one foot below its rim at the time of Bennett's work and his soundings were reported in depths below the rim.

Some investigations were made by the California State Water Commission in 1912. There were followed by a more complete report on Goose Lake which was included in the "Report on Pit River Basin" in 1915 by O.W. Peterson. In this report it was estimated that a drainage cut 20 miles long would lower the lake 26 feet below its then outlet and could provide an annual water supply of 150,000 acre feet.

Bulletin 41 of the California Division of Water Resources, Pit River Investigation, 1933, contains comments on the past and recent stages of Goose Lake. Since 1945 additional investigations have been made by the State of California as a part of its state wide water resources work.

OVERFLOW CHANNEL FROM GOOSE LAKE

When Goose Lake reaches a sufficiently high stage it overflows to Pit River. Such overflows have occurred for only a few brief periods in the last 100 years. Some early records are expressed in the elevation of the lake below its rim so that the determination of the elevation of the rim is required for the interpretations of these records.

Overflow occurs over a broad flat ridge between Goose Lake and the head of Pit River. The overflow channel is small and winding and the controlling elevation for overflow cannot be determined by eye. Some past surveys have not extended along the overflow channel far enough to reach the controlling elevation.

Bennett's 1904 map (U. S. Bureau of Reclamation) bases the contours in the lake on the depth of the lake at its overflow elevation. He found the lake one foot below its rim but did not leave any references from which his elevations could be reproduced. The writer has made observations of the depth of area covered by Bennett's soundings which could be correlated with present elevations. Five such results gave a mean elevation of the rim, as used by Bennett of 4716 feet, present datum, as the most probable value for the elevation of the rim used by Bennett.

Levels to the outlet of Goose Lake were run on Oct. 6, 1955 by Mr. Kenneth N. Phillips of the U. S. G. S. He found the elevation of the bottom of the shallow cut in the rim, at the point he considered to be the rim, to be 4715.2 feet, datum of 1929.

Additional levels in this area were run by the California Department of Water Resources in 1959; a high elevation of 4716 feet was found in the outlet channel at a point somewhat north of the crest of the ridge across the outlet area. This survey also found little variation in the elevation of the outlet channel for a distance of over 1/2 mile over the crest.

Based on these results an elevation of overflow from Goose Lake of 4716 feet, present datum, has been accepted and used in the writer's work on Goose Lake.

OVERFLOW FROM GOOSE LAKE

There are different accounts of the times at which Goose Lake has overflowed to Pit River. The following discussion is limited to overflow during historic time.

The earliest report found by the writer is that by Symons in 1877 who states that overflow had occurred eight years previously. This would be in 1869. This result was used in U. S. G. S. Water Supply Paper 220 in 1908, and Water Supply Paper 363 in 1914. It was also used by Russell in 1882. Symons and Russell did their field work close enough to this reported time of overflow to have secured accounts from still living local residents.

The 1915 report on Pit River by Peterson states that overflow occurred in 1868. Mr. C. E. Grunsky, Asst. State Engineer in California from 1878 to 1884, has reported overflow in 1868.

A precipitation record for this period was secured at Fort Bidwell. This record shows a precipitation of 35.70 inches in 1866-67, 31.40 inches in 1867-68 and 8.43 inches in 1868-69. From these records and other sources Kenneth N. Phillips of the U. S. Geological Survey has concluded that the reported overflow of Goose Lake occurred in 1868 rather than in 1869.

Mr. Phillips' conclusion has been accepted by the writer. The precipitation at Fort Bidwell in 1867-68 was about double the mean for the 74 years of record there and would have resulted in a material rise in Goose Lake. The below average precipitation in 1869 would not be expected to maintain the lake at the elevation it may have reached in 1868.

It has been concluded that Goose Lake reached its overflow elevation of 4716 feet in 1868 but did not rise high enough to cause any material amount of overflow. Goose Lake probably fell in 1869 from 1 to 1 1/2 feet below its 1868 elevation. It probably rose about 3 or 4 feet from 1867 to 1868 and a similar amount from 1866 to 1867.

The 1895 report of the California Commissioner of Public Works includes a report by Manson and Grunsky relating to Goose Lake in which it was stated "It is quite probable that no water from this part of its watershed has reached Sacramento River since 1862." There is a similar statement in the 1912 report of the California State Water Commission. Grunsky repeated the statement regarding overflow in 1862 in the <u>Transactions of the Commonwealth Club</u> (Volume II, no. 2, Dec. 1926). These statements regarding overflow in 1862 do not include support for this conclusion. Settlement around Goose Lake had not begun in 1862 and no reference to overflow in that year has been found in the early reports. Overflow could have occurred in 1862. However, as Goose Lake was relatively low as late as 1854, overflow by 1862 would require a more rapid build up of storage in the lake than would be expected even though 1861-62 was one of the years of largest runoff and may have been the year of maximum runoff in northern California since settlement had begun. It is concluded that Goose Lake did not overflow in 1862 and an elevation of 4707 is estimated to have been as high as the lake probably rose in that year.

Overflow in 1871 is reported in Bulletin 41 of the California Division of Water Resources, <u>Pit River Investigation</u>, and in 1875 in <u>Achowawi Geography</u> by Fred B. Kniffen (University of California Publication in American Archeology and Ethnology, 1928). Neither of these results are supported by other references which the writer has found and they have not been accepted. Overflow in these years would disagree with the elevations derived from the meander survey and the account by Powers.

The reported overflow in 1898 in Bulletin 41 also lacks other support. No actual records of the elevation of Goose Lake from 1887 to 1904 have been found and overflow might have occurred in 1898. As 1898 is within the period when Louers is reported to have started to cut the rim of the lake, the lake would have been relatively high. If any substantial overflow occurred Louers would not have needed to make his cut. It has been concluded that Goose Lake may have reached elevation 4714 feet but did not overflow in 1898.

There is no other support for the overflow in 1910 reported by Davis in "Lakes in California" in the Calif. Journal of Mines and Geology, 1933-34. This was within the period when Goose Lake was used to transport settlers from the end of the railroad to Lakeview and the location of the docks indicate that the lake was at a relatively high stage. Any overflow in 1910 would have attracted enough interest to have been recorded. An elevation in 1910 of 4713 has been assumed.

The preceding discussion leaves only the years 1868 and 1881 in which overflow from Goose Lake has occurred which are adequately supported. Overflow in these two years has been accepted. All reports on overflow either omit comments on its amount or mention that it occurred only during short periods of strong north winds. The effect of such winds is observable at lower lake stages when the water may be blown over substantial areas at its south end. In any estimates of the water supply of Goose Lake, no account needs to be taken of the volume of overflow which may have occurred since 1840.

FLUCTUATIONS OF GOOSE LAKE 1831 TO 1960

The available information on the elevation of Goose Lake from 1831 to 1960 has been plotted in Fig. 6. The sources of the earlier results shown are also indicated. These have been discussed.

There are some relatively long periods during which no records are available. Rather than connecting the available records by a straight line representing a uniform rate of fluctuation, these periods have been interpolated by using the derived indices of precipitation for the intervening years. Such interpolation is not a substitute for actual records but is considered to represent a more probable actual fluctuation than would be secured by a straight line variation.

Figure 6 is considered to represent the best results for the fluctuations of Goose Lake which can be derived from the available information. While there are omissions and some uncertainties in these results, the fluctuations shown in Fig. 6 are considered to represent a generally correct picture of what has happened on Goose Lake for the period shown.

The results shown in Fig. 6 are the historical fluctuations. The lake elevations in recent years are not directly comparable with those prior to 1900 as the consumptive use of irrigation supplied by the tributary streams has reduced the natural inflow to the lake. An attempt to allow for the effect of such depletion is made later.

The only available precipitation record that may be applicable to Goose Lake for the years 1854 to 1868 is that at Sacramento. From 1855 to 1862 the mean index of precipitation at Sacramento was 96 per cent of the long time mean. In this period only 1862 had more than average precipitation. On this basis Goose Lake probably rose slowly from 1854 to 1862 but the inflow in 1862 would not be expected to have been excessive enough to have raised the lake to its overflow elevation.

The total indicated rise from 1854 to 1868 was 18 feet. Based on the precipitation at Sacramento, the larger part of this rise would have occurred in 1862 and in 1868 with smaller gains in 1860, 1865 and 1867. In 1864 the

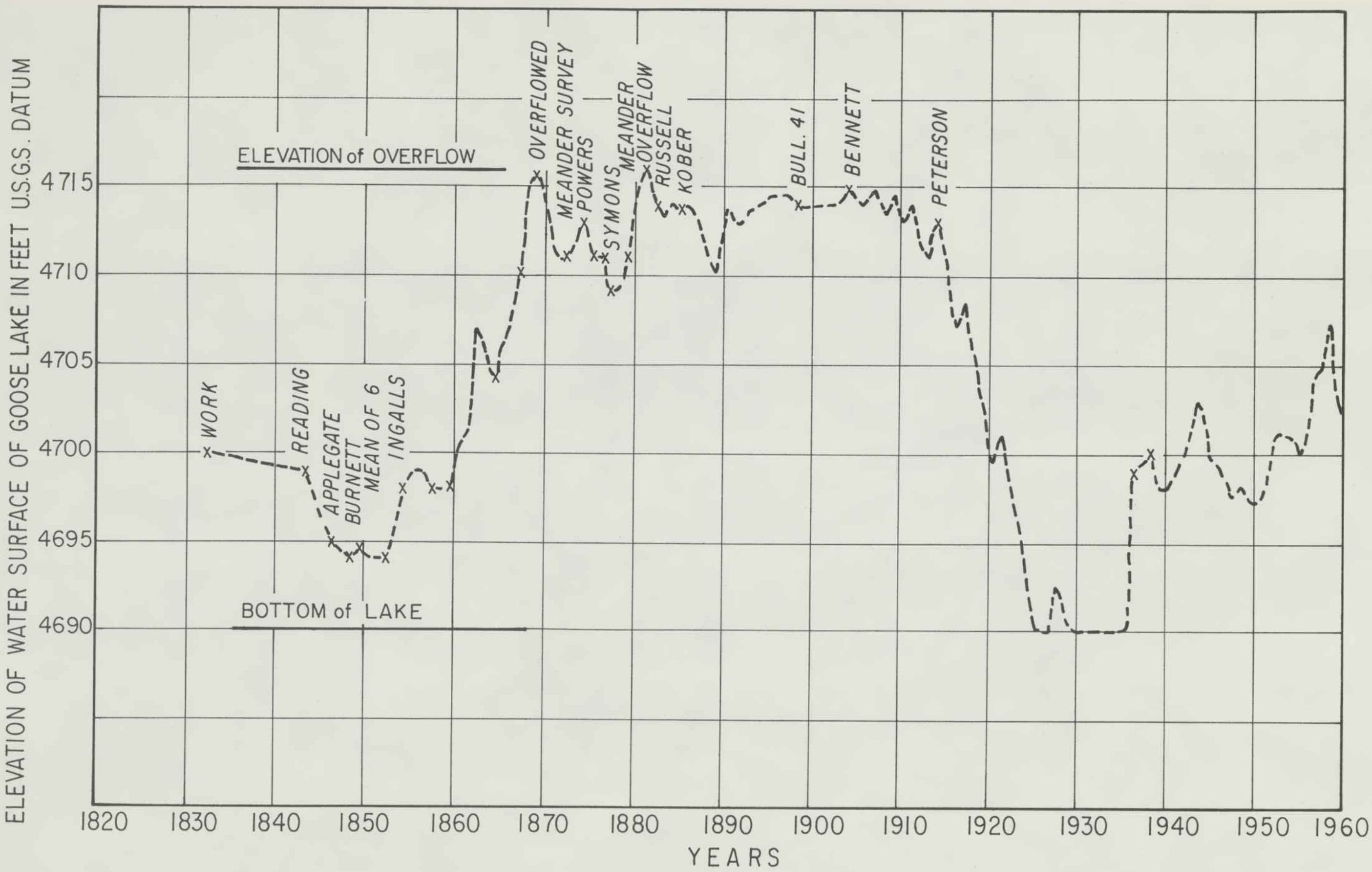


FIG.6 ELEVATION OF GOOSE LAKE, 1831 TO 1960

precipitation index was 40 per cent. Lowering probably occurred in 1857, 1864 and 1868.

The 18 foot rise in Goose Lake in the 14 years from 1854 to 1868 has been distributed on Fig. 6 on the basis of the preceding comments. Two-thirds of this rise has been assigned to 1862 and to 1868; in the other years the lake is shown as having raised or lowered by small amounts.

From 1885 to 1898 direct records have not been found. The Lake County Examiner of April 17, 1899, reported that Goose Lake covered almost 300 square miles although there had been little inflow in 1898. The fluctuations in this period shown on Fig. 6 were based on the use of the precipitation indices shown in Table 1 for this area.

Direct records of the elevation of Goose Lake from 1914 to 1925 have not been found. In these eleven years the lake lowered from 4713 feet to dryness at 4690 feet. The mean precipitation during this period was 80 per cent of the long time mean with only 2 years exceeding 100 per cent. The reduced rainfall on the lake increased the net depth of evaporation. This, with the effect of increased diversion for irrigation, probably resulted in lowering the lake as much as three feet per year in the years having below average precipitation. The fluctuations of the lake shown for this period on Fig. 6 are based on these assumptions.

The preceding discussion has developed all of the records of the elevation of Goose Lake that the writer has been able to find. The interpolations used between times of direct records have been shown on Fig. 6 as definite elevations. As previously mentioned, such specific results should not obscure the basic lack of direct observations in such interpolated periods. These specific results should represent an improvement over a straight line variation between times of record but are only a partial substitute for more frequent records.

WATER SUPPLY OF GOOSE LAKE 1831-1960

The water supply of the Goose Lake drainage area can be computed from the fluctuations of the lake, evaporation from and rainfall on its area for the period before depletion of the inflow began to be a factor. Comparisons for the period after about 1900 require that allowance be made for the consumptive use for irrigation.

In computing the runoff of the drainage area of Goose Lake from the record of the lake, surface outflow can be neglected. The infrequent and small amounts of such outflow are too small to require consideration. Subsurface outflow can also be accepted as zero as the lake occupies the bottom of a closed basin from which any seepage would have a long distance to travel to reach any available outlet. The lake bed deposit is also relatively fine and generally impervious.

Some inflow may occur from springs in the lake bed. Any such springs have only a minor amount of total discharge; this is shown by the condition of the lake bed when the lake went dry from 1926 to 1931. In deriving the total runoff of the drainage area of the lake it is unnecessary to distinguish between surface and subsurface inflow.

Evaporation from the lake is the main item in the disposal of the inflow.

Direct records of the inflow to Goose Lake are fragmentary as several of its inflow streams have not been measured. Based on results from other similar lakes in the western Great Basin, the mean annual gross evaporation from Goose Lake has been estimated to be 3.5 feet. The basis for this estimate has been discussed previously in this report.

The mean of the precipitation at Lakeview and Alturas has been used as the average precipitation on Goose Lake. The annual mean for these stations in use by the U. S. Weather Bureau in 1960 was 14.25 inches at Lakeview and 12.53 inches at Alturas. Both records are available for most of the years since 1914. Where direct records are not available the precipitation indices previously discussed have been used.

The inflow to Goose Lake has been reduced since settlement of the adjacent lands by the consumptive use for irrigation; by the evaporation from constructed reservoirs; and by additional consumptive use on areas marginal to the lake resulting from spreading of waste waters from irrigation. Estimates of the areas irrigated at different times have been made based on the U. S. Census of Irrigation and water right records. The average consumptive use for the climatic and crop conditions in this area has been estimated to be 2 acre-feet per acre. The evaporation from constructed reservoirs has been estimated to be 5000 acre feet per year since Drews Reservoir was constructed, with a reduction for the years 1926-35 when less storage was secured. The additional consumptive use from marginal areas has been estimated to be 10,000 acre feet per year under present conditions. These results and their increase to their present amounts are shown in Table 4.

The individual items used in computing the runoff of the drainage area of Goose Lake have been combined in Table 5. The time intervals used were selected to correspond with the years in which records of the elevation of Goose Lake are available. The results begin with the end of 1831 when the elevation of the lake is estimated from the account of John Work.

The method of computation is shown by the column headings in Table 5. The mean area of the lake for any period is the average of the area at the beginning and end of the period. The precipitation on the lake is based on the Lakeview-Alturas records since 1914 and precipitation indices lack to 1853. Prior to 1853 the mean annual precipitation was used as there are no records from which variations from the mean can be derived. The gross evaporation is computed as the mean area of the lake times 3.5 feet annual depth of evaporation. The change in volume of storage in the lake is the difference at the beginning and end of the period. The mean annual inflow to Goose Lake is the net evaporation from the lake plus or minus any change in the volume of storage in the lake.

The results for the inflow to Goose Lake (Col. 13) have been increased by the estimated amounts of consumptive use for different periods (Col. 14) to give the estimated total mean annual runoff for each period in Col. 15 and the total for each period in Col. 16.

The estimated mean annual total runoff for the 129 year period shown in Table 5 is 253,500 acre feet.. While it is estimated that the depletion at present is about one-third of this total runoff, for the entire period the estimated depletion represents only about one-eighth of the total.

In Col. 17 of Table 5 the total runoff for each period has been expressed

Table 4 Estimated Depletion in the Inflow to Goose Lake Resulting from Irrigation

Results are in Acre-feet except as shown

Period	Estimated Mean Area Irrigated Acres	Estimated Consumptive Use for Irrigation	Estimated Evaporation from Constructed Reservoirs	Estimated Consumptive Use from Marginal Areas	Estimated Total Depletion
1882 - 1889	5,000	10,000			10,000
1890 - 1904	10,000	20,000			20,000
1905 - 11	15,000	30,000			30,000
1912 - 1919	20,000	40,000	5,000		45,000
1920 - 25	25,000	50,000	5,000	7,500	62,500
1926 - 35	30,000	60,000	3,500	5,000	68,500
1936 - 60	35,000	70,000	5,000	10,000	85,000

Table 5 Computed Runoff of Drainage Area of Goose Lake 1832 to 1960

Areas are in Acres - Volumes are in 1000 acres-feet - Elevations and Depths are in Feet

Column 1 Period Years-Inclusive	2 Years in Period	3 Elevation of Lake at End of Period	4 Area of Lake at End of Period	5 Mean Area of Lake during Period	6 Volume in Lake at End of Period	7 Total change in Volume in Lake during Period	8 Mean Precipitation for Period: Index	9 Mean Precipitation for Period: Depth	10 Total Mean Annual Precipitation on Lake	11 Mean Annual Gross Evaporation	12 Mean Annual Change in Storage	13 Mean Annual Inflow to Goose Lake	14 Mean Annual Depletion	15 Mean Annual Total Runoff	16 Total Runoff for Period	17 Total Runoff Per Cent of Mean for Period	18 Total Runoff Per Cent Departure from Mean	19 Accumulated Departure from Mean in Per Cent of Annual Mean
1831		4700	92		469.6													
1832-43	12	4699	87.4	90.2	380.0	-89.6			102	315	-7	206		206	2472	81	-221	-221
1844-46	3	4695	55	71.2	79.5	-300.5			74	248	-100	74		74	222	29	-213	-434
1847-52	6	4694	38.4	46.7	32.6	-46.9			52	163	-8	103		103	618	41	-354	-788
1853-54	2	4698	83.5	61.0	294.4	+261.8	143	1.60	98	214	+132	248		248	496	98	-4	-792
1855-59	5	4698	83.5	83.5	294.4	0	78	.87	73	292	0	219		219	1095	86	-70	-862
1860-62	3	4707	114	98.8	1140.0	+845.6	129	1.44	143	348	+282	487		487	1461	192	+276	-586
1863-64	2	4704	107.6	110.8	842.0	-298	50	.56	62	386	-149	178		175	350	69	-62	-648
1865-69	5	4716	124	115.8	2232.7	+1390.7	120	1.34	155	404	+278	527		527	2635	208	+540	+108
1870-71	2	4711	119	121.5	1580.0	-652.7	56	.63	76	425	-326	23		23	46	9	-182	-290
1872-74	3	4713	122	120.5	1840.0	+260	109	1.22	147	422	+87	362		362	1086	143	+129	-161
1875-78	4	4709	117	119.5	1350.0	-490	91	1.02	122	419	-122	175		175	700	69	-124	-285
1879-81	3	4716	124	120.5	2232.7	+882.7	114	1.28	154	422	+294	562		562	1686	222	+366	+81
1882-87	6	4713	122	123	1840.0	-392.7	92	1.03	127	430	-65	238	10	248	1488	98	-12	+69
1888-89	2	4710	118	120	1470.0	-370	66	.74	89	420	-185	146	10	156	312	62	-76	-7
1890-1904	15	4715	123	120.5	2103.0	+633	109	1.22	147	422	+42	317	20	337	5055	133	+495	+488
1905-11	7	4714	122	122.5	1980.0	-123	111	1.24	152	428	-17	259	30	289	2023	114	+98	+586
1912-13	2	4711	119	120.5	1580.0	-400	69	.77	93	422	-200	129	45	174	348	69	-62	+524
1914	1	4713	122	120.5	1840.0	+260	117	1.31	158	422	+260	524	45	569	569	224	+124	+648
1915-19	5	4702.5	102	112	700.0	-1140	84	.94	105	392	-228	59	45	104	520	41	-295	+353
1920-22	3	4698.5	85	92.5	337.0	-363	103	1.15	106	326	-121	99	62	161	483	63	-111	+242
1923-25	3	4690	0	42.5	0	-337	72	.81	34	149	-112	3	62	65	195	26	-222	+20
1926-27	2	4692.5	6.4	3.2	1.1	+1.1	92	1.03	3	11	+1	9	68	77	154	30	-140	-120
1928-29	2	4690	0	3.2	0	-1.1	72	.81	3	11	-1	7	68	75	150	30	-140	-260
1930-35	6	4690	0	0	0	0	77	.86	0	0	0	0	68	68	408	27	-438	-698
1936	1	4699	87.4	43.7	380.0	+380	107	1.20	53	153	+380	480	85	565	565	223	+123	-575
1937-43	7	4703	104	95.7	740.0	+360	111	1.24	131	336	+51	256	85	341	2387	134	+238	-337
1944-51	8	4698.5	85	94.5	337.0	-403	96	1.07	101	331	-50	180	85	265	2120	104	+32	-305
1952	1	4701	95	90	560.0	+223	168	1.88	169	315	+223	369	85	454	454	179	+79	-226
1953-55	3	4700	92	93.5	469.6	-90.2	100	1.12	105	327	-30	192	85	277	831	109	+27	-199
1956-58	3	4707.5	114	103.0	1190.0	+720.4	135	1.51	156	360	+240	444	85	529	1587	209	+327	+128
1959-60	2	4702	100	107.0	650.0	-540	82	.92	99	374	-270	5	85	90	180	36	-128	0
Total	129																	
Annual Mean									105.5	325.5	+1.5		32.6		253.5		0	

as a percentage of the mean for the 129 year period. Such percentages represent a more convenient unit for comparison with the mean for different periods and for comparisons with variations on other lakes.

There are five periods in Table 5 in which the derived runoff is more than twice the 129 year mean. These are 1865-69, 1879-81, 1914, 1936 and 1956-58. Individual years in the three periods of more than a single year may have exceeded the runoff in 1914 and 1936. What may have been the maximum runoff in the entire period in 1862 is obscurred in the mean for the three years 1860-62. The results in Table 5 indicate that single years may have a runoff as large as 250 per cent of the long time mean.

The procedure used in deriving the results in Table 5 is mathematically sound but the results can be no better than the supporting data on which they rest. While the numerical results for some of the different periods may be open to question, the overall results are considered to represent a generally consistent picture of the extent of the runoff of the drainage area of Goose Lake and its variation over the periods shown. Chance errors should be self balancing.

The mean annual runoff derived in Table 5 of 253,500 acre-feet represents an average of 231 acre-feet per square mile from the drainage area of 1100 square miles. This is equivalent to an average of about 4.3 inches depth of annual runoff.

One of the main purposes of the writer's work on Goose Lake has been to determine whether the period in the 1840's had a more severe deficiency in water supply than any similar period since. Col. 17 of Table 5 is the result.

For nine years from 1844 to 1852 the mean annual runoff of the drainage area of Goose Lake derived in Table 5 was 93,000 acre feet equal to 37 per cent of the 129 year mean. For the 13 years 1923 to 1935 the derived mean annual runoff was 70,000 acre feet equal to 28 per cent of the 129 year mean. These results indicate that for Goose Lake the water supply deficiency in this later period was both more severe and lasted longer than that of the earlier period.

In Column 19 of Table 5 the results in Col. 17 have been expressed in their accumulated departures from the mean for the 129 year period. These accumulated departures have been plotted in Figure 7. These results show the trends that have occurred over this period. The accumulated variations from the mean are quite marked. In the first 28 years the runoff averaged 69 per cent of the 129 year mean. This was followed by 55 years in which the average runoff was 127 per cent of the mean. The next 21 years had an average runoff of 36 per cent of the mean and the remaining 25 years, 128 per cent. The wide range of these variations over such long periods illustrates the difficulty of making use of this type of water supply. The use of a larger proportion of the long time mean supply than can be met during long periods of deficiency requires either larger carryover storage than may be feasible, or crop conditions where the area irrigated in any year can be adjusted to the water supply available in that year.

The results in Table 5 and Figure 7 are considered to represent a reasonably correct picture of the water supply of the drainage area of Goose Lake for the period covered. The extent to which various parts of these results rest on insufficient records requiring interpolations and estimates

FIG. 7 ACCUMULATED DEPARTURE FROM THE MEAN OF RUNOFF OF DRAINAGE AREA OF GOOSE LAKE

prevents these results from being more than such a picture. The main item in the resulting runoff is the area of the lake and the resulting evaporation. It is considered that the fluctuations of the lake as shown in Fig. 6 are sufficiently representative of the actual results so that the area of the lake for different parts of the 129 year period are correct within an acceptable percentage of error. Any error in the depth of mean annual evaporation would have an equal relative effect on all parts of the period.

A comparison of the precipitation indices in Col. 8 of Table 5 with the percentage of the mean annual runoff in Col. 17 shows some periods in which the runoff does not reflect the character of the precipitation. This result is considered to be due mainly to the inadequacy of the records of precipitation from which the precipitation indices were derived, particularly prior to 1914.

INFLOW TO GOOSE LAKE PRIOR TO 1831

The first report on Goose Lake in 1832 represents a fairly low stage from which the lake continued to lower until 1852. The elevation of the lake in 1831 can be used as a base from which some conclusions can be drawn regarding the inflow in preceding years.

The mean annual runoff derived in Table 5 will supply the mean annual net evaporation on an average lake area of 108,000 acres. For such an area the lake would be at elevation 4704.5 feet and would contain 900,000 acre-feet. The description of the lake in 1831 indicates that it had reached an elevation 12.5 feet below such an average area at the end of 1831 with an area of 92,000 acres and a volume of 470,000 acre feet. On this basis for some period prior to 1831 the inflow had been less than the 129 year mean. The period in which the lake had lowered to its 1831 elevation may have been one of short duration and severe shortage or it may have been one of greater length and less annual deficiency.

There are some clues to what the elevation of Goose Lake may have been at some times prior to 1831. There are undated Indian traditions relating to earlier drying of the lake. Kniffen (Achumawi Geography, B. Kniffen, Univ. of California Publ. in Amer. Archeology and Ethnology, 1928) quotes an Indian tradition that Goose Lake had been dry five times. He also reports that when the lake became dry in 1926, heaps of obsidian chips were found within the lake bed area indicating that at some lake stages, Indian camps were used there.

Mr. Everly, a long time resident on the west side of Goose Lake, has told the writer that there were stumps of trees 75 to 80 years old exposed one-fourth mile from the west shore at his place. This is the area in which trees were growing in 1955 and where the lake bed remained moist in 1926.

The conclusion is supported that other relatively low stages of Goose Lake occurred prior to 1832 which were as low or lower than that reached in 1852. They may have been as low as that reached in 1926, although the use of tributary streams for irrigation prevents conditions in 1926 being a direct comparison with earlier periods.

Some of the evidence regarding earlier low stages is tangible though general. Arrow heads around spring areas in the lake bed indicate camps or concentration of hunting at remaining water holes. Stumps in the lower elevations of the lake bed show stages below the elevation of the stumps for as long as the age of the tree.

There is general support for a conclusion that Goose Lake had periods of reduced inflow prior to 1832 of equal or greater severity than that from 1840 to 1860. These deficient periods may have extended over longer periods than those that have occurred since.

Goose Lake may also have had extended periods during which its inflow exceeded the mean for 1831 to 1960. To maintain the lake at its present elevation of overflow would require an average inflow of 300,000 acre feet per year. This is about 18 per cent more than the average runoff for the last 129 years.

There are beach lines around Goose Lake at about the elevation of its present overflow. These are sufficiently extensive in some areas to have been used as the grade for the present railroad. These beaches indicate that at some periods in the past Goose Lake has received sufficient inflow to maintain its elevation at or near the present rim. There is no presently known basis for fixing the time when such overflows may have occurred.

QUALITY OF WATER IN GOOSE LAKE

The available records relating to the quality of the water in Goose Lake consist of general early comments relating to its taste or smell and chemical analyses at later dates. The general comments in the emigrants' accounts from 1849 to 1852 described the water of Goose Lake as generally unusable. This confirms information on the low stages of the lake in these years. Some comments termed it "almost putrid, nauseous to the taste", and "impregnated with salt." By 1854 Ingalls (Report of Rufus Ingalls. Exec. Doc., House, 1st Sess, 34th Cong, 1855-56) describes the lake as "a most lovely sheet of fresh water, with myriads of shore birds and water fowl around it." Accounts in 1877 and 1886 describe the water as "much better than ordinary sink water", and "slightly alkaline to the taste."

The available analysis of the water of Goose Lake are shown in Table 6. The first two are samples taken before the lake became dry in 1926. The sample in 1912 may have been more carefully analysed and can be accepted as representing the total tons of solubles in Goose Lake in that year.

The 1941 sample was collected from the dredger cut at Willow Creek in May when both Willow and Lassen Creeks were at their higher stages. Their inflow had not become mixed with the lake water and this sample was not representative of the lake average. The 1953 sample taken when the lake was still low shows a reduction in total tons of solubles from 1912 of nearly 60 per cent. Later samples show even less total tons of solubles.

The ten analyses from 1953 to 1958 give an average total content of solubles in Goose Lake of 940,000 tons. This is 36 per cent of the total content found in 1912. These individual samples vary from 765,000 to 1,100,000 tons. The highest tonnage is indicated by the 1953 sample taken at the south end of the lake away from the major sources of inflow. The lowest tonnage is shown by two samples, 1954 and 1958 taken nearer the eastern sources of inflow before the seasonal mixing may have taken place. The mean tonnage of all of the ten analyses is probably representative of the total soluble content of Goose Lake in these years.

The analyses in Table 6 since 1953 naturally raises the question of what has become of the other 1,500,000 tons of solubles that were in Goose Lake prior to its becoming dry in 1926.

During the period from 1926 to 1934 when Goose Lake was practically dry, newspaper reports describe dust storms blowing across the lake bed and dust clouds moving to the south. The writer encountered one such storm when passing by the lake in 1931. Such wind movements could and apparently did remove much of the salts deposited on the lake bed when the lake became dry.

It is unfortunate that more samples were not secured and analysed as Goose Lake lowered to dryness in 1926 and as it refilled after 1935. An unusual opportunity to secure a more complete accord of what happens to the soluble contents of a lake when it goes dry and refills was lost when such samples were not secured. Such results might aid in an understanding of what happened to the solubles in the water of Lake Lahontan as the different parts of its area became dry.

Table 6 Analyses of the Water of Goose Lake

Date of sampling	Elevation of Lake feet	Volume of Lake Acre-feet	Total Solubles Parts per Million	Total Solubles in Lake in Tons	Sample Taken by or Reference	Location of Sample
8-23-1904	4715	2,160,000	1143	3,360,000	Bennett	Pre-Drying in 1926
5-12-1912	4712.5	1,800,000	1063	2,600,000	W.S.P. 363	
5-15-1941	4699	380,000	381	200,000	Harding	47N 14E-16
9-16-1953	4701.5	610,000	1340	1,100,000	California Dept. of Water Resources	45N 13E-3
5-15-1954	4701.5	610,000	868	720,000		45N 13E-1A
9-4-1957	4703.7	820,000	826	920,000		46N 13E-34
9-4-1957	4703.7	820,000	824	918,000		48N-13E 32
8-13-1955	4700	440,000	1485	890,000	Harding	State Line West
8-13-1955	4700	440,000	1520	910,000	"	West side
8-23-1956	4704.5	900,000	835	1,020,000	"	State Line West
7-9-1958	4704.5	900,000	840	1,030,000	"	McGinty Pt
7-9-1958	4704.5	900,000	750	915,000	"	State Line West
7-9-1958	4704.5	900,000	625	765,000	"	State Line East

EAGLE LAKE

INTRODUCTION

Eagle Lake is within the Great Basin. It is at a higher elevation and is not a remnant of Lake Lahontan. It is on the upper part of the drainage area of Willow Creek about 15 miles northwest of Susanville in Lassen County, California.

At its higher stages Eagle Lake has an area of nearly 30,000 acres and a maximum depth of about 100 feet. It is at elevation 5,100 feet.

In geological terms Eagle Lake is relatively recent. It appears to have been formed by a lava flow across the course of Willow Creek, a tributary of Susan River and Honey Lake. The age of Eagle Lake, and the amount, if any, of percolation through or under the lava flow are matters on which past conclusions have differed. The amount of any such leakage is insufficient to affect the usefulness of the Eagle Lake as a climatic indicator.

The natural conditions affecting Eagle Lake were undisturbed until 1923. Irrigation around the lake had been negligible in extent and other developments within its drainage area had been insufficient to affect its water supply. In 1923 the lake was tapped by a tunnel to Willow Creek. Diversion continued intermittently until 1935; for these years the fluctuations of the lake do not reflect the balance between inflow and evaporation. While adequate records of this diversion were not kept, its amount can be estimated from the partial measurements that were made. Since 1935 the tunnel has been closed and Eagle Lake is again reaching a balance between its inflow and its evaporation.

Direct records of the fluctuation of Eagle Lake begin with the meander survey of 1875. Occasional records are available until 1915. Since 1915 generally adequate records have been secured.

Eagle Lake receives sufficient precipitation around parts of its margin to sustain forest growth. The lake rose from 1880 to 1915 and submerged an extensive area around its southern shore on which there were growing trees. This area was again exposed by the lowering of the lake since 1917. The stumps of these trees were preserved in the 1930's so that ring counts of their age could be made. The writer made age counts on many of these stumps and determined the elevation of the ground on which each tree had grown. From these observations, the period of time during which the lake was below the elevation of the ground on which the tree had grown was determined. The lake had not risen above such elevations during the life of the tree.

These tree records indicate the maximum stages that Eagle Lake has reached during the past 400 years as trees of such an age are growing around the lake just above its 1915 high water elevation.

The writer's work on Eagle Lake began in 1915 and has continued intermittently to date. As in all his work on the enclosed lakes of the western Great Basin the writer has had much cooperation and assistance from many individuals and organizations. The sources used directly in this report are cited where they have been used. Particular mention should be made of the late Joseph Grinnell whose early work on the natural history of this area called attention to what could be learned from the "stump forest" at Eagle Lake. To all of those who have assisted in this work the writer extends his thanks.

DATUM USED ON EAGLE LAKE

The early Land Office and topographic surveys of Eagle Lake left no bench marks which can be defined in terms of present datum. In his work on the tunnel project, Leon Bly set a gage in 1915 which was generally used until U. S. G. S. datum results became available. All results used in this report are expressed in terms of the present U. S. G. S. datum. The zero on the Bly gage had an elevation in terms of the present U. S. G. S. datum of 5016.77 feet.

AREA AND CAPACITY

Like other similar lakes there were early reports that Eagle Lake was very deep. The first soundings known were made by Bly in 1915. A more complete survey was made by the State Department of Water Resources in 1957 and additional work was done by the State Department of Fish and Game in 1961. Composite area and capacity curves using all of these results are shown in Figure 8.

INDIAN LEGENDS REGARDING EAGLE LAKE

Like most similar areas there are Indian legends regarding the past history of Eagle Lake. Some of such legends relate to the lake having been dry at its narrows at times prior to white settlement. There are two narrows in Eagle Lake. The more southerly one is off from Pelican Point and the more northerly one is off from Buck Point. The southern narrows is deeper than the northern and the Indian legends should be applicable to the northern narrows. The lake area south of the southern narrows includes the deepest part of the lake. The main tributary of the lake, Pine Creek, enters the lake on the north.

The minimum elevation of the lake bed in the northern narrows is about 5088 feet. This is 3 feet lower than the minimum lake elevation of record reached in 1937 and 11 feet lower than the elevation on which the lowest remaining stump grew. The lake may have lowered so that the northern narrows could be crossed by the Indians. The more probably date of any such lowering would be in or prior to the 1840's. Descriptive accounts of early explorers indicate a size and shape of Eagle Lake after 1850 extending through the northern narrows.

EARLY REPORTS ON EAGLE LAKE

The discovery of Eagle Lake is claimed by J. Goldsborough Bruff in 1850 while prospecting with Lassen in this area. James P. Beckwourth was in this area in 1845 and may have seen Eagle Lake. Bruff's 1851 map shows Eagle Lake with an oval shape without the actual irregular outline. Emory's 1857 map has a correctly shaped Eagle Lake.

The first Land Office surveys on Eagle Lake were made in 1875. It was visited in 1877 by Lt. T. W. Symons who describes the lake in the Annual Report of the Secretary of War for 1878. Symons states that a scheme was being talked about for bringing the water of Eagle Lake to the Honey Lake Valley. This

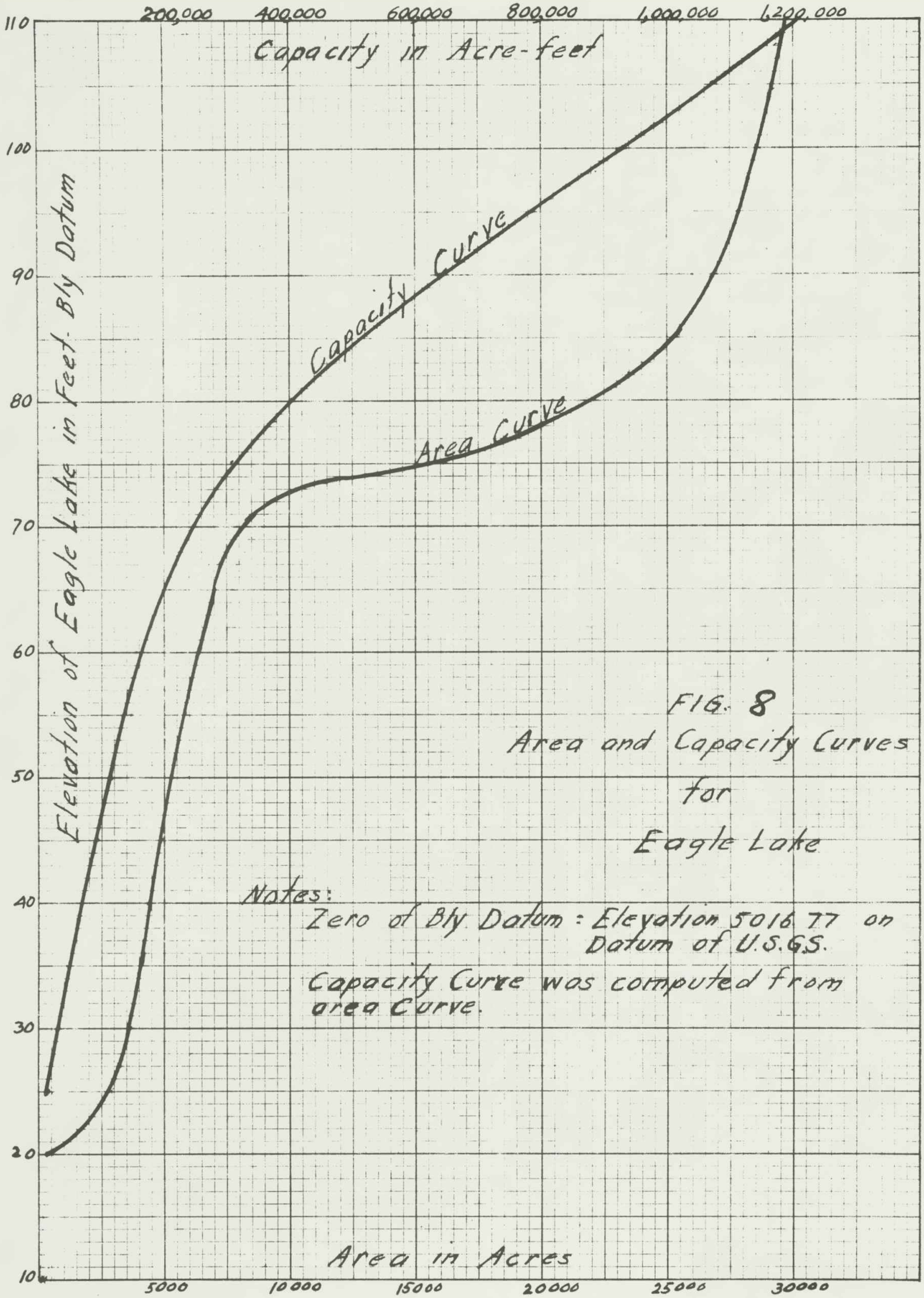


FIG. 8
Area and Capacity Curves
for
Eagle Lake

could have been the reason for the Land Office survey in 1875 before settlement had occurred around Eagle Lake.

Eagle Lake is shown on the map of the "Geographic Survey West of the 100th Meridian" (Wheeler Survey) in 1878 and is described by I. C. Russell (Monograph 11, U. S. G. S., Geological History of Lake Lahontan, 1885).

None of these early reports enable the elevation of Eagle Lake to be defined in terms of present datum except the 1875 U. S. Land Office meander of the lake. Some meander corners have been located. The extent of some of the bays shown on this survey enable one to define the probably elevation of the lake at the time of this survey. The most definite of these results is the extent of the bay on the north side of Pelican Point. Eagle Lake would need to be above elevation 5,111 to enable water to submerge the entrance to this bay and to fill it.

The Wheeler Survey map shows a small island on the outer part of Pelican Point. Levels were run to this area by the writer in 1935. From these results it has been concluded that Eagle Lake was at elevation 5,012 feet in 1877.

ELEVATIONS REPORTED BY LEON BLY

Leon Bly was the engineer and promoter of the plan to divert the water of Eagle Lake to Willow Creek for use in the Honey Lake Valley. His field work began in 1915. Bly sought all sources of information on the past stages of Eagle Lake. As there were no U. S. G. S. datum bench marks in this area in 1915, Bly established his own gage at Gallatin's and recorded his results in terms of the assumed datum of this gage. The zero of Bly's gage has since been found to have an elevation of 5,016.77 feet U. S. G. S. datum. Bly reported nine elevations of Eagle Lake from 1875 to 1915. His result for 1875 was 5,109 feet; this agrees with the writer's conclusion for the low water elevation in 1875. Bly identified elevations from statements of residents for 1900, 1904, 1911, 1913 and 1914. These have been used and are shown on Fig. 9.

EARLY DIVERSION PROJECTS FROM EAGLE LAKE

In 1875 the Lassen Flume and Land Co. (Merrill Project) started a tunnel to divert Eagle Lake to Willow Creek. The first Desert Land Act passed by Congress applied to the lands this project proposed to irrigate. The history of this project has been sought in contemporary newspaper accounts and reports. The lower portal of the tunnel and the inlet cut to the upper portal remain. This fragmentary information does not define the elevation of Eagle Lake at the time this project was active.

The Eagle Lake Land and Irrigation Co. had a project to pump from the lake over the low point in its rim to Willow Creek and Honey Lake Valley. The pump was installed in a cove on the eastern shore of the lake north of the later Bly Tunnel and just south of the inlet of the Merrill project. The foundation of this pump still remains. In 1935 some of the lumber used in the flume into which the pump discharged was along its alignment. The cut make in the ridge can still be traced. The so-called Hutchinson house built adjacent to the pump remained in 1935 but only the fallen frame remained in 1962. A lift of about

45 feet would have been needed to pump into this cut over the ridge. From the reports and newspaper accounts during the active period of this project it has been concluded that Eagle Lake was at elevation 5112.5 at its low point in 1892.

BLY PROJECT

In 1915 Leon Bly began work on the project to lower Eagle Lake by a tunnel to Willow Creek and to secure a water supply by reducing the area and evaporation from the lake. This project was later taken over and built by the Tule and the Baxter Creek Irrigation Districts. The tunnel was constructed and operated intermittently from 1923 to 1935. The financial failure of the project caused its abandonment.

Since 1915 generally adequate records of the elevation of Eagle Lake have been secured. These include records by Bly, by the Districts, and in recent years by the California Department of Water Resources. Since October 1956 the state has maintained a recording gage on the lake.

BIOLOGY OF EAGLE LAKE

Several reports have been made on the birds and fishes of Eagle Lake. These have included both scientific investigations and reports, and fanciful, popular accounts. Some of these sources include comments which can be interpreted in terms of the elevation of the lake at the time the field work was done. These results have been used as a general check on the more definite results available from other sources. The most extensive account is that in <u>Vertebrate Natural History of a Section of Northern California through the Lassen Peak Region</u>, University of California Publications in Zoology, Vol. 35, 1930, by Grinnell, Dixon and Linsdale.

FLUCTUATIONS OF EAGLE LAKE 1875-1960

The available records of the elevation of Eagle Lake from 1875 to 1960 have been plotted in Figure 9 to indicate the fluctuations of the lake during this period. For the earlier years when actual observations were infrequent the fluctuations between points of record have been interpolated on the basis of the indices of wetness applicable to this area. These indices have been previously discussed.

The fluctuations shown in Fig. 9 are the historical results. Prior to 1923 these reflect the relationship of inflow to evaporation from the lake. From 1923 to 1935 the lowering shown is the combined result of below average inflow and diversion through the Bly Tunnel. After 1935 the inflow and evaporation are on their pre-tunnel basis.

RESULTS BASED ON SUBMERGED TREES

The preceding discussion of the fluctuations of Eagle Lake since 1875 has been based on the observations of the elevation of the lake. Prior to 1875 other sources of information have to be used if the fluctuations are to

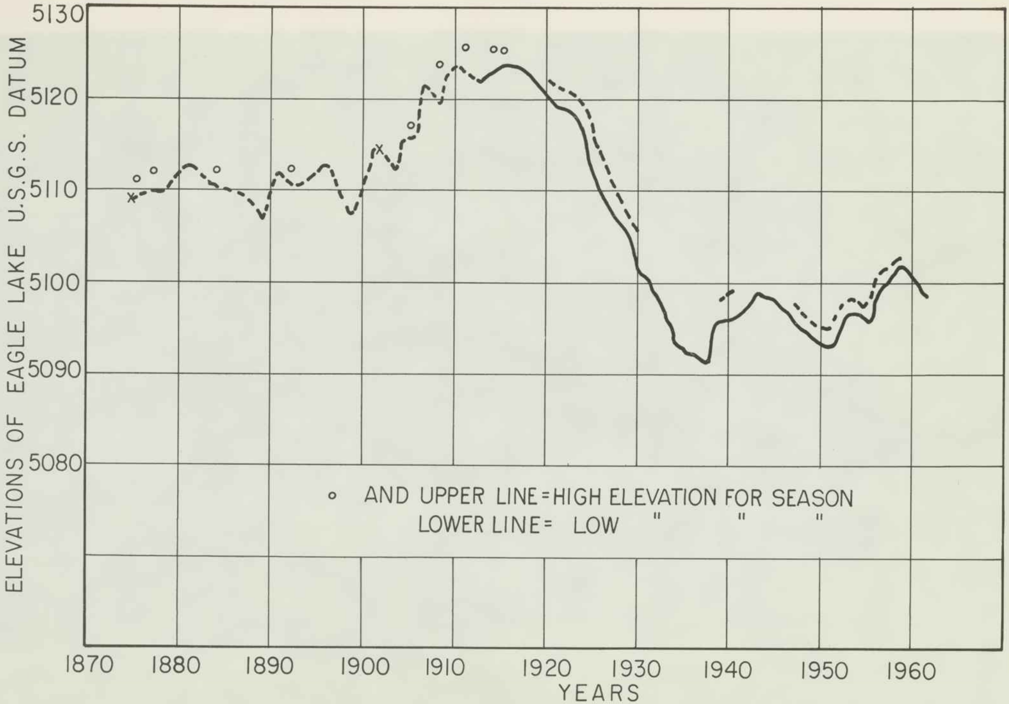


FIG. 9 FLUCTUATIONS OF EAGLE LAKE 1875 TO 1960

be derived. For Eagle Lake there is an extensive record left by the stumps of trees which grew prior to 1875 that were killed by the later rise of the lake. The forest growth on parts of the shore of Eagle Lake furnishes an unusually good record for interpreting past elevations of the lake.

The stub forest at Eagle Lake has been noticed and described in articles and reports since 1881. Definite attempts to correlate the age of these trees and the elevations of the ground on which they grew with the fluctuations of the lake were not made in any early reports found by the writer. Beginning in 1931 the writer made numerous counts of the annual rings of these stumps and determined the elevation at which they had grown. While decay had occurred by the 1930's, there were numerous stumps on which full ring counts could be secured. At present nearly all stumps have decayed to an extent which prevents securing similar results.

The formerly submerged portions of these drowned trees were preserved by the water during their period of submergence. They had generally broken off at about their depths of submergence. When the lake receded following its maximum stage in 1917, the stumps remained on the unwatered areas. By using the records of lake elevation in recent years, the year in which the lake rose so as to submerge the area on which a tree had grown could be determined. From these results the period equal to the age of the tree during which the tree grew could be derived.

The appearance of this stub forest in recent years is shown in Figures 10 to 15. Figure 10 is an aerial view showing the general extent of the area at the south end of the lake submerged in 1917 on which these trees grew. The lake in 1961 was at about the elevation of the lower stump. Gallatin's Beach is in the foreground and Pike's Point in the middle distance.

Figures 11 to 15 are views of portions of the stub forest taken at various times from 1921 to 1955. They show the general character of the trees in the stub-forest and their progressive deterioration over this period. The old trees had fallen by 1955 and decay of the stumps was well advanced. The start of the natural reforestation of this area also shows in some of the later views.

The tree ring counts on the stumps of these submerged trees have been used by the writer only to determine the total age of the trees. Some preliminary work was done on the thickness of the individual rings as a possible basis for interpreting the annual water supply during the period of growth of the tree. While there were noticeable variations in the thickness of the individual annual rings, the uncertainty regarding the effect of sub-irrigation from the lake, which might be harmful or beneficial, depending on the lake stage, was considered to be too great to justify detailed study of tree ring thicknesses. Narrow rings might reflect the difficulty of the tree in maintaining itself with the lake approaching the elevation at which the tree grew, or they might reflect reduced growth resulting from drouth due to low lake stages. In some stumps the outside rings were narrow which probably indicates the harmful effect of high water as the lake rose to a height sufficient to kill the tree.

Table 7 shows the results of the ring counts recorded by the writer. Many more counts were made but not recorded where younger trees were found at similar elevations to older trees. Table 7 also includes the computed dates at which the oldest tree at each elevation was killed.

The results in Table 7 have been plotted in Figure 16. The interpretations of the writer regarding the past stages of Eagle Lake are also shown.

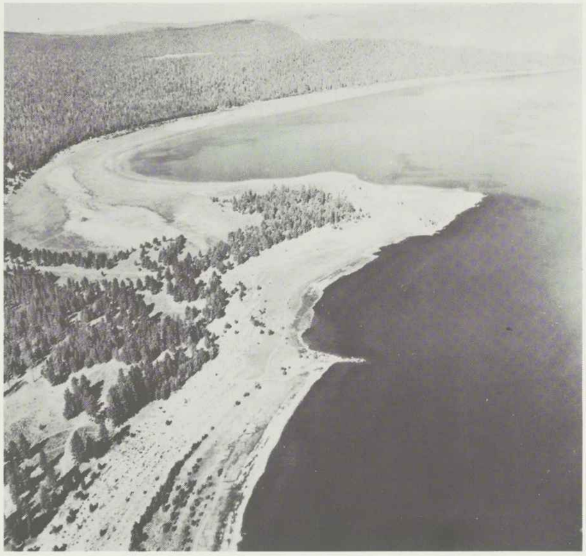


Figure 10.

General View of Stub Forest Area at South End of Eagle Lake. Taken in 1961.

Courtesy of California Department of Water Resources.

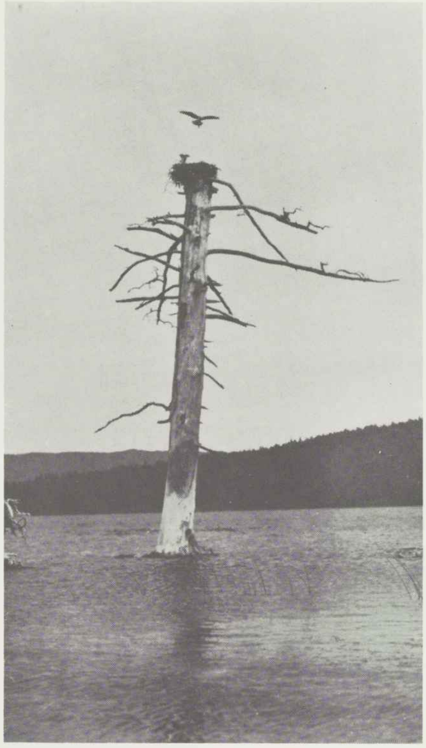


Figure 11.

Submerged Tree in Eagle Lake, 1921.

From Vertebrate Natural History of a Section of Northern California through the Lassen Peak Region, by Grinnell, Dixon and Linsdale. University of California Publications in Zoology, Vol. 30, 1930, Fig. 128.

Figure 12.

Stub Forest at South End of Eagle Lake, 1925.

From Vertebrate Natural History of a Section of Northern California through the Lassen Peak Region, by Grinnell, Dixon and Linsdale. University of California Publications in Zoology, Vol. 30, 1930, Fig. 71.

Figure 13.

Stub Forest at South End of Eagle Lake.

Taken in 1934 by S. T. Harding to show trees killed by the rise of the Lake prior to 1917.

Figure 14.

Stub Forest Area at South End of Eagle Lake.

Looking west from Gallatin's. Stephen T. Harding is standing by one of the trees. Taken in 1934 by S. T. Harding.

Figure 15.

Remains of Stub Forest at South End of Eagle Lake and West of Gallatin's in 1955. Taken by S. T. Harding.

Table 7 - Results from Trees submerged by the Rise of Eagle Lake Prior to 1917

Elevations are in Feet - U.S.G.S. Datum

Elevation of Ground on which Trees Grew	Age of Trees as shown by Count of Their Annual Rings	Probable Year in which oldest Trees were killed	Latest Year in which oldest tree may have started
5099	100	1862	1762
5107	18	1862	1844
5108	38, 44	1868	1824
5109	20, 34	1872	1838
5112	48	1875	1827
5113	73, 75	1877	1802
5114	60	1880	1820
5115	58, 74, 85, 97, 108, 121, 136	1880	1744
5116	37, 45, 65, 68, 69, 76, 77, 80, 85, 175, 245	1895	1650
5117	192	1895	1703
5118	128 128, 130, 150, 188	1905	1717
5119	100, 112, 140, 151, 152	1906	1754
5120	215, 220, 235	1906	1671
5121	138	1906	1768
5122	236	1906	1670
over 5126	Mature trees up to 400±	alive	1535±

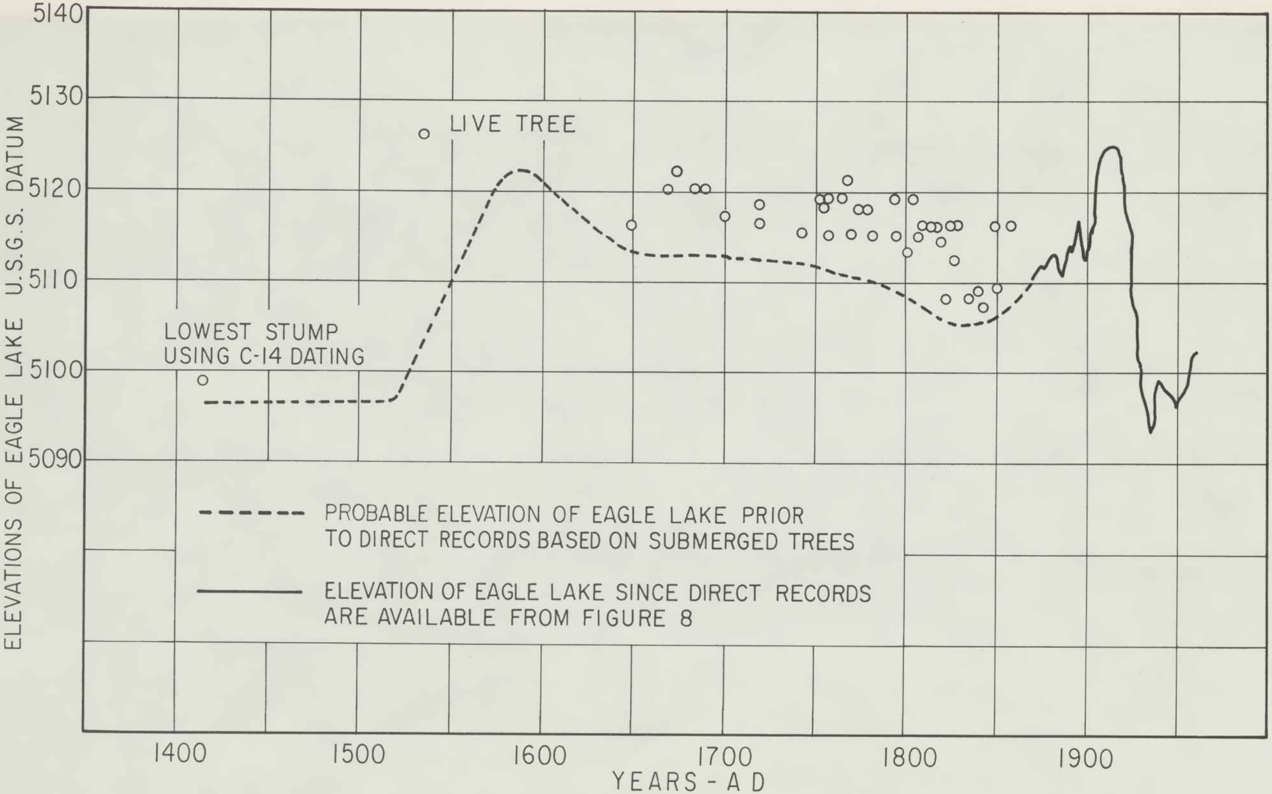


FIG. 16 PROBABLE RANGE OF FLUCTUATION OF EAGLE LAKE 1400-1960
BASED ON CARBON - 14 RATINGS OF LOWEST STUMP

The controlling tree in these results is one growing at elevation 5099 having about 100 rings. This tree grew on ground eight feet lower than any other; the writer examined the entire lake shore in the 1930's, from Spaldings around the south end to the inlet of the Bly tunnel, and found no stumps on ground as low as this particular stump.

The appearance of this lowest stump is shown in Figures 17 and 18. Shortly after the picture in Figure 18 was taken, this stump was overturned. It grew where its roots were firmly imbedded in rocky soil. Its roots were exposed by erosion around the stump and could be followed into the soil under the stump. The heart wood had decayed but a direct count of 80 rings was obtained with a part of the diameter, probably representing in excess of 20 rings, not countable. An age of 100 years has been used; the actual age is probably somewhat greater. This stump grew on Pikes Point about one-half mile west of Gallatins.

The sturdiness of this stump and its persistence in remaining in place is in contrast to the record of similar trees that grew at higher elevations which have decayed and disappeared. Its recent condition is shown in Figures 17 and 18. There had been no measurable change in its condition between 1934, when first examined by the writer, and 1961, except possibly some increase in the central decay. The outer wood has remained firm.

CARBON-14 DATING OF LOWEST STUMP

In the writer's earlier work on Eagle Lake it had been assumed that all of the stub forest had been killed during the rise of the lake which culminated in 1917. On this basis the lowest stump would have been submerged in about 1850 and have grown from 1750 to its submergence.

In 1962 the California Department of Water Resources secured a sample of the wood of this lowest stump growing at an elevation of 5099 feet. This sample was Carbon 14 dated by the Scripps Institute of Oceanography. The age was reported as 440 ± 100 years. This result requires that a new interpretation be placed on the fluctuations of Eagle Lake prior to about 1600.

If this lowest stump is 440 years old it would have been killed in 1522. This date is subject to a variation of as much as 100 years in either direction; the mean result has been used. This places Eagle Lake at elevation 5099 in 1520. For this tree to have reached an age of 100 years in 1520, Eagle Lake would have had to have been below elevation 5099 continuously from 1420 to 1520.

For this lowest stump to have been preserved since 1520 it would either have been continuously submerged, or periods when Eagle Lake fell below elevation 5099 would have to have been relatively brief. Acceptance of the Carbon 14 dating places Eagle Lake generally above elevation 5099 from 1520 to 1930.

The record of the higher stumps on Eagle Lake defines the elevation above which the lake did not rise for the times controlled by their age and the elevation of their stumps. As far as known to the writer no C-14 datings have been secured on these higher stumps. The present condition of these higher stumps supports the conclusion that they grew in the period immediately preceding their submergence since 1860. They have been plotted on Figure 16 on the basis of this conclusion.

On Figure 16 the interpreted elevation of Eagle Lake from 1650 to 1850 has been based on the assumption that the lake remained low enough for these trees

Figure 17.

Lowest Stump on South Shore of Eagle Lake.

H. H. Harding (6 ft. 3 in.) is standing at the side of this stump. Taken in 1935 by S. T. Harding.

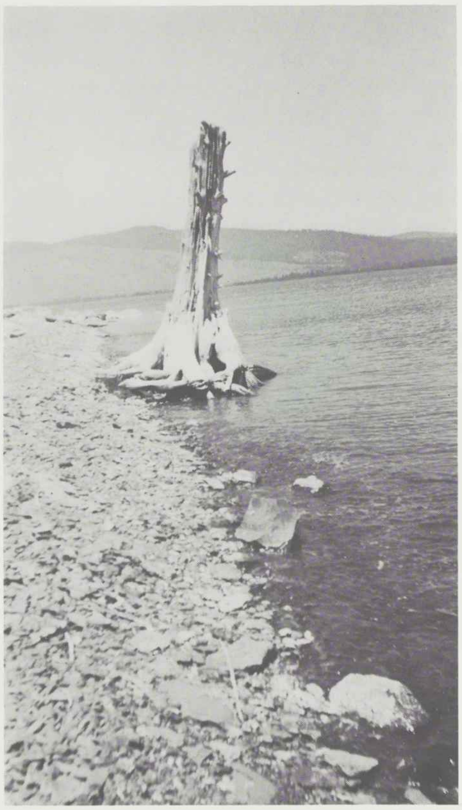


Figure 18.

Lowest Stump on Eagle Lake in 1961.

Shortly after this picture was taken this tump was pulled over. Taken by S. T. Harding on June 3, 1961.

to have grown in this period. If Eagle Lake had risen materially above the elevation shown on Figure 16 in this period, the period of growth of these higher trees would have been some earlier period of similar lake elevation. Eagle Lake may have fallen below the elevation shown in Figure 16 between 1650 and 1850. The lake probably fluctuated in this period below the line shown on Figure 16, but it did not fall low enough to expose the lowest stump long enough to have caused its decay.

The conclusion that all but the lowest of the submerged trees grew in the period immediately preceding the rise of the lake which reached its maximum in 1917 is also supported by the condition of these trees in 1915. Many were still standing as shown in Figures 11, 12 and 13.

From 1520 to 1650 the elevation of Eagle Lake is only defined at the two ends of this period. The lake probably fluctuated between elevations 5100 and 5120 in these years. Eagle Lake could have risen as high as elevation 5122 in this period but would have had to lower to elevation 5115 prior to 1650 to enable the 245 year old stump at elevation 5116 to have grown before its submergence in 1895.

The most probable fluctuations of Eagle Lake from 1520 to 1650 appear to be that shown on Figure 16. A rise to about elevation 5,120 probably occurred, otherwise older stumps would have grown between elevations 5115 and 5120. The actual fluctuations between 1520 and 1650 were probably more irregular than that shown by the generalized line of Figure 16.

MAXIMUM PAST STAGES OF EAGLE LAKE

There have been some reports that Eagle Lake has been at stages higher than it reached in 1917 at some time in the past. The writer has found no evidence of such stages. Eagle Lake is relatively young geologically and this conclusion relates to the present Eagle Lake since its formation.

A limit to the height to which Eagle Lake may have risen is set by the elevation of the low point in its rim. This is about elevation 5,160 feet or 35 feet above the 1916 elevation.

There are no signs on this rim that overflow has occurred. There are trees on the rim on which 400 annual ring counts have been made. There are no beaches or terraces around Eagle Lake at the elevation of this rim.

Even if Eagle Lake has not risen to its rim it may have risen above the 1917 elevation at some time since it was formed. The writer has examined the shore of Eagle Lake around nearly all of its length and has found no beaches above its 1917 elevation. There are beaches in loose gravel south of the inlet to the Bly tunnel below the 1917 lake elevation. These appear to have been formed as the lake elevation has varied in recent years. There are also beaches on the west side of the lake where the material may be loose enough to be subject to wave action but these are below the 1917 lake elevation.

Hubbs and Miller (Bulletin of the University of Utah, Vol. 38, No. 20) report finding a well-defined terrace 50 feet above the existing elevation of the lake, a beach pebble 10 feet higher and a possible terrace was seen 30 feet higher. Eagle Lake was at about elevation 5,097 at the time of these observations. The well defined terrace would be at elevation 5,147 which would be about 23 feet above the 1917 elevation of the lake. The possible terrace would be about 15 feet above the elevation of the rim. J. B. Kimsey (Life

History of the Tui Chub of Eagle Lake, M. A. Thesis 1951, University of California, Berkeley) has reported a terrace at an elevation about 14 feet above the elevation of the rim. He found this terrace on one of the points projecting into the lake from its western shore. An examination of this area was made by the writer in 1962. What appears to be a terrace from a distance was found to be the top of the talus slope of the lava rock lying at the foot of the lava flow forming the point.

If Eagle Lake has been formed since the higher stages of Lake Lahontan, there would be no higher beaches on Eagle Lake contemporaneous with Lahontan. It is the writer's conclusion that the elevation reached by Eagle Lake in 1917 is the highest it has reached since its formation.

INFLOW TO EAGLE LAKE 1875 TO 1960

The inflow to Eagle Lake can be derived from the rainfall on the lake, the gross evaporation, the change in volume in the lake and the outflow. Information is available on each of these items.

The nearest precipitation station is at Susanville. Some short period records indicate that the precipitation at Susanville is representative of that on Eagle Lake. The Susanville record begins in 1889. For prior years the indices previously discussed have been used.

In the late summer months the lowering of Eagle Lake represents the evaporation as inflow is very small. As previously discussed such records and comparisons with other lakes having records for the full year support a conclusion that the annual gross evaporation from Eagle Lake is 3.50 feet.

Early reports assumed that the flow of the springs in the upper Willow Creek Valley had their sources in Eagle Lake. The quality of the water from these springs differs from that in Eagle Lake. The volume of flow from these springs diminished in the 1930's when Eagle Lake was low but has increased in later years when Eagle Lake has remained low. These springs appear to be fed from other sources than Eagle Lake. The only outflow needing to be considered is the discharge through the Bly tunnel. Some records of this are available and its total amount can be estimated within an allowable amount of uncertainty.

Using these items relating to the water supply of Eagle Lake the inflow since 1875 has been computed. This has been done by years. Interpolations were made for the elevation of Eagle Lake where annual records were not available. While all of the required records are not complete, the computations are considered to furnish a basis suitable to be used in studying the variations in the inflow.

The resulting inflow derived as described is shown in Table 8. For the 86 year period the resulting mean annual inflow is 52,000 acre-feet.

The inflow to Eagle Lake in Table 8 has varied from 8,000 to 150,000 acre-feet in individual years. The mean for five consecutive years has varied from 23,000 to 97,000 acre-feet and for ten consecutive years from 25,000 to 87,000 acre-feet.

In Table 8 the inflow to Eagle Lake for selected periods since 1875 is also shown. For the 41 years in the first three of these periods, the inflow to Eagle Lake was 62,800 acre-feet equal to 120 percent of the 86 year mean. For the 20 years 1916 to 1935, the next two periods, the inflow was only 31,700 acre-feet or 61 percent of the 86 year mean and about one-half of the

Table 8 Computed Inflow to Eagle Lake - Thousands of Acre-feet except as noted

Col. 1 Year	2 Low Elevation of Lake-Bly Datum in ft.	3 Area of Lake in 1000 Acres	4 Storage in Lake in 1000 Ac.Ft	5 Precipitation in Per Cent of Mean	6 Estimated Precipitation on Lake: Depth in Feet	7 Estimated Precipitation on Lake: Total	8 Estimated Gross Evaporation	9 Annual Change in Storage	10 Indicated Inflow for year
	92	27.2	706						
1875	92	27.2	706	66	0.96	26	95	0	69
76	93	27.4	733	136	1.98	54	96	+27	69
77	93	27.4	733	66	.96	26	96	0	70
78	93	27.4	733	96	1.40	38	96	0	58
79	95	27.8	789	102	1.48	41	96	+56	112
80	96	28.0	817	130	1.89	53	97	+28	73
81	96	28.0	817	110	1.60	45	98	0	53
82	95	27.8	789	95	1.38	38	98	-28	31
83	94	27.6	761	77	1.12	31	97	-28	38
84	93	27.4	733	113	1.64	45	97	-28	23
85	93	27.4	733	80	1.16	32	96	0	64
86	93	27.4	733	115	1.67	46	96	0	50
87	92	27.2	706	75	1.09	30	96	-27	38
88	91	27.0	679	56	.82	22	95	-27	45
89	90	26.8	652	75	1.09	29	94	-27	38
90	95	27.8	789	190	3.02	84	94	+137	150
91	94	27.6	761	83	1.69	47	97	-28	20
92	93	27.4	733	87	1.69	46	95	-28	22
93	94	27.6	761	134	2.63	73	96	+28	52
94	94	27.6	761	102	1.69	47	97	0	50
95	96	28.0	817	124	2.34	65	97	+56	89
96	95	27.8	789	126	2.14	59	98	-28	10
97	94	27.6	761	112	1.96	54	97	-28	15
98	93	27.4	733	65	1.12	31	97	-28	37
99	92	26.8	706	80	1.02	27	96	-27	40
1900	95	27.8	789	109	1.63	45	94	+83	135
01	98	28.3	873	107	1.75	50	97	+84	133
02	97	28.1	845	100	1.53	43	99	-28	27
03	96	27.8	817	93	1.30	36	98	-28	33
04	99	28.4	907	135	2.02	57	97	+84	126
05	99	28.4	901	96	1.29	37	99	0	62
06	101	28.6	959	120	1.66	47	99	+58	111
07	105	29.1	1074	148	2.70	79	100	+115	138
08	104	29.0	1045	76	1.38	40	102	-29	32
09	104	28.9	1045	120	1.75	51	101	0	50
10	107	29.2	1132	85	1.12	33	101	+87	156
11	106	29.2	1103	130	2.17	63	102	-29	10
12	105	29.1	1074	61	.79	23	102	-29	50
13	105	29.1	1074	77	2.08	61	102	0	41
14	107	29.2	1132	122	2.12	62	102	+58	98

11 Year	12 Low Elevation of Lake Bly Datum in ft.	13 Area of Lake in 1000 Acres	14 Storage in Lake	15 Precipitation in Per Cent of Mean	16 Estimated Precipitation on Lake: Depth in Feet	17 Estimated Precipitation on Lake: Total	18 Estimated Gross Evaporation	19 Annual Change in Storage	20 Indicated Inflow for year
1915	106	29.1	1109	92	86	25	102	-23	54
16	106.7	29.2	1129	106	1.78	52	102	+20	70
17	106.4	29.2	1120	85	1.30	38	102	-9	55
18	105.3	29.1	1088	61	1.04	30	102	-32	40
19	103.5	28.9	1036	83	1.83	53	101	-38	10
20	103	28.9	1022	61	1.50	43	101	-28	30
21	102	28.8	993	112	1.26	36	101	-29	36
22	102.5	28.8	1007		1.93	56	101	+14	59
23	101.5	28.7	978		1.83	53	101	-29	19
24	98.5	28.3	898		.72	21	99	-80	-2
25	95.2	27.8	800		1.29	36	97	-98	-37
26	92.3	27.3	720		1.15	32	95	-80	-17
27	91.1	27.0	687		1.57	43	94	-33	18
28	89.2	26.6	636		1.19	33	93	-51	9
29	86.5	25.9	565		.81	22	91	-71	-2
30	84.4	25.1	511		1.44	37	88	-54	-3
31	83.1	24.2	479		.83	21	84	-32	31
32	80.35	22.1	415		1.22	29	77	-64	-16
33	78.5	20.0	376		.76	15	70	-39	16
34	76.	17.4	329		1.06	18	61	-47	-4
35	75.5	17.0	321		1.41	24	60	-8	28
36	75.5	17.0	32.1		1.45	25	60	0	35
37	74	14.0	298		1.18	17	49	-23	9
38	79	20.7	385		2.74	57	72	+87	102
39	79	20.7	385		.78	16	72	0	56
40	79.5	21.1	396		1.78	38	74	+11	47
41	80	21.8	407		1.79	39	76	+11	48
42	82.5	23.7	464		1.95	46	83	+57	94
43	82	23.3	452		1.52	36	82	-12	34
44	81	22.4	429		1.11	25	78	-23	30
45	81	22.4	429		.96	22	78	0	56
46	80	21.8	407		1.02	22	76	-22	32
47	78.8	20.3	382		.92	21	71	-25	25
48	77.5	19.0	356		.70	16	66	-26	24
49	77	18.6	346		.46	10	65	-10	45
50	76	17.4	328		1.11	23	61	-18	20
51	76	17.4	328		1.61	31	61	0	30
52	80	21.7	406		1.78	40	76	+78	114
53	80.4	22.0	415		1.32	30	77	+9	56
54	86	21.7	406		.88	20	76	-9	47

21 Year	22 Low Elevation of Lake Bly Datum in ft.	23 Area of Lake in 1000 Acres	24 Storage in Lake	25	26 Estimated Precipitation on Lake: Depth in Feet	27 Estimated Precipitation on Lake: Total	28 Estimated Gross Evaporation	29 Annual Change in Storage	30 Indicated Inflow for year
1955	78.5	20.1	375		.61	14	70	-31	25
56	83	24.1	473		2.18	55	84	+98	127
57	83.2	24.2	478		1.27	32	85	+5	58
58	85.4	25.7	533		1.90	49	90	+55	96
59	84.6	25.1	513		1.11	28	88	-20	40
60	83	24.1	474		1.06	27	84	-39	18

A	B
5	24
10	8
40	3
40	23
40	58
30	39
20	18
10	7
25	56
30	14
25	41
15	11
5	33
295	335

Results by Period

Totals	Yrs.	Precipitation on Lake	Gross Evaporation	Change in Storage	Total Inflow	Mean Annual Inflow
1875-89	15	556	1441	-54	831	55.4
1890-1905	16	801	1553	+249	1001	63.0
1906-1915	10	484	1016	+208	740	74.0
1916-1922	7	308	710	-102	300	42.9
1923-1935	13	384	1110	-686	335	25.8
1936-1942	7	238	486	+143	391	55.9
1943-1960	18	501	1368	+10	877	53.7
Total	86	3272	7684	-232	4475	
Mean		38	89	-3	52	

A = Outflow through Bly Tunnel

B: Total Inflow to Eagle Lake including Tunnel Outflow in Column A

S.T.H.

preceding 41 years. For the 25 years 1936 to 1960 the inflow has been about equal to the 86 year mean.

The preceding comparisons illustrate the widely variable water supply conditions to which areas in the western Great Basin are subject.

The annual inflows derived in Table 8 were computed in terms of their percentage of the 86 year mean and the accumulated departure from the mean determined. The results are plotted in Figure 19. Figure 19 illustrates the period of increased inflow starting in 1899 and continuing to 1917 and the deficient inflow from 1917 to 1937. There has been only limited recovery in the elevation of Eagle Lake since the closing of the Bly Tunnel. Since 1937 Eagle Lake has remained at stages generally lower than prevailed from 1875 to 1899.

INFLOW TO EAGLE LAKE FROM 1420 TO 1850

The fluctuations of Eagle Lake derived from the submerged trees can be used to compute the inflow to the lake for periods prior to the direct observations of lake elevation. This has been done in Table 9 using the fluctuations shown in Figure 16.

For the 100 year period in which the lowest stump grew the indicated inflow to Eagle Lake is 85 percent of the 430 year total period. This is the largest difference from the mean of any period of similar length. Whether this tree grew from 1420 to 1520 as indicated by the C-14 dating, this stump could only have grown during some 100 year period of similar inflow.

For the other periods from 1520 to 1850 shown in Table 9 the average variation from the mean was 10 percent or less. The longer periods probably included shorter ones of both greater and less variations from the mean than are indicated for the longer periods.

The record of the submerged trees around Eagle Lake supports the following conclusions:

1. These trees show elevations above which Eagle Lake has not risen during the period of growth of each tree. They do not show how much lower the lake may have fallen during their period of growth.
2. Acceptance of the C-14 dating of the lowest stump places its time of growth from 1420 to 1520 A. D. Whenever it may have grown there was a 100 year period when Eagle Lake remained lower than it has been for any similar length of time since.
3. Eagle Lake reached an elevation in 1917 higher than any it had reached for the preceding 300 years and probably higher than it may have reached at any time in its past.
4. From 1875 to 1915 the inflow to Eagle Lake exceeded that of any period since 1650 A. D.
5. The reduced inflow since 1917 and the effect of diversion through the Bly Tunnel lowered Eagle Lake in 1935 slightly below the elevation at which the lowest stump could grow. The lake would not have reached this elevation without the diversion through the tunnel. Since 1935 Eagle Lake has risen above this elevation about eight feet.

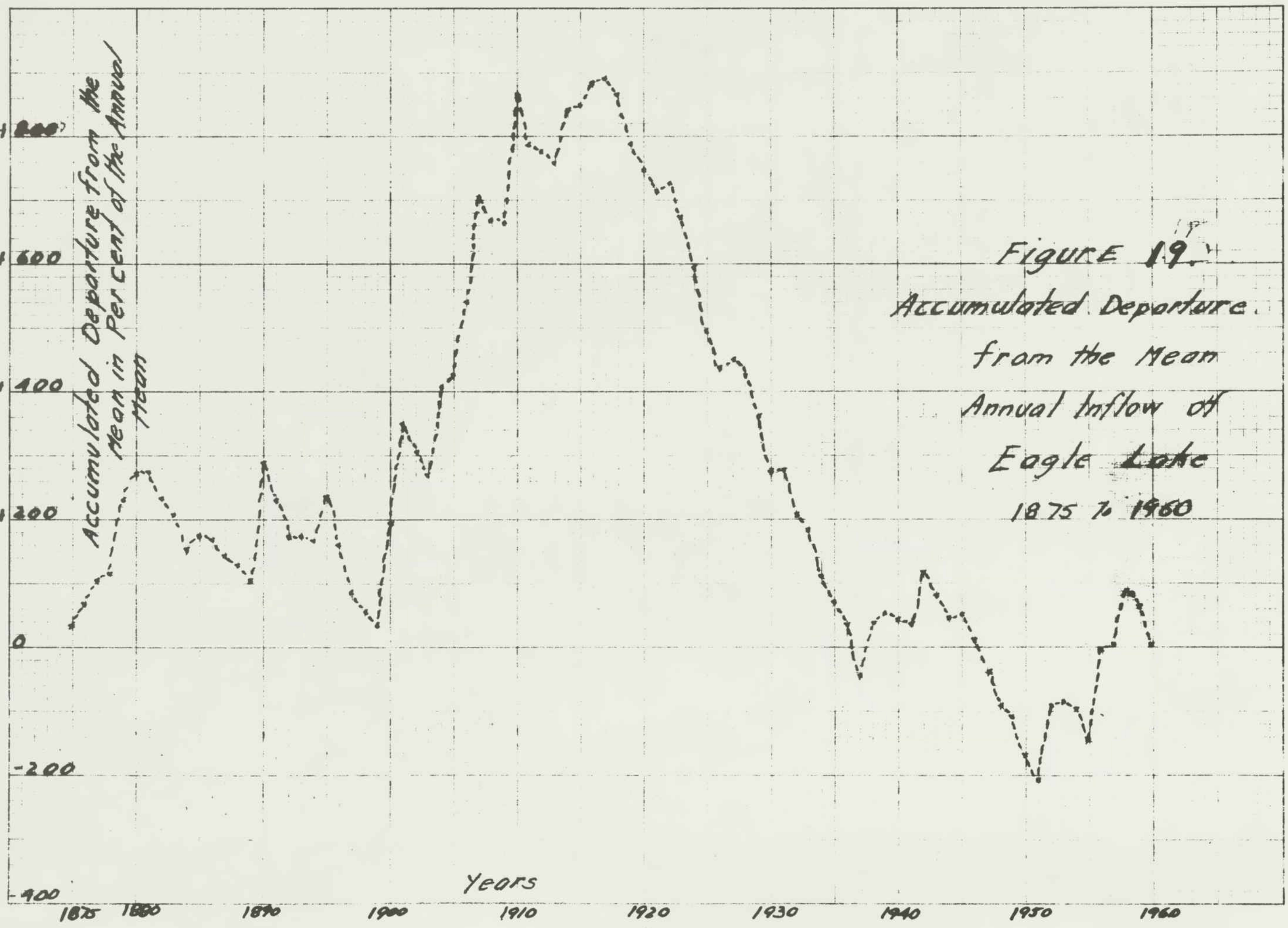


FIGURE 19.
Accumulated Departure from the Mean Annual Inflow of Eagle Lake 1875 to 1960

Table 9 Estimated Inflow to Eagle Lake for Period 1420 to 1850 A.D.

Period	1420-1520	1520-1650	1650-1750	1750-1850	1420-1850
Years in Period	100	130	100	100	430
Elevation of Lake					
Beginning	5097	5097	5113	5112	5097
End	5097	5113	5112	5105	5105
Area of Lake in Acres					
Beginning	21800	21800	28000	27800	21800
End	21800	28000	27800	26200	26200
Volume in Lake in 1000 Acre-feet					
Beginning	403	403	817	789	403
End	403	817	789	600	600
Total Change	0	+414	-2.8	-189	+197
Mean Annual Change	0	+3.2	-0.3	-1.9	+0.5
Mean Annual Net Evaporation	45	52	58	56	53
Indicated Mean Annual Inflow for Period in 1000 Acre-feet	45	55	58	54	53
In Per Cent of 430 Year Mean	85	104	109	102	100
In Per Cent of Mean for 1902-59	91	111	117	109	107

6. How Eagle Lake may have fluctuated below the elevations controlled by the submerged trees from 1640 to 1840 A. D. is not shown by the available tree records. The lake probably at times fell below the line shown on Figure 16 as the elevation above which the lake could not have risen without killing the trees which were killed after 1875. How lengthy such periods may have been and how low the lake may have fallen is not defined by the tree records. If the lake had lowered below the elevation of the lowest stump for any lengthy period since 1550 A. D., this stump would probably have decayed and not been preserved until the lake fell below its elevation in about 1930.

EFFECT OF DIVERSION THROUGH BLY TUNNEL

Diversions were made from Eagle Lake through the Bly Tunnel from 1923 to 1935. These were irregular in time and in amount. Based on available records the writer has estimated that the total amount was 295,000 acre-feet. The period of diversion was one of reduced runoff and Eagle Lake would have lowered in these years if there had been no tunnel outflow.

Enclosed lakes adjust their elevations to variations in their inflow by the changed loss by evaporation as the lake area rises or falls. A routing of Eagle Lake was made based on no outflow having occurred. For the period of diversion Eagle Lake lowered 27 feet. The routing indicated it would have lowered 17 feet with no tunnel and would have been 10 feet higher in 1935 without the tunnel than its actual elevation.

Since 1935 Eagle Lake has been gradually reducing the effect on its elevation resulting from the tunnel diversion. The smaller actual lake area than the area would have been without tunnel diversion results in smaller evaporation then would have occurred without diversion. A routing of Eagle Lake from 1935 to 1960 as it would have fluctuated without tunnel diversion indicates that the lake would only have been one foot higher in 1960 without tunnel diversion than its actual elevation. In 1960 Eagle Lake had risen eight feet from its 1935 elevation. Without tunnel diversion the ten foot higher elevation than the actual in 1935 had been reduced to one foot.

QUALITY OF WATER

The water in Eagle Lake contains more solubles than are desirable in use for irrigation but is not brackish.

A considerable number of analyses of the water in Eagle Lake are available from 1922 to 1958. During this period the volume in the lake has varied from 1,120,000 to 330,000 acre-feet. From 1923 to 1935 the draft through the Bly Tunnel removed about 30 per cent of the water that was in the lake in 1923.

A complete analysis of a sample of the water in Eagle Lake in 1922 was made prior to any diversion through the Bly tunnel. This showed a total content of solubles of 752 p.p.m. This represented a total soluble content of 1,080,000 tons in the 1,060,000 acre-feet then in the lake. By September 1928 the volume in the lake had decreased to 780,000 acre-feet with a total mean solubles of 2 samples of 745 p.p.m. and a total tonnage of salts of 800,000. By 1928, the estimated discharge of the Bly Tunnel had been 165,000 acre-feet. From 1922 to 1928 the diversion through the Bly tunnel accounted for about 60 per cent of the reduction in the storage in the lake. The rest was accounted for by the excess of the evaporation over the inflow. The six years, 1923 to 1928, had an inflow of 50 per cent of the long time mean.

At the end of the diversion through the Bly tunnel in 1935 an anlysis of the lake found 1077 p.p.m. resulting in a total of 350,000 tons in the lake.

During the period of diversion through the tunnel from 1923 to 1935 the 295,000 acre-feet diverted had a probable average soluble content of 1.4 tons per acre foot or a total of 410,000 tons. The decrease in total tons of solubles in the lake from 1923 to 1958 was 565,000 acre-feet. About 72 per-cent of the reduction in total solubles in the lake appears to have been accounted for by diversion through the tunnel.

The preceding results have been based on single samples of the lake water. For this extent of sampling the results are probably as consistent as may be expected.

Since 1935 more frequent samples have been analysed by the California Department of Water Resources and for the writer by the Plant Nutrition Laboratory of the University of California at Berkeley. For 14 samples from 1935 to 1958, the total tonnage of solubles in the lake has varied from 425,000 to 555,000 tons with an average of 490,000 tons.

PYRAMID AND WINNEMUCCA LAKES

INTRODUCTION

Pyramid and Winnemucca Lakes receive the undiverted runoff of the Truckee River. At its higher recent stages Pyramid Lake had an area of about 130,000 acres, a maximum depth of about 350 feet, and contained 25,000,000 acre-feet. At its highest recent stage Winnemucca Lake had an area of about 60,000 acres, a maximum depth of 80 feet, and contained a volume of 3,500,000 acre-feet.

As the result of the diversions from the Truckee River, the inflow to these lakes is now insufficient to maintain their former areas. Winnemucca Lake became dry in 1939 and Pyramid Lake is lowering at an average rate of about 1.5 feet per year.

In deriving the early runoff of the Truckee River based on the evaporation of the enclosed lakes into which it discharges, it is necessary to consider both Pyramid and Winnemucca Lakes. Prior to recent changes in the area of overflow Truckee River divided between the two lakes and at its higher stages Pyramid Lake overflowed to Winnemucca Lake through Mud Slough.

Winnemucca Lake has received only intermittent inflow since 1911. Some inflow has occurred when Pyramid Lake is below the elevation of overflow to Winnemucca Lake as the Truckee River, at times, divided on its delta and the eastern branches reached Mud Slough. Winnemucca Lake is now shut off from further inflow from the Truckee River by the closed highway fill across Mud Slough.

The Truckee River is the largest of the streams on the eastern slope of the Sierras which discharges into enclosed lakes in the western Great Basin. The pioneer trail to California over Donner Pass followed the Truckee River for much of its length. However, it reached the river about 20 miles above Pyramid Lake and the diary accounts by the early emigrants do not help to define its early stages. The first direct account is by the Fremont expedition in 1844. Other sources enable a fairly adequate record of the fluctuations of these two lakes to be derived from 1844 to 1926. In 1926 the Truckee River Water Master installed a gaging station on Truckee River just above Pyramid Lake and a record of the inflow has been secured since that year.

The precipitation on these two lakes is insufficient to support tree growth. Some trees have grown along the inlet channels. Stumps along these channels give an indication of lake stages prior to 1844.

There is a marked white line on the rocks around both lakes which was deposited at former but recent lake stages. Pyramid Lake has submerged this line at some times within its observed history. This line on Pyramid Lake is level and is above the elevation of the recent overflow to Winnemucca Lake. The white line on Winnemucca Lake is similar to that on Pyramid Lake but at a lower elevation indicating that the inflow within the period when these lines were formed was not large enough for Winnemucca Lake to rise to the elevation which would submerge their connecting channel.

The writer's work on the Truckee River began in 1917 in connection with the adjudication of the water rights on the river. His engineering work relating to Lake Tahoe and the Truckee River continued intermittently until 1962. Beginning in the 1930's, studies of these two lakes were undertaken as a matter of personal interest. Much of the writer's work was done in association with the late E. P. Osgood. Numerous field trips and library searches have been made during the past 30 years. The conclusions expressed in the report are based on the results of all of this work.

As in all similar work the writer is indebted to many individuals and sources for assistance. E. P. Osgood has been mentioned. George Hardman with Cruz Venstrum has also done much work on these lakes and their results have been of much help. The first Truckee River watermaster, the late Harry C. Dukes, started the record of the inflow from the Truckee River and assembled early records on Pyramid Lake. Harry B. Richards made available the records of the Truckee Carson Irrigation District. To these and many others the writer is glad to express his obligation for their assistance.

AREA AND CAPACITY

The only available soundings of Pyramid and Winnemucca Lakes are those made by I. C. Russell in 1883. Fig. 20 is a reproduction of Plate IX of Russell's Geological History of Lake Lahonton (U. S. G. S. Monograph 11-1885). The areas within each sub-lacustral contour shown on Fig. 20 were scaled and area and capacity curves derived. These results are shown in Fig. 21. These results are in general agreement with the area shown for these lakes on the recent Nixon and Lovelock U. S. G. S. sheets for the area and elevation of the lakes at the time these sheets were surveyed.

THE WHITE LINE ON PYRAMID AND WINNEMUCCA LAKES

Around the shores and on the islands in these lakes there is a prominent white line. On Pyramid Island this deposit forms a shelf. Generally it is a deposit from the waters of the lake, partly a chemical concentration and partly a band deposited by lake growths. It has a uniform elevation around each lake with the white line on Winnemucca Lake about 15 feet lower than that on Pyramid Lake. It has the appearance of being a recurrent elevation which the lakes have reached with sufficient frequency and duration to have formed the deposits of which it is composed. Fremont noted this line in 1844 and interpreted it to be the elevation to which Pyramid Lake rose during the spring inflow. As the lake was 12 feet below the white line when Fremont first saw it, evaporation would not have caused this much lowering since the preceding spring.

Pyramid Lake has risen above the elevation of its white line three times for a total of about 12 years from 1860 to 1900. It has retained its promnence and identity since before 1844 although it has not been submerged in the last 70 years. The white line has been used as a reference from which the elevation of the lake and other features around the lake can be defined in terms of the present datum of the U. S. Coast and Geodetic Survey.

On Pyramid Island there is a shelf which has been formed on the side of the island just below the white line. This is five to 15 feet wide and is most marked on the eastern or inshore side. Figure 22 is a picture of the

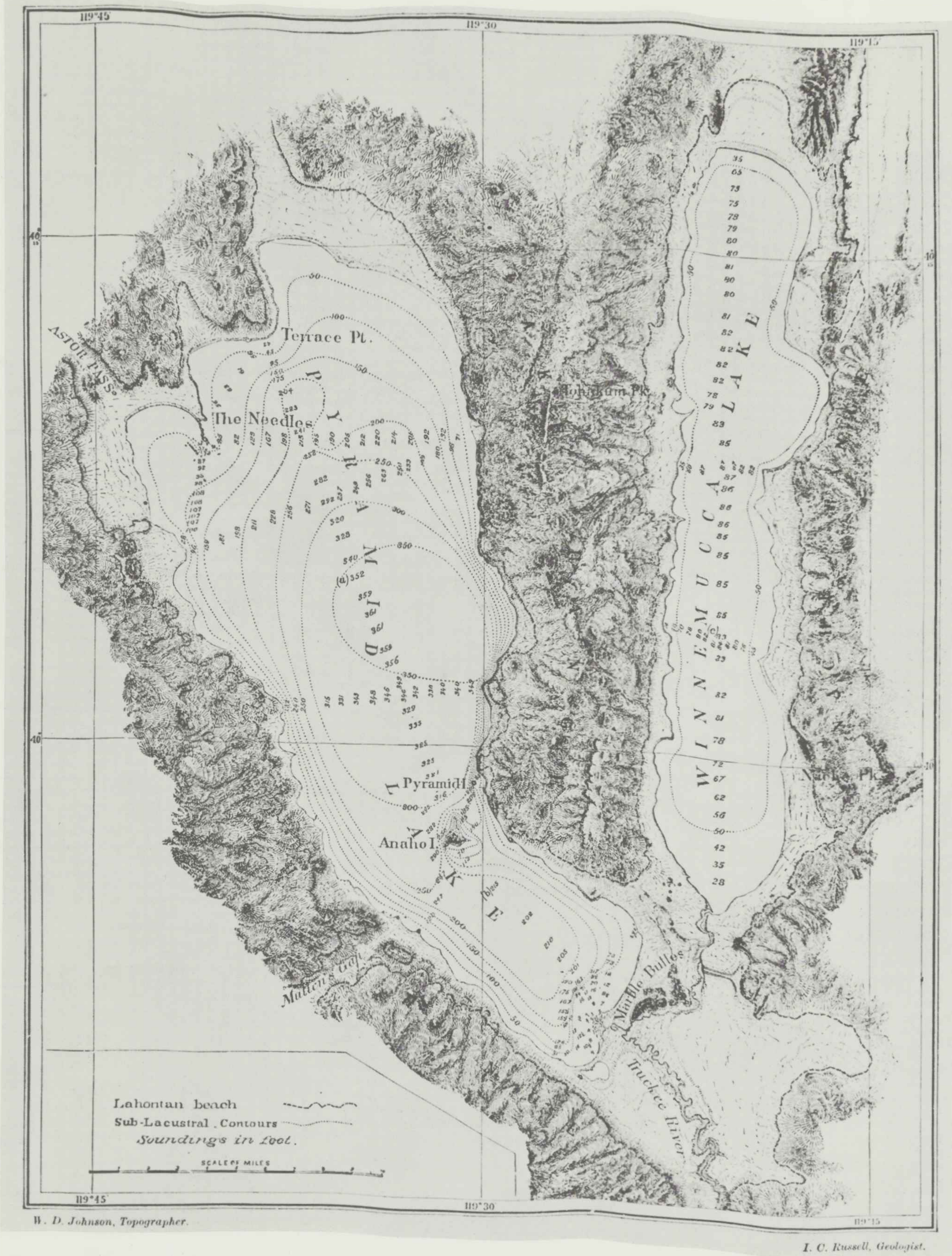


Figure 20.

Map of Pyramid and Winnemucca Lakes.

Plate IX in Geological history of Lake Lahontan by I. C. Russell, U. S. G. S. Monograph 11-1885.

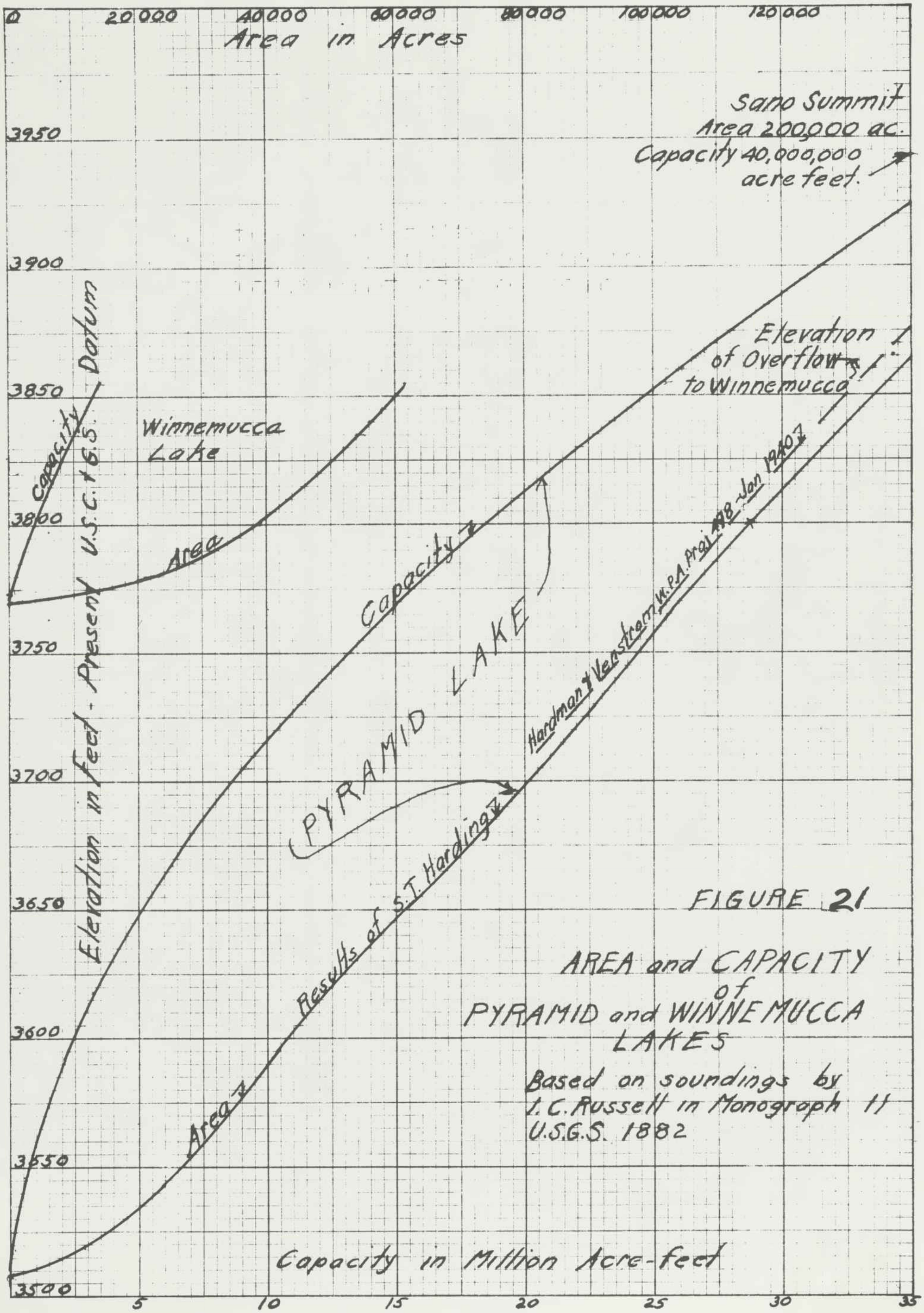


FIGURE 21

AREA and CAPACITY
of
PYRAMID and WINNEMUCCA
LAKES

Based on soundings by
I.C. Russell in Monograph 11
U.S.G.S. 1882

shelf or terrace showing also the white line on the adjacent inshore rocks. Figure 23 is a general view showing Pyramid Island and the adjacent shore. The shore which has been exposed by the lowering of the lake shows a marked color contrast with the rocks above the white line. The recent periods when the lake was above the white line did not have a sufficient duration to leave a similar whitening of the rocks above the main white line. The shelf on Pyramid Island is a deposit on the slopes of what appears to have been the original form of the island rather than a terrace cut into the original rock.

There are reports of springs that discharged above the lake elevation from the sides of Pyramid Island. In the U. S. Geological Exploration of the 40th Parallel (Vol. 2, p. 822, 1877), Arnold Hague states:

> "The pyramid which gives the name to the lake is a tufaencrusted island --- has a warm spring about half way up its slopes --- the terrace beaches are also indistinctly brought out on the pyramid."

The spring reported by Hague has not had a noticeable flow in recent years. The water in the lake has been warmed by the small flow from springs near the recent elevation of the lake.

The Pyramid Island shelf appears to have been formed by the deposit of tufa resulting from the flow of springs from Pyramid Island. The lake would need to have been at or near the elevation of the shelf in order for such tufa deposits to be made. Such springs no longer exist at this elevation. This does not detract from the above conclusion as past reports indicate that the present conditions differ from those within the historic past. The absence of similar tufa deposits on other rocks around the lake just below the white line can be accounted for by the absence of springs near such rocks.

As the formation of this tufa shelf on Pyramid Island would occur slowly, the above conclusion regarding how it was formed indicates that in recent times Pyramid Lake has been above the white line for only limited periods but that it has been at or near the white line for sufficient periods of time in the past to have enabled this tufa to form. As is brought out later, the elevation of the shelf on Pyramid Island is related to the elevation of overflow to Winnemucca Lake.

The main white line on Pyramid Lake is a band which varies in width. There are some less pronounced white lines at other elevations. The most definite white line has been levelled in at several locations and at different times by the writer and others. From all of these results an elevation of 3872.5 feet present datum has been adopted by the writer for the top of the main white line.

ELEVATIONS OF PYRAMID LAKE PRIOR TO 1844

There are no known direct records of the elevation of Pyramid Lake prior to 1844 when Fremont's report enables the elevation to be determined at the time he travelled around the lake. There are two indirect records which have been found. These are based on the stumps of trees which grew along the inlet channel of Truckee River at elevations lower than that of the lake in 1844, and on the exposed cross-section of the Truckee River delta resulting from its erosion following the recent lowering of the lake.

Russell (1882) quotes George Frazier, a local resident, as stating that

Figure 22.

Pyramid Island.

View from point somewhat north of the position from which
pictures in King's and Russell's reports were taken.
E. P. Osgood is in the foreground. Taken May 16, 1937.

Figure 23.

View of Pyramid Island from the Southeast.
Taken June 18, 1934 by S. T. Harding.

dead trees were standing in Pyramid Lake in 1862 as evidence that the lake had risen previous to that year. Neither Fremont, King or others who have described the lake prior to 1882 mention such trees. Trees submerged in 1862 in Pyramid Lake would have remained submerged, except for brief periods, until they were exposed since 1920 by the continued lowering of the lake. A search for such stumps was made by the writer in 1939. They would be found, if at all, on the delta of Truckee River as this stream was the only source of water supply for their growth. The remnants of such trees were found in 1939. Figure 24 is a picture of one such stump. The lowest stumps found grew on ground at about elevation 3857. Decay had progressed too far for ring counts to be made. As they were rapidly growing willows or cottonwoods their size indicated ages of 15 to 20 years. They grew at elevations about four feet lower than that of the lake in 1844. Their growth indicates a drier period from about 1820 to 1844 during which the inflow to Pyramid Lake had been insufficient to maintain the lake at its 1844 elevation.

The Truckee River deposited its load of eroded material on its delta which extended into the southern end of Pyramid Lake. Russell in 1882 shows a generally smooth shallow area of the lake around its southern end breaking off into greater depths at the face of this deposit (Figure 20). Since Pyramid Lake has lowered below this deposit the Truckee River has cut a channel through its former delta exposing a section of the former deposits 20 to 25 feet thick. A typical view of such an eroded bank is shown in Fig. 25. This shows the usual type of delta stratification. These strata are thicker near the upper part of the delta becoming thinner near the former shore lines of the lake. This recently eroded inlet channel is generally about one-half mile wide.

This evenly sloping delta area within the lake was below the elevations to which Pyramid Lake rose prior to 1820. It ended in a steep front extending down to meet the general pre-delta lake bed surface. This front was 25 to 30 feet in height and is a feature of the present exposed topography of the southern end of the lake. Pyramid Lake was at elevation 3867 feet when Russell's sounding were made in 1882. He shows an area about a mile wide around the southern shore having depths of water of from three to five feet. Part of this area would have been exposed when the trees whose stumps remained in 1939 were growing.

This steep break in the lake bed within the zone of recent variation in lake elevation provides a basis for interpreting some of the recent history of Pyramid Lake. If the lake had lowered much below the top of this even slope, the additional grade of the Truckee River would have resulted in its cutting through its delta similar to its recent action. The top of the steep slope represents an elevation below which the lake has not lowered for any lengthy period during the time the present delta was being deposited.

Levels were run to the top of this steep slope and elevations varying from 3851.5 to 3853 were obtained. This break in the slope would be within the lake at the time it was formed and represent a lake elevation of about 3855. It is considered that the lake did not fall below elevation 3852, except for some short periods, during the time when this delta was being deposited. There is no definite basis on which the time required for Truckee River to supply the former delta deposit can be computed, but the volume of

Figure 24.

Stump of Tree which grew on Delta of Truckee River.

The area on which this tree grew has been exposed by the lowering of Pyramid Lake. Taken July 11, 1939 by S. T. Harding.

Figure 25.

Eroded Bank of Truckee River in Former Delta in Pyramid Lake.

This view shows the south bank over 20 feet high 5/8 mile west from spill of Truckee River. Yellow gravel strata are interbedded with silt layers. This area is too low for any roots of former trees to show. Taken September 16, 1958 by S. T. Harding.

the deposit indicates that a relatively long period would be required. It is the writer's conclusion that Pyramid Lake has not been below elevation 3852, except perhaps briefly, for a period exceeding 200 years prior to the life of the trees on the delta whose stumps remained in 1939. The lake would need to be at or below elevation 3852 for 15 to 20 years prior to 1844 to permit the growth of these trees.

ELEVATION OF PYRAMID LAKE IN 1844

Fremont travelled along the east side of Pyramid Lake in January 1844. His diary enables the existing elevation of the lake to be determined. He states that "by the mark of the waterline along the shores, the spring level is about 12 feet above the present water". This water line is the present white line and Fremont's statement places the lake at elevation 3860.5 in January 1844. Fremont's report also contains a sketch of Pyramid Island and his camp on the adjacent shore. This sketch from Fremont's report of his 1842 to 1844 expedition is reproduced here as Fig. 26. The writer took this sketch to the area and by lining up the various features shown found the rock on which Fremont's artist Charles Preuss probably sat when he made the sketch. By identifying the water line on the different rocks and securing its elevation from present levels, the elevation of the lake was determined to have been 3860.5. This confirms the quotation above from Fremont's diary.

Fremont also camped at the mouth of Truckee River. His diary and map indicate that there was no flow from Pyramid Lake to Winnemucca Lake in January 1844.

OTHER EARLY REPORTS

The Surveyor General of California in his report for 1856 describes the observations he made on a trip down the Truckee River to Pyramid Lake. His account of the conditions at the division of flow between Pyramid and Winnemucca Lake has been interpreted by the writer to represent an elevation of 3860 feet for Pyramid Lake in 1856.

De Groot's 1861 Map of Nevada Territory gives some information relating to the stage of Pyramid Lake although the lake is incorrectly shaped on the map. From the conditions shown at the division of the flow of Truckee River between Pyramid and Winnemucca Lakes the writer has concluded that Pyramid Lake had risen to the elevation of overflow to Winnemucca Lake by 1861 but that the amount of any such flow to Winnemucca Lake had not been sufficient to create more than a small lake there.

The U. S. Geographical Surveys West of the 100th Meridian (Wheeler Survey, 1879) includes a brief account of explorations in and around the Pyramid Lake area in 1865 and 1866. While Williamson's report includes some information which is helpful in deriving the then size of Winnemucca Lake it does not enable the elevation of Pyramid Lake to be defined. His description of Pyramid Lake indicates that it had risen above the elevation of overflow to Winnemucca Lake since 1856.

The U. S. Geographical Exploration of the 40th Parallel, (King Survey, 1878) included field work from 1867 to 1872. For the first time an

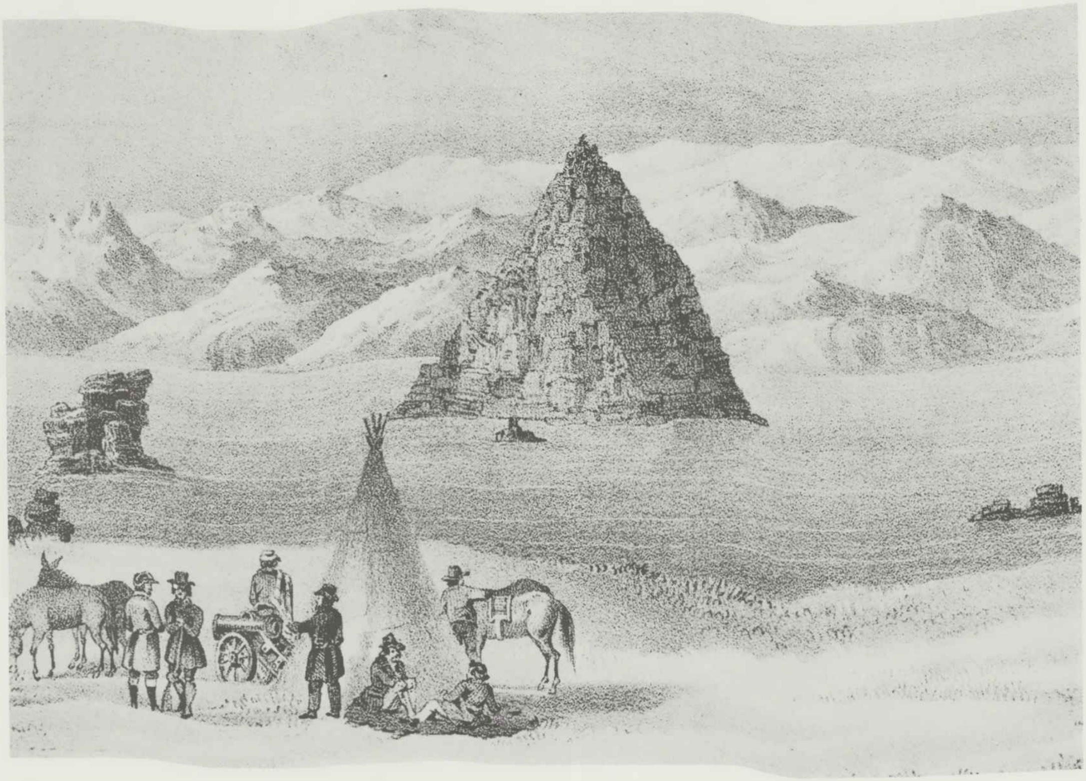


Figure 26.

Photograph of Plate on page 216 of Fremont's report of his 1842-1844 Expedition.

This plate is based on a sketch by Preuss. It is a fairly accurate rendering of the relative position of the inshore rocks as well as the form of the Island. It was used to locate the 1844 water line from which levels to present day elevations were taken.

actual photograph was made of Pyramid Island from which its elevation at the time it was taken can be derived. King reports that Pyramid Lake rose nine feet from 1867 to 1871. While the photograph of Pyramid Island is definite, the date at which it was taken is uncertain. This picture of Pyramid Island (Plate XXXIII in the King report) is reproduced here as Figure 27. A picture taken by the writer from the same point is shown in Figure 28.

By identifying several points on the water lines shown in the King Photograph in the field and determining their elevation, the writer has concluded that the lake was at elevation 3876 when this photograph was taken. This result agrees with the conclusion of Hardman and Venstrom and is consistent with the comments by Russell. (American Geophysical Union, Transactions of 1941, pp.71-90)

Whether the King photograph was taken in 1867 or 1871 materially affects the resulting figures for inflow to Pyramid Lake between these dates. If it was taken in 1867 and the lake rose nine feet by 1871, the 1871 elevation would be 3885 feet. If the photograph was taken in 1871 Pyramid Lake would have been at elevation 3867 in 1867, and at elevation 3876 in 1871. All of the available references and reports that he could find have been reviewed by the writer in an effort to determine the date of this photograph. The reports of the field work credit this photograph to O'Sullivan. He worked in this area in 1867 and may not have revisited it in 1871. The nine foot rise between 1867 and 1871 is consistent with other general water supply information for these years. However the rise to 1867 based on similar general information would not be large enough for Pyramid Lake to have reached elevation 3876 in 1867. Also an elevation of 3885 is not consistent with the elevation by Russell in 1882.

From their study of these records, Hardman and Venstrom concluded that this photograph was taken in 1871. The writer has reached the same conclusion in his separate investigations. The elevation of Pyramid Lake in 1867 of 3867 feet and in 1871 of 3876 feet has been used.

OTHER RECORDS PRIOR TO 1882

There are some general records applicable to Pyramid Lake prior to 1882. Russell quotes a local settler, George Frazier, who was a trader and also handled fish sales for the Indians. He should have been in close contact with local conditions. Frazier reported that Pyramid Lake rose 10 to 15 feet in 1868, that it continued to rise in 1869 with overflow to Winnemucca Lake in these two years. These years were within the 1867 to 1871 period in which King reports a nine foot rise. By inference at least, Frazier's statement can be interpreted to mean that overflow did not occur in 1867. King's results are probably based on more definite measurements and have been used with Frazier's comments serving to place most of the nine foot rise in 1868. Some lowering may have occurred in 1870 and 1871.

Russell also quotes Frazier to the effect that a gravel bar closed the channel to Pyramid Lake in 1876 with all Truckee River flow going to Winnemucca Lake.

Sheets B and D of the Atlas Sheets of the U. S. Geographical Survey West of the 100th Meridian show Pyramid Lake at elevation 3848 and Winnemucca at 3825. Presumably these observations were made at the same time and represent

Figure 27.

Pyramid Island and Inshore Rocks.

Reproduction of Plate XXIII of King's Report of the Exploration of the 40th Parallel.

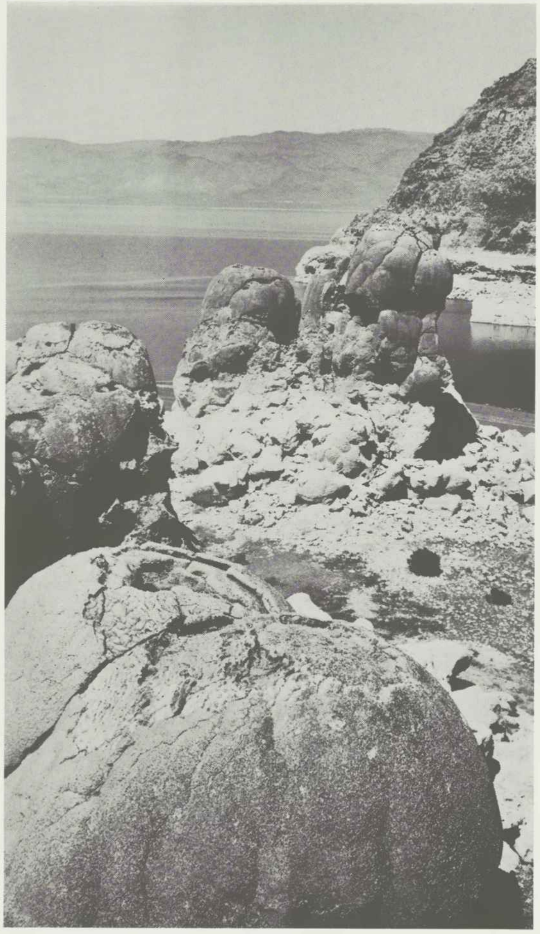


Figure 28.

Tufa Domes opposite Pyramid Island.

View from the same position from which Plate XXIII in King's Report of the Exploration of the 40th Parallel was taken. Taken July 11, 1939 by S. T. Harding.

a difference of 23 feet between the two lakes in 1879. These results are later than those of King which give differences of 80 feet in 1867 and 67 feet in 1871. All of these results are based on barometric observations as there were no sea level surveys in this area at that time.

The saw mills on the upper Truckee River sent large amounts of saw dust down to Pyramid Lake in the years when there was extensive lumbering to supply the Virginia City mines. This saw dust is reported to have caused changes in the channel to Pyramid Lake and at times to have increased the flow to Winnemucca Lake.

RUSSELL'S RESULTS IN 1882

Monograph 11 of the U. S. Geological Survey of I.C. Russell is entitled Geological History of Lake Lahontan (1885). It has become the classic description of Lake Lahontan. It also contains much information regarding the present Pyramid Lake. Russell's field work was done in 1882.

Russell's report includes several plates which are photographs of rocks around the lake on which the existing water line can be identified in terms of present datum. Figure 29 is a view in the Needles which is Russell's Plate XIII. A similar picture taken in 1937 by the writer is shown in Figure 30.

Russell also shows three rocks in the southeast part of the lake which extended above the water in 1882. He measured the height of each rock above the then lake surface. These rocks were out of water in 1939 when the writer took their picture (Figure 31) and measured their heights above the white line.

The results from the interpretations of four photographs and the three rocks gave a mean elevation of Pyramid Lake in 1882 of 3866.9 feet. Harry C. Dukes, using adjustments for changes in datum, derived an elevation of 3866.82 feet on Sept. 9, 1882, based on Russell's reported elevation on that date. This is a close agreement and Dukes' result has been used.

RESULTS FROM U. S. G. S. QUADRANGLE SHEETS

The early quadrangle sheets covering Pyramid Lake were based on the Wheeler Survey. The elevations shown for the lake are not convertible to present datum.

The Wadsworth 1894 sheet was based on topography taken in 1890. Pyramid Lake is shown at elevation 3880. This is subject to a reduction of 4.18 feet for present datum.

The recent (1957) Lovelock, Nixon, and Sutcliffe sheets are based on aerial photographs. These were made at a time when direct observations on the elevation of the lake were being secured and are not needed to determine the lake elevation at the time these surveys were made.

RESULTS 1867 TO 1926

Records during this period were sought and compiled by A. B. Purton in 1934 while District Engineer for the U. S. G. S., and by Harry C. Dukes, then Truckee River Water Master. These results are shown in Table 10. The values

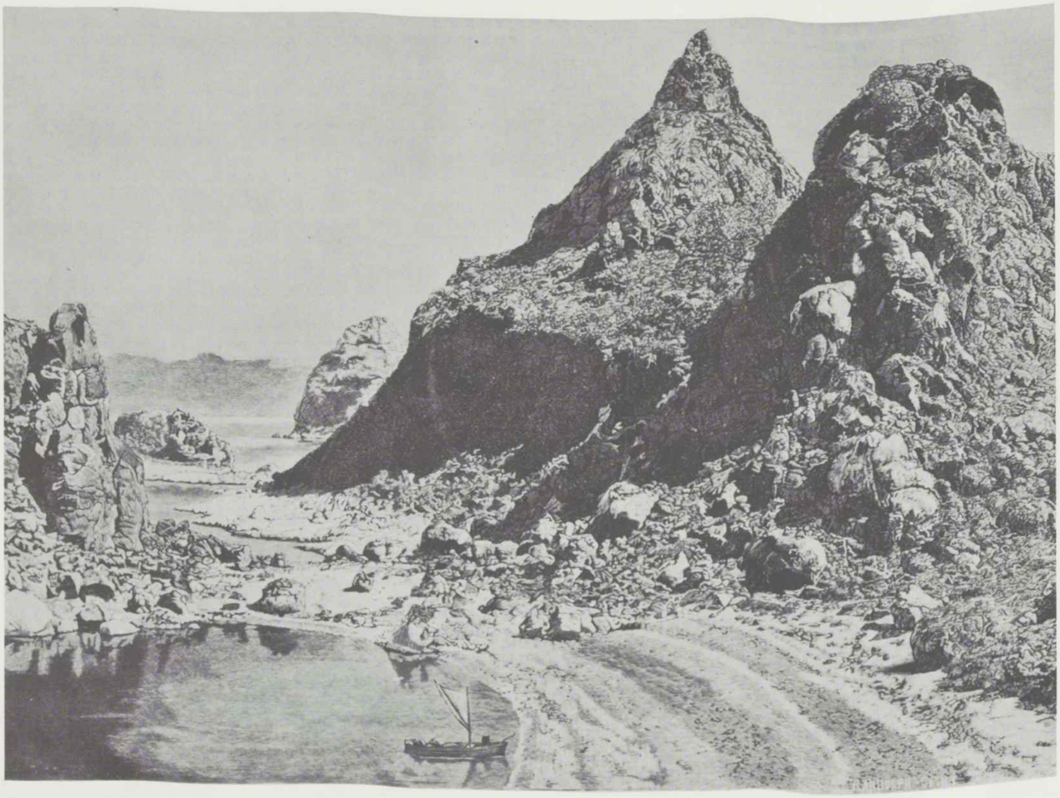


Figure 29.

Among the Needles, Pyramid Lake, Nevada.

Plate XIII of Monograph 11 of the U. S. G. S. Geological history of Lake Lahontan by I. C. Russell. This view is dated 1882.

Figure 30.

Among the Needles, Pyramid Lake, Nevada.

The same view as Plate XIII of Russell's Geological history of Lake Lahontan, Monograph 11 of the U. S. Geological Survey.
Taken September 12, 1937 by S. T. Harding.

Figure 31.

Picture of the X, Y, and Z rocks shown on Plate IX of Russell's Monograph 11, <u>Geological History of Lake Lahontan</u>. Taken July 11, 1939 by S. T. Harding.

Table 10 Records of Elevation of Pyramid Lake Prior to 1927

Comparison of Results obtained from District Engineer U.S.G.S (Salt Lake City) and from Harry C. Dukes, Truckee River Water Master in 1934.

Date	U.S.G.S Record	Duke's Record U.S.C.&G.S. Datum	Difference Duke minus U.S.G.S.	Observers listed on Duke's Record
1867	3881	3876.82	-4.18	King (Russell) ①
1871	3890	3885.82	-4.18	" ①
1882-9-9	3871	3866.82	-4.18	Russell
1889		3860.82		Sutcliffe (Jones)
1890		3877.82		"
1890	3880	3875.82	-4.18	U.S.G.S.
1891	3883			
1904	3861	3861.82	+0.82	U.S.B.R
1909-4-16	3868.6	3869.12	+0.52	S.P. Co.
1911-July	3869.1			
Aug.	3868.9			
Sept	3868.4			
Oct	3868.1			
1912-6-14	3866	3866.82	+0.82	S.P. Co
1913-7-7	3864	3864.82	+0.82	J.C. Jones
1914-2-28	3863.6	3864.12	+0.52	"
7-20	3865.8	3866.28	+0.48	"
1915	3861.			
1917	3860.8	3861.35	+0.55	Sutcliffe (Jones)
1922-8-26	3855.6	3856.08	+0.48	U.S.B. R
9-15	3855.0	3855.54	+0.54	S.P. Co
1924-3-22	3853.4	3853.92	+0.52	J.C. Jones
1926 6-11	3847.9	3848.42	+0.52	U.S.B.R

① See preceding discussion dating Kings picture in 1871 with an elevation of 3876 + making the elevation in 1867 equal to 3867 feet and in 1871 to 3876 feet.

derived by Duke have been used by the writer.

Duke's list includes records in 1890 and 1891 secured by Jones from Sutcliffe. Sutcliffe was the early settler on the west shore of the lake at what is still known as Sutcliffe. These records were based on the elevation of rocks which were laid bare by the lowering of the lake in 1889 and covered by the rise in 1890. These results represent a rise of 17 feet in the very wet year of 1889-90. This year had the maximum precipitation of any year since the records began in 1872. Other sources indicate that Mud Slough was closed during much of 1890. The rise in Pyramid Lake was undoubtedly large and may have been as much as 17 feet.

Saw dust nearly closed the channel to Pyramid Lake in 1888 and closed it completely in part of 1890. This caused much concern as it was feared that Pyramid Lake would become too salty for the survival of its fish if this continued. The Indians derived their main income from the sale of Pyramid Lake trout. A memorial was addressed to Congress by the Nevada Legislature in 1891 after the Indians had placed a dam in Mud Slough to return the flow to Pyramid Lake. The various reports made at this time do not include direct records of the elevation of Pyramid Lake.

In 1904 while making investigations of lands in the Reservation, the U. S. Reclamation Service secured the 1904 elevation shown in Table 10. Another record credited to the Southern Pacific Co. was secured in 1909. From 1909 to 1926, the longest period without an observation of the elevation of Pyramid Lake is 1917 to 1922.

ELEVATIONS OF PYRAMID LAKE 1903-05

Gaging stations were maintained on the Truckee River at Nixon and on Winnemucca Slough in 1903 to 1905. These records do not include observations on the elevation of Pyramid Lake. An analysis of the flow to Winnemucca Lake in comparison with the total flow of Truckee River enables the remaining flow to Pyramid Lake to be computed and the elevations of Pyramid Lake resulting from such inflow to be derived. The writer has concluded that Pyramid Lake was continuously below the elevation of its overflow to Mud Slough during this period. Flow in Mud Slough appears to have occurred as the result of the Truckee River flow dividing on its delta instead of by back flow from Pyramid Lake. There is one 1904 record of the elevation of Pyramid Lake, previously mentioned, which is about 1.2 feet below the elevation of inflow to the recent channel of Mud Slough. The elevation of Pyramid Lake while these stream records were being secured has been computed backward and forward for this 1904 elevation using the inflow and net evaporation from the lake for the period covered by these stream flow records.

ELEVATIONS OF PYRAMID LAKE SINCE 1927

Sufficiently frequent observations of the elevation of Pyramid Lake since 1927 have been made by the Truckee River Water Master and the U. S. G. S. to define its fluctuations. In Table 11 the available elevations of Pyramid Lake on the first of each month based on these records are shown from 1927 to 1960.

SUMMARY OF ELEVATIONS OF PYRAMID LAKE

The preceding discussion has included all of the information which the writer has been able to find on the elevations of Pyramid Lake since 1844. These have been plotted in Figure 32. An estimate of the fluctuations from 1810 to 1844 has also been included in Figure 32 based on the stumps and beach elevations on the delta of Truckee River.

The first observation is that of Fremont in January 1844 giving an elevation of 3860.5 feet. This is defined within a narrow range. It indicates that the stumps found along the inlet channel of Truckee River on land as low as elevations 3856 had been submerged prior to 1844. Assuming that they had been killed six or eight years prior to 1844 in order to allow time for the lake to rise to its 1844 elevation places the lake at an elevation of about 3855 feet in 1837. As the size of these stumps indicates an age of 15 to 20 years, the lake would have been below elevation 3855 for this length of time prior to about 1837. In Figure 32 the lake has been shown at elevation 3852 back to 1810. If the lake had been higher in this period these trees would have been killed prior to 1837. If the lake had been much below elevation 3852 in these years the regular beach formed by Russell in 1882 at this elevation would probably have been eroded by the Truckee River inflow.

While records of precipitation in California were not begun until 1849, some general comments on earlier years are available. Those of General John Bidwell have been quoted earlier in this report.

An extreme shortage or excess of precipitation in the Sacramento Valley is usually reflected in the drainage area of Truckee River. The California drought of 1840-41 probably occurred while the trees on the Truckee River channel were still alive. The lower of these trees had been submerged by 1844 when Fremont's record of the elevation of the lake was secured. In Figure 32 it has been assumed that these trees were killed by the rise of Pyramid Lake to elevation 3860.5 in 1842.

The next derived elevation of Pyramid Lake is 3860 feet in 1856. This is closely the same elevation as in 1844. In Figure 32 the elevation of the lake from 1844 to 1856 has been sketched in based on Bidwell's statements to 1850 supporting a rise with a corresponding lowering to 1856.

The next record of elevation of Pyramid Lake is in 1867 based on the interpretation of King's Plate XXIII (See previous discussion). This indicates a rise of 7 feet from 1856 to 1867. As this eleven year period included two years of excessive runoff, Pyramid Lake was probably above its 1867 elevation during part of this period.

There are accounts of great floods in 1861-62 in both California and in Nevada. These describe the great flood flows in December and January but do not include comments from which the volume of the annual flow can be derived. The storms causing these floods may and probably did remove much of the snow then on the drainage areas. The total runoff of the year 1861-62 may not have been as excessive as the rate of flow during these winter storms. A rise of Pyramid Lake to elevation 3875 appears to be as high as the lake could have risen and then lowered to elevation 3867 in 1867. This conclusion has been used in Figure 32. The fluctuation of Pyramid Lake from 1856 to 1867 in Figure 32 has been sketched in based on rises in 1860 and 1862 with sufficient

Table II Elevation of Pyramid Lake on First of Each Month. In terms of U.S.C.&G.S. Datum 1927-1960
Add 3800 ft. to Elevations shown until October 1959

Year	Jan	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct	Nov	Dec.
1927	(45.0)				46.0	46.4	46.5	46.0	45.5	44.9		
28	(43.8)			44.8	45.1	44.9	44.7	44.4	43.9	43.5	43.2	
29	(42.1)					41.35	41.15					
30	(38.4)											
31	(35.1)										31.5	31.5
32	31.6	31.5	31.4	31.35	31.5	31.7	31.7	31.3	30.8	30.35	29.95	29.5
33	29.2	28.9	28.55	28.25	27.8	27.5	27.4	27.2	26.8	26.5	26.3	26.0
34	25.8	25.65	25.5	25.3	25.25	25.0	24.8	24.5	23.9	23.25	22.95	22.75
35	22.45	22.24	22.11	21.93	22.0	22.3	22.4	21.94	21.5	21.18	20.7	20.24
36	19.82	19.77	19.57	19.50	19.65	20.05	20.12	19.7	19.25	18.75	18.31	18.02
37	17.68	17.04	16.87	17.59	18.20	18.50	18.29	18.1	17.7	17.0	16.66	16.5
38	17.07	16.71	16.62	16.9	18.0	20.4	21.3	21.2	20.65	20.19	19.8	19.65
39	19.75	19.78	19.81	19.87	19.87	19.7	19.33	18.8	18.32	17.73	17.42	17.2
40	17.06	16.95	16.80	17.03	17.94	18.73	18.6	18.1	17.55	16.9	16.7	16.6
41	16.65	16.9	17.02	16.97	16.88	16.9	16.97	16.64	16.17	15.58	15.21	15.13
42	15.17	15.25	15.94	16.50	17.06	17.68	18.20	18.10	17.55	17.08	16.58	16.4
43	16.52	17.3	18.4	19.5	21.0	21.5	21.5	21.15	20.45	20.12	19.65	19.4
44	19.17	19.09	18.94	19.1	19.25	19.15	18.87	18.45	17.95	17.40	17.00	16.72
45	16.5	16.47	16.55	16.37	16.68	17.0	16.92	16.5	16.04	15.6	15.25	14.8
46	14.7	14.8	14.75	15.0	15.15	15.5	15.1	14.8	14.37	13.65	13.78	12.9
47	12.6	12.44	12.2	11.9	11.85	12.43	12.55	12.5	12.3	11.00	10.65	10.3
48	10.05	09.8	09.7									
49			05.5						05.1	04.6	04.2	03.9
50	03.6	03.5	03.3	03.3	03.3	03.5	03.3	02.9	02.4	02.1	01.7	02.4
51	04.1	04.9	05.3							03.6	03.1	02.8
52	02.8	03.2	04.0	04.8	06.8	10.0	10.6	10.4	09.8	09.5	09.1	08.8
53	08.7	08.9	08.9	09.4	09.4	09.4	09.8	09.7	09.1	08.6	08.1	07.9
54	07.6	07.4	07.3	07.4	07.3	07.1						04.65
55	04.3	04.2	04.1	03.9	03.6	03.3	02.95	02.45				01.6
56	02.5											
57	04.2			03.3				02.80	02.26			01.25
58	(01.7)							04.20	3.85	3.40	2.80	2.50
59	2.35	2.25	2.00	2.00	1.80	1.55	1.35	0.85	0.20	*99.75	99.25	98.95
60	98.65	98.40	98.50	98.30	98.20	97.80	97.50	97.1	96.7	96.4		

* From here on add 3700 to elevations shown

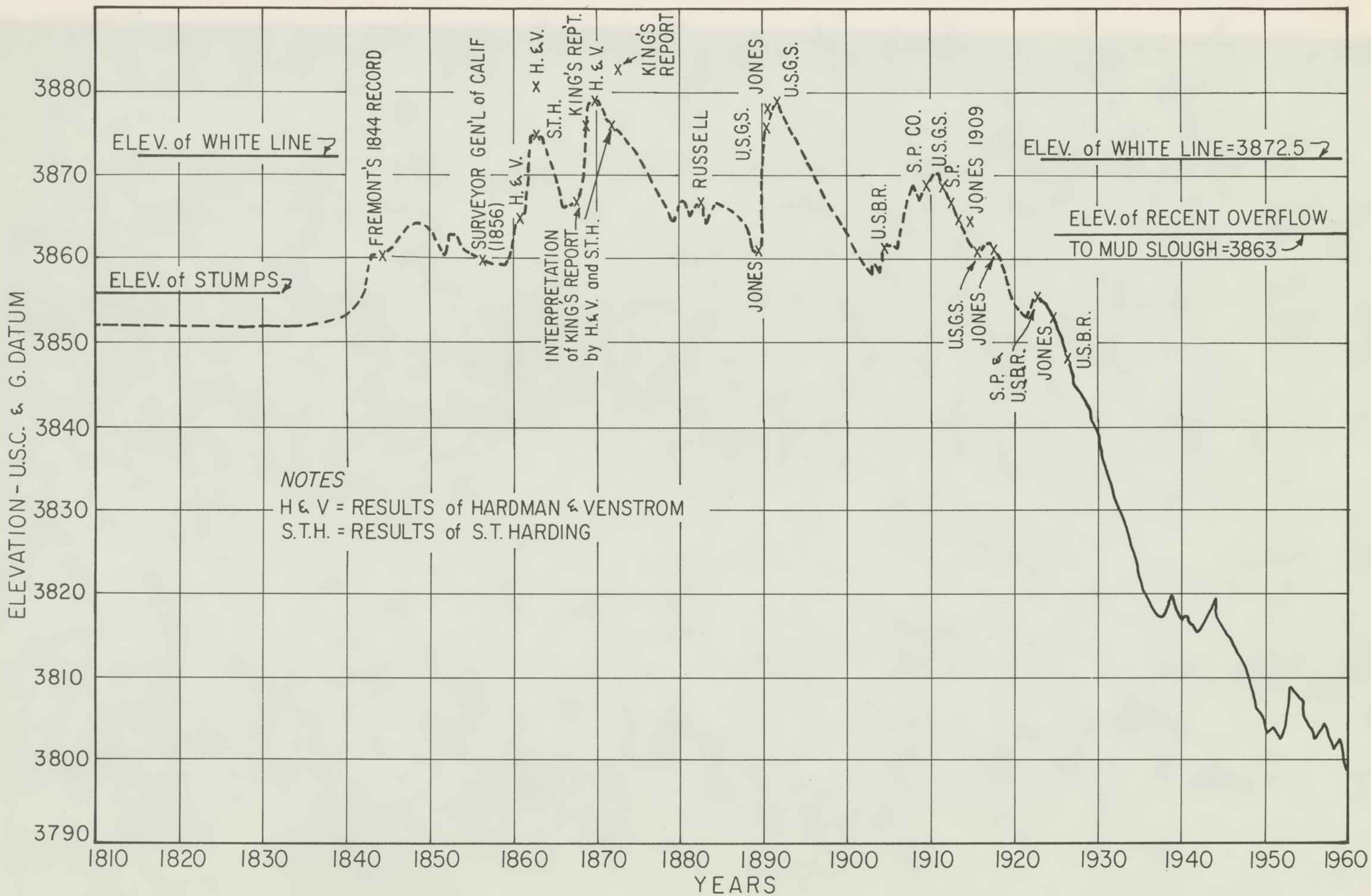


FIG. 32 FLUCTUATIONS OF PYRAMID LAKE, 1810-1960

lowering in the other years to bring the lake to elevation 3867 in 1867.

King reports a nine foot rise in Pyramid Lake from 1867 to 1871. There are no other records between these years. The year 1868 was one of large precipitation. Pyramid Lake may have risen 12 feet in 1868 to elevation 3879 and lowered 3 feet by 1871. The fluctuations shown on Figure 32 have been based on this assumption.

In 1870 precipitation records applicable to the Truckee River drainage area began to be kept so that an estimate of the general character of the water supply for each year can be made. Annual indices of precipitation were derived (see previous discussion) and used to interpolate the probable fluctuations of Pyramid Lake between the times of direct record. This procedure adds detail to the fluctuations shown on Figure 32. While at best such interpolations are uncertain in their details, the fluctuations shown in Figure 32 are considered to represent more nearly the actual fluctuations that occurred than would be shown by straight lines connecting the points of actual observations. Such uncertainties apply mainly to the period from about 1870 to 1910. Since 1910 records have been secured of the elevation of Pyramid Lake with sufficient frequency to remove the need for such interpretations.

There are no direct records of the elevation of Pyramid Lake from 1871 to Russell's record in 1882. A total lowering of nine feet occurred in this period. No extremes in the runoff in this period are reflected in the precipitation or other records. The fluctuation shown in Figure 32 for these years has been sketched in to reflect the general variations in precipitation during these years. Similar conditions and results apply from 1882 to Jones' result for 1889.

From 1891 to 1904 Pyramid Lake was above the recent elevation of overflow to Winnemucca Lake and probably lowered fairly steadily. The elevation of this overflow may have been higher than 3863 feet in the earlier part of this period and Mud Slough may have been eroded by this overflow. Pyramid Lake rose above its white line for the last time in 1891.

From 1904 to 1926 records have been secured with sufficient frequency to define the fluctuations of Pyramid Lake with reasonable closeness. Since 1926 monthly records of the elevation have been secured with few omissions.

Figure 32 presents the picture of the elevation of Pyramid Lake during the past 150 years. A substantial rise prior to 1870 is shown, a lowering to 1889, a major single year rise in 1889-90, further lowering to 1904 and another rise to 1910. After 1910 the diversions of the Truckee Canal prevent the fluctuations of Pyramid Lake from reflecting the runoff of its tributary drainage area.

Figure 32 shows Pyramid Lake to have been above its white line in three periods, reaching peak elevations in 1862, 1871, and 1891. The lake was generally above the recent elevation of overflow to Mud Slough from 1860 to 1914. This does not represent continuous flow to Winnemucca Lake as channel conditions have changed over this period. These changes are discussed more fully later in connection with the record of flow to Winnemucca Lake.

The results shown on Figure 32 for the fluctuations of Pyramid Lake are considered to represent the most probable elevations insofar as the available information permits them to be derived. These fluctuations are considered to be adequate for use in estimating the inflow to Pyramid Lake over the period shown. They are used later, together with similar fluctuations on Winnemucca Lake, in making estimates of the runoff of Truckee River for the past 150 years.

MUD OR WINNEMUCCA SLOUGH

Truckee River and Pyramid Lake discharge to Winnemucca Lake through what has generally been known as Mud Slough. It has also been called Winnemucca Slough. This channel had its inlet in the east bank of Truckee River and reached the southern slope of Marble Bluff about one-half mile below its head. The recently issued Nixon sheet of the U. S. G. S. designates this channel as Mud Lake Slough.

Such a channel apparently existed in 1844. The map in Fremont's report shows a small tributary to Truckee River just south of Marble Bluff. It is shown as having a closed drainage area to the east without extending to the area of Winnemucca Lake.

The controlling elevation of the inlet to Mud Slough in recent years, before it was closed by construction work near its inlet, was 3863.0 feet U. S. C. and G. S. datum. This channel in places has a rock bottom and apparently has not had a lower elevation. It may have been higher at some periods when it did not receive inflow. During any extended periods without flow, wind action on the dry sand in this area may have made sand deposits in the channel. Later large flows might erode any such deposits. In the Gibson report to the Indian Service in 1888, cutting to a depth of six feet in Mud Slough is mentioned as having occurred.

The discharge records in 1904-05 indicate a within-bank capacity of less than 1000 second feet. At the higher stages of Pyramid Lake, the lake spread over the channel banks at the inlet.

The last reported flow in Mud Slough was a small discharge in 1937 resulting from a division of Truckee River on its delta. The last preceding flow had been in 1928.

Several reports describe the result of saw dust dams affecting the flow to Pyramid Lake and in Mud Slough. These dams formed in the usual process of delta deposits. There were also artificial changes made around 1890 which increased and then reduced the flow into Mud Slough. The record is not sufficiently complete to define the conditions of inflow over the past 100 years except as they are reflected in the fluctuations of Winnemucca Lake.

The fill across Mud Slough for the Nixon-Gerlach highway has ended further direct inflow from Truckee River to Mud Slough. The only Truckee River water now reaching Mud Slough is a small amount of tail and waste water from the irrigation laterals of the Indian Service which extend into this area on the east side of Truckee River. This results in standing water in the low places along the slough but does not represent any material amounts of runoff. Such inflow does not reach the former bed of Winnemucca Lake.

FLUCTUATIONS OF WINNEMUCCA LAKE

In order to estimate the runoff of Truckee River prior to its direct measurement, a record of the fluctutations of Winnemucca Lake is required for use with similar results for Pyramid Lake. Winnemucca Lake was not on the routes of exploration until 1855. The writer has searched for all available information and has used the results to derive a history of Winnemucca Lake similar to that derived previously in this report for Pyramid Lake.

Winnemucca Lake was dry in 1844 and remained nearly dry until about 1858. It received relatively large amounts of inflow from 1860 to 1890. There is a similar white line around Winnemucca Lake to that on Pyramid Lake.

The first available report the writer has found relating to Winnemucca Lake area is Fremont's account of his trip in this area in January 1844. Fremont came in from the north, went up San Emidio Canyon and climbed an adjacent peak from which he could see the surrounding area. He gave an enthusiastic account of the view of Pyramid Lake but omits any description of a lake in the Winnemucca Lake bed area. Fremont then travelled along the east side of Pyramid Lake and camped at the mouth of Truckee River. He met and talked with Indians there. Fremont makes no mention of a Winnemucca Lake and his map shows no channel between the two lakes. Fremont was looking for a westward flowing river. If there had been a lake in the Winnemucca Lake bed or a flow from Pyramid Lake in Mud Slough, Fremont would have noted it and mentioned it in his diary. It is concluded the Winnemucca Lake was dry in 1844.

In 1886, in his Memoirs of My Life, Fremont included a map of the country he had explored. This map presumably shows the areas as he found them. Fremont must have heard of Winnemucca Lake by 1886. His failure to include it in this map is further indication that he did not find a lake there in 1844.

There are reports of Indian accounts told to early settlers of Winnemucca Lake having been dry prior to exploration of this area by the whites. Honest John, an Indian, told J. R. McCullough of Fernley of his grandfather having lived on grazing land above the northwest part of the lake. Later the water "come but go and come and go, then come and stay and make big water". (Reported to E. P. Osgood) Correlating ages and dates Honest John probably knew this area from about 1850 and the filling of the lake mentioned would be since that time.

The Pyramid Lake Indian Reservation was first created by a land withdrawal in 1859. An Indian Service map of 1858 has been reported by Osgood to show Winnemucca Lake about 4 miles long. For the flat bottom of the lake this would represent a depth of only one or two feet.

The Annual Report of the Surveyor-General of California for 1856 states, relating to Truckee River:

> "The river has two mouths; one branch turning abruptly off, within 300 yards of Pyramid Lake, and running in a circle to the SE and NE, at five miles empties into Mud Lake, which is to the northeast of Pyramid Lake."

This statement indicates that in 1856 Pyramid Lake was below the elevation of the inlet to Mud Slough and that any flow to Winnemucca Lake at that time had resulted from the division of Truckee River above Pyramid Lake. The 1858 Indian Service map indicates that the amount of any such flow to Winnemucca Lake prior to 1858 had been small.

There are numerous maps of the general area which were made during the period 1850 to 1867 which include Pyramid and Winnemucca Lakes. Some of these were based on explorations and many were compiled for emigrant use from the result of these explorations. Pyramid and Winnemucca Lakes were off the mainroutes used in these years, and direct statements regarding the size of Winnemucca Lake are lacking. Many of these early maps are described in Wheat's Maps of the California Gold Region and his later Mapping the Trans-Mississippi West.

An examination of these maps and a review of the reports made during the 1850's indicates that Winnemucca Lake was either dry or contained only small amounts of water until 1861-62. In this year of very large runoff Winnemucca appears to have received sufficient inflow to have had a substantial volume and area.

King's Exploration of the 40th Parallel is the first direct report relating to Winnemucca Lake. King's field work was done from 1867 to 1871. He reports that Winnemucca Lake was 80 feet lower than Pyramid Lake in 1867 and that Winnemucca Lake rose 22 feet between 1867 and 1871. King's map of Winnemucca Lake was made in 1867 and shows a length of 24 miles and a maximum width of five miles with an area of about 55,000 acres. This area represents an elevation of 3838 feet present datum. This elevation is about 50 feet higher than the elevation derived from King's statement of difference in elevation of the two lakes in 1867. The differences in elevation stated by King were probably based on barometric levels. The results indicated by the map have been accepted.

Russell's work in 1882 (Monograph 11, U. S. G. S., Geological History of Lake Lahontan) was the most complete survey to that date of these two lakes, and also includes results on previous stages of these lakes based on recollections of early settlers. Russell quotes George Frazier, a local settler since 1862, to the effect that Winnemucca Lake had been low prior to 1862 but had risen some 25 feet by 1882. There were dead trees in the lake along the inlet channel into the lake which had been submerged by 1862. A large inflow occurred in 1868 which raised Pyramid Lake above the elevation of inflow to Mud Slough and overflow to Winnemucca Lake occurred in 1868 and 1869. In 1876 the inlet to Pyramid Lake was closed by a gravel bar and all of the flow went to Winnemucca. Russell states, regarding Frazier's statements:

> "These observations, although not of scientific accuracy, are yet of value, and have been confirmed by other people who have been acquainted with these Lakes for a number of years."

In May 1937 E. P. Osgood and the writer followed the course of the former inlet channel to Winnemucca Lake seeking any remaining evidence of the trees which Russell reported. Stumps were found at several places along this channel. These were six to 12 inches in diameter and extended two to three feet above the ground. A view of one of these stumps is shown in Figure 33. These stumps were too large and too badly decayed to have grown and died in recent years. The lowest stumps were on ground at about elevation 3805 feet where Russell shows a depth of the lake of 40 feet in 1882. These trees could have maintained their growth on the irregular inflow to Winnemucca Lake prior to 1867 when they were submerged. They remained submerged until about 1930.

Figure 33.

Stump along inlet channel from Truckee River into Winnemucca Lake. Taken May 15, 1937 by S. T. Harding. E, P. Osgood is standing by one of the larger stumps.

These stumps are the remains of the line of trees reported to have been submerged by the rise of the Lake in the 1880's. They could still be traced from the inlet into the lake bed in 1937.

Figure 34.

White Line on North Shore of Winnemucca Lake.

Taken June 18, 1937 near B. M. 3887 by S. T. Harding.

A map of the Mud Slough and adjacent portions of the two lakes was prepared in 1922 by L. F. Canterbury as a part of the U. S. Reclamation Service investigations in this area. These results are in the files of the Truckee-Carson Irrigation District at Fallon. Canterbury also reported three elevations of Winnemucca Lake. Adjusted to present datum these are 3846 feet in 1909; 3821.6 in 1922; and 3811 in 1926.

Canterbury also prepared a graph showing past fluctuations of Winnemucca Lake. He showed some points as records for which he did not indicate the source. He shows an elevation of 3792 present datum in 1867 which is consistent with other records. Elevations of 3817 to 3818 feet are also shown for 1868-1869 and 1870.

E. P. Osgood's records beginning in 1935 have been discussed previously in connection with the evaporation from Winnemucca Lake. These records show a lake elevation of 3787 feet in May 1935 to the practical drying of the lake in 1939 at elevation 3775. Osgood also made soundings on Winnemucca Lake in 1936. When expressed in terms of present U. S. G. S. datum they confirmed the soundings made by Russell in 1882 when expressed in the same datum.

Winnemucca Lake has a "white line" similar to that on Pyramid Lake. This is still clearly visible as shown in Figure 34. Osgood secured an elevation of 3853 feet present datum for this white line. This is 15 feet below the elevation of the white line on Pyramid Lake and five feet below the present elevation of inflow to Mud Slough. Osgood also reported a terrace on Winnemucca Lake at the same elevation as its white line.

Hardman and Venstrom (American Geophysical Union, Transactions of 1941, pp. 71--90) comment on the elevations of Winnemucca Lake since 1882. They quote R. H. Cowles, whose ranch buildings are located on Winnemucca Slough at about elevation 3860, that the lake never rose to these buildings. The highest recent beachline on Winnemucca Lake was found to be at about elevation 3854.5 which is the elevation found by Russell in 1882. This is about 1.5 feet above the white line. Observations by the above authors and E. P. Osgood in 1938 of the vegetation above and below this highest beach line showed marked differences in general appearances, color and age. From these results Hardman and Venstrom concluded that Winnemucca Lake has not been above an elevation of about 3855 in recent years.

SUMMARY OF FLUCTUATIONS OF WINNEMUCCA LAKE

The available information and the writers' conclusions regarding the elevations of Winnemucca Lake since 1810 are plotted on Figure 35. Most of these results have been discussed.

This record of Winnemucca Lake is fragmentary and only part is based on direct observations tied to known elevations. Interpretation of these results are required and the results of different interpreters may vary. Overall the fluctuations shown are considered to represent a fairly correct determination of the fluctuation of Winnemucca Lake for the period covered.

Some of the results shown on Figure 35 are in disagreement. Frazier's statements regarding 1862 are inconsistent with DeGroot's 1864 map. The year 1861-62 is generally recognized as having had a very large runoff in the area. A large rise is considered to have occurred in Pyramid Lake but it does not

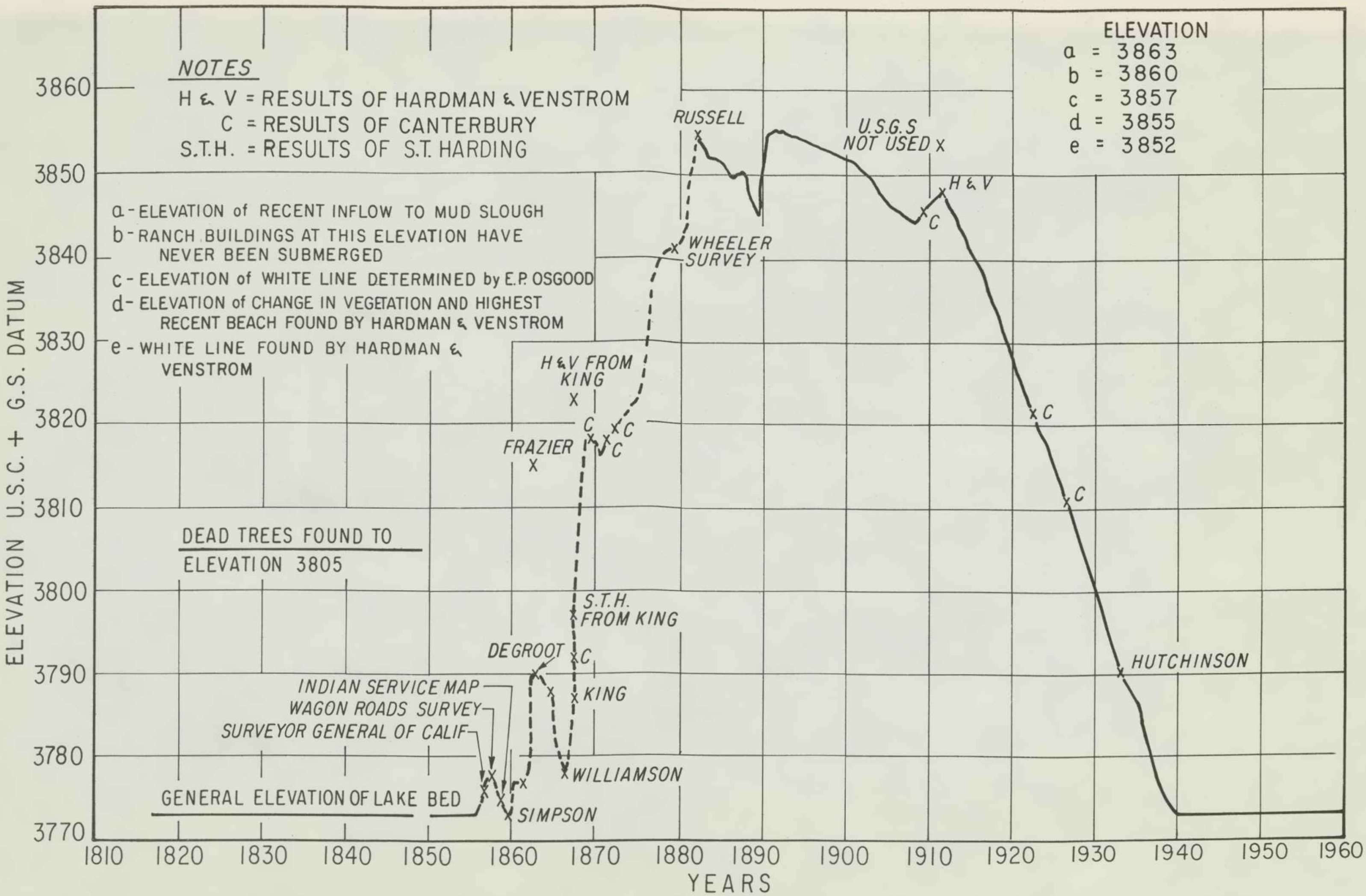


FIG. 35 FLUCTUATIONS OF WINNEMUCCA LAKE, 1810 TO 1960

follow that a similar rise occurred in Winnemucca Lake. Pyramid Lake was near the present inlet elevation to Mud Slough in 1861 but existing channel conditions are not known. As there had been little flow in Mud Slough for a relatively long period prior to 1861, the capacity of the slough was probably smaller than it became in later years of large flow. A major inflow to Winnemucca Lake in 1861-62 probably did not occur. It has been assumed that the lake rose only to a height from which it could lower to the area shown by DeGroot's map in 1864.

For 1911 the elevation in U. S. G. S. Bulletin 654 adjusted to present datum has been used. For the 28 years from 1911 to 1939 Winnemucca lowered 75 feet to dryness. This is an average rate of lowering of 2.7 feet per year. As the net evaporation that has been derived for Winnemucca Lake is 3.56 feet per year this average rate of lowering indicates that inflow occurred at some time during this period. Records are not available on the times or amounts of such inflow and a generally uniform lowering between the points of record has been shown on Figure 35. From 1911 to 1922 the mean annual rate of lowering was 2.45 feet indicating that the inflow in these years exceeded the 28 year average.

The results shown in Figure 35 have been used in the derivation of the runoff of the Truckee River at Nixon.

MEASURED INFLOW TO PYRAMID LAKE

The inflow to Pyramid Lake, except that from the Truckee River, is negligible in amount. Winnemucca has been a dry playa since its inflow from the Truckee River has been cut off. There is no indication of any seepage from either lake; the beds of both are lower than the adjacent areas in which such seepage might appear. There have been a few springs in Pyramid Lake. These have been small flows at a few tufa domes. The springs formerly reported to issue from Pyramid Island above the lake surface no longer flow.

The first Truckee River Water Master, Harry C. Dukes, began a record of the flow of the Truckee River just above its entry to Pyramid Lake in 1928. This record with a few omissions, is available to date. It is shown in Table 12. A similar record below Derby Dam was secured from 1927 to 1933. The difference in these two records, at times when both were secured, represents the net results of seepage inflow, mainly from the Truckee Canal and diversions for the Pyramid Lake Indian Reservation.

RAINFALL ON PYRAMID AND WINNEMUCCA LAKES

The nearest precipitation station to Pyramid Lake is at Nixon at the south end of the lake. The record from 1927 to 1955 had a mean annual precipitation of 6.7 inches. This record and that at Lahontan Dam for some later years are shown in Table 13.

U. S. Weather Bureau records for over 40 years at Empire have a mean annual precipitation of 5.25 inches and at Sand Pass of 6.53 inches. These stations are in the desert area north of Pyramid and Winnemucca Lakes.

Table 12 Measured Inflow to Pyramid Lake from Truckee River. Records of Truckee River Water Master

Thousands of Acre-feet

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
Passing Derby Dam													
1927	1.4	27.1	36.0	76.7	110.8	74.3	2.0	1.7	2.3	2.9	1.1	7.6	343.9
28	25.5	15.2	134.7	63.7	34.8	1.4	1.6	1.5	1.2	1.4	.6	2.5	284.1
29	6.1	.8	1.1	.7	1.9	1.6	1.1	1.2	.8	.3	.1	3.5	19.2
30	.1	.1	6.3	18.7	3.4	1.0	.9	.8	.5	.1	.1	.2	32.2
31	.2	.2	.4	.4	1.0	.8	.4	.3	.3	.2	.1	.1	4.4
32	.2	.2	4.3	26.2	53.3	22.6	.9	1.0	.5	.3	.2	.2	109.9
33	.2	.2	.4	.5	6.0	12.8	.8	.6	.5	.3	.3	.3	22.9
Below Pyramid Dam													
1928							0	.0	.7	1.9	1.9	2.6	
29	8.9	1.7	1.4	1.0	1.9	5.1*	0	0	0	.7	1.2	5.4	27.3
30	1.5	1.2	6.7	19.8	3.5	.6	0	.0	0.1	1.7	1.7	1.6	38.4
31	1.7	1.0	.2	.2	0	0	0	.1	0	0	1.1	1.2	5.5
32	1.9	1.9	6.7	26.8	49.4	25.6	.4	.0	0	0.9	2.1	2.0	117.7
33	1.9	1.9	2.2	1.2	3.6*	16.8	.2	0	0	.6	2.8	3.0	34.2
34	2.4	2.1	5.3	2.8	.2*	1.2	0	0	.2	1.8	2.1	1.8	19.9
35	1.7	1.6	1.4	40.9	54.2	20.7	0	0	0	.7	2.2	2.1	125.5
36	3.2	5.9	16.9	64.8	58.7	23.5	.6	.4	2.6	3.9	3.1	2.5	186.1
37	3.1	31.7	37.8	61.4	42.8	4.1	.0	0	0	5.1	2.4	68.3	256.7
38	11.6	35.0	56.0	145.4	248.6	142.5	19.4	1.2	1.9	8.7	28.4	31.2	729.9
39	15.0	23.2	25.8	14.2	1.5	1.2	0	0	.6	2.1	2.3	2.3	88.2
40	4.4	6.2	49.2	106.0	88.2	17.8	.7	0	1.2	3.3	22.9	39.8	339.7
41	36.9	22.7	3.8	1.7	33.6	26.9	1.2	1.2	.8	1.5	9.0	39.1	178.4
42	57.2	73.3	45.7	86.4	86.3	135.6	15.2	.1	1.4	2.7	8.5	28.2	540.6
43	94.1	145.2	137.8	163.7	85.8	29.9	2.5	1.8	2.1	10.5	9.6	4.3	687.3
44	2.6	3.8	30.0	14.9	7.4	2.6	0.9	.6	.6	1.5	4.4	2.6	71.9
45	2.2	13.1	7.7	23.7	67.7	18.9	1.6	.6	1.4	3.3	6.4	21.5	168.1
46	24.9	28.7	18.8	52.5	49.8	4.9	.6	.3	1.0	1.8	10.8	17.1	211.2
47	29.4	11.0	3.1	1.2	4.6	.6	0	.3	.8	2.0	1.7	1.5	56.2
48	1.2	1.2	1.2	1.8	4.3	15.8	.3	0	.8	1.5	1.2	1.6	30.9
49	1.2	1.1	1.3	1.6	5.3	.5	.1	.1	0	.1	1.2	1.7	14.2
50	1.6	1.6	1.7	20.8	46.0	20.1	.6	.0	1.0	2.2	94.8	198.1	388.5
51	113.2	64.6	41.2	11.9	10.2	5.8	.6	.7	1.3	1.7	2.4	9.9	263.5
52	47.0	113.6	108.8	211.3	329.6	179.0	22.4	1.9	8.3	5.1	6.1	17.5	1050.6
53	36.0	44.2	6.5	14.3	52.3	75.8	19.7	.3	6	1.4	2.6	2.5	256.2
54	2.3	1.7	7.6	11.0	14.8	1.6	.2	1.1	1.3	2.0	2.7	2.5	48.8
55	1.8	1.7	1.9	1.8	1.8	.2	0	.0	.4	1.8	1.8		13.2
56	89.3	65.4	67.9	77.5	104.1	108.0	6.8	.1	.4	1.9	3.2	3.3	527.9
57	3.3	8.5	28.3	3.4	25.0	41.0	.5	.0	1.0	2.5	2.4	2.5	118.4
Mean for 29 yrs 1929-1957	20.7	24.6	24.9	40.8	51.1	31.9	3.2	0.4	1.0	2.6	8.4	17.8	227.4
1958	2.0	7.0	4.6	150.0	263.7	69.5	2.9	6.8	1.6	1.8	3.6	2.2	515.7
1959	3.2	2.4	1.8	1.2	1.6	1.1	1.3	1.6	1.8	1.4	1.4	1.6	20.4
1960	1.6	4.6	2.5	2.6	4.0	6.9	1.2	1.9	2.1	(1.4)	(1.4)	(1.6)	35.2

Table 13 Precipitation at Nixon in feet
Used for Precipitation on Pyramid Lake
For Jan. 1927 to April 1928 record is that of Lahontan

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug	Sept.	Oct.	Nov.	Dec.	Total
1927	.01	.04	.02	.04	0	.01	.01	.01	.03	.04	.01	.02	.24
28	.01	.01	.04	0	0	.03	0	.03	0	0	.04	.01	.17
29	.01	.03	.06	.01	0	.08	0	0	0	0	0	.04	.23
30	.02	.03	.01	.08	.09	0	.02	.02	.21	.10	.08	0	.66
31	.03	.07	.02	.06	.02	.03	.01	.02	.03	0	.06	.09	.44
32	.07	.05	.02	.13	.02	.02	0	0	.02	0	0	.02	.35
33	.09	.03	.01	.01	.05	.01	0	0	0	.06	.01	.05	.32
34	.03	.05	.02	0	.04	.17	0	0	.03	.11	.10	.09	.64
35	.07	.08	.04	.08	.06	0	0	.02	0	.03	.11	.05	.54
36	.04	.07	0	0	.01	.13	.05	.06	.01	.03	0	.14	.54
37	.09	.06	.02	.01	.01	0	.06	0	0	.02	.03	.14	.44
38	.02	.14	.07	.04	.09	.13	.03	.02	.04	.08	.04	0	.70
39	.07	.06	.03	.01	.05	.01	.01	.02	.04	.11	.02	.05	.50
40	.21	.05	.04	.08	.03	.07	.05	0	.08	.07	.07	17	.88
41	.06	.17	.02	.05	.05	.10	.07	.07	.01	.17	.07	10	.94
42	.11	.05	.07	0	.05	.06	.02	0	.01	.03	.07	.09	.56
43	.34	.08	.17	.03	0	.11	.09	0	0	.15	.08	.05	1.10
44	.16	.16	.10	.12	.03	.06	0	0	.04	.05	12	.03	.87
45	.01	30	08	.01	.06	.15	.01	.01	0	.07	.04	.06	.80
46	.06	02	.15	.01	.02	0	.02	0	.03	.17	.07	.04	.59
47	.06	.08	.02	02	.10	.02	0	0	0	.02	.05	.01	.38
48	0	.07	0	(.04)	(.04)	.02	0	0	0	.05	.01	.01	.24
49	.02	.03	.01	.01	.06	0	0	0	0	.01	.01	.01	.16
50	.02	0	0	.01	0	.03	(.02)	0	.07	.06	.28	.11	.60
51	.04	.15	0	.07	0	0	0	0	.01	.12	.03	(.06)	.48
52	.12	.04	.25	.09	0	.01	.06	0	.04	.02	.01	.05	.69
53	.04	0	.01	.03	.16	.03	0	.05	0	.01	0	0	.33
54	.02	.04	.10	.06	0	.08	0	0	0	0	.03	.02	.35
55	0	.02	.01	0	.06	0	0	0	.10	.05	0	.12	.36
Mean for 29 yrs 1927-1955	.07	.07	.05	.04	.04	.05	.02	.01	.03	.06	.06	.06	0.56

Nixon 25 years 1928-52 + Lahontan Dam for Remainder

Precipitation at Lahontan Dam

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug	Sept.	Oct.	Nov.	Dec.	Total
1956	(.12)	0	0	.04	07	.01	0	0	0	.03	0	0	.28
57	.07	.03	0	.01	.05	.02	0	0	0	.06	.03	0	.27
58	02	(05)	.03	.04	.02	.09	0	.03	0	0	.01	.01	.30
59	0	.05	0	0	.02	0	.01	.01	.06	0	0	0	.15
Mean*	.04	.06	.03	.03	.04	.03	.01	.01	.02	.03	.02	.05	.37

*Long time Annual Mean at Lahontan Dam.

EVAPORATION FROM PYRAMID LAKE

The evaporation from Pyramid Lake can be computed from the inflow, the rainfall on the lake, and the change in the lake elevation. Records for this computation are avialable on a monthly basis since 1927. The results are shown in Table 14. The adjustments made in adapting the available records to monthly results are shown on Table 14. The annual results have been previously discussed.

The lake elevations have been read on an open water gage and have been subject to some wave action. Some results in months of excessive inflow were not used in computing the means. The basis of the selection of the months used in deriving the means is shown on Table 14. The mean annual derived evaporation from Table 14 is 4.00 feet per year. This is the gross evaporation without reduction for rainfall on the lake. The mean annual evaporation derived from annual records, using all records without rejection of any months, was 3.94 feet, indicating that the adjustments made in Table 14 tended to be self balancing.

EVAPORATION FROM WINNEMUCCA LAKE

From 1935 to 1938, when Winnemucca Lake varied from about 10 feet in depth to dryness, E. P. Osgood secured a record of its rate of lowering which can be used to derive the monthly evaporation from the lake. These results are shown in Table 15. The mean results have been discussed previously. Comparable results for Pyramid Lake are also shown.

While the mean annual evaporation from Pyramid and Winnemucca Lakes is closely the same, there are material differences in their monthly amounts. These are the result of the differences in the depth of the two lakes in these years and the differences the storage and release of absorbed heat in the different parts of the year.

These results were presented and discussed in an article of the writer ("Evaporation from Pyramid and Winnemucca Lakes, Nevada," Journal of the Irrigation and Drainage Division, Proceedings of the American Society of Civil Engineers, Vol. 88, No. IR 1, March, 1962). This article also included a comparison of the temperature loops for these two lakes which is reproduced here as Figure 36.

DERIVED INFLOW TO PYRAMID AND WINNEMUCCA LAKES

The available records and the resulting estimate of the various items which affect the inflow to these lakes have been discussed. Since 1927 there is a direct record of this inflow. This has been used to derive the rate of evaporation from these lakes and this rate has been applied to the fluctuations of the lakes prior to 1928 to derive the inflow that would be required to supply the evaporation.

The derived inflow prior to 1928 is shown in Table 16. As previously discussed this has been carried back to 1780 based on the assumption that Pyramid Lake had taken 30 years to lower from its white line prior to 1839 and also 30 years to rise to its white line prior to 1809. After 1839 the periods used have been controlled by the time at which records

Table 14 Summary of Available Records of Evaporation from Pyramid Lake. Computed from Inflow, Rainfall and Fluctuations of Lake. Results of S.T. Harding

Year	Jan.	Feb	Mar	Apr.	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
1927					0.42	0.46	.52	.52	.65				
28				② .18	② .26	.23	.30	② .53	② .40	.31			
29													
30													
31													
32	② .18	② .17	.12	.19	.21	② .22	.40	② .50	.47	.41	.47	.34	3.88
33	.40	.39	② .33	.46	② .38	② .24	② .30	② .30	② .30	② .26	.33	.27	3.96
34	.20	.22	.26	② .07	.29	.38	.30	.60	.68	.42	.32	.40	4.14
35	.29	.22	.23	.14	② .20	.27	.46	.46	.32	② .52	② .59	.49	4.19
36	② .21	② .21	.21	.37	.09	.25	.48	.51	.53	.50	.32	.50	4.18
37	③ .76	③ .49	③ .39	③ .10	③ .06	.24	.25	.40	.70	.40	.21	.13	3.15
38	③ .48	③ .52	③ .25	③ .13	③ -.28	.38	.29	58	.51	.54	.42	.16	3.98
39	② .16	② .22	.20	.12	.23	.39	.54	.50	.63	.44	.26	.21	3.90
40	.36	.25	.21	① .04	① -.04	.34	.55	.55	.71	.27	.35	.42	4.01
41	① .10	① .24	.10	.15	.30	.25	.41	.55	.61	.55	.22	.38	3.86
42	① .50	① -.04	① .12	① .15	① .13	① .65	.24	② .55	② .49	.55	.32	.20	3.62
43	① .32	① .16	① .18	① -.15	① .19	.35	.46	.71	.35	.70	.44	.28	3.99
44	.26	.34	.19	.09	.19	.36	.43	.51	.59	.46	.44	.27	4.13
45	③ .06	③ .33	.32	① -.11	② .29	② .38	.44	.48	.45	.45	.54	.34	3.97
46	.16	② .16	② .21	.29	.08	.44	.32	.43	.76	65	.44	.48	4.42
47	① .46	① .41	.35	③ .08	③ -.44	③ -.10	③ .05	③ .20	③ 1.31	.39	.41	.27	3.39
48	.26	.18											
49									.50	.41	.31	.31	
50	.13	.21	② .01	.19	.20	.40	.43	50	.38	.48	.39	.11	3.43
51	.21	.30 <				③ 2.39			>	.63	.35	.14	4.02
52	① .12	① .21	① .38	① -.11	① -.39	① .94	.45	.62	.41	.46	.36	.30	3.75
53								③ .18	.49	.55	.27	.28	
54	.22	.17	.11	③ .05	.23	.29							
55	.35	.13	.13	.22	③ .38	.30	.35	.50					
56													
57								.54					
Mean	.24	.24	.20	.21	.23	.32	.40	.52	.52	.46	.36	.30	4.00
Number of Years in Mean	14	14	14	12	14	19	20	21	21	22	21	21	
1958								② .52	② .50	② .50	.34	.18	
59	.13	③ .23	③ .12	.21	.28	② .31	② .42	.68	.53	.51	.31	.31	4.04
60	.26	③ -0.6	.23	② .25	② 27	41	31	41	.42	.31			

① Months of large inflow - Not used in mean
② Adjusted with adjacent months
③ Apparently some error in records - Omitted from mean

Table 15 Computation of Evaporation from Winnemucca Lake based on Records of E.P. Osgood.

Date	Change in Lake Elevation	Rainfall during Month	Indicated Evaporation
1935			
May	-0.40	.06	0.46
June	-0.76	0	0.76
July	-0.68	0	0.68
Aug.	-0.66	.02	0.68
Sept.	-0.50	0	0.50
Oct.	-0.26	.03	0.29
Nov.	-0.02	.11	0.13
Dec.	+0.02	.05	0.03
Year	-3.26	.27	3.53
1936			
Jan.	+0.06	.04	-0.02
Feb.	-0.09	.07	0.16
Mar.	-0.24	0	0.24
Apr.	-0.57	0	0.57
May	-0.55	.01	0.56
June	-0.55	.13	0.68
July	-0.60	.05	0.65
Aug.	-0.45	.06	0.51
Sept.	-0.15	.01	0.16
Oct.	-0.15	.04	0.19
Nov.	-0.17	0	0.17
Dec.	0	.14	0.14
Year	3.46	.55	4.01
1937			
Jan.	+0.07	.09	.02
Feb.	+0.19	.06	-0.13
Mar.	-0.16	.02	0.18
Apr.	-0.38	.01	0.39
May	-0.50	.01	0.51
June	-0.75	0	0.75
July	-0.62	.06	0.68
Aug.	-0.81	0	0.81
Sept.	-0.37	0	0.37
Oct.	-0.12	.02	0.14
Nov.	-0.08	.03	0.11
Dec.	+0.23	.14	-0.09
Year	3.30	0.44	3.74

Date	Change in Lake Elevation	Rain fall during Month	Indicated Evaporation
1938			
Jan	-0.08	.02	0.10
Feb	+0.28	.14	-0.14
Mar	-0.18	.07	0.25
Apr	-0.11	.04	0.15
May	-0.44	.09	0.53
June	-0.40	.13	0.53
July	-0.47	.03	0.50
Aug	-0.38	.02	0.40
Sept.	-0.18	.04	0.22
Oct.	+0.12	.08	-.04
Nov	+0.06	.04	-.02
Dec.		0	
Year	1.78	.70	2.48

Indicated Evaporation in Feet

Month	1935	1936	1937	1938	Mean	Mean Pyramid Lake	Mean Air Temperature
Jan		-0.02*	.02	0.10	0.06	.24	30.8
Feb		0.16	-0.13*	-0.14*	0.16	.24	36.6
Mar		0.24	0.18	0.25	0.23	.20	42.9
Apr		0.57	0.39	.15	0.38	.21	49.2
May	0.46	0.56	0.51	.53	0.51	.23	56.7
June	0.76	0.68	0.75	.53	0.68	.32	63.0
July	0.68	0.65	0.68	.50	0.63	.40	71.7
Aug.	0.68	0.51	0.81	.40	0.60	.52	70.6
Sept.	0.50	0.16	0.37	.22	0.31	.52	62.5
Oct.	0.29	0.19	0.14	-.04*	0.20	.46	52.4
Nov.	0.13	0.17	0.11	-.02*	0.14	.36	41.2
Dec.	0.03	0.14	-0.09*		0.08	.30	34.7
	3.53	4.01			3.98	4.00	51.0

*Omitted from Mean-Inflow Indicated

J.T.H.

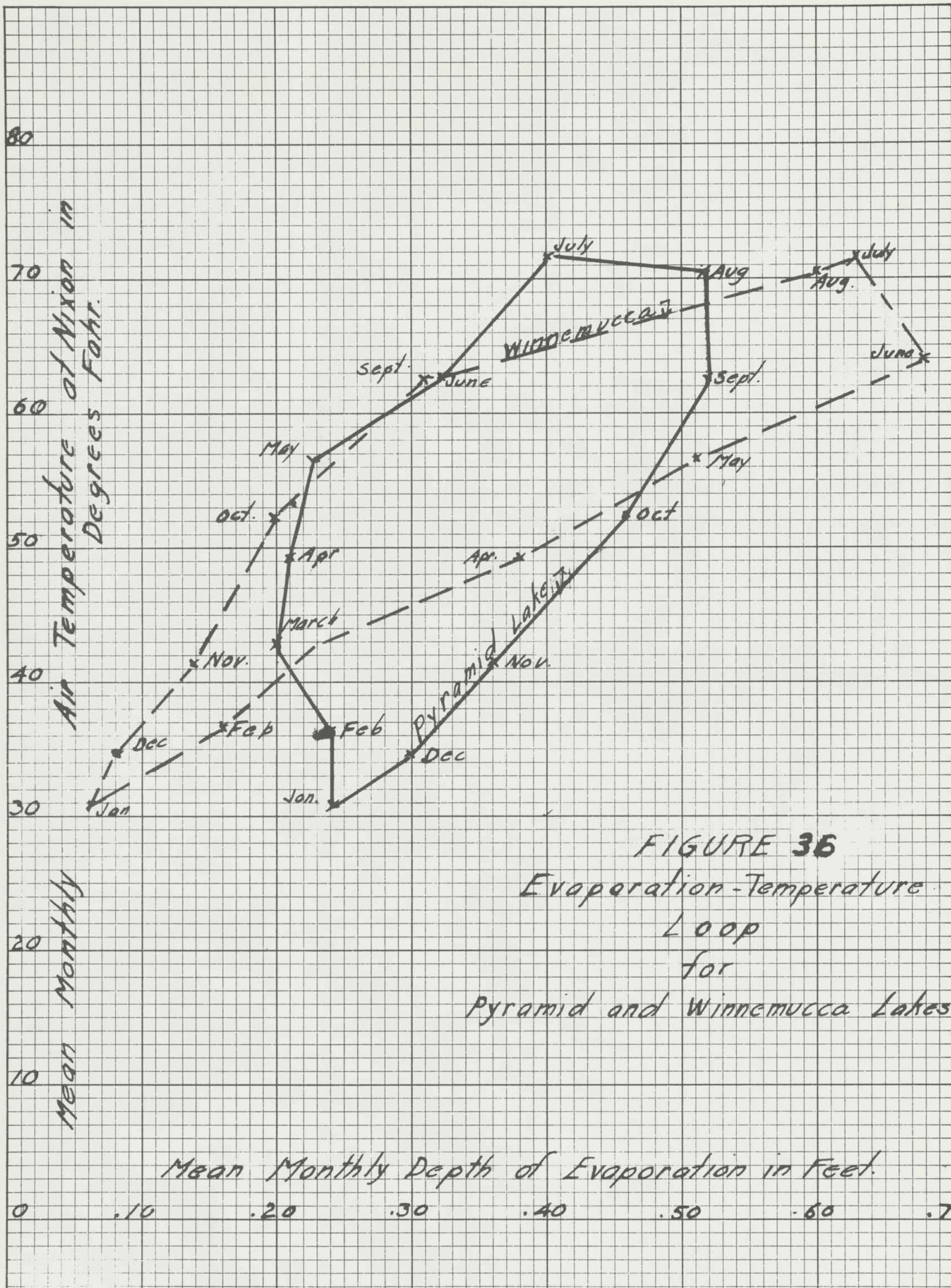


FIGURE 36
Evaporation - Temperature
Loop
for
Pyramid and Winnemucca Lakes

Table 16 - Computed Inflow to Pyramid and Winnemucca Lakes 1780 to 1927
In Thousand Acre-feet except as noted

S.T.H

PYRAMID LAKE

Period Calendar Years	Number of Years in Period	Mean Annual Rain-fall. Depth in Feet	Beginning of Each Period: Elevation of Lake in Feet	Beginning of Each Period: Area of Lake in 1000 acres	Change in Storage in Each Period: Total for Period	Change in Storage in Each Period: Annual Mean	Evaporation: Mean Area of Lake in 1000 acres	Evaporation: Gross Evaporation Annual	Rain-fall on Lake. Total Annual Mean	Indicated Mean Annual Inflow	Indicated Total Inflow for Period
1780-1809	30	.50	3872	138	-2680	-89	134	536	72	375	11250
1810-1839	30	.50	3852	130	+260	+9	130.5	522	65	466	13980
1840-1842	3	.65	3854	131	+930	+310	132.5	530	86	754	2262
1843-1849	7	.60	3861	134	+134	+19	134	536	80	475	3323
1850-1851	2	.45	3862	134	+133	+68	134.5	538	60	546	1092
1852-1853	2	.65	3863	135	+408	+204	135.5	542	88	658	1316
1854-1858	5	.50	3866	136	-945	-189	135	540	68	283	1415
1859-1860	2	.70	3859	134	+810	+405	135	540	94	851	1702
1861	1	1.00	3865	136	+1375	+1375	137.3	550	138	1787	1787
1862-1864	3	.50	3875	139	-690	-230	138.5	554	69	255	765
1865-1866	2	.50	3870	138	-411	-206	137.5	550	68	276	552
1867-1868	2	.75	3867	137	+1670	+835	139.3	558	104	1289	2578
1869-1870	2	.50	3879	142	-423	-214	141	564	70	280	560
1871-1878	8	.50	3876	140	-1508	-190	138	552	69	293	2344
1879-1881	2	.50	3865	136	+273	+91	136.3	546	68	569	1707
1882-1883	2	[illegible]	3867	137	0	0	137	548	61	487	974
1884-1888	5	.50	3867	137	-812	-162	135.5	542	68	312	1560
1889	1	.55	3861	134	+2050	+2050	137	548	75	2523	2523
1890	1	.95	3876	140	+423	+423	141	564	134	853	853
1891-1902	12	.60	3879	142	-2900	-242	138	552	83	227	2724
1903	1	.55	3858	134	+ 0	0	134	536	74	462	462
1904-1905	2	.65	3858	134	+402	+201	134	536	87	650	1300
1906-1908	3	.60	3861	134	+1084	+361	135.5	542	81	822	2466
1909-1911	3	.65	3869	137	-274	-91	137	548	89	368	1104
1912-1913	2	.55	3867	137	-274	-137	136.3	546	75	334	668
1914-1915	2	.57	3865	136	-540	-270	135	540	77	193	386
1916-1917	2	.60	3861	134	-134	-67	134	536	80	389	778
1918-1921	4	.60	3860	134	-730	-182	132.5	530	80	268	1072
1922	1	.80	3854.5	132	0	0	132	528	105	423	423
1923	1	.45	3854.5	132	-198	-198	131.5	526	59	269	269
1924	1	.30	3853.0	131	-390	-390	130.3	522	39	93	93
1925	1	.50	3850.	130	-324	-324	129.5	518	65	129	129
1926	1	.60	3847.5	129	-320	-320	128.5	514	77	117	117
1927	1		3847.5	128							
147 Year Mean						-24		538	74		440

WINNEMUCCA LAKE

Period Calendar Years	Beginning of Each Period: Elevation of Lake in Feet	Beginning of Each Period: Area in 1000 acres	Beginning of Each Period: Capacity	Change in storage in Each Period: Total for Period	Change in storage in Each Period: Annual Mean	Evaporation: Mean Area of Lake in 1000 acres	Evaporation: Gross Annual Evaporation	Annual Rain-fall on Lake	Indicated Total Mean Annual Inflow	Indicated Total Inflow for Period
1780-1809	3773			0					0	0
1810-1839	3773			0					0	0
1840-1842	3773			0					0	0
1843-1849	3773			0					0	0
1850-1851	3773			0					0	0
1852-1853	3773			0					0	0
1854-1858	3773 1856 3777	 16	0 90	+90 -90	+45 -30	8 8	32 32	4 2	{29	145
1859-1860	3773	0	0	+90	+45	7	28	5	68	136
1861	3777	14	90	+260	+260	22	88	22	326	326
1862-1864	3789	31	350	-90	-30	30	120	15	75	225
1865-1866	3786	29	260	-160	-80	24	96	12	4	8
1867-1868	3778	19	100	+1370	+685	34	136	26	795	1590
1869-1870	3818	48	1470	-40	-20	48	192	24	148	296
1871-1878	3817	47	1430	+1200	+150	52	208	26	332	2656
1879-1881	3841	56	2630	+870	+290	58	232	29	493	1479
1882-1883	3855	61	3500	-210	-105	60	240	27	108	216
1884-1888	3852	60	3290	-420	-84	59	236	30	122	610
1889	3845	58	2870	+630	+630	60	240	33	837	837
1890	3855	61	3500	0	0	61	244	58	186	186
1891-1902	3855	61	3500	-330	-26	60	240	36	178	2136
1903	3850	60	3170	-120	-120	60	240	33	87	87
1904-1905	3848	59	3050	-130	-65	58	232	38	129	258
1906-1908	3846	58	2920	0	0	58	232	35	197	591
1909-1911	3846	58	2920	+130	+43	58	232	38	237	711
1912-1913	3848	59	3050	-300	-150	58	232	32	50	100
1914-1915	3843	57	2750	-230	-115	56	224	29	80	160
1916-1917	3839	56	2520	-220	-110	55	220	33	77	154
1918-1921	3835	54	2300	-640	-160	52	208	31	17	68
1922	3822	49	1660	-90	-90	48	192	38	64	64
1923	3820	48	1570	-90	-90	48	192	22	80	80
1924	3818	47	1480	-100	-100	47	188	14	74	74
1925	3816	46	1380	-130	-130	46	184	23	31	31
1926	3813	45	1280	-130	-130	45	180	22	28	28
1927	3810	44	1120							
147 Year Mean							96	14	+8	90

BOTH LAKES

Period Calendar Years	Indicated Total Inflow for Period	Indicated Mean Annual Inflow
1780-1809	11250	375
1810-1839	13980	466
1840-1842	2262	754
1843-1849	3325	475
1850-1851	1092	546
1852-1853	1316	658
1854-1858	1561	312
1859-1860	1838	919
1861	2113	2113
1862-1864	990	330
1865-1866	560	280
1867-1868	4168	2084
1869-1870	856	428
1871-1878	5000	625
1879-1881	3186	1062
1882-1883	1190	595
1884-1888	2170	434
1889	3360	3360
1890	1039	1039
1891-1902	4860	405
1903	549	549
1904-1905	1558	779
1906-1908	3057	1019
1909-1911	1815	605
1912-1913	768	384
1914-1915	546	273
1916-1917	932	466
1918-1921	1140	285
1922	487	487
1923	349	349
1924	167	167
1925	160	160
1926	145	145
1927		
147 Year Mean		530

of the elevation of Pyramid Lake are available and to combine series of years having similar excesses or deficiencies.

Prior to 1927 the gross evaporation for each year was assumed to be equal to the annual mean. The mean precipitation on the lakes was assumed to be the same as that for the later period of record. It was adjusted for each period to reflect the indicated inflow, being assumed to be above the mean for periods when the lake was rising and below the average when the lake was falling. The precipitation is only about 12% of the gross evaporation, so such variations make only a small difference in the total net evaporation.

The remainder of the computations used in deriving the inflow are indicated by the column headings. The same process was used for Winnemucca Lake. The results for the two lakes are combined in the last column in Table 16.

The results for 1927 to 1960 are available in the direct record of the flow of Truckee River below Pyramid Dam in Table 12.

EFFECT OF STORAGE IN LAKE TAHOE

In deriving the total runoff of the drainage area of the Truckee River, account needs to be taken of the change in storage in Lake Tahoe if annual results are being derived. Lake Tahoe has a usable storage capacity of 720,000 acre-feet. As its area is practically constant at 120,000 acres within the six feet in which it is regulated, the evaporation from the lake is also practically constant.

Records of the elevation of Lake Tahoe are available since 1900 from which the annual changes in storage can be computed. These results are shown in Table 17.

EFFECT OF IRRIGATION FROM TRUCKEE RIVER

Irrigation from the Truckee River has reduced the inflow to Pyramid and Winnemucca Lakes at an increasing rate since irrigation began in about 1860. The present canals, except the Truckee Canal of the Newlands Project, have priority dates which are generally earlier than 1880.

There are some results on the area irrigated in the United States Census of Irrigation. By estimating the area irrigated whose return flow comes back to the Truckee River and using an estimate of the consumptive use of this area, an estimate of the stream depletion can be made. As the area irrigated is largely in forage crops, an average consumptive use of 2.5 acre-feet per acre has been used. Combining these results gives an estimated stream depletion increasing from 10,000 acre-feet in 1861 to 100,000 in 1903. Since 1903 a general value of 100,000 acre-feet per year has been used with some reduction in years of known shortage in supply.

Since 1905 water has been diverted from the Truckee River through the Truckee Canal for use where its return flow does not reach the Truckee River except for seepage from the upper part of the canal. A record of this diversion has been kept and has been used for this item.

These results for stream flow depletion have been used in the later computations of the total runoff of the drainage area of Truckee River.

Table 17 - Storage in Lake Tahoe Since 1900
Thousands of Acre-feet

Year	Storage on Jan. 1 Historical	Change in Storage during Year	Change in Storage During Period
1901	376.9	+144.1	
2	521.0	- 29.3	
3	491.7	+ 31.4	
4	523.4	+ 60.7	
5	584.7	- 195.6	
6	389.1	+ 201.8	
7	590.9	+ 67.6	-12.2
8	658.5	- 281.6	
9	376.9	+ 177.1	
10	554.0	- 212.4	108.7
11	341.6	+ 144.0	
12	485.6	- 146.4	-209.8
13	339.2	- 63.4	
14	275.8	+ 223.2	+211.0
15	499.0	- 12.2	
16	486.8	+ 145.9	+158.7
17	632.7	- 87.2	
18	545.5	- 132.0	
19	413.5	- 132.8	
20	280.7	- 68.2	-314.7
21	212.5	+ 18.3	
22	230.8	+ 112.0	
23	342.8	- 54.8	
24	288.0	- 290.4	
25	- 2.4	+ 121.4	
26	119.0	- 48.6	
27	70.4	+ 189.6	
28	260.0	- 179.2	
29	140.8	- 136.0	
30	4.8	- 14.7	
31	- 9.7	- 64.2	
32	- 73.9	+ 47.2	
33	- 26.7	+ 27.9	
34	- 4.8	- 138.1	
35	-142.9	+ 59.3	
36	- 83.6	+ 214.7	
37	131.1	+ 77.8	
38	208.9	+ 259.6	
39	468.5	- 297.3	

Year	Storage on Jan. 1 Historical	Change in storage during Year
1940	171.2	+253.3
41	424.5	+ 98.9
42	523.4	+ 81.0
43	604.4	+ 155.5
44	448.9	- 85.4
45	363.5	+ 163.6
46	527.1	- 19.6
47	507.5	- 252.4
48	255.1	- 55.9
49	199.2	- 139.8
50	59.4	+ 536.4
51	595.8	- 19.7
52	576.1	- 3.1
53	573	- 5.8
54	515	-109
55	406	+23
56	429	+138
57	567	-57
58	510	+5
59	515	-258
60	257	-155
61	102	

S.T.H

TOTAL RUNOFF OF THE DRAINAGE AREA OF TRUCKEE RIVER

The inflow to Pyramid and Winnemucca Lakes, the change in storage in Lake Tahoe when available, the estimated depletion resulting from irrigation, and the diversions by the Truckee Canal can be combined to compute the total runoff of the Truckee River. This has been done in Table 18. The results have been expressed in acre-feet and also in percentage of the 181 and 121 year means. The 181 year period includes the 60 years prior to 1840 for which no direct records are available. The 121 year mean represents the period of observed results.

The total runoff of the drainage area of Truckee River as derived in Table 18 represents what is considered to be the best results that are obtainable from the available records for the unimpaired runoff during the 181 year period shown. The extent to which past records have had to be interpreted and judgment used in deriving these results has been described. While there can be no complete substitute for the type of annual records which have been available since 1927, it is considered that the results for years prior to 1927 shown in Table 18 are representative of the actual variations in runoff which occurred in this period.

The mean annual runoff of the Truckee River in Table 18 for the first 147 years of the total 181 year period is closely equal to that of the last 34 years. However the division of this runoff between inflow to the lake and depletion and diversion in the earlier and later parts of the total period is materially different. In the last 34 years shown, instead of all of the runoff reaching the lake as it did at the beginning of the period, an average of only 41 percent reached the lakes. The average annual inflow to the lakes for the last 34 years shown has been nearly 250,000 acre-feet. Over one-half of the total occurred in seven years of the 34 year period.

The variations in the runoff of the Truckee River that have occurred during the 181 years shown in Table 18 can be discussed more conveniently in terms of their percentages of the annual mean. Such percentages for each period and the accumlated departures from the mean are shown in Table 18. The accumulated departures have been plotted in Figure 37. Overall there was a deficiency below the mean from 1810 to 1860, a general excess extending to about 1920 and less variation from the mean to 1960.

In Table 19 the variations of the runoff results in Table 18 have been segregated to show the variations which have occurred. Different 30 year periods have varied from 64 to 118 percent of the 181 year mean. This is a relatively wide variation for periods of such length. For the four periods of 30 years since 1840, the variations have been less than 20 percent. For the 60 years from 1780 to 1839 the indicated mean annual runoff was 72 percent of the ensuing 121 years.

Table 19 also shows the maximum and minimum shorter periods. The maximum single year was 583 percent of the mean and the minimum year was 15 percent. One 8 year period had an average runoff of 170 percent of the mean and one 7 year period only 46 percent of the mean. These results illustrate why complete regulation of this runoff will not be possible with any practical amount of storage.

Table 18 - Derived Total Runoff of the Drainage Area of Truckee River 1780 To 1960
In Thousands of Acre-feet except as noted

Period	Number of Years in Period	Mean Annual Supply: Inflow To Lakes	Mean Annual Supply: Annual Change in Storage in Tahoe	Mean Annual Supply: Truckee River Deplotion	Mean Annual Supply: Truckee Canal Diversion	Mean Annual Supply: Total Runoff Annual Mean for Period	Total Runoff for Period	Variations from Mean in Per Cent: Mean Annual Per cent of Mean	Variations from Mean in Per Cent: Total Per cent for Period	Accumulated Variation from Mean for 181 year Period	121 Year Period Variation from Mean: Annual in Per Cent of Mean	121 Year Period: Total Per cent for Period	121 Year Period: Accumulated Variation from 121 Year Period
1780-1809	30	375				375	11250	63.8	1914	-1086			
1810-1839	30	466				466	13980	79.3	2379	-1707			
1840-42	3	754				754	2262	128	384	-1623	113	339	+39
1843-49	7	475				475	3325	81	567	-1756	71	497	-164
1850-51	2	546				546	1092	93	186	-1770	82	164	-200
1852-53	2	658				658	1316	112	224	-1746	98	196	-204
1854-58	5	312				312	1560	53	265	-1981	46	230	-474
1859-60	2	919				919	1838	156	312	-1869	137	274	-400
1861	1	2113		10		2123	2123	361	361	-1608	317	317	-182
1862-64	3	330		20		350	1050	59	177	-1731	52	156	-327
1865-66	2	280		30		310	620	53	106	-1825	46	92	-435
1867-68	2	2084		30		2114	4228	360	720	-1303	316	632	-3
1869-70	2	428		35		463	926	79	158	-1347	69	138	-65
1871-78	8	625		40		665	5320	113	904	-1243	99	792	-73
1879-81	3	1062		40		1102	3306	187	563	-980	164	492	+119
1882-83	2	595		45		639	1280	108	216	-964	95	190	+109
1884-88	5	434		50		484	2420	82.3	412	-1052	72	360	-31
1889	1	3360		65		3425	3425	583	583	-569	511	511	+380
1890	1	1039		70		1109	1109	188	188	-481	165	165	+445
1891-1902	12	405	0	85		490	5880	83.3	1000	-681	73	876	+121
1903	1	549	+31	100		680	680	115	115	-666	101	101	+122
1904	1	1179	+61	100		1340	1340	228	228	-538	200	200	+222
1905	1	476	-196	100	100	480	480	82	82	-556	72	72	+194
1906-08	3	1019	-4	100	150	1265	3795	215	645	-211	188	564	+458
1909-11	3	605	+36	100	180	921	2763	157	471	-40	137	411	+569
1912-13	2	384	-105	100	190	569	1138	97	194	-46	85	170	+539
1914-15	2	273	+106	100	190	669	1338	114	228	-18	100	200	+539
1916-17	2	466	+30	100	186	782	1564	133	266	+48	117	234	+573
1918-21	4	285	-79	90	234	530	2120	90	360	+8	79	316	+489
1922	1	487	+112	100	222	921	921	156	156	+64	137	137	+526
1923	1	349	-55	90	274	658	658	112	112	+76	98	98	+524
1924	1	167	-290	90	122	89	89	15	15	-9	13	13	+437
1925	1	160	+121	90	264	635	635	108	108	-1	95	95	+432
1926	1	145	-49	90	178	364	364	62	62	-39	54	54	+386
147 Year Mean		530	-3	31	29		587						

Year	Mean Annual Supply: Inflow to Lakes	Annual Change in Storage in Tahoe	Truckee River Deplotion	Truckee Canal Diversion	Total Run off	Variation from Annual Mean in Per Cent, 181 Years: Runoff for Year	181 Years: Accumulated Variation from Mean	121 Years: Runoff for Year	121 Years: Accumulated Variation from Mean
1927	326	+190	90	319	925	158	+19	138	+424
1928	269	-119	100	184	434	74	-7	65	+389
1929	9	-136	90	181	144	24	-83	22	+311
1930	5	-15	90	242	323	55	-128	47	+258
1931	8	-64	90	83	117	20	-208	17	+175
1932	153	+47	100	231	531	90	-218	79	+154
1933	32	+22	90	138	282	48	-270	42	+96
1934	1	-138	90	126	79	13	-357	12	+8
1935	99	+59	90	192	440	75	-382	68	-26
1936	156	+215	100	272	743	126	-356	111	-15
1937	348	+78	100	183	709	120	-336	105	-10
1938	709	+260	100	134	1203	205	-231	179	+69
1939	95	-297	100	211	109	19	-312	16	-15
1940	320	+253	100	236	909	154	-258	135	+20
1941	184	+99	100	269	652	111	-247	97	+17
1942	561	+81	100	189	931	158	-189	139	+56
1943	654	-155	100	221	820	139	-150	121	+77
1944	156	-86	100	270	440	75	-175	66	+43
1945	163	+164	100	269	696	118	-157	104	+47
1946	151	-19	100	258	490	83	-174	73	+20
1947	124	-252	100	248	220	37	-237	33	-47
1948	23	-56	100	291	358	61	-276	53	-94
1949	106	-140	100	261	327	56	-320	49	-145
1950	443	+537	100	364	1444	245	-175	215	-30
1951	251	-20	100	323	654	111	-164	98	-32
1952	1049	-3	100	358	1504	256	-8	224	+92
1953	294	-58	100	370	706	120	+12	105	+97
1954	39	-109	100	310	340	58	-30	51	+48
1955	208	+23	100	258	589	100	-30	88	+36
1956	611	+138	100	343	1194	203	+73	178	+114
1957	136	-57	100	369	546	93	+66	81	+95
1958	516	+5	100	369	990	168	+134	147	+142
1959	20	-258	100	268	130	22	+56	19	+61
1960	25	-155	100	289	259	44	0	39	0
34 Year Mean	242	+1	98	254	595				
181 Year Mean	476	-2	43	71	588				

STH.

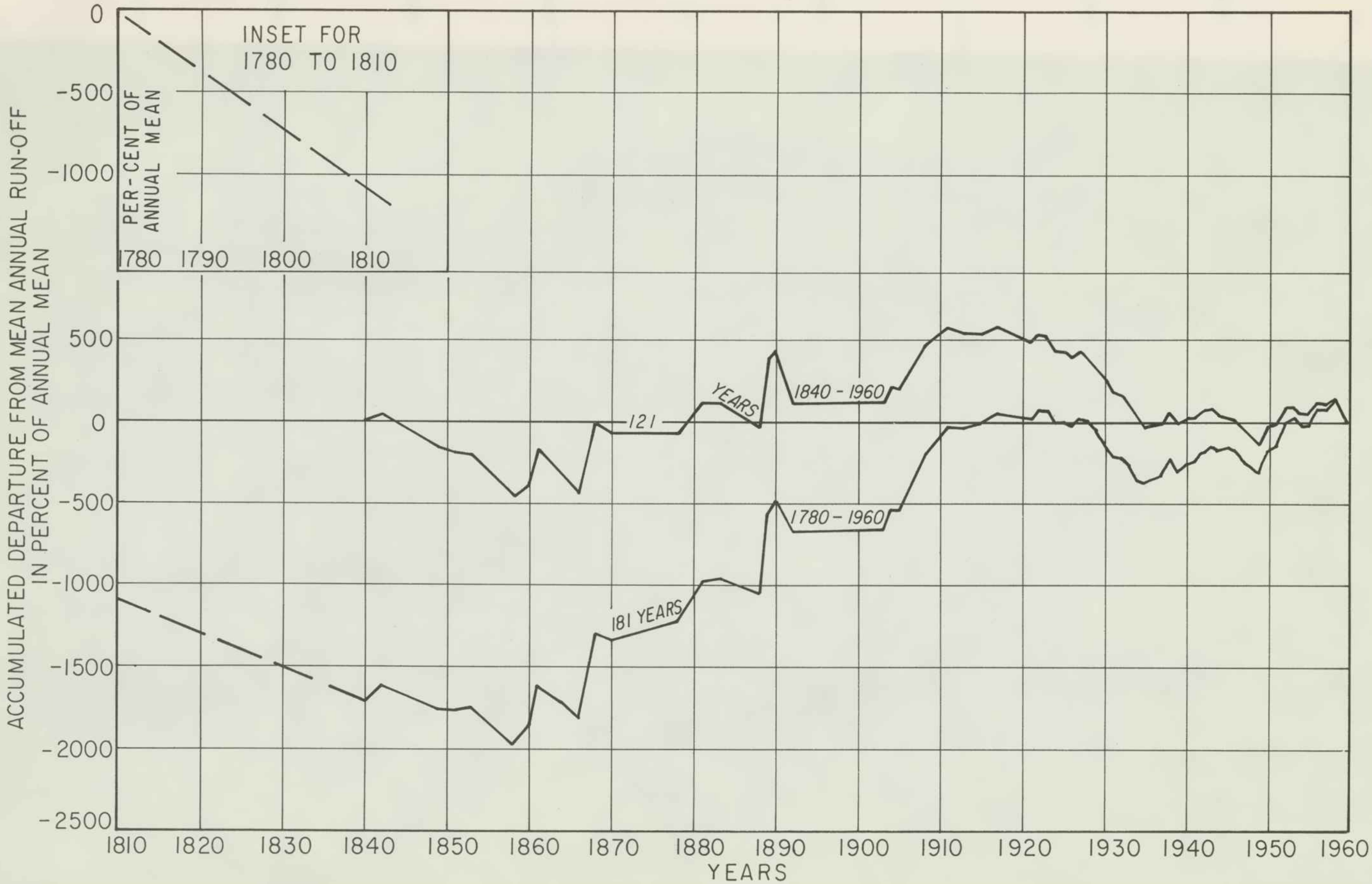


FIG. 37 ACCUMULATED DEPARTURE FROM MEAN OF TOTAL RUNOFF
OF DRAINAGE AREA OF TRUCKEE RIVER, 1780 - 1960

Table 19- Variations in Total Runoff of Drainage Area of Truckee River 1780 to 1960

Period	Years in Period	Mean Annual Runoff: Acre-feet	Mean Annual Runoff: Per Cent of 181 Year Mean
1780-1809	30	375,000	64
1810-1839	30	466,000	79
1840-1868	29	670,000	114
1869-1902	34	694,000	118
1903-1933	31	665,000	113
1934-1960	27	647,000	110
1780-1960	181	588,000	100
1780-1839	60	420,000	71.5
1840-1960	121	671,000	114
Maximum Single Years			
1861	1	2,123,000	361
1889	1	3,425,000	583
1904	1	1,340,000	228
1938	1	1,203,000	205
1950	1	1,444,000	245
1952	1	1,504,000	256
1956	1	1,194,000	203
Maximum Consecutive Years after 1840			
1861-68	8	1,003,000	170
1936-38	3	885,000	150
1950-53	4	1,077,000	182
Minimum Single Years			
1924	1	89,000	15
1929	1	144,000	24
1931	1	117,000	20
1934	1	79,000	13
1939	1	109,000	19
1959	1	130,000	22
Minimum Consecutive Years after 1840			
1928-1934	7	273,000	46
1947-1949	3	302,000	51
1959-1960	2	195,000	33

S.T.H.

QUALITY OF WATER IN PYRAMID LAKE

The available analyses of the water in Pyramid Lake secured in and prior to 1914 were assembled by E. Claude Jones in Publication 352 of the Carnegie Institute of Washington. Some samples have also been collected by the writer which have been analysed by the Division of Plant Nutrition of the University of California. These results are shown in Table 20. They have been used with the volume of water in Pyramid Lake at the times the samples were taken to compute the total content of solubles in the lake. These results are also shown in Table 20.

The total solubles in parts per million in Pyramid Lake during the nearly 100 years represented by these results has varied consistently with the volume of storage in the lake. The samples to 1914 were secured when Pyramid Lake contained about 50 percent more water than during the later years and the total solubles were about two-thirds of that contained in the later samples.

The total tonnage of solubles in Pyramid Lake from 1867 to 1914 as shown by the four analyses in Table 20 remained practically constant. This indicates that the overflow from Pyramid Lake to Winnemucca Lake which occurred during much of this period did not remove any large amounts of solubles from Pyramid Lake. This, in turn, indicates that the flow to Winnemucca Lake was largely from the inflow from the Truckee River rather than overflow from Pyramid Lake after the Truckee River inflow had become mixed with the Pyramid Lake water. During this period about one-third of the inflow to the two lakes went to Winnemucca Lake (Table 16).

Bulletin 9 of the U. S. Geological Survey reports the analysis of four samples from Pyramid Lake taken in 1882. These samples consisted of surface and deep water at the north and at the south ends of the lake. The individual samples varied less than one percent in their content of total solubles. The mean result for these analyses is shown in Col. 2 of Table 20. These results indicate that the water in Pyramid Lake becomes well mixed under wind and density current action, and the inflow from Truckee River does not remain at the south end of the lake.

An analysis of a sample of the water of Winnemucca Lake in 1882 by Russell is also reported in Bulletin 9 of the U. S. Geological Survey. The total solubles were within one percent of those found in the water of Pyramid Lake in 1882. At the time this sample was taken Winnemucca Lake was at its highest recent stage and contained about 3,500,000 acre-feet. Its solubles content was the result of its inflow from Truckee River and Pyramid Lake and absorption of salts from its previously dry lake bed. The storage in Winnemucca Lake in 1882 was about one-eighth of that in Pyramid Lake. The filling of Winnemucca Lake did not reduce the total solubles content of Pyramid Lake.

Analysis of the inflow from Truckee River in U. S. Geological Survey Water Supply Paper 274 indicates an average total solubles content of 143 p. p. m. This is 2.8 percent of the average content in the lake from 1949 to 1958. In this period the inflow to the lake was 3,200,000 acre-feet equal to 17 percent of the 1958 storage in Pyramid Lake. Based on this quality of the Truckee River inflow, this amount of inflow would have increased the total solubles in Pyramid Lake by one-half of one percent. This is less than the expected variation between individual samples.

Table 20 - Analyses of Water of Pyramid Lake

Solubles are in Parts per Million

Item	1	2	3	4	5	6	7	8	9
Conductance					850	775	785	800	749
pH					9.15	8.9	9.0	9.0	9.1
Ca		.9	16	22	20	12	10	10	35
Mg	129	90	78	77	165	108	105	115	85
Na	1323	1294	1251	— *	1675	1660	1565	1610	1520
CO_2	257	499	160	173	220	300	240	220	215
HCO_3			681	956	995	800	590	950	1170
SO_4	140	182	183	196	265	270	250	285	235
Cl	1387	1319	1455	1470	2050	2036	1900	1700	1615
Si	39	33	2	4					
P			100	-					
K		70							
Total	3275	3496	3496	3515 **	5390	5186	4760	4890	4875
Elevation of Lake	3867	3867	3865	3866	3805	3803	3806	3802	3804
Million Ac. Ft in Lake	27.1	27.1	26.7	26.9	18.9	18.7	19.0	18.7	18.9
Total Solubles in Million Tons	120	128	126	127	138	132	123	125	125

Source	Location & Date of Sample
1	King's Survey of 40th Parallel Vol. 1, p 528 - 1867
2	Mean of 4 Samples by Russell in 1882
3	Jones - 1913 in Carnegie Pub. 352
4	" 1914 " " 352
	Samples by S.T Harding
5	Sept. 23, 1949 at Pyramid Island
6	Aug. 4, 1955 - Mean of 2 - at Needles & Pyramid Island
7	Aug. 21, 1956 At Sutcliffe
8	July 25, 1957 At Pyramid Island
9	Sept. 11, 1958 " " "

* not computed
** Computed Na included

While the chemical analyses of the water in Pyramid Lake are limited in number they are consistent in their results. Pyramid Lake now presents an opportunity to follow the concentration of its waters as it lowers. It is hoped that more complete and frequent samples will be secured. Such results would have interest both for following any deposit of solubles on the unwatered portion of the lake and also in determining the effect of increased salt content on the variations of fish now in Pyramid Lake.

RECESSION OF LAKE LAHONTAN

Pyramid Lake is the largest remnant of Lake Lahontan. While outside the scope of this report, there is interest in how Lake Lahontan may have receded to the present Pyramid Lake. In his work on Pyramid Lake the writer has assembled the present elevations at which overflow from Pyramid Lake would occur in different directions. The results are shown in Figure 38. It is thought that all of the results in Figure 38 have been reduced correctly to the present datum.

In the first two columns in Figure 38 the elevations of the terraces above Pyramid Lake which are considered to represent former stages of Lake Lahontan are shown. The next two columns show the elevations of the controlling passes found by Jones and by the writer. The recent elevations of Pyramid Lake are shown in the fifth column. The last column relates to Winnemucca Lake.

The relative freshness of the water of Pyramid Lake has been a puzzle to the geologists studying Lake Lahontan. If Pyramid Lake is a remnant of Lake Lahontan, the quality of its water should reflect the concentration resulting from the shrinking of Lake Lahontan. While events occurring through periods of geologic time are beyond the purposes of this report, figure 38 indicates the directions in which outflow from Pyramid Lake would occur at its different elevations.

There has also been controversy over the extent to which overflow is shown in the present appearance of Emerson Pass. The writer has found no indications in its present surface conditions that overflow from Pyramid Lake has occurred through this pass.

Overflow from the north end of Winnemucca Lake would take place over a broad ridge with an indefinite crest. The Lovelock sheet of the U. S. G. S. maps indicates that this crest has an elevation of about 4700 feet. This is higher than the maximum stage of Lake Lahontan. Russell's map of Lake Lahontan shows no connection of Winnemucca Lake at its northern end with Lake Lahontan.

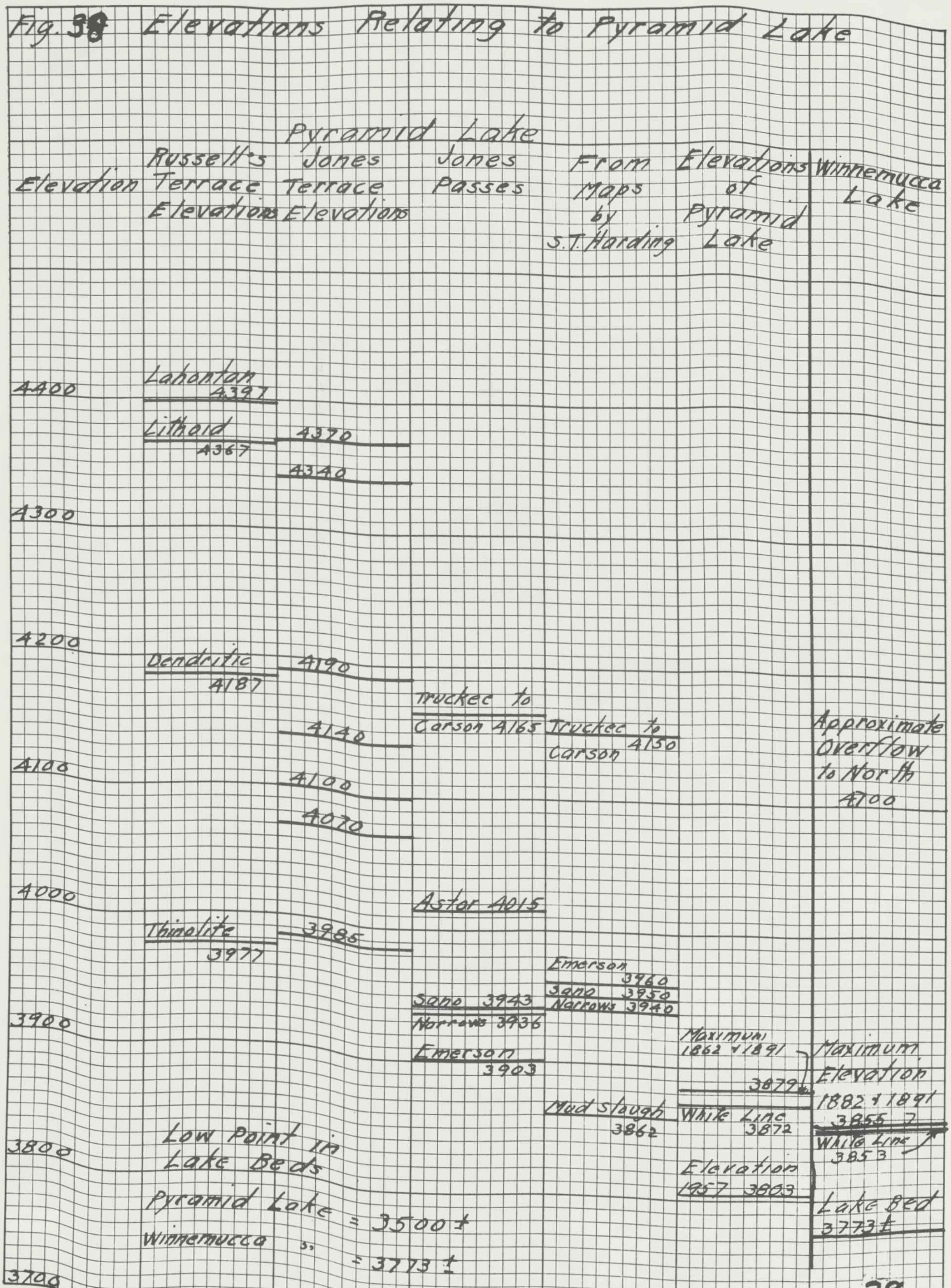


Figure 38

S.T.H.

LAKE TAHOE

Lake Tahoe is not an enclosed lake and its fluctuations do not measure its inflow. It has a place in this report as a tributary source of the inflow to Pyramid Lake and because of the results of Carbon 14 dating of stumps of trees which grew at elevations lower than the present rim of the lake.

Lake Tahoe overflows its rim which has a present elevation of 6223 feet. The restricted capacity of its natural overflow channel has always operated as a control on its discharge. This natural control has been superseded in part by the dam constructed on Truckee River below the rim which is operated to control the outflow from the lake and to limit its fluctuations within a six foot range.

In some past geologic time, Lake Tahoe had its outlet over a basalt flow across the Truckee River downstream from the present rim. At this time the lake had a materially higher elevation than its present rim. This former rim was eroded and has been replaced as a control of the lake by the present rim.

The area of Lake Tahoe is 37 percent of its drainage area. In periods of reduced runoff the evaporation from the lake exceeds its inflow. The lake has lowered below its rim at several different times during the period of record. The area of the lake is practically constant within its range of fluctuation so that the evaporation is not reduced even when the lake falls below its rim. About 40 percent of the mean annual inflow to Lake Tahoe is required to supply its evaporation leaving only about 60 percent to supply usable outflow. For the six years 1928-29 to 1933-34, the net evaporation from Lake Tahoe exceeded its inflow.

Lake Tahoe was not on any of the main routes of emigrant travel and early reports regarding it are less numerous than those for some other lakes. Early descriptions are usually in general terms and do not enable the elevation of the lake to be determined. Fremont saw the lake from a distance in 1844.

The records of the elevation of Lake Tahoe prior to 1900 are fragmentary and incomplete. No record has been found prior to 1870 when the first dam at the outlet was constructed. The available records from 1870 to 1900 show that the lake was low in 1888, reached its rim in 1889 and rose to 6228.05 in 1890. There was a high elevation of 6229.02 feet in 1895.

A continuous record of the elevation of Lake Tahoe is available since 1900. The elevations of the lake are plotted in Figure 39. The lake has fluctuated between elevations 6223.0 and 6229.0 except for occasional times when it has fallen below its rim or for brief periods when it has gone above 6229.0.

There is also a record of the outflow of Lake Tahoe since 1900. This has varied from 5,100 to 390,000 acre-feet per year with an annual mean of 177,100 acre-feet.

The inflow to Lake Tahoe since 1900 can be computed from the gross evaporation, the rainfall on the lake and the fluctuations of the lake. The gross evaporation has been previously discussed. A uniform amount of 375,000 acre feet per year has been used. The available records indicate a mean annual precipitation on the lake of 25 inches. The changes in storage in the lake can be computed from the records of lake elevation. Such computations by the writer are shown in Table 21. The mean annual inflow for this period is

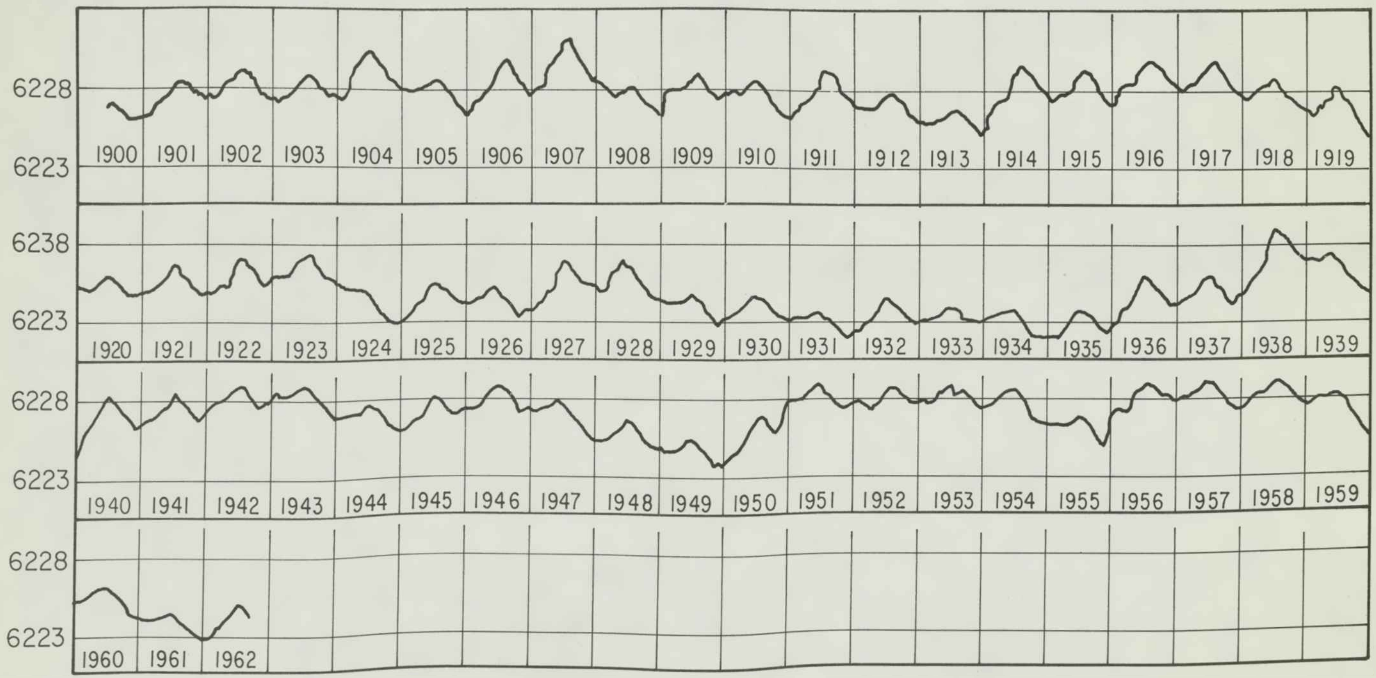


FIG. 39 ELEVATION OF LAKE TAHOE SINCE 1900

Table 21 Computed Inflow to Lake Tahoe

Quantities of Water are in terms of 1000 acre-feet

Water Year	Outflow	Storage in Lake Tahoe		Evaporation			Computed Total Inflow	Per Cent of Mean	Accumulated Departure from Mean	Precipitation at Tahoe City in Per Cent of Mean 1910-60	Inflow to Lake Tahoe 1910-60 in Per Cent of Mean for this Period
		Beginning of Year	Change in Year	Index of Precipitation	Rainfall on Lake	Net Evaporation					
1900											
1900-01	96.7	356.2	+219.9	120	300	75	391.6	131	+31		
02	126.7	576.1	+12.3	87	217	158	297.0	99	+30		
03	155.7	588.4	-6.1	89	222	153	302.6	101	+31		
04	390.0	582.3	+120.5	131	327	48	558.5	187	+118		
05	280.5	702.8	-176.9	87	217	158	261.6	88	+106		
06	360.5	525.9	+169.5	136	340	35	565.0	189	+195		
07	656.9	695.4	+110.8	152	380	-5	762.7	256	+351		
08	383.8	806.2	-331.6	77	192	183	235.2	79	+330		
09	327.6	474.6	+75.8	120	300	75	478.4	160	+390		
10	347.5	550.4	-114.9	103	258	117	349.6	117	+407	103	126
11	312.7	435.5	+162.7	143	358	17	492.4	165	+472	143	178
12	186.8	598.2	-142.0	53	132	243	287.8	96	+468	53	104
13	169.0	456.2	-120.7	78	195	180	228.3	76	+444	78	83
14	147.9	335.5	+316.8	150	375	0	464.7	155	+499	150	168
15	191.2	652.3	-65.1	88	220	155	281.1	94	+493	88	102
16	195.0	587.2	+120.5	122	305	70	385.5	129	+522	123	139
17	279.5	707.7	-46.8	106	262	113	345.7	116	+538	106	125
18	227.7	660.9	-146.0	85	212	163	244.7	82	+520	85	90
19	191.7	514.9	-138.4	112	280	95	148.3	50	+470	112	54
20	178.0	376.5	-168.8	77	192	183	192.2	64	+434	77	70
21	104.6	207.7	+77.9	122	305	70	252.5	85	+419	123	91
22	164.1	285.6	+76.7	114	285	90	330.8	111	+430	114	120
23	174.0	362.3	+46.3	101	252	123	343.3	115	+445	102	125
24	178.2	408.6	-371.0	47	118	257	64.2	22	+367	47	23
25	58.9	37.6	+149.4	84	210	165	373.3	125	+392	84	135
26	62.8	187.0	-125.1	83	207	168	105.7	35	+327	83	38
27	61.3	61.9	+249.2	112	280	95	405.5	136	+363	112	147
28	165.2	311.1	-73.0	103	258	117	209.2	70	+333	103	76
29	77.5	238.1	-187.1	69	172	203	93.4	31	+264	69	34
30	50.8	51.0	+112.1	90	225	150	212.9	71	+235	90	77
31	4.7	63.1	-140.7	59	148	227	91.0	30	+165	59	33
32	16.0	-77.6	+158.9	111	278	97	271.9	91	+156	111	99
33	5.1	81.3	-94.6	63	158	217	127.5	43	+99	63	46
34	41.0	-13.3	-77.6	73	182	193	156.4	52	+51	73	57
35	7.9	-90.9	+180.0	97	242	133	220.9	74	+25	97	80
36	63.9	-10.9	+219.8	113	282	93	376.7	126	+51	114	137
37	107.4	208.9	-32.8	85	212	163	237.6	80	+31	85	87
38	96.4	176.1	+418.5	168	420	-45	469.9	157	+88	168	170
39	223.9	594.6	-300.5	56	140	235	158.4	53	+41	56	57

Table 21 Cont'd Computed Inflow to Lake Tahoe

Quantities of Water are in terms of 1000 Acre-feet

Water Year	Outflow	Storage in Lake Tahoe: Beginning of Year	Storage in Lake Tahoe: Change in Year	Evaporation: Index of Precipitation	Evaporation: Rainfall on Lake	Evaporation: Net Evaporation	Computed Total Inflow	Per Cent of Mean	Accumulated Departure from Mean	Precipitation at Tahoe City in Per Cent of Mean 1910-60	Inflow to Lake Tahoe 1910-60 in Per Cent of Mean for this Period
1939-40	110.3	294.1	+165.8	137	342	33	309.1	103	+44	137	112
41	106.7	459.9	+58.7	100	250	125	290.4	97	+41	100	105
42	277.6	518.6	+66.1	114	237	138	481.7	161	+102	115	175
43	354.9	584.7	+3.7	117	292	83	441.6	148	+150	117	160
44	143.6	588.4	-171.2	67	165	210	182.4	61	+111	67	66
45	119.9	417.2	+46.4	106	265	110	276.3	93	+104	107	100
46	103.8	463.6	+96.6	106	265	110	310.4	104	+108	107	113
47	147.7	560.2	-166.2	82	205	170	151.5	51	+59	82	55
48	143.6	394.0	-113.3	83	207	168	198.3	66	+25	83	72
49	130.1	280.7	-152.0	71	178	197	175.1	59	-16	71	63
50	71.6	128.7	+208.0	104	260	115	394.6	132	+16	104	143
51	223.4	336.7	+202.6	154	385	-10	416.0	139	+55	154	151
52	457.1	539.3	+105.5	181	452	-77	485.6	163	+118	182	176
53	240.4	644.8	-3.5	105	258	117	353.9	119	+137	105	128
54	154.8	641.3	-160.6	75	188	187	181.2	61	+98	75	66
55	112.2	480.7	-192.7	71	178	197	116.5	39	+37	71	42
56	157.0	288.0	+353.4	163	408	-33	477.4	160	+97	163	173
57	185.2	641.4	-61.6	101	252	123	246.6	82	+79	102	90
58	307.2	579.8	+60.2	128	315	60	427.4	144	+123	128	155
59	158.8	640.0	-221.5	72	180	195	132.3	44	+67	72	48
60	147.6	418.5	-205.9	87	217	158	99.7	33	0	87	36
61		212.6									
Mean	178.7	-2.4			252.6	122.4	298.7				

298,700 acre-feet varying from 91,000 to 762,000 acre-feet in individual years.

The accumulated departures from the mean of the inflow to Lake Tahoe from 1901 to 1960 are shown in Figure 40. Figure 40 shows the much above average inflow for the earlier part of this period from 1901 to 1917, the deficient period from 1918 to 1935 and the more nearly average inflow from 1936 to 1960 that is shown by other records in this general area.

STUMPS IN LAKE TAHOE

There are trees growing around much of the shore of Lake Tahoe on ground just above elevation 6229. Some of these trees are of full size and age and indicate that the lake has not risen above this elevation during the life of the tree.

There are also stumps in Lake Tahoe of trees which grew on ground which is below the elevation of the present rim. Such stumps occur at the former Tallac resort near the southwest part of the lake. These stumps have shown above the lake surface when the lake has fallen below its rim. They were examined by the writer in 1934 when the lake was below its rim and in 1961 when the lake again lowered. In 1961 samples from these stumps were secured by the California Department of Water Resources and Carbon 14 dated.

Figure 41 is a view of one of these stumps taken when Lake Tahoe was three inches below its rim in 1934. Figure 42 shows the largest of these stumps taken when the lake was at elevation 6223.25 in 1961. A total of eleven of these stumps have been found in this area growing on ground having present elevations up to two feet below the rim of the lake.

Prior to 1961 the writer had assumed that these trees had grown in some period shortly prior to 1860 when Lake Tahoe had been below its rim long anough to permit their growth. The low stages found for other lakes in the 1840's and the state of preservation of these stumps supported such an assumption.

Samples of the wood from two of these stumps have been dated. A sample from one stump gave an age of 4460 ± 250 years. Two tests on the other sample gave dates 4790 ± 200 and 4250 ± 200 years.

The rings on these stumps could be counted in 1934. Such counts on the remaining portions indicated ages up to 150 years at the elevation of the rim and 100 years for trees which had grown 2 feet below the elevation of the rim.

Such stumps below the rim have been found only at Tallac. These trees grew in good soil offshore from the course of Fallen Leaf Creek. Fallen Leaf Lake smooths out the stream flow from its drainage area and retains the eroded material. Filling of Lake Tahoe in this area may have been slow. Some covering of stumps at similar elevations at other points around the lake may have occurred. While the failure to find other submerged stumps around the lake is not fully explained, such failure does not cast doubt on the actual existence of the Tallac stumps. These are well preserved and well rooted into the present lake bed.

The results of the Carbon 14 dating require a new approach to the record presented by these stumps. If it is nearly 5000 years since these trees were submerged, some regimen of Lake Tahoe is required under which these stumps could have been preserved for this length of time. Any long periods of exposure to the air would have resulted in their decay and disappearance.

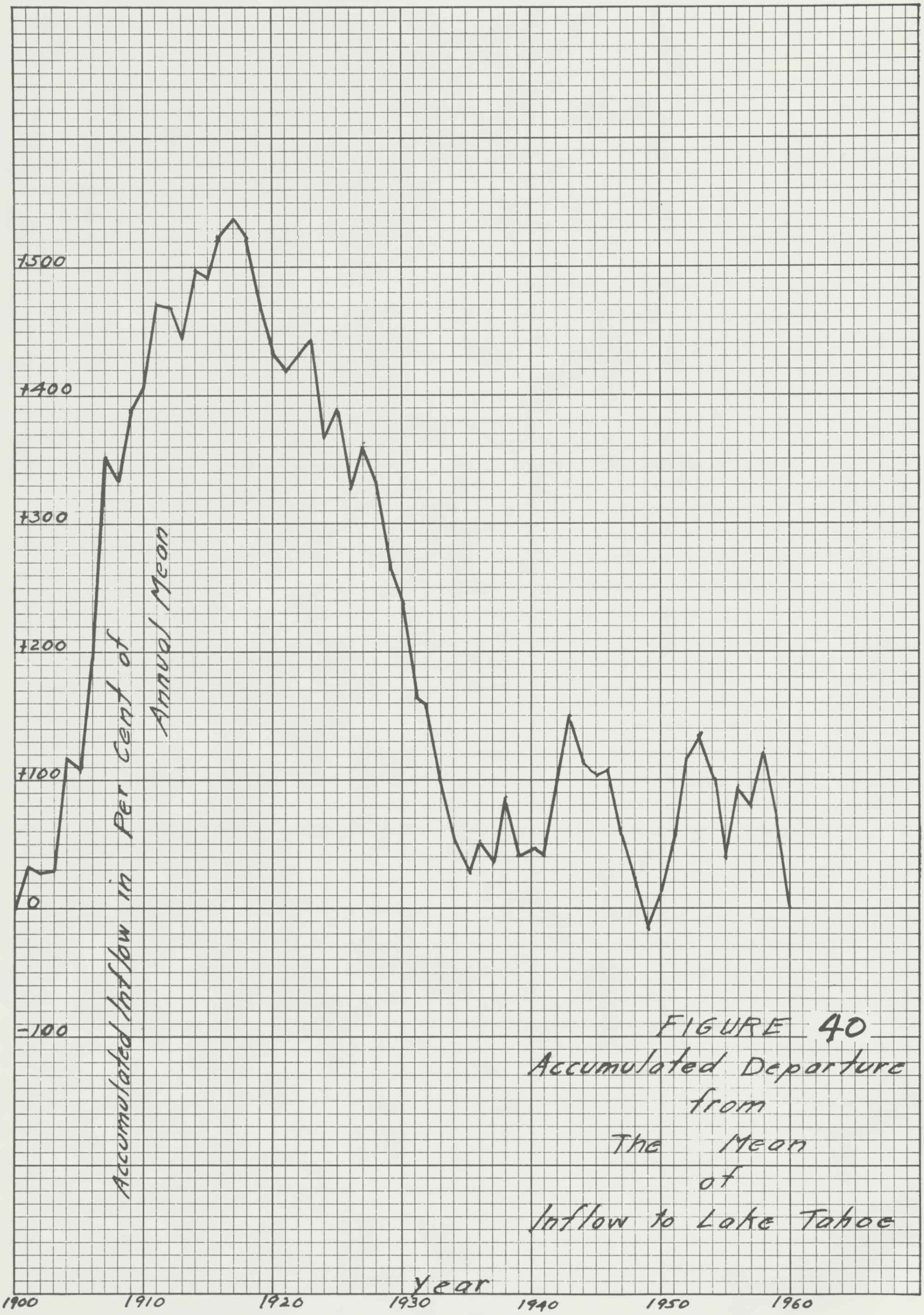

+500
+400
+300
+200
+100
0
-100
Accumulated Inflow in Per Cent of Annual Mean
Year
1900
1910
1920
1930
1940
1950
1960
FIGURE 40
Accumulated Departure from The Mean of Inflow to Lake Tahoe

Figure 41.

Stump in Lake Tahoe having 75 countable rings.

Taken September 1, 1934 by S. T. Harding when the Lake was 0.3 ft. below the elevation of its outlet rim.

Figure 42.

Largest Stump in Lake Tahoe, at Baldwin Beach (formerly Tallac). Taken September 27, 1961 by S. T. Harding when the Lake was 0.25 feet below the elevation of its overflow rim.

Two samples of the wood of this stump have been Carbon-14 dated and found to have an average age of 4,500 years.

The reported age of these stumps is sufficiently long to include time for climate changes and orographic movement. A rise in the elevation of the rim of the lake or a subsidence of the area of the stumps of a few feet could account for their submergence. There are indications of a fault across the rim which has resulted in a small displacement of the clay now forming the rim.

The following conclusions regarding the record disclosed by these stumps have been reached.

1. These Tahoe stumps have not been out of water for any continuous period as long as 100 years since they were first submerged. The present condition of these stumps support this conclusion regardless of the C-14 dating.
2. Whenever these trees may have grown there was a period of over 100 years when Lake Tahoe was below the elevation at which they grew. This is axiomatic regardless of the relative elevations of the rim of the lake and the ground on which they grew.
3. If the age of these stumps is nearly 5000 years there has been time for orographic movements to have occurred and the relative elevations of the rim of Lake Tahoe and the ground on which these trees grew may have changed within such a period.
4. If no orographic movement has occurred and these stumps are 4500 years old, there has been only one period as long as 100 years in the 4500 years in which these trees could have grown. This follows from item 1 above and the time in which such stumps would decay.
5. If these stumps are 4500 years old they do not aid in interpreting the elevations of Lake Tahoe during the past 300 to 400 years except to indicate that the lake has not been below their elevation long enough in this period for the stumps to have decayed.

SAND DUNES AT KINGS BEACH

There are sand dunes at Kings Beach on the north shore of Lake Tahoe which were 15 to 20 feet high. At usual stages of Lake Tahoe there is insufficient shore between the lake and the dunes to provide an area from which the sand to build these dunes could be derived. It has been suggested that these dunes might have had their origin in a period when Tahoe was below its recent elevations and there was sufficient shore area exposed to provide the sand supply. Figure 43 is a picture of this dune taken in 1939.

Development of the area of these dunes has now largely changed their original character. They were examined by the writer in 1939 before such local development had occurred. These dunes had the characteristic shape of sand movement under wind action. The inshore slope was steep. They started at the existing lake elevation of 6328 feet. The dunes appeared to be relatively stable and not to be making further growth. Some blow outs in the dunes had developed. Trees were growing on these dunes. On one recently cut pine stump a count of 248 rings was made. The sand had been blown out from around the roots of this stump.

It does not appear that these Kings Beach sand dunes furnish a clue to the elevation of Lake Tahoe during the life of the trees that have been growing on

Figure 43.

Large Fir Tree growing on Sand Dune at Kings Beach on North Shore of Lake Tahoe. Taken June 15, 1939 by S. T. Harding.

them for the past 250 years. Whatever may have been the conditions under which they were formed, their time of formation appears to have been prior to A. D. 1700.

WALKER LAKE

Walker Lake receives the inflow of the Walker River. This drainage area is between that of Carson River on the north and Mono Lake on the south. When sounded by Russell in 1882, the lake had a maximum depth of about 225 feet. It has a broad flat bottom at about elevation 3860 feet. In 1882 Walker Lake had an area of about 65,000 acres with a length of about 26 miles and width of four to five miles. The lake has lowered over 100 feet from its high elevation in 1870 as a result of the depletion of its inflow resulting from irrigation from Walker River.

While some information regarding the elevation of Walker Lake is available prior to 1882, this early record is less extensive and less complete than that for some of the other enclosed lakes in the western Great Basin. There is an adequate record of inflow since 1928 from which the evaporation from the lake can be derived. The extent and character of the diversions from Walker River make an estimate of the depletion resulting from such use subject to large uncertainties and it has not been attempted. The available records on the fluctuation of Walker Lake have usefulness as a check on the results for the same periods on the results for other lakes.

The available results on the elevation of Walker Lake are shown in Figure 44. The points for 1861 and 1868 were derived from a report in 1868 of the U. S. Indian Service describing the flooding of the Indian Agents garden and house. Mr. E. W. Kronquist was engineer for the Indian Service at Schurz for nearly 20 years and found support for the results shown in Figure 44 which are marked K. Mr. Kronquist made these results available to the writer in the 1930's and also supplied them to the Nevada Highway Department for use in locating the highway on the west side of the lake.

Where was Indian Agent's house?!

In 1882 I. C. Russell worked in the area of Walker Lake in his study of Lake Lahontan. The elevation in this year is taken from Monograph 11 of the U. S. G. S. Since 1928 the U. S. G. S. has maintained a gage near Hawthorne and has secured sufficient records to define the elevation of the lake from 1928 to-date.

In 1845 E. M. Kern traveled around Walker Lake. Kern's journal states that the lake was 22 miles in length and 11 or 12 miles wide in its widest part (quoted in Exploration Across the Great Basin of the Territory of Utah, by Capt. J. H. Simpson, 1859). Applying this length to the map prepared by Russell indicates an elevation of Walker Lake in 1845 as shown on Figure 44 or 4035 feet. While the other enclosed lakes in this general area were at relatively low stages in the 1840's it is improbable that Walker Lake rose as much prior to 1861 as would be required to reach the indicated elevation in that year. While Kern traveled the length of the lake his report of its length was not based on a direct measurement. Kern's statement of the width of the lake is much in excess of the actual width.

The mean results derived for the evaporation from Walker Lake have been presented earlier in this report. These are based on the record of inflow from Walker River, precipitation on the Lake based on the records at Schurz and Hawthorne and the fluctuations of the lake. The available records enabled the monthly evaporation to be computed for most of the months from 1928 to 1960 as shown in Table 23. Usable results were obtained for from 16 to 26

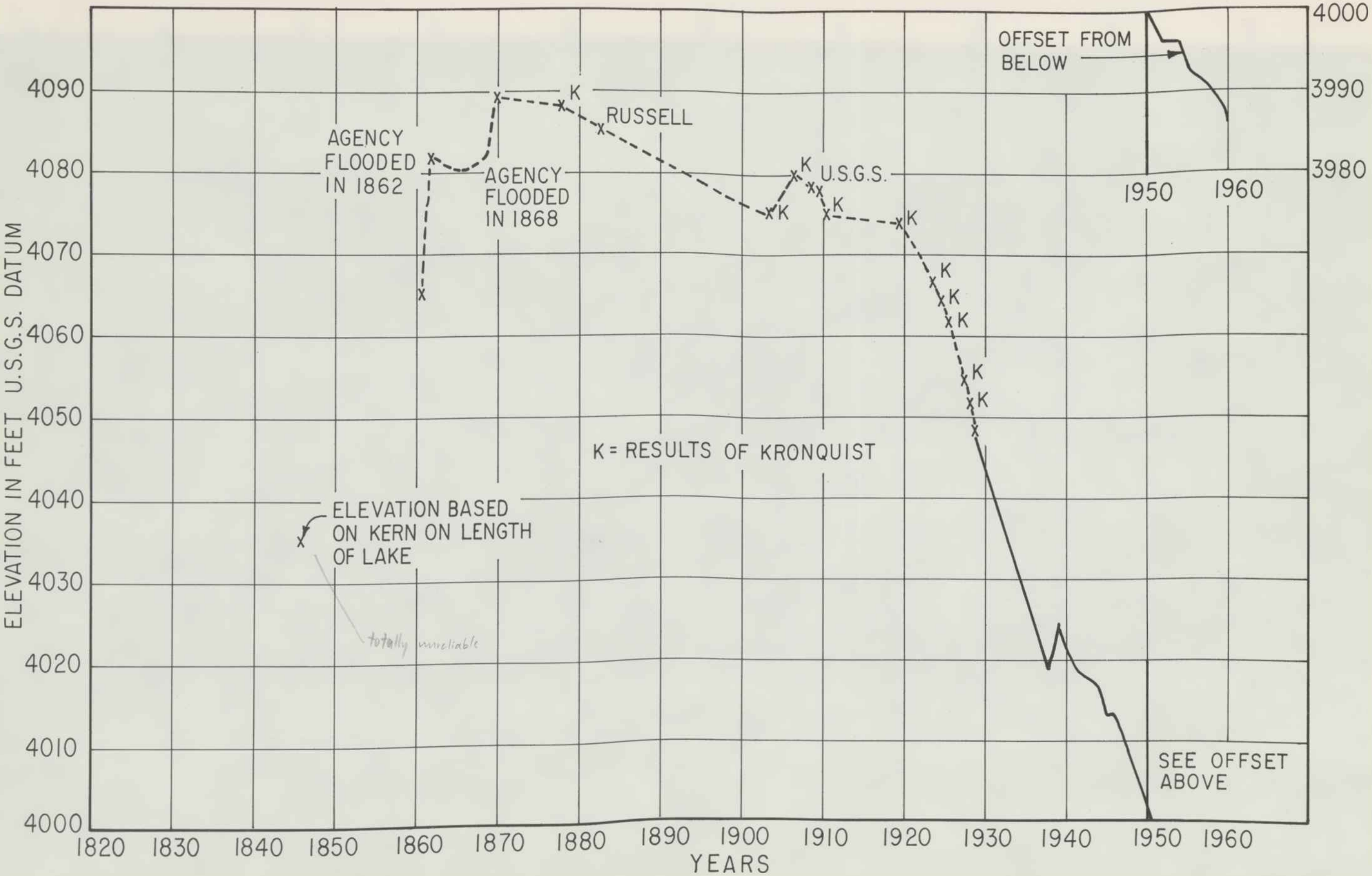


FIG. 44 FLUCTUATIONS IN THE ELEVATION OF WALKER LAKE, 1845 TO 1960

Table 23 Evaporation from Walker Lake

Depth of Evaporation in Feet

① Adjusted with Adjacent Months

② Omitted from Mean-Some apparent error in records

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
1928								.75	.50	.45	.21	.28	
29	.10①	.07①	.26①	.18	.21	.36	.45	.56	.63	.45	.30	18	3.69
30	.26	.14	.23	.24	.31	.52	.52①	.53	.68	.48	.31	.16	4.40
31	.04	.19	.13①	.28①	.24②	.43①	.51①	.46	.65	.52	.47	.33	4.25
32	.16	.39②	.23	.20	.03	.51②	70②	.50	.53	.45	.36	.23	4.17
33													
34	.17①	.17	.11①	.20①	.17	45	.46	.63	.60	.56	.46	.24①	3.93
35	12	.14	.24	.24	.32②	30②	.41	.44①	.50	.30	.25	.13	4.32
36	.19	.24	.04	.16	.95	.96②	67②	.59①	.42	.37	.35	.18	3.29
37	.19						.48②	.50①	.60①	.34②	.32		5.07②
38	.16	+.11②	.40②	.25	.33	1.27②	46	.32②	.47②	.64②	.49②	-.07②	4.29
39	.19	.64②	.11②	.43②	.33②	.15②	.41①	.64②	.83②	.09	.35①	.22①	4.38
40	.25	.13	.30②	.39	.27	.48①	.50①	.26	.05②	.34	36	.28①	3.59
41	.15	-.34②	-.08②	.33	.44	.94②	.79②	36	.44	.32①	.31①	.26①	3.93
42	.15	.28	.21	.29	.34①	54	.67①	.28	.99②	.34	.38①	.26①	4.73
43	.35②	.07②	.47②	.40②	.25	47①	48①	.55	.49	.65	.37①	.18	4.73
44	.35②	15②	.65②	.32②	.23	.34	45①	.52①	.45	52	.45	.29	4.72
45	0②	.18②	.23①	0②	-.06②	-.87②	-.36②	.72②	1.51②	.99②	.36①	.21	3.84
46	.20①	.20①	.20①	.26	.51②	.34②	.48②	.47	.50	55①	.31	.19	4.11
47	.16①	.10①	.22	.14	.33①	.41	.40	.55①	.49	.61	.32	.35	4.08
48	.15	.14	.17②	.22①	.26①	.30①	40	.50	.60				
49				.19①	.20	.15②	.50	.50	40	.40	34①	.30①	
50	.11	.10	.21	.26②	.30	40①	52①	.50	48	.35	1.16②		
51			-.07②	.13	.16	43	.53	.39	58	.53			4.39
52													
53													
54					.29	30①	.47①	.60①	.70	.40	.42		
55							.35①	.56					
56					.70②	1.72②	1.56②	.63	.57①	.50①			
57	.12	.18	.28	.15	.05	45①	.60①	51	.83②	.45	.29	.21	
58	.23	.17	.15	.28	.27	.57①	.56①	.53	.58	.48①	.31	.16	4.31
59	.16	.14①	.12①	.13	.22	.45	.43	.57①	.60①	.45	.40	.23	4.45
60							60①	56	.50①		.30		3.57
Years used	20	16	17	20	20	16	22	26	23	24	24	21	
Computed Means	.16	.16	.19	.24	.26	.47	.49	.52	.58	.44	.34	.23	4.08
Rounded Mean	.15	.15	.20	.25	.25	.45	.50	.50	.60	.45	.35	.25	4.10
Mean Air Temp.	31.7	37.4	44.2	50.4	58.5	66.2	73.1	71.1	62.0	52.4	40.6	32.8	51.7

years for the different months in this 33 year period.

Walker Lake has been deep enough to store the early season heat it receives and to release it later in the year. This results in its monthly evaporation temperature loop having the clock wise form as shown in Figure 45.

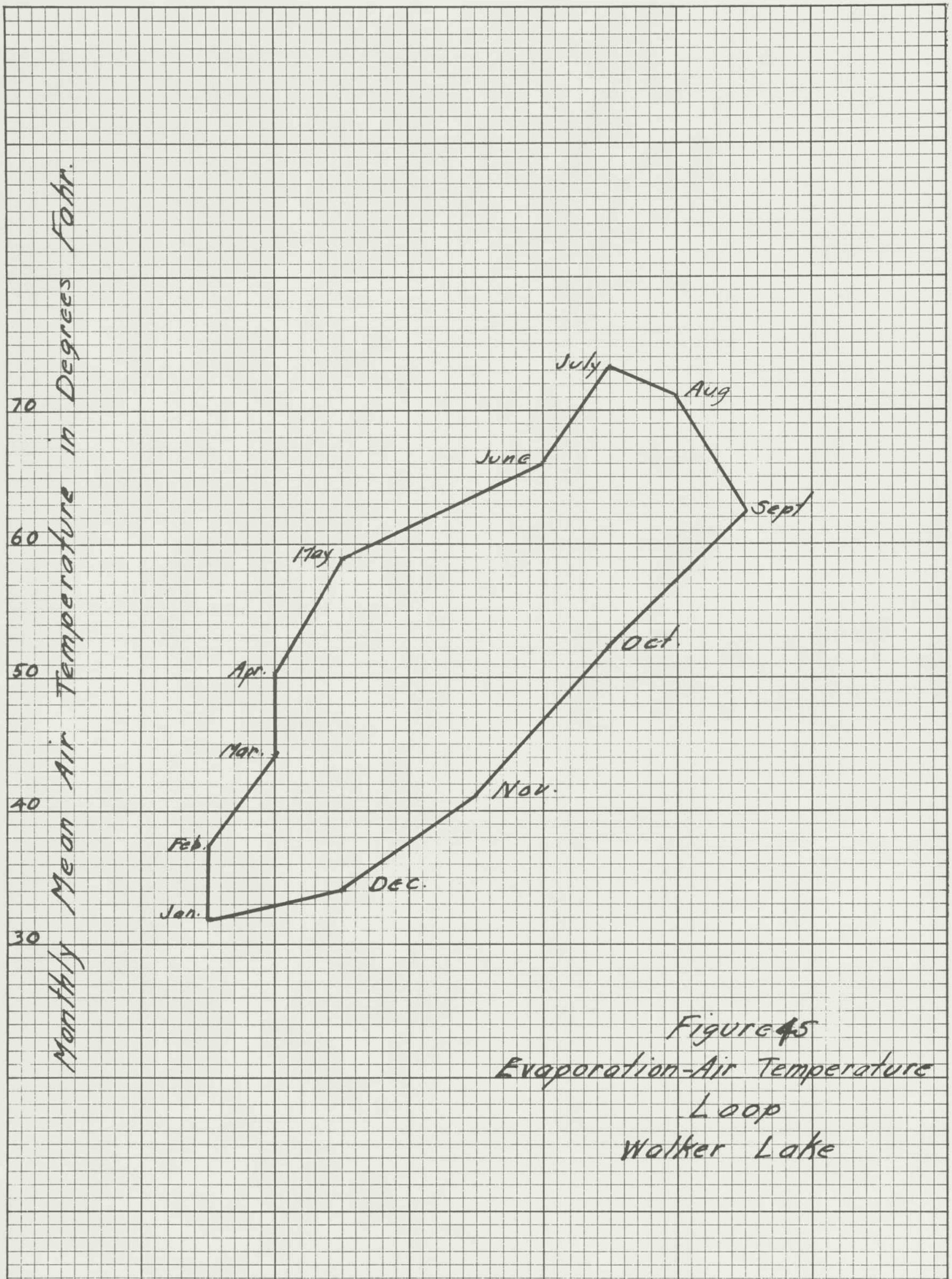
Only a few analyses of the water of Walker Lake are available. Some general comments are included in early reports. Kern in 1845 described the water as "exceedingly bad and salty" which indicates a relatively low stage of the lake. Fremont also called the water "saline" in 1845. In 1882 Russell secured top and bottom samples both of which showed about 2500 p.p.m. of total solubles. A sample taken by the writer in 1958 showed 6740 p.p.m. In 1882 Walker Lake contained 8,450,000 acre-feet, in 1958 this was reduced to 3,350,000 acre-feet. These results indicate that the total content of solubles in the lake in 1882 was 28,800,000 tons and in 1958 of 30,800,000 tons. These results are within the probable error resulting from a single sample and the additional solubles received in the 76 years between these samples.

The fluctuations of Walker Lake shown in Figure 44 furnish a basis for conclusions regarding the relative water supply of the drainage basin of the lake prior to about 1910. The rise shown from 1861 to 1882 and the maintenance of the lake elevation to about 1910, despite the increasing effect of irrigation, indicate an inflow during this 50 year period materially greater than that which produced the 1861 elevation. From 1861 to 1910 Walker Lake rose 10 feet and increased its volume by 800,000 acre-feet. During this period the mean area of the lake was about 65,000 acres. For this period the indicated mean annual inflow to the lake is about 255,000 and the runoff of the drainage area of the lake is this amount plus an uncertain amount for the gradually increasing depletion from irrigation.

The inflow prior to 1861 resulted in the lake elevation in that year. A mean annual inflow of 230,000 acre-feet would be needed to maintain the lake at its 1861 elevation. If the lake had been higher than its 1861 elevation prior to that year the annual inflow would have been less than 230,000 acre-feet by whatever amount was required to lower the lake to its 1861 elevation. If the lake had been lower prior to 1861 the inflow would need to exceed the above inflow in order to raise the lake. Kern's 1845 account indicates that the lake rose from 1845 to 1861 and the probable mean annual inflow for these 17 years exceeded 230,000 acre-feet.

If Walker Lake rose from its 1845 stage to its 1861 elevation, there would have been a period prior to 1845 when the annual inflow was less than 230,000 acre-feet. Russell's 1882 analysis shows a soluble content of 2500 p.p.m. Both Kern and Fremont call the water strongly alkaline in 1845. If Walker Lake was at elevation 4035 feet in 1845, to meet Kern's statement regarding its length it would have contained 5,300,000 acre-feet and, based on Russell's analysis, had a content of total solubles of about 4000 p.p.m. This is an insufficient amount of solubles to support Kern's and Fremont's statements regarding the quality of the water in the lake. On this basis Walker Lake would need to be below elevation 4035 in 1845 which, in turn, would require a greater rise to 1861 than 20 feet.

While the available information relating to past elevations of Walker Lake is not sufficient to define its fluctuations prior to about 1900 adequately, certain results can be derived in relative terms even though specific



Monthly Mean Air Temperature in Degrees Fahr.
Depth of Evaporation in Feet
0
30
40
50
60
70
.10
.20
.30
.40
.50
.60
Jan.
Feb.
Mar.
Apr.
May
June
July
Aug
Sept
Oct.
Nov.
Dec.
Figure 45
Evaporation-Air Temperature
Loop
Walker Lake

numerical results may be subject to error.

The available records support a conclusion that Walker Lake rose substantially from 1861 to the early 1880's when the effect of depletion from irrigation began to be felt. There is support for a conclusion that the lake was lower prior to 1861 than its elevation in that year. During some period prior to 1861 the inflow would have been less than that required to maintain the lake at its 1861 elevation in order for the lake to have lowered to its 1845 elevation. While these differences in the quantity of inflow can only be expressed in general terms there is support for the direction and nature of these changes.

MONO LAKE

INTRODUCTION

Mono Lake is the most southern of the enclosed lakes in the western Great Basin area included in this report. Of the lakes that have been discussed, its fluctuations are the best indicator of the variations of the runoff of its drainage basin. Until 1940, the reduction in its inflow resulting from use within its basin was negligible in amount. The diversions from its basin, beginning in 1940 by the City of Los Angeles, have been measured. The lake was meandered in 1857, and identification of the location of meander corners enables derivation of its elevation at that time. Other available records supply sufficient information to enable the fluctuations of the lake to 1912 to be reasonably well defined. Since 1912 there are adequate direct gage height records to define the fluctuation. There are also some submerged trees from which earlier fluctuations can be interpreted.

At its highest recent stage, Mono Lake had an area of 56,500 acres, a maximum depth of about 170 feet and a volume of about 4,800,000 acre-feet. The lake contains two islands; the larger of these islands, Paoho, is surrounded by shallow water which reduces the lake volume. The water is salty; at its highest recent stage the total solubles content was about 45,000 p.p.m. This had increased by the lowering of the lake and concentration of its waters to 63,000 p.p.m. in 1960. The water of Mono Lake is now about twice as salty as sea water but still has only about one-quarter of the total solubles content of the water in Great Salt Lake at its lower recent elevation.

AREA AND CAPACITY

I. C. Russell sounded Mono Lake in 1883 and reported depth contours from which the existing area and capacity of the lake have been derived.[1] The 1934 and 1951 results of the City of Los Angeles are shown in Figure 46.[2] The difference is the result of the correction in the elevation of the lake at the time of Russell's sounding made after the emergence of Russell's 1883 bench-mark.

EARLY REPORTS

The first recorded visit to Mono Lake is that of Jedediah S. Smith in 1825. Smith's account does not include information from which the elevation of the lake can be derived. The first reported settlement is in 1854. The meander surveys followed in 1857. One of the first published reports relating to Mono Lake is that of J. D. Whitney, based on his work in 1863. Whitney's report supports a conclusion that Mono Lake was not above elevation 6410 in

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[1] I. C. Russell, Quaternary History of Mono Valley, California, Eighth Annual Report of the U. S. Geological Survey, Vol. 1, 1886-87, p. 261.

[2] Los Angeles Bureau of Water and Power, Hydrologic Section, Revised January 4, 1951, Unpublished.

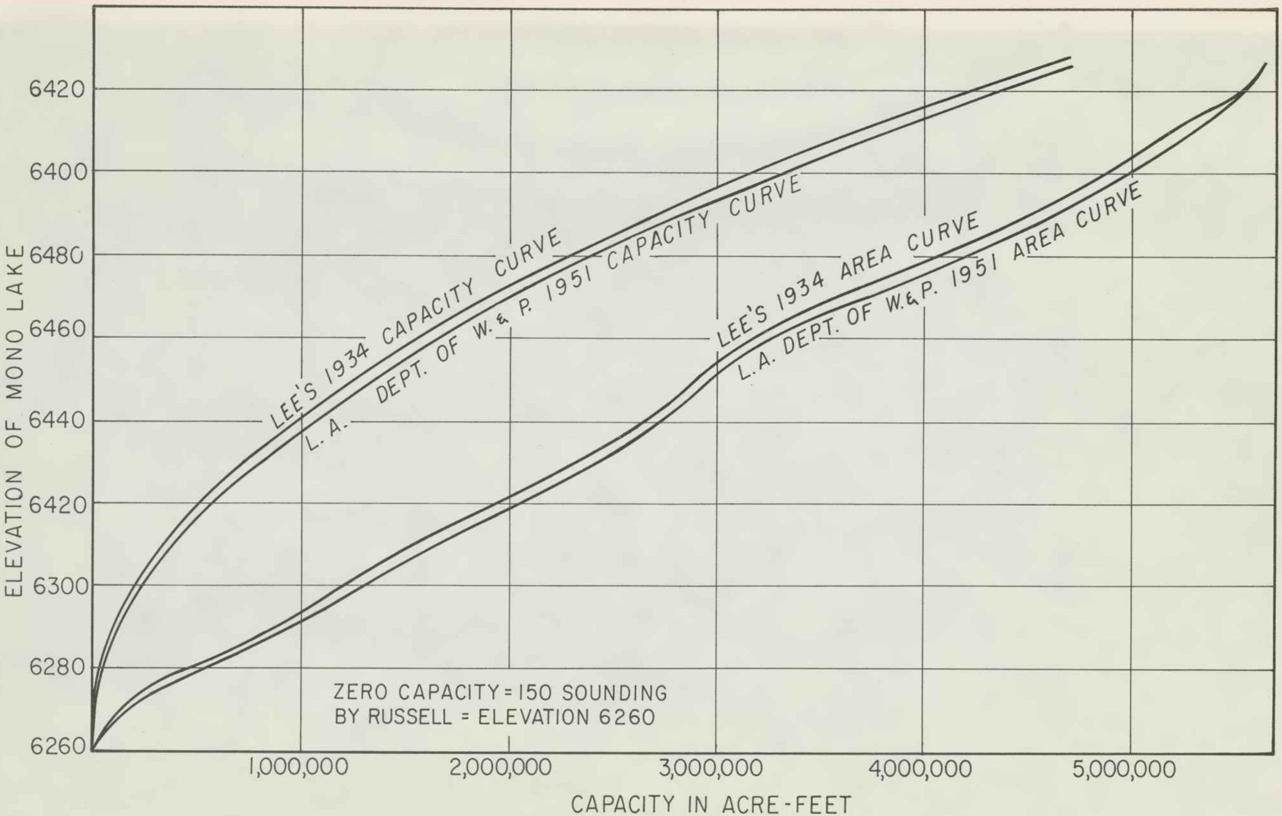


FIG. 46 AREA AND CAPACITY OF MONO LAKE

the early 1860's but does not define how much lower it may have been.[1] William H. Brewer described Mono Lake based on his visit there in 1863, but his account does not enable the then elevation of the lake to be identified.[2]

John F. Kidder, California Surveyor General, also made a report in 1864. He states that there was a water line 22 feet above the lake at an elevation where the lava was abruptly broken off.[3] Later information indicates that Mono Lake was probably at about elevation 6380 at this time. The lake lowered below elevation 6400 in 1960; no marked water line such as that described by Kidder has been reported since 1960.

King describes Mono Lake in the Exploration of the 40th Parallel stating that the lake showed a rise in 1864. The comments on rises on other lakes and, based on such general comparisons, King's report might be interpreted as indicating a rise of 10 to 15 feet on Mono Lake from 1857 to 1864. This period includes the very wet season of 1861-62.

J. LeConte visited Mono Lake in 1870, 1872 and 1875. In his report he states that the lake had been rising for the past 10 to 15 years. He found early sheep corrals and trails submerged many feet. Brush on the Island was submerged in water five feet deep. He quotes local residents to the effect that there had been a rise of 10 to 12 feet in 10 to 15 years.[4]

The most extensive investigation and report on Mono Lake is I. C. Russell's Quaternary History of Mono Valley, California in the Eighth Annual Report of the U. S. Geological Survey. Russell's main field work was done in 1883. He placed a bench-mark at the existing water line on Negit Island to record the elevation of the lake (Figure 47). Mono Lake rose and remained above this bench-mark from 1883 to 1950. When Russell's mark emerged in 1950, it was found to have an elevation of 6410 feet.

While Russell's bench-mark was submerged, other items in his report were used to derive the elevation of the lake in 1883. Using four of such other items in 1935, the writer also derived an elevation of Mono Lake in 1883 of 6410 feet.

Russell reported that it was thought by some that Mono Lake had risen 15 to 20 feet in the preceding 20 to 25 years. The beach on the west side of the lake had been submerged nearly to the base of the mountains by 1883. A cabin was reported to have been built on the north side of Negit Island which was wholly submerged in 1883.

Now that Russell's bench-mark has become available his comments can be converted into dates and elevations. The rise of 15 to 20 feet in 20 to 25 years would represent a lake elevation of 6385 in 1863 and 6390 in 1868 if the maximum rise reported is assigned to the longer time. If the cabin required a depth at its site of 10 feet for its submergence, the lake would probably have been below elevation 6395 in 1861.

[1] J. D. Whitney, Report of Geological Survey of California, Vol. 1: "Progress and Synopsis of Field Work for 1860-64."

[2] William H. Brewer, Up and Down California.

[3] John F. Kidder, Appendix to Legislative Journals, 15th Session, California, 1863-64.

[4] J. LeConte, "Extinct Volcanoes about Mono Lake," American Journal of Science, Third Series, Vol. 18, 1879, p. 35.

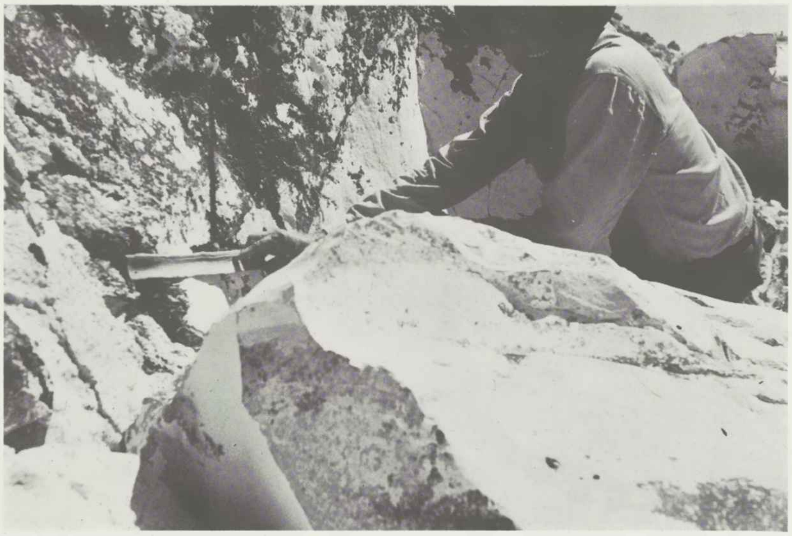


Figure 47.

Russell's Bench Mark on Negit Island in Mono Lake.

Taken August 9, 1960. The pointer held by the author covers the horizontal bar of the mark. The vertical bar of the inverted T is shown.

Ellsworth Huntington comments on trees he found to be nearly 150 years old which were killed by the rise of Mono Lake in 1914.[1] A similar tree was cut by the writer in 1934. A ring count gave an age of 83 years. Huntington's results indicate that Mono Lake had not risen above elevation 6419 in some continuous past period of 150 years. The tree cut by the writer was on higher ground and of shorter life. These trees were killed by the rise of the lake in 1914 so that their period of growth immediately preceeded that year.

The Southern Sierra Power Company had power plants on tributaries to Mono Lake. Through Mr. Thomas H. Means, the company in 1931 supplied the writer with results it had found relating to past elevations of Mono Lake. Adjusted to present datum these results included elevations of Mono Lake on July 27, 1898 of 6418 feet; in Oct., 1909 of 6422.5; and on Nov. 27, 1914 of 6424.6. Based on observed land marks, Mr. Jake Mattley, a local resident, concluded that Mono Lake rose 25 feet from 1886 to 1928 with the more rapid rise occurring from 1906 to 1912.

Much of Mono Lake was meandered in 1857. The City of Los Angeles has located some of the meander corners and determined elevation. H. B. Lynch made similar determinations for the Metropolitan Water District in 1933. The writer has transferred the 1857 meander lines to the recent U. S. G. S. quadrangle sheets in this area. Lynch derived an elevation of Mono Lake in 1857 of 6376 feet. The writer has concluded that this result is supported by these results and has used it in his work on Mono Lake.

There are several elevations of Mono Lake shown on the U. S. G. S. quadrangle sheets covering parts of Mono Lake. Some uncertain changes in datum are involved for the earlier maps. Elevations of 6416.2 on July 27, 1898 and 6420.9 in Oct., 1909 have been derived from those results.

FLUCTUATIONS OF MONO LAKE 1857 TO 1912

The earliest derived elevation of Mono Lake is that for 1857 based on the meander survey of the lake. There are other supported elevations in 1883, 1898 and 1909. In addition there are general statements regarding the amount of change in the elevation of the lake over different periods. These results, by themselves, are insufficient to enable the annual elevations to be derived from 1857 to 1912 when regular observations began.

As an aid in the interpolation of the fluctuations of Mono Lake from 1857 to 1912, the writer has used precipitation and runoff indices for this area. These are expressed in percentages of their mean and were used as a guide in the distribution of the known overall fluctuations to individual years. While not a substitute for actual records, the resulting fluctuations shown on Figure 48 should be more representative of the actual fluctuations than a straight line connecting the known points.

A similar procedure was used by H. B. Lynch in his work on Mono Lake. His results have also been plotted on Figure 48.[2] The variations between the

[1]E. Huntington, Civilization and Climate, 3d Edition, 1924, p. 326.

[2]Henry B. Lynch, "Pacific Coast Rainfall-wide Fluctuations in Hundred Years," Western Construction News, July, 1948, p. 76.

result derived by Lynch and the writer illustrate the degree of uncertainty involved in such estimates. In Figure 48 the derived fluctuations of Mono Lake from 1857 to 1912 and the recorded results since 1912 are shown. This shows the generally steady rise during the period from 1860 to 1920, a lowering of 12 feet from 1920 to 1935, then a generally steady elevation to 1945 when the effect of the diversion by Los Angeles began to be felt with a steady lowering from 1945 to date.

The fluctuations of Mono Lake shown on Figure 48 have been used later in the computations of the inflow to the lake from 1857 to 1960.

RUNOFF OF DRAINAGE BASIN OF MONO LAKE 1857-1960

The fluctuations of Mono Lake, together with its area and capacity curve, enable the changes in the volume in the lake and the area exposed to evaporation and precipitation on the lake to be derived for any time period covered by the records of the elevation of the lake. These items enable the inflow to the lake to be computed for the same time periods.

Prior to 1940, when diversion by Los Angeles began, the inflow to Mono Lake represented the runoff of its tributary drainage area. Consumptive use resulting from diversions within the Mono Lake basin has been and still is a minor element in its water supply. The diversion out of the Mono Basin has been measured. There are some springs discharging into Mono Lake. The amount of such inflow is not measurable but is not considered to be large. Springs in the recently exposed lake bed are small seeps. It is not necessary to separate spring and surface inflow in the derivation of the total inflow. There are no known leakages from the lake.

The rate of evaporation from Mono Lake has been derived in preceding portions of this report. The mean annual gross evaporation has been estimated to be 3.25 feet. The records of precipitation on the lake are inadequate. Based on the available records the writer has estimated the mean annual precipitation on the lake to be eight inches. This has been varied in individual years by the use of the precipitation indices derived for this general area.

The computations used to derive the runoff of the drainage basin of Mono Lake from 1857 to 1959 are shown in Table 24. The mean for this period is 151,100 acre-feet. The variations in this runoff during different parts of this 102 year period are also shown in Table 24. The runoff of the first 54 years from 1857 to 1911 was 110 per cent, and of the last 48 years from 1912 to 1959 was 89 per cent of the 102 year mean. The runoff for this first period was 124 per cent of that of the second period.

The general character of the variations in the inflow to Mono Lake during this 102 year period is shown by the accumulated departures plotted in Figure 49. The excess inflow to 1918 represents an accumulated departure from the mean of nearly six years of mean annual inflow, with a similar total deficiency from 1919 to 1959.

SUBMERGED VEGETATION ON MONO LAKE

Some trees and brush have been submerged by the rise of the lake on the

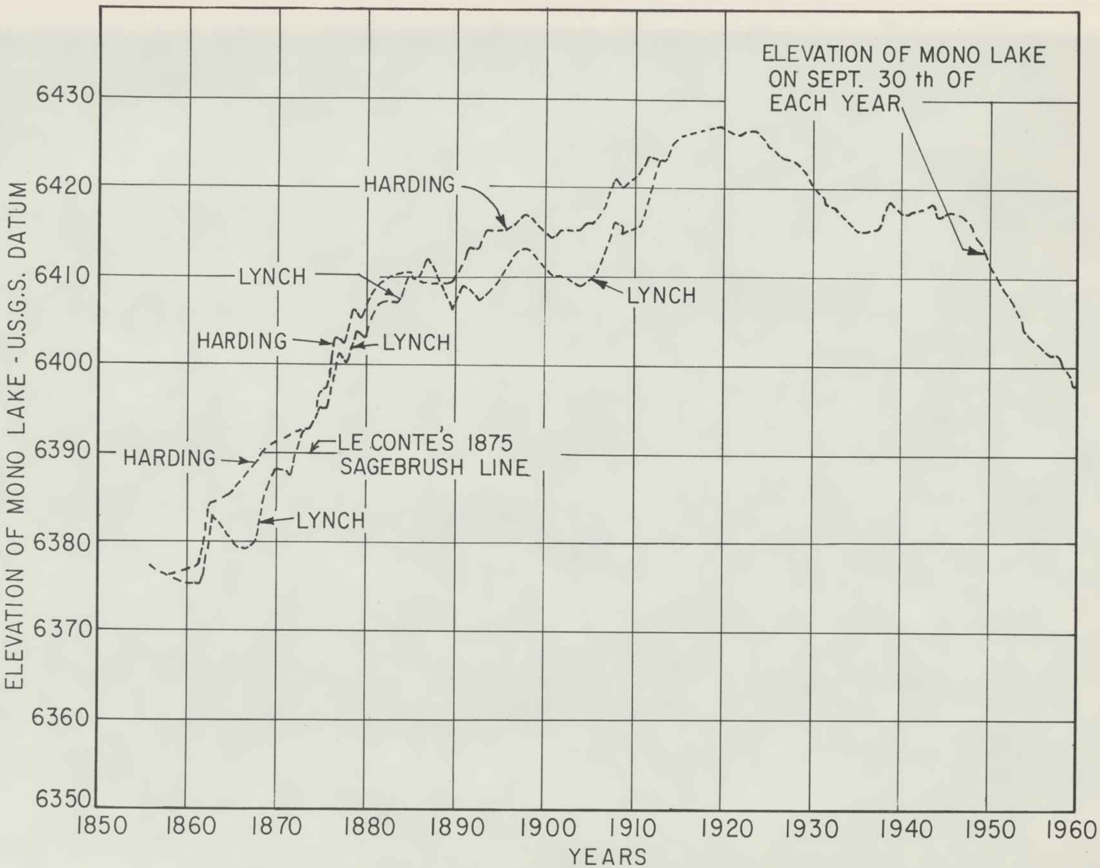


FIG. 48 FLUCTUATIONS OF MONO LAKE, 1857 - 1960

Table 24 Computed Inflow to Mono Lake - Thousands of Acre-feet

Period or year (Col. 1)	End of Period: Elevation of Lake Feet (2)	End of Period: Area of Lake 1000 Acres (3)	Precipitation: Index Per Cent (4)	Precipitation: Depth in Feet (5)	Precipitation: Total Annual 1000 Acre-feet (6)	Gross Annual Evaporation (7)	Change in storage in Lake (8)	Out-flow (9)	Computed Annual Inflow (10)	Per Cent of 102 year Mean (11)	Accumulated Per Cent of Mean (12)
	6376	40.1									
1857-64	6385	44.9	115	.77	33	138	+383		160	106	+42
1865-68	6390	46.5	130	.87	40	149	+228		166	110	+82
69-83	6410	52.9	140	.94	47	162	+994		181	120	+382
84-98	16	54.7	120	.80	43	175	+322		153	101	+397
99-11	23.5	56.1	130	.87	48	180	+417		164	108	+514
1912	23.2	56.1	106	.71	40	183	-17		126	83	+497
13	23.1	56.1	101	.67	38	182	-6		138	91	+488
14	25.0	56.3	184	.56	31	183	+106		258	171	+559
15	(25.5)	56.4	128	.86	48	183	+28		163	108	+567
16	26.1	56.5	132	88	50	184	+34		168	111	+578
17	26.4	56.5	120	.80	45	184	+17		156	103	+581
18	26.7	56.5	120	.80	45	184	+17		156	103	+584
19	26.9	56.5	175	.77	44	184	+11		151	100	+584
20	26.0	56.4	70	.47	27	183	-50		106	70	+554
21	25.9	56.4	103	.69	39	183	-6		138	91	+545
22	26.4	56.5	128	.86	49	184	+28		163	108	+553
23	26.5	56.5	112	.75	42	184	0		142	94	+547
24	25.3	56.3	57	.38	21	183	-17		145	96	+543
25	24.3	56.2	66	.44	25	182	-56		101	67	+510
26	23.4	56.1	69	.46	26	182	-50		106	70	+480
27	23.2	56.1	99	.66	37	182	-11		134	88	+468
28	22.5	56.0	77	.52	29	182	-39		114	75	+443
29	21.1	55.8	49	.33	18	182	-77		87	57	+400
30	19.7	55.8	49	.33	18	181	-77		86	57	+357
31	18.3	55.3	49	.33	18	180	-88		74	49	+306
32	17.9	55.2	88	.59	.33	180	-22		125	82	+288
33	16.6	54.8	53	.36	.20	178	-72		86	57	+245
34	15.4	54.5	56	.38	.20	177	-65		92	61	+206
35	14.9	54.3	83	.56	30	177	-27		120	79	+185
36	15.1	54.4	112	.76	41	177	+11		147	97	+182
37	15.1	54.4	104	.70	38	177	0		139	92	+174
38	18.2	55.3	230	1.54	.85	179	+172		266	176	+250
39	17.7	55.0	85	.57	.31	179	-28		120	79	+229
40	16.9	54.9	73	.49	.27	178	-44	1	108	71	+200
41	17.1	55.0	137	.92	.51	179	+11	33	172	113	+213
42	17.5	55.1	126	.84	.46	179	+22	7	162	107	+220
43	18.1	55.3	137	.92	.51	180	+33	10	172	113	+233
44	16.7	54.8	86	.58	.32	178	-77	52	121	80	+213
45	17.2	55.0	127	.85	.47	179	+28	4	164	109	+222
46	17.0	54.9	96	.64	.35	178	-11	0	132	87	+209

Period or Year (13)	End of Period: Elevation of Lake feet (14)	End of Period: Acres of Lake 1000 Acres (15)	Precipitation: Index Per Cent (16)	Precipitation: Depth in Feet (17)	Precipitation: Total Annual 1000 Acre-feet (18)	Gross Evaporation Annual (19)	Change in Storage in Lake (20)	Out-flow (21)	Computed Annual Inflow (22)	Per Cent of 102 Year Mean (23)	Accumulated Per Cent of Mean (24)
1947	6416.3	54.7	99	.66	36	178	-38	31	135	89	+198
48	14.1	54.1	82	.55	30	176	-119	87	114	75	+173
49	12.1	53.5	82	.55	29	174	-107	82	120	79	+152
50	10.1	53.0	90	.60	32	173	-106	94	129	85	+137
51	8.25	52.3	98	66	35	170	-97	96	134	88	+125
52	8.75	52.5	125	.84	44	171	-26	9	110	73	+98
53	7.60	52.1	105	.70	36	170	-60	69	143	94	+92
54	5.27	51.4	80	.54	28	167	-120	44	63	42	+34
55	3.18	50.7	86	.58	29	165	-106	92	122	81	+15
56	2.17	50.4	120	.80	40	164	-51	85	158	104	+19
57	1.15	50.1	91	.61	31	163	-52	46	126	83	+2
58	1.58	50.5	134	.90	45	164	+22	31	172	114	+16
59	63 99.79	49.6	91	.61	30	162	-89	84	127	84	0
1960	97.65	48.9									

102 Year Total 15417 10200

Mean 151.1

Partial Periods

Period	Number of Years	Total Inflow	Annual Mean	Per Cent of 102 year Mean
1857-83	26	4499	173	115
1884-1911	28	4427	158	105
1912-18	7	1165	166	110
1919-37	19	2256	119	79
1938-47	10	1552	155	103
1947-59	12	1518	126	83
	102	15417	151	100
1912-59	48	6491	135	89

S.TH

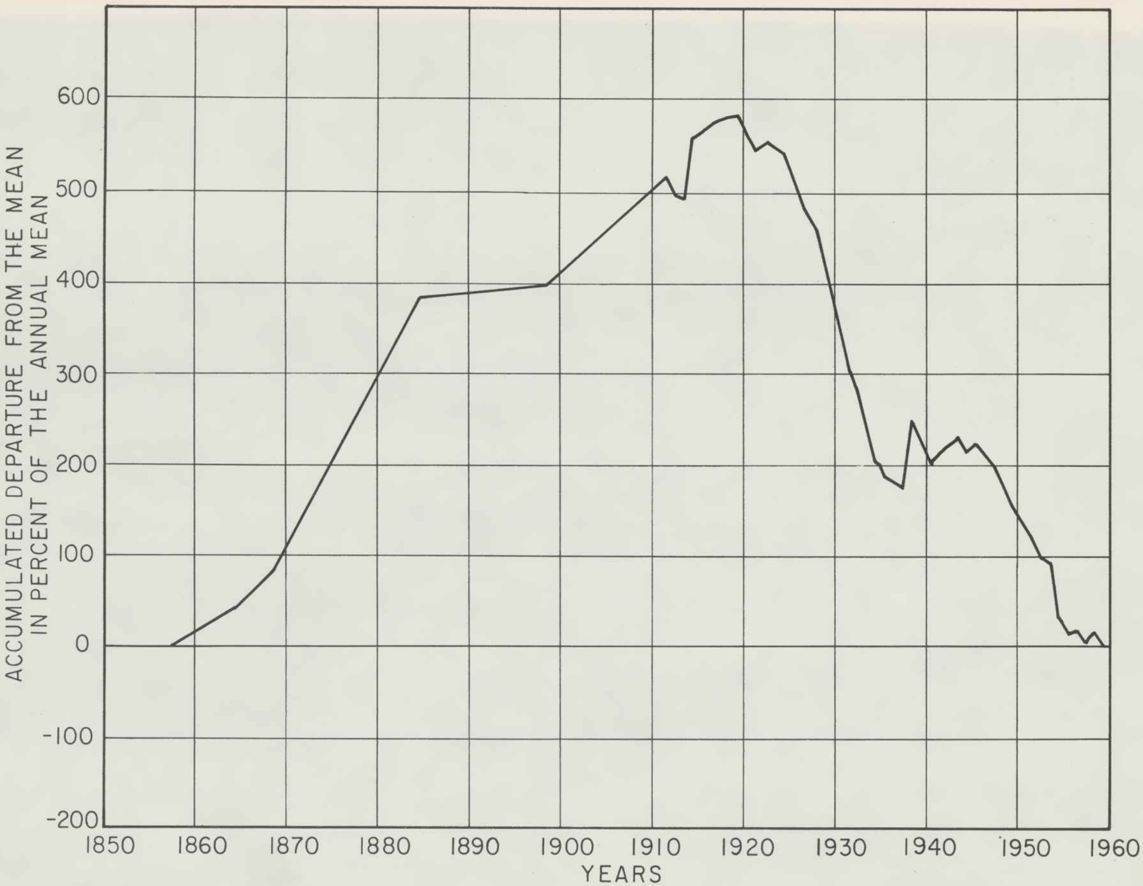


FIG. 49 INFLOW TO MONO LAKE. ACCUMULATED DEPARTURE FROM THE MEAN
FOR THE 102 YEARS 1858 TO 1959

southwestern portion of Mono Lake. Mountain mahogany grew on the rocky slopes north of Leevining, and pines and cottonwood grew on the delta of Leevining Creek. Mountain mahogany over 100 years old was submerged by the rise of the lake prior to 1914. Stumps and downed trees have been exposed at lower elevations by the recession of the lake since 1940.

In 1962 Mono Lake was about 20 feet higher than its elevation in 1857. Further lowering will occur as a result of the present diversion of its inflow. As this lowering takes place there will be an opportunity to examine the exposed lake bed and perhaps to find stumps of former trees at lower elevations. The following discussion is based on the observations that can be made at this time.

In 1960 Donald B. Lawrence secured a sample from a stump on the south shore of the lake which has been Carbon 14 dated as 920 ± 90 years.[1] A view of this stump is shown in Figure 50. The C-14 result places the date at which this tree was killed by a rise of the lake at about 1000 A.D. A count by the writer of the remaining wood in 1960 indicated a probable growing life of about 50 years. To have been preserved 900 years this stump had to have been submerged all, or nearly all, of this period.

This stump represents a fifty year period in which Mono Lake was below elevation 6400 feet. It was out of water prior to 1875 and became submerged by the rise of the lake at that time. The writer had assumed that this tree grew in the period immediately preceding 1875.

This Carbon 14 dating requires a different estimate of the past elevations of Mono Lake. While this stump was tufa coated so that its usual process of decay was retarded, to have been preserved for 900 years would require that it was submerged for the major part of this period. Uncoated stumps around Eagle Lake have decayed in about 40 years of exposure to the air.

Two fallen trees were exposed by the lowering of Mono Lake in 1961. These had been uprooted on the south shore of the lake east of the mouth of Leevining Creek. They are shown in Figures 51 and 52. They grew on ground at elevation 6398 feet. Increment borer cores indicated ages of 60 and 75 years. As the ground on which they grew is marshy, they are probably cottonwood. They are over two feet in diameter. The wood was fairly well preserved with the interior of the trees somewhat soggy.

No Carbon 14 dating has been secured of the wood in these trees. They could have grown in a period preceding 1875 when the rise of the lake submerged the ground on which they grew, or they may have grown in some earlier period and have been preserved by their continuous submergence until exposed by the lowering of the lake at some time prior to 1857. The entire trees had been tufa coated which would indicate a relatively long period of submergence.

[1]Donald B. Lawrence & Elizabeth G. Lawrence, "Response of Enclosed Lakes to Current Glaciopluvial Climatic Conditions in Middle Latitude, Western North America," Annals of the New York Academy of Sciences, Vol. 95, Art. 1, 1961, p. 341.

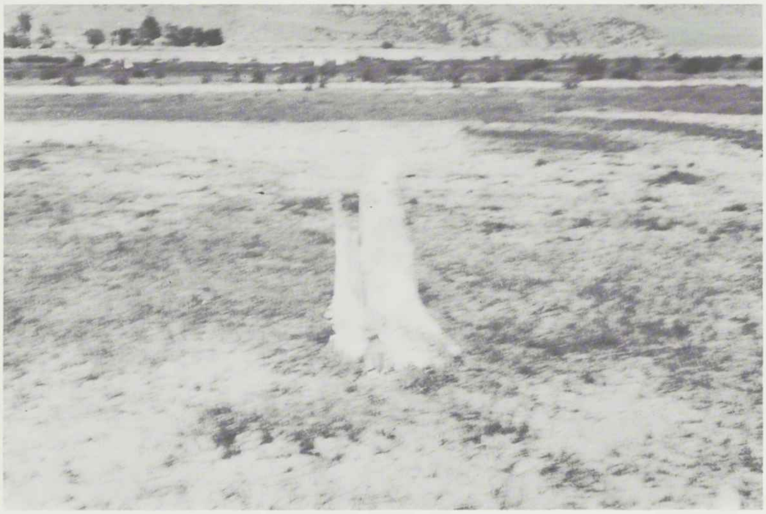


Figure 50.

Stump on south shore of Mono Lake.

Taken July 31, 1962 by S. T. Harding. This is the stump from which D. B. Lawrence took his sample for Carbon-14 dating.

Figure 51.

Trunk and base of fallen tree on south shore of Mono Lake. Taken July 17, 1961 by S. T. Harding.

This is the more easterly of the two fallen trees, about one-fourth mile east of the mouth of Leevining Creek. This tree grew on ground at about elevation 6398. The view shows the uprooted base and the tufa deposits around it. The second tree in this area is in the background.

Figure 52.

Fallen Tree on South Shore of Mono Lake.

This is the more westerly of the two down trees in this area about one-fourth mile east of the mouth of Leevining Creek. The base of this tree is on ground having an elevation of about 6398 feet. The extent of the tufa coating on this tree shows clearly in this view.

INFLOW TO MONO LAKE PRIOR TO 1857

Starting with the elevation of Mono Lake in 1857 conclusions can be drawn regarding the probable fluctuations of the lake prior to that date. Mono Lake was about 20 feet lower in 1857 than it was in 1962. Its preceding inflow would have been an amount which would have resulted in this elevation. Under present diversions, and with an average runoff similar to that since 1857, Mono Lake will not reach its 1857 elevation until about 1980.

At its 1857 elevation of 6376 feet, Mono Lake had an area of about 40,000 acres. To maintain this area an annual inflow of about 100,000 acre-feet is required. This is only about two-thirds of the mean annual inflow since 1857.

There would need to be a period of undefined length prior to 1857 in which the inflow to the lake was insufficient to maintain the lake at a higher elevation. The driest period since 1857 has been the 19 years from 1919 to 1937 when the inflow was 79 per cent of the 102 year mean from 1857 to 1959. The inflow to Mono Lake for some period prior to 1857 would need to have been over 15 per cent less than that for any period since 1857 in order that the lake would lower to its 1857 elevation.

Mono Lake may have been lower than its 1857 elevation prior to that year. If this was the case there would need to be a period of larger inflow to raise the lake to its 1857 elevation. Such a period would have to be preceded by a period in which the lake lowered below its 1857 elevation. In such a lowering period the inflow would be even less than that required to maintain the lake at its 1857 elevation.

On the eastern shore of Mono Lake there are stratified clay beds which have been eroded by the lake when it has been at its recent elevations. These beds appear to have been formed by volcanic discharge of fine materials. They show stratification similar to those in delta formations but there are no local streams entering this side of the lake. Mono Lake has now receded well away from the base of this bluff. While the present conditions indicate the results of the past actions of the lake, they do not supply a basis for dating past elevations of Mono Lake.

QUALITY OF WATER IN MONO LAKE

The quality of the water in Mono Lake has been the subject of several general (and sometimes fanciful) accounts. Fortunately, enough actual analyses during the last 80 years are available to enable determination of the variations that have occurred in its quality.

Russell reports an analysis of the water in Mono Lake in 1883.[1] A more careful analysis of the same water was made by Chatard. The content of total solubles was 5.35 per cent. For 3,840,000 acre-feet, the volume in Mono Lake at this time, this analysis represents a total soluble content of 275 million tons.[2]

[1] Russell, Quaternary History of Mono Valley, Calif.

[2] F. W. Clarke, "Data on Geochemistry," U. S. G. S. Bull. 770, 1924.

Since 1930 the City of Los Angeles has analysed the water of Mono Lake at various times. These results were made available to the writer. Typical analyses are shown in Table 25.

All of these analyses have been computed in terms of the total tonnages of solubles in the lake water. The total volume of water in the lake has also been determined at the times the samples were secured. These results are shown in Table 25.

The results in Table 25 have been plotted in Figure 53. The total tons of solubles in Mono Lake has remained relatively constant during the reduction in its volume from 1930 to 1960 of over 25 percent. The results of the 1883 sample are also shown in Figure 53. The average total tonnage of solubles for the samples from 1940 to 1960 is about 290 million tons. The result for the 1883 sample of 275 million tons leaves room for some increase from 1883 to 1940, although the difference in these results of five percent is within the range of the individual samples from 1940 to 1960.

THE FUTURE OF MONO LAKE

The future elevations of Mono Lake will be determined mainly by the amount of the diversion from its basin. The present canals in the basin and the tunnel from the basin of the City of Los Angeles have an average diversion capability which may be equal to two-thirds of the mean annual runoff tributary to Mono Lake. For continued operation of the present works, the future mean annual inflow to Mono Lake may be about 50,000 acre-feet. For the net annual evaporation rate of 2.6 feet, such an inflow will maintain a lake having an area of about 20,000 acres. Mono Lake has such an area when it is at elevation 6320 feet. This is about 75 feet lower than the elevation of the lake in 1962. Even with no inflow, 30 years would be required for Mono Lake to lower to this elevation. The rate of lowering will be reduced as the lake approaches a balance with such a supply, and a much longer period than 30 years will be required before such a new balance is reached.

If Mono Lake lowers to elevation 6320 feet, it will contain about 700,000 acre-feet, equal to about one-fourth of its present volume. This, in turn, will result in increasing the present soluble content about four times to about 25 percent. Some crystallization of salts may occur before the lake lowers to elevation 6320.

Table 25 Analyses of Water of Mono Lake made available by City of Los Angeles

Per cent by Weight

Date	Lake Elevation	Specific gravity	Na CO3	Na HCO3	Na Cl	K Cl	Na sulfate	Na sulfide	Na Tetraborate	Silica	Na Phosphate	Na Arsenate	Ca HCO3	Mg HCO3	Phosphoric acid	Total Per Cent by weight	Total Tons x10[6]
7-16-1930	6419.82	—	1.77		1.58	.17	.845	-	.113	.017			.002	.004	.003	4.504	
9-26-1937	6414.64	1.042	1.502	.706	1.681	.189	.907	.343	.116	.0018			.0010	.0157	.0033	5.116	
6-22-1940	6417.49	1.041	1.53	.51	1.60	.196	.89	.0021	.116	.002	.0072		.0046	.0015		4.8594	292.3
5-4-1948	6415.18	1.048	1.30	.65	1.67	.22	.88	0	.1145	.0002	.012	.0015				4.8482	284.8
9-30-1948	6413.69	1.044	1.43	.82	1.72	.178	.96	0	.12	.0022	.008	.0025				5.2407	300.7
9-30-1950	6409.72	1.047	1.42	.85	1.83	.183	.994	0	.121	.001	.0076	.0088				5.3994	294.3
May 1952	6408.31	1.0476	1.44	.83	1.80	.21	1.03	0	.1251	.0027	.0096	.0029	.0055	.0133		5.466	292.2
Oct 1953	6407.23	1.048	1.46	.89	1.88	.19	1.03	0	.124	.0013	.0075	.0026				5.5854	294.4
9-30-1955	6402.81	1.0508	1.82	.51	2.02	.17	1.13	0	.14	.004	.0087	.003				5.8057	288.0
" 85' depth	6402.81	1.0509	1.46	1.02	1.98	.16	1.08	0	.13	.003	.0087	.003				5.8447	289.9
Sept. 1958	6401.55	1.053	1.63	.95	1.79	.16	1.08	.004	.13	.001	.011					5.756	
Sept. 1960	6397.42	1.056	1.67	1.00	2.14	.23	1.14	.001	.16		.011	.001				6.353	

Computations by S.T. Harding

	Elevation	Area Acres	Volume 1000 Acre-feet	Total Solubles %	weight per Ac. Ft. with solubles in 1000 tons	Total tons of Water 10[6]	Total tons solubles 10[6]
7-16-1930	6419.82	55600	4372	4.504	1421	6200	280
9-26-1937	6414.64	54300	4088	5.116	1430	5850	299
6-22-1940	6417.49	55100	4245	4.8594	1426	6050	294
5-4-1948	6415.18	54400	4118	4.8482	1426	5880	285
9-30-1948	6413.69	54000	4036	5.2407	1431	5800	304
9-30-1950	6409.72	52800	3825	5.3994	1433	5480	296
May 1952	6408.31	52400	3751	5.466	1434	5370	293
Oct. 1953	6407.23	52000	3695	5.5854	1436	5320	296
9-30-1955	6402.81	50600	3467	5.8057	1439	4990	290
" [illegible]-1955	6402.81	50600	3467	5.8447	1440	5000	292
Sept. 1958	6411.55	50200	3404	5.756	1438	4900	282
Sept. 1960	6397.42	48900	3200	6.353	1446	4630	294

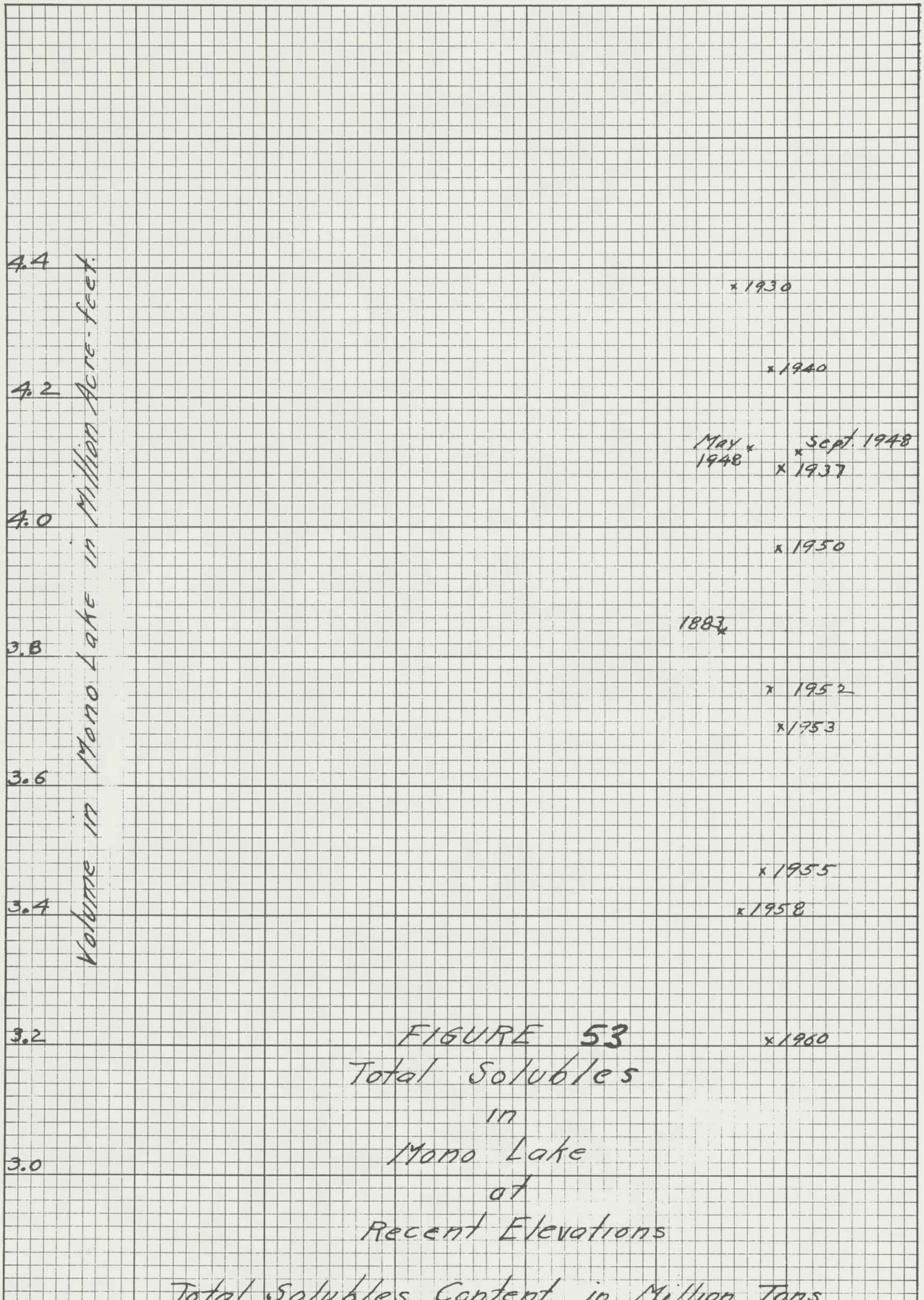


FIGURE 53
Total Solubles
in
Mono Lake
at
Recent Elevations

MINOR LAKES

The term minor lakes is used for lakes whose available records represent a minor item in deriving the past water supply of the western Great Basin. They may not be minor in their importance in their own area.

Some of these lakes contribute to the general water supply picture at times, particularly in periods of deficient runoff. Their records have been sought to the extent that they may have usefulness but the writer has not attempted a complete study of their history. Each of these lakes is discussed to the extent that it may contribute to the purposes of this report.

TULE LAKE

Tule Lake and Lost River are in the Klamath River drainage area west of the Great Basin. The early accounts describe a so-called Indian ford, the crossing shown to the early explorers in this area by the Indians. This ford was described as a natural bridge under which Lost River was thought to flow. Later it was found that the rock formation was solid. The present diversion dam near Merrill is built on this formation. It could be used as a ford during the lower stages of Tule Lake but was subject to deeper overflow when Tule Lake rose.

Reports from 1846 to 1855 all show the natural bridge in use as a ford indicating a relatively low stage for Tule Lake. Indian legends report Klamath Marsh to have been dry in the 1840's.

While these reports are general, they indicate that the relatively low stage of Goose Lake in the 1840's also was applicable to Tule Lake to the west.

SURPRISE VALLEY LAKES

The Surprise Valley Lakes lie east of the Warner Range along the California-Nevada line in northeastern California. These three lakes have fluctuated during their observed history. They are shallow and have gone dry at times. In recent years the use of their inflow for irrigation has reduced their water supply.

The frequency with which these lakes become dry places them in the class of playas. Prior to diversion of their tributary inflow, some water remained in one or more of the three lakes except during sustained drouths.

The first account of these lakes in 1840 by Applegate indicates that there was only one small lake.[1] This represents almost complete dryness. Available accounts in 1849 establish that Upper and Middle Lakes were dry in that year. These results are consistent with that for other areas in the western Great Basin during the 1840's.

SNAG LAKE

Snag Lake, in the southeastern part of Lassen National Park, was formed

[1] Lindsey Applegate, "Notes and Reminiscences of Laying Out and Establishing the Old Emigrant Road into Southern Oregon in the Year 1846," Oregon Historical Society Quarterly, Vol. 22, 1921, p. 12.

by a lava flow across the valley which it occupies. This flow is relatively recent, perhaps about 250 years ago, although conclusions on its age vary. Until recently there were dead trees submerged in the lake whose trunks extended above the water. The lake had been 10 to 12 feet higher than its elevation in 1960. The available records do not enable such fluctuations to be dated. Snag Lake is interesting in itself but its past record does not add to the information on past water supply secured from other enclosed lakes in this area. Carbon 14 dating on the submerged trees might aid in fixing the date of the formation of Snag Lake.

CRATER LAKE, LASSEN COUNTY, CALIFORNIA

Crater Lake near Bogard, Lassen County, California, is a small lake on which records of elevation have not been kept. Trees around the lake indicate that the lake has been about 10 feet higher at some time in the past, probably about 1915 as the trees now growing in this area are young. A comparison of the expected runoff of the tributary area and the probable evaporation from the lake indicates that some leakage probably occurs. While the area of this lake is only about 25 acres, it is a little gem set in a forested crater.

HORSE LAKE

Horse Lake is a semi-playa situated north of Susanville, Lassen County, California. It has gone dry at times. In years of unusually large inflow it overflows to Pete's Creek, a tributary to Honey Lake. Available records do not cover its elevation. The first reported overflow occurred in 1869.

HONEY LAKE

Honey Lake in eastern Lassen County, California, usually contains water but has gone dry at times. Its inflow is now reduced by the depletion resulting from irrigation on its drainage area. The available records are not sufficient for its fluctuations to be derived. Prior to irrigation the area of the lake varied from zero to 64,000 acres. In an 1845 account by James P. Beckwourth the lake is described as a large body of brackish muddy water with 1000 Indians living around its shore.[1] The lake was reported to have been dry in 1859 and relatively high in 1868. These early accounts show water in the lake in the 1840's but do not define its elevation. If the lake went dry in 1859, the 1850's would have had a greater deficiency in inflow than the 1840's.

HUMBOLDT LAKE

Humboldt Lake or Sink was on the main travelled route in the 1840's and there are numerous references to it in the diaries of the emigrants. These, however, do not define its stage. There is also uncertainty regarding the

[1] J. P. Beckwourth, quoted by Fariss and Smith in History of Plumas, Lassen and Sierra Counties, 1882.

condition of its outlet through the bar across its southern end. The first report by Ogden in 1829 indicates a lake without outflow.[1] In 1841 Bidwell reports a stagnant lake without outflow.[2] Other reports during the 1840's use such terms as "a sea of slime"[3] and refer to the water as smelling like rotten eggs.[4] In July 1850, outflow was reported by Ledyard.[5] The lake was called brackish and shallow in August 1850 by Loveland.[6] By 1860 Horace Greeley reports it as a fine sheet of water having an outlet stream.[7]

After 1860 the increased inflow and later the construction of the dam in the outlet channel resulted in higher elevations in Humboldt Lake. It became dry again in 1880. After 1880 the depletion in inflow resulting from upstream irrigation resulted in generally low stage of the lake.

The available reports relating to Humboldt Lake are consistent with those of other enclosed lakes in this area. There were similar low stages prior to 1850 with a rise in the 1850's which was maintained until depletion from irrigation caused reduction in the inflow.

LAKES IN NORTHEASTERN NEVADA

There are some enclosed lakes in the Great Basin in northeastern Nevada whose fluctuations, prior to the diversion of their tributary inflow, reflected the variations in the water supply of their drainage areas. These lakes are generally shallow and can be classified as playas. This group includes Ruby, Franklin, Goshoot (Goshute), Snow Water or Eagle and Diamond Lakes. Ruby and Franklin Lakes are interconnected; the others are in separate basins. The limited information regarding these lakes is insufficient to enable their variations during the past 100 years to be defined. The reports of Beckwith and Simpson indicate lower stages of these lakes in the 1850's than those that occurred after 1860.

OWENS LAKE

Owens Lake formerly received the runoff of the Owens River and fluctuated with its variations. By the 1870's and 1880's diversions from the river for irrigation began to deplete the inflow. Later the diversions by the Los Angeles Aqueduct resulted in Owens Lake becoming dry.

Owens Lake is further south than the other lakes studied by the writer. No separate search was made for early reports on the lake. Where information was found incidentally while working on other lakes, it was noted. Based on Fremont's account Owens Lake appears to have been relatively low in the 1840's although there was a large shallow body of water.

[1] P. S. Ogden, "The Peter Skane Ogden Journals," Oregon Historical Society Quarterly, Vol. XI, 1910.

[2] John Bidwell, Echoes of the Past about California.

[3] Reuben C. Shaw, Across the Plains in '49, p. 137.

[4] Journal of Heinrich Lienhard, trans. from German by Erwin G. and Elizabeth Gudde, 1961.

[5] Edgar M. Ledyard, Journal of Birmingham Emigrating Company.

[6] Cyrus Loveland and Richard Dillon, California Trail Herd.

[7] Horace Greeley, Overland Journey to California.

VARIATIONS IN THE RUNOFF OF THE WESTERN GREAT BASIN
DERIVED FROM THE RECORDS OF THE ENCLOSED LAKES

The available records and other information relating to several of the enclosed lakes in the western Great Basin have been presented and used to derive the runoff of their drainage areas. For some of these lakes these results cover periods as long as the past 300 to 400 years. Fairly complete annual records are available since about 1900. The results for Goose, Eagle, Pyramid-Winnemucca, Tahoe and Mono Lakes can be used to indicate the variations that have occurred during this 60 year period of record. The available information on the fluctuation of these lakes prior to 1900 can then be used to compare the earlier runoff with that since 1900. From about 1850 to 1900 there are some direct observations on these lakes. General conditions prior to 1850 can be derived for some of these lakes from tree records.

The western Great Basin is an area of general water deficiency. The ultimate development that may be made in this area from its own water supply will be dependent on the extent to which its own stream flow can be regulated to meet the demands for its use. While the preceding results in this report have been expressed mainly in terms of their percentage of the mean, it is the variations from the mean which determine the extent to which the runoff can be utilized.

Storage capacities of from six to to times the mean annual runoff would have been required to equalize the annual stream flow in the period 1902 to 1959. There are no available reservoir sites on the tributaries to the enclosed lakes which have sufficient capacity at feasible costs to provide this extent of regulation. The usable storage capacity of Lake Tahoe is about four times its mean annual outflow. This storage is insufficient to prevent both shortages in its outflow in period of deficiency and spills in periods of excess supply. Tahoe has the further disadvantage that it does not go dry and stop its evaporation loss at times of deficient inflow.

Even if reservoir sites of low cost with capacities in excess of the needs were available, complete use of the streams of the western Great Basin could not be secured. Reservoirs result in losses of their inflow by evaporation. For long periods of carryover storage the evaporation loss from the reservoirs may consume the additional supply stored in reservoirs of large enough capacity to provide such periods of storage. The part of the runoff which is not used by direct diversion, and which cannot be stored in available reservoirs of feasible cost, will continue to maintain enclosed lakes of substantial area.

Among the questions which need to be answered in planning additional water development in the western Great Basin is the extent to which carryover storage will be required to meet the requirements in the critical periods of deficiency in runoff. For irrigation use some shortages in supply can be endured without large loss and severe deficiencies may affect the crop yields only in the periods in which they occur. For municipal and industrial use the extent to which shortages can be endured is limited, and the future new supplies for such uses will need to be more fully protected against shortages than those for irrigation. In the future there will be an increased demand for water for municipal and industrial use. The costs of the remaining projects have approached and will soon exceed the value of the irrigation which they can supply.

In some areas shortages in the surface stream flow can be met by increased draft on the local groundwater. Use of groundwater in the areas of these western Great Basin streams has not, as yet, been extensive enough to create an overdraft on the ground water. While the available ground water supplies in some areas are sufficient to be helpful in meeting shortages, they do not appear to be large enough, based on the results of investigations to date, to meet major stream deficiencies.

One of the purposes of the writer in his work on these enclosed lakes, in addition to the general interest in their history, has been the desire to extend the observed record over longer periods of time and to compare the periods of deficiency that have occurred within the period of direct records with those indicated by earlier results. While the extent and character of the variations in the future water supply cannot be predicted with certainty, either as to their extent or the time of their occurrence, the best basis for forecasting the future is to assume that what has happened in the past will be repeated in the future. For this purpose, the longer the past record the greater is the probability that it will include the extremes in the runoff that may recur in the future.

Much effort has been expended in the past in attempting to define cycles which occur in the variations in precipitation in this and other areas. Such efforts have not been successful in deriving cycles which can be used to forecast the character of the water supply. The variations which occur do not follow a predictable pattern.

Various investigators have thought that they have found cycles of periods which have occurred in the water supply, or in items which might be related to the variations in precipitation, such as sunspots. The writer has been interested in the existence of such cycles, if they exist, and has followed many of these results. In the writer's opinion, no cycles in the water supply have been found that can be used to predict its future extent, and past results do not encourage hope that they may be found.

The variations in the water supply of the western Great Basin can best be discussed in the three periods represented by the extent of the available information. These are the period of generally adequate records since 1901, the period of some records from 1850 to 1900, and the period of interpretation of other sources prior to 1850. These periods have been used.

RUNOFF FROM 1902 TO 1959.

There are sufficient records from which the annual runoff of the drainage areas of Goose, Eagle, Pyramid-Winnemucca and Mono Lakes can be derived from 1902 to date. Similar information is available for the inflow to Lake Tahoe. These results have been discussed and the conclusions reached have been presented in preceding portions of this report for each of these lakes. The additions of the records since 1959 would add to but not essentially change the conclusions reached from the records to 1959.

The records for these separate drainage areas can be compared most conveniently when expressed in terms of their percentage of their own means for a common period. This has been done. The results are shown in Table 26 for each year of this 50 year period. The actual runoff in acre-feet for each source has been derived in the discussion of each of these drainage areas in the preceding portions of this report.

For most of the years in this period, annual results were available. These results were derived mainly from the fluctuations of the enclosed lakes. At some times records of the annual elevations are not available. For such periods only the average inflow for the period can be derived and has been used. For such periods the result for the different lakes are not fully comparable.

A long record for a drainage area can be used as the key to the past variations in runoff which have occurred on its drainage area. To apply results for a drainage area to other areas requires a knowledge of what areas are subject to the same annual variations. One test for such areal variations can be made by using the results for the five drainage areas tributary to the lakes previously listed.

In Table 27 the results from Table 26 have been used to derive the minimum periods of from one to 20 years. The minimum single years in this period are less than 30 percent of the period mean except for Mono Lake and are below 20 percent of the mean for two of the five drainage areas.

Deficient years may occur in sequence as shown by the minimum two and five consecutive year means. The five year means in Table 27 are less than one-half of the 58 year mean for three of the five areas. The minimum seven year period is included in Table 27 to cover the deficient runoff from 1928 to 1934. For four of the five areas, the 10 year minimum runoff is less than 60 percent of the 58 year mean. Four of the five areas show a minimum 20 year period of 75 percent or less of the 58 year mean.

In Table 27 the variations above the mean for the 58 years 1902-1959 are also shown. These show that single years and two years in succession may exceed twice the mean. Ten year periods may have runoffs of 150 percent and 20 year periods 125 percent of the mean. For periods up to 10 years the variations for Mono Lake are smaller than those for the other areas. The results for Lake Tahoe for inflows above the mean are similar to those for the entire drainage area of the Truckee River.

There are differences in the extent of the variations in the runoff of these six drainage areas. Mono Lake is subject to less wide variations than the others. This may be the result of its location in the area of overlap between the storms coming from the south and those entering California from the north. For the Truckee River drainage area tributary to Pyramid Lake, the higher drainage area of Lake Tahoe is subject to less wide variations than the entire drainage area. This would be expected as the drainage area of Lake Tahoe receives larger precipitation than the average for the remainder of the drainage area.

No single expression is a full measure of the degree of variability in the runoff of these different areas. Alternate methods have been used.

To secure a general picture of the variation of each area over the 58 year period used, the annual percentages of the mean were computed in terms of their accumulated departures from their means. These were then plotted for each of the five areas. The results are shown in Figure 54.

Table 26 Runoff of Drainage Areas of Enclosed Lakes in the Western Great Basin 1902-1959 In Per Cent of their Annual Means for this Period

Year	Goose Lake	Eagle Lake	Pyramid Winnemucca Lakes	Lake Tahoe	Mono Lake
1901-02	141	55	74	99	118
03	141	67	103	101	118
04	141	255	203	186	118
05	121	125	73	87	118
06	121	224	191	188	118
07	121	279	191	253	118
08	121	65	191	78	118
09	121	101	139	159	118
10	121	315	139	117	118
11	121	20	139	164	118
12	72	101	86	96	90
13	72	83	86	76	99
14	238	197	101	155	186
15	43	109	101	94	117
16	43	141	118	129	121
17	43	111	118	115	112
18	43	81	80	82	112
19	43	20	80	49	108
20	67	61	80	64	76
21	67	73	80	84	99
22	67	119	139	107	117
23	27	48	100	114	102
24	27	16	13	21	104
25	27	6	96	124	73
26	32	46	55	35	76
27	32	117	140	135	96
28	31	79	66	69	82
29	31	36	22	31	62
30	28	14	49	71	62
31	28	113	18	30	53
32	28	28	80	90	90
33	28	83	43	43	62
34	28	22	72	52	66
35	28	67	66	73	86
36	236	71	113	126	105
37	142	18	107	79	100
38	142	206	182	156	191
39	142	173	76	53	86
40	142	95	137	103	78
41	142	97	99	97	124
1941-42	142	189	141	160	73
43	142	69	124	147	124
44	111	61	67	61	87
45	111	113	105	92	118
46	111	65	74	103	95
47	111	50	33	51	97
48	111	48	54	66	82
49	111	91	50	58	86
50	111	40	219	132	93
51	111	60	99	139	96
52	190	230	228	162	77
53	116	113	107	118	103
54	116	95	51	60	45
55	116	50	89	39	88
56	221	257	180	159	113
57	221	117	83	82	91
58	221	194	150	142	124
59	38	81	20	44	91
Mean	100	100	100	100	100
Mean Annual Runoff in 1000 Acre-feet	239.	49.5	660.	300.5	139.

Table 27 Minimum and Maximum Periods of Runoff for Drainage Areas of Lakes in the Western Great Basin 1902-1959

In Per Cent of Annual Mean for the 58 Year Period.

Consecutive Years	Goose Lake Years	Goose Lake Run-off	Eagle Lake Years	Eagle Lake Run-off	Pyramid Lake Years	Pyramid Lake Run-off	Mono Lake Years	Mono Lake Run-off	Lake Tahoe Years	Lake Tahoe Run-off
Minimum Periods										
1 year	1924	27	1925	6	1934	12	1954	45	1924	21
2 years	1924-25	27	1924-25	11	1923-34	28	1930-31	58	1933-34	48
5 years	1930-34	28	1923-27	47	1930-34	40	1929-33	66	1929-33	53
7 years	1928-34	28	1924-30	45	1928-34	41	1928-34	68	1928-34	55
10 years	1923-32	29	1923-32	50	1926-35	55	1925-34	72	1926-35	63
20 years	1916-35	37	1918-37	56	1920-39	70	1923-42	89	1918-37	74
Maximum Periods										
1 year	1914	238	1910	315	1952	228	1932	191	1907	253
2 years	1957-58	221	1906-07	262	1906-07	191	1937-38	146	1906-07	220
5 years	1954-58	179	1906-10	197	1906-10	170	1914-18	130	1906-10	159
10 years	1949-58	153	1904-13	157	1903-12	145	1907-16	120	1902-11	143
20 years	1939-58	140	1903-22	127	1903-22	122	1902-21	115	1904-23	120

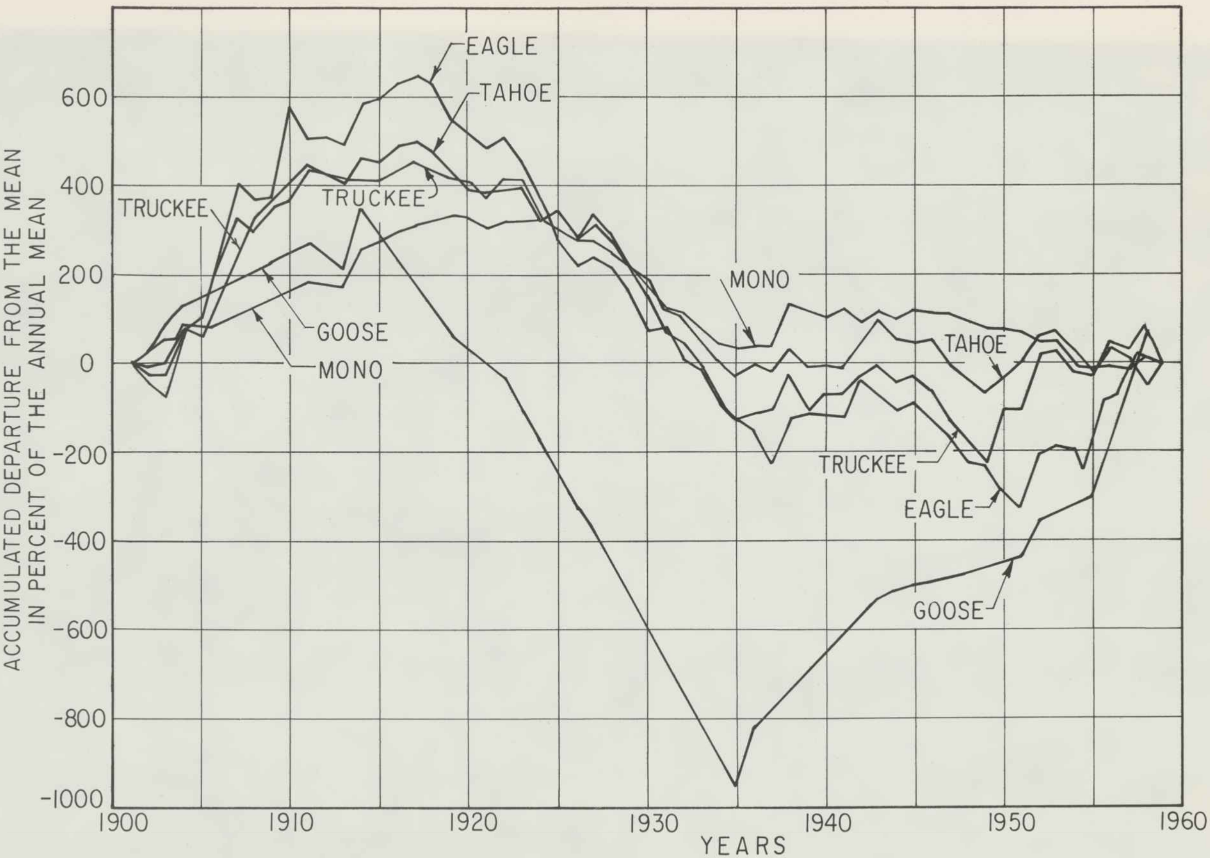


FIG. 54 ACCUMULATED DEPARTURES FROM THE MEAN OF THE RUNOFF OF DRAINAGE AREAS IN THE WESTERN GREAT BASIN 1902 - 1959

Figure 54 shows some periods in which some of these areas had similar values for their accumulated departures from their means, and some in which there were relatively wide differences. The Goose Lake area shows the widest differences from the others. Mono Lake had smaller accumlated departures than the other areas.

The drainage areas shown in Figure 54 extend for a distance of about 300 miles along the eastern slope of the Sierras and the Cascade range. Goose Lake is within the area of influence of the storms having a more northerly course, and Mono Lake receives some storms from the southwest. The other areas are within the Central California influences and receive the moisture that remains after such storms have crossed the crest of the Sierras. While a general similarity might be anticipated in the annual variations in the runoff of these areas, full agreement would not be expected.

In Figure 54 the results for Lake Tahoe and the entire drainage area of the Truckee River are in generally good agreement. This would be expected as the drainage area of Lake Tahoe is an important part of that of the Truckee River. Eagle Lake shows a generally similar pattern to that of the Truckee River, with a somewhat wider range in its accumlated departure from its mean. These three areas show runoffs in excess of their 58 year means from 1902 to about 1917. This was followed by a period of reduced runoff extending to 1937. Since 1937 the variations from the mean have been smaller. The results for these three periods for these three areas are as follows:

Mean Annual Runoff in Per Cent of
58 Year Mean, 1902-1959

	Years	Drainage Area of Eagle Lake	Lake Tahoe	Entire Truckee River
1902-1917	16	141	131	128
1918-37	20	56	74	72
1938-59	22	111	101	105

The periods shown in this table are longer than those for which it is usually practicable to equalize the runoff by storage.

From 1918 to 1937 the mean runoff of Eagle Lake was 44 percent below its 58 year mean. From 1902 to 1917 the runoff was 41 percent above the same mean. Complete storage in this earlier period would not have met the shortage of the second period. Eagle Lake has adequate capacity below its rim to control the variations in its inflow, but its area is relatively large in relation to its storage capacity, and increased storage results in increased evaporation. This is illustrated by the results previously discussed where the effect of the diversion from Eagle Lake through the Bly Tunnel ending in 1935 has now been offset by the increased evaporation that would have occurred if the water diverted had remained in the lake. For Goose Lake similar comparisons to those previously discussed for Eagle Lake and Truckee River give the following results:

Period	Years	Goose Lake Mean Annual Runoff in Per Cent of 58 Year Mean.
1902-14	13	127
1915-35	21	38
1936-59	24	140

These results for Goose Lake illustrate the wider range of variation to which its inflow is subject than in the case of Eagle Lake. It will not be feasible to regulate fully the inflow to Goose Lake and there will always be substantial average annual inflow remaining under any presently foreseeable conditions. As Goose Lake is relatively shallow, it went dry in much of the 1915-35 period and it can be expected to go dry again when similar periods occur in the future.

D. B. Lawrence, in an article entitled "Response of Enclosed Lakes to Current Glaciopluvial Climatic Conditions in Middle Latitude Western North America,"[1] summarized his conclusions as follows:

> A survey of the history of fluctuations of 20 enclosed lakes from northern California to Central British Columbia showed strong growth since 1940 with crests ranging from 1952 to the summer of the survey, 1960. The more recent crests, chiefly in 1957, 1958 and 1960, tended to occur in the more northerly parts of the area.

Lawrence found that Albert Lake in Oregon, about 30 miles north of Goose Lake, had risen by 1958 to nearly all-time record stages. Records since 1915 compiled by Kenneth N. Phillips of the U. S. Geological Survey show its highest stage to have been reached in 1960. For the five years from 1955 to 1959 the inflow to Goose Lake was 160 percent of its 58 year mean. For the same years Eagle Lake had an average inflow of 150 percent of its 58 year annual mean; the Truckee River and Mono Lake runoff was less than 10 percent above their similar means.

For Mono Lake the accumulated departures from the mean show the following results:

Period	Years	Mean Annual Runoff in Per Cent of 58 Year Mean
1902-19	18	118
1920-35	16	82
1936-59	24	99

For this 58 year period the runoff of the drainage area of Mono Lake shows a much smaller range of variation from the mean than that of the other streams previously discussed.

[1]*Annals of the New York Academy of Sciences*, Vol. 95, Art. 1, pp. 341-350, 1961.

The results of another effort to find a basis for comparison of the run-off of these areas are shown in Figure 55. The five year progressive means were computed and the results for the last year in each five year period plotted for its last year. The results are generally similar to those for the accumulated departures from the mean shown in Figure 54. Here again Goose Lake shows the widest variation from the other areas.

Further smoothing of the results in Figure 55 would still show the period of excess runoff from 1902 to about 1917, the deficient period from about 1917 to 1935, and variable results having a runoff more nearly equal to the 58 year mean from 1936 to 1959. The first of these two periods differ in the extent of their variation from the mean, but all of the drainage areas shown reflect the marked difference between the two periods.

The mean variation from its own mean for each of the five drainage areas for the 58 year period from 1902 to 1959 is shown in the following tabulation. These results are in terms of the average departure from its own mean, either plus or minus.

Drainage Area	Average Variation from the Mean in Per Cent of the Annual Mean.
Goose Lake	49
Eagle Lake	52
Truckee River	42
Lake Tahoe	37
Mono Lake	19

The preceding results for 1902 to 1959 represent variations in runoff during a 58 year period in which the conclusions reached are supported by generally adequate records. The available information on periods prior to 1902 is less complete. It has been used to determine whether more extreme variations in the runoff of these areas have occurred in these earlier years rather than to derive annual detail.

RUNOFF FROM 1850 TO 1901

The records since 1902 enable the runoff of the drainage areas tributary to the enclosed lakes of the western Great Basin to be derived generally on an annual basis. This has been done and the results have been discussed.

Observations of the enclosed lakes from which their elevations can be derived began to be made about 1850. From this time to 1902 there are sufficient records to enable the general fluctuations of these lakes to be defined. However the available information does not permit results for each year to be determined and only the mean runoff from the periods between the times when the lake elevations are available can be computed. Even incomplete records enable the derivation of fluctuations of these lakes and the runoff of their tributary drainage areas, so that the general variations in runoff from 1850 to 1901 can be computed and compared with the results from 1902 to 1959.

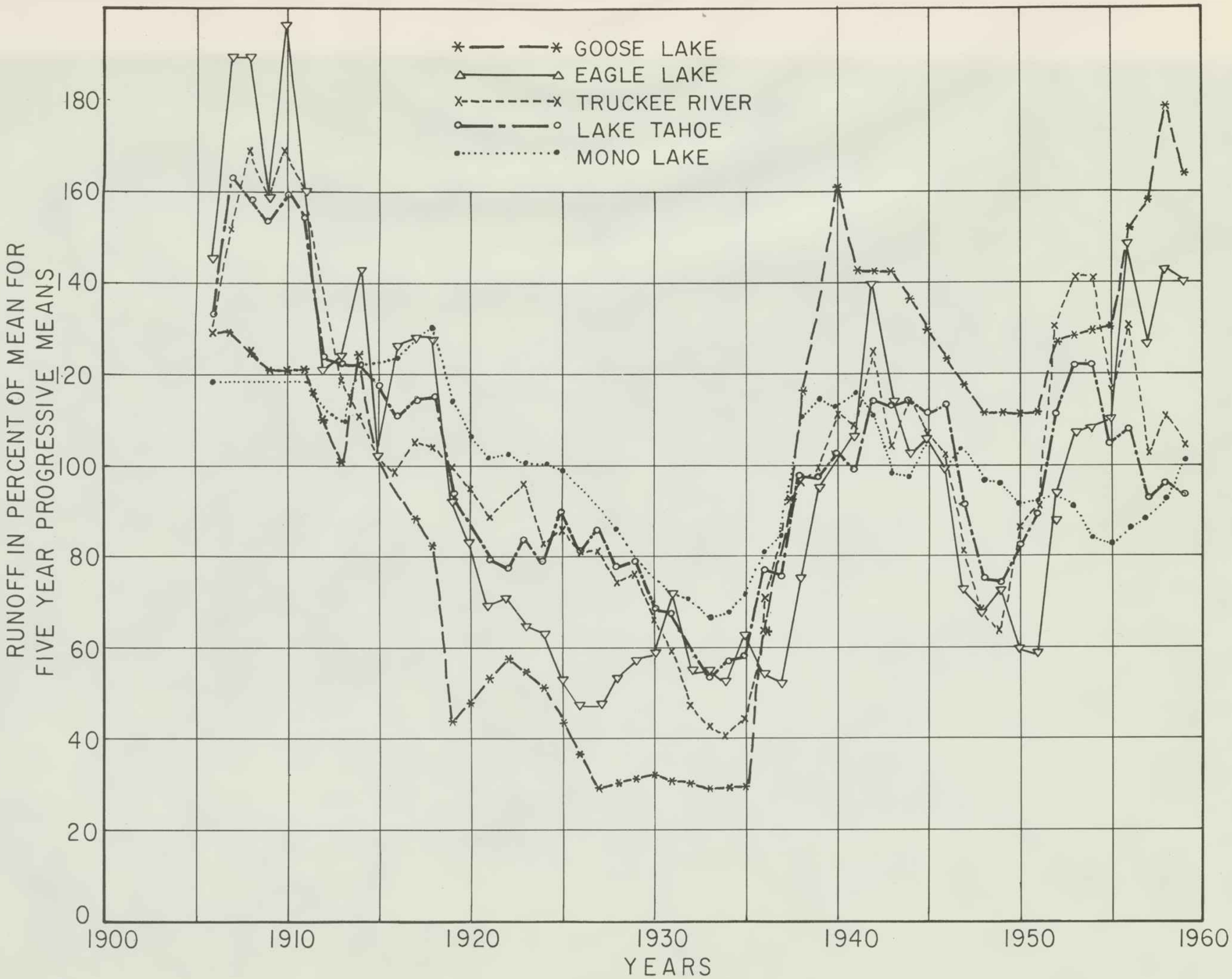


FIG. 55 FIVE YEAR PROGRESSIVE MEANS FOR THE RUNOFF OF DRAINAGE AREAS IN THE WESTERN GREAT BASIN - 1902 - 1959

The completeness of the records from 1850 to 1901 varies for the four enclosed lakes. Records for Lake Tahoe prior to 1902 are insufficient to enable its fluctuations to be defined. The results have been discussed for each lake in the earlier portions of this report. The parts of this period for which the runoff can be derived are shown by these results.

On Goose Lake the elevation of the lake is well established in 1849. For Eagle Lake the first record of its elevation is in 1875. For Pyramid and Winnemucca Lakes, Fremont's account in 1844 enables their then elevations to be determined. The 1857 meander survey of Mono Lake starts the direct observations there.

The results for each lake have been summarized for this period followed by a comparison of the individual lakes and conclusions regarding the variations in runoff which occurred in this period.

GOOSE LAKE

The inflow to Goose Lake for five periods of about 10 years each between 1850 and 1901 is shown in Table 28. These show a deficient inflow in the 1850's, a large excess in the 1860's, another deficiency in the 1870's with somwhat above average for the last two periods. As a whole the 52 years from 1850 to 1901 had a runoff of the drainage area of Goose Lake 26 percent greater than the mean for the 59 years 1902 to 1959.

EAGLE LAKE

For Eagle Lake from 1850 to 1902 there are enough records to indicate its fluctuations from 1875 to 1902. For 1850 to 1875 the record of the submerged stumps enables the elevation above which the lake did not rise to be approximated. These results indicate a general rise from 1850 to 1875 of four feet, a lowering of two feet from 1876 to 1889, and a rise of seven feet to 1902. The derived inflow to Eagle Lake for these four periods in this 52 year period is shown in Table 29. The results for the last two periods are those previously derived in Table 8; those for the first two periods are computed on the basis shown. For the 52 years 1850-1901 the mean annual inflow to Eagle Lake was 119 percent of that for the next 58 years.

PYRAMID AND WINNEMUCCA LAKES

The total runoff of the drainage area tributary to Pyramid and Winnemucca Lakes is the equivalent to the runoff of the drainage area of Truckee River as the remaining drainage tributary to the lakes has a negligible runoff. The runoff of Truckee River for the years 1850 to 1902 has been derived in the report on Pyramid and Winnemucca Lakes. The results for the portions of this period which represent similar amounts of runoff for which records of lake elevations are available are shown in Table 30.

Figure 30 shows that the runoff of the Truckee River was deficient in the 1850's and above the mean for the remainder of the period 1850 to 1901. For the entire 52 years from 1850 to 1901 the excess runoff of the Truckee River was not as large as that for Goose and Eagle Lakes.

Table 28 Inflow to Goose Lake 1850 to 1901

Period	Years in Period	Mean Annual Inflow during Period. in 1000 Acre-feet	Mean Annual Inflow during Period. In Per Cent of 52 Year Mean	Mean Annual Inflow In Per Cent of 1902-1959 Mean
1850 - 1859	10	190	63	79
1860 - 1869	10	444	147	186
1870 - 1878	9	204	68	85
1879 - 1889	11	317	105	132
1890 - 1901	12	337	112	141
1850 - 1901	52	302	100	126

Table 29 Estimated Inflow to Eagle Lake for Period 1850 to 1901

Period	1850-60	1861-75	1876-89	1890-1901	1850-1901
Years in Period	11	15	14	12	52
Elevation of Lake					
Beginning of Period	5105	5107	5109	5107	5105
End of Period	5107	5109	5107	5114	5114
Area of Lake in Acres					
Beginning of Period	26200	26800	27200		
End of Period	26800	27200	26800		
Mean	26500	27000	27000		
Volume in Lake in 1000 Acre-feet					
Beginning of Period	600	653	708		
End of Period	653	708	653		
Change - Total	+53	+55	-55		
" Annual Mean	+5	+4	-4		
Mean annual Total Net Evaporation in 1000 acre-feet	55	56			
Indicated Mean Annual Inflow for Period in 1000 acre-feet	60	60	54.4	62.8	59.1
In Per Cent of 52 year Mean	102	102	92	106	100
In Per Cent of Mean for 1902-1960	121	121	110	127	119

Table 30 Runoff of Drainage Area of Truckee River - 1850-1901.

Period	1850-58	1859-68	1869-90	1891-1901	1850-1901
Years in period	9	10	22	11	52
Mean Annual Runoff in 1000 Acre-feet	441	986	808	490	712
Mean Annual Runoff in Per cent of 52 Yr. mean	62	138	113	69	100
Mean Annual Runoff in Per Cent of 58 Years 1902-1959	67	149	122	74	108

MONO LAKE

For Mono Lake the earliest record is that derived from the meander survey in 1857. Results for the mean inflow for three periods from 1858 to 1901 are obtainable from the results in Table 24. For 1850 to 1857 the estimated inflow has been computed on the assumption that Mono Lake has an area for this eight year period equal to that in 1857. An average annual inflow of 100,000 acre-feet would be needed to maintain this area. These results are shown in Table 31.

The mean inflow for the 52 years from 1850 to 1901 was 112 percent of that for the 58 years from 1902 to 1959. The inflow from 1850 to 1857 was somewhat less than that in any similar period after 1901, and was nearly as large 1858 to 1868 as that in any 10 year period since 1901.

KING'S REPORT

In the U. S. Geological Survey of the 40th Parallel Horace King discusses general climatic conditions in the Great Basin. This report was published in 1878; the main field work was done from 1867 to 1871. After commenting on the rise of Salt Lake in preceding years King states (p. 525):

> The cycle of moisture which has recorded itself in the increased volume of Salt Lake is also evident in many other localities and in different ways. Mono and Owen's Lakes at the east base of the Sierras show a corresponding rise, and, as has been stated before all the residual lakes in the basin of Lake Lahontan evince the same change...
>
> It becomes a question of great interest to determine whether this recently observed climatic oscillation is within the range of frequent occurrence, or whether it is a noteworthy departure from the climatic habit of the immediate past. Some light is thrown on this question in the alpine regions of the Sierra Nevada and the higher points of the desert ranges. The phenomena, however, are so much more clearly shown upon the Sierra summit, that I confine myself to this region in discussing this point.
>
> Below the line of perpetual snow is a variable, open region of about 1,000 feet in altitude, in which the tree-growth is rather scarce and comprises only strictly alpine species. Below that point, from Alaska nearly to the Mexican line, is a continuous dense growth of coniferous forest. A very large number of observations on the average age of the timber growth at its upper limits shows a mean of about 250 years. Since the late cycle of increased moisture, the winter accumulation of snow on the Sierra summit is evidently greater than since the earliest growth of the present forest.
>
> The barren zone which I have mentioned, between the perpetual snow and the main timber growth, represents a region where the snows accumulate too thickly for the propagation of the coniferous species, and may be said to express the downward limit of the encroachment of snow for 250 years.
>
> In the present climatic change the snow accumulation is greater and extensive avalanches where the topographic configuration favors,

Table 31 Inflow to Mono Lake 1850-1901

Item	Periods				
	1850 to 1857	1858 to 1868	1869 to 1883	1884 to 1901	1850 to 1901
Years in Period	8	11	15	18	52
Derived Mean Annual Inflow in 1000 Acre-feet	100	162	181	153	155
Per Cent of 52 Year Mean	65	105	117	99	100
Per Cent of 58 Year-Mean 1902-59	72	117	130	110	112

have begun to pour down into the true forest belt and to sweep before their rush considerable areas of native growth. An avalanche starting in a high alpine gorge ploughs its way downward, not infrequently mowing down a half mile of adult trees. It is obvious that no such avalanche could possible have occurred during the generation and growth of this forest.

On the summit of the Central Pacific Railroad Pass are a considerable number of well grown coniferous trees. An examination of them showed that they were at that time being seriously damaged, and in some cases actually killed, by the drifting snow-crystals borne of the strong west winds during the winter storms, the notch or depression of the pass making a sort of funnel, through which the wind blows with unusual violence, concentrating its freight of sharp snow crystals, which not only wore away some of the foliage of the trees, but actually cut off the bark from exposed positions and sawed into the wood for several inches. An inspection of the branches thus cut showed that the annual rings had formerly perfected themselves and that the snow had worn off considerable portions, often several inches, of the thickness of the wood, leaving a smooth polished surface, displaying the cut edges of the layers of annual growth. From these facts it would appear that the existing climatic oscillation began before the year 1820, and was the first of its kind for over 250 years. The year 1866 is about the date of the increase in Salt Lake. Mono Lake showed a rise in 1864 and the destructive Sierra avalanches began about 1860. Although unimportant in the general results, this oscillation becomes a matter of very great interest from a theoretical point of view.

SUMMARY

Based on the available lake records and King's observations, the 1860's may have had the largest runoff of any decade within the period of record. The available results are not sufficient to define the runoff of this period in specific terms; it may have and probably did exceed the runoff in any decade since 1900.

None of these lakes show any periods of major deficiency in their inflow from 1860 to 1901. The available results indicate that the relatively low stages of these lakes in the 1840's continued into the 1850's. In the 1850's Winnemucca Lake continued to be dry, Goose Lake was generally low and Mono Lake was at its lowest observed elevation in 1857. The decade from 1850 to 1860 had an average runoff which appears to have been 70 to 80 percent of the 1902-1959 mean except for Eagle Lake which may have started the rise which continued generally until 1915.

Beginning in 1861-62 runoff was generally above the average for 1902-59 for a period which extended to about 1917. This applied to all lakes; the only deficiency appears to have been on Goose Lake in the 1870's and on Truckee River in the early 1890's. Overall this period appears to have had the largest runoff of any of similar length within the time covered by this report. This included the time to which King's comments on the conditions of the trees at

the Sierra summit apply, and extends through the construction of most of the present projects in this area.

RUNOFF PRIOR TO 1850

While there are only a few observations from which the elevation of the enclosed lakes in the western Great Basin can be derived prior to 1850, there are some other results which can be used to indicate at least the general limitations on the fluctuations of these lakes and their inflow in earlier years.

The results that have been discussed in earlier portions of this report represent conditions within the last 500 years except for two Carbon 14 dates of greater age. They cover what may be considered as historical time as distinguished from geological time. They represent fluctuations under climatic conditions similar to those at present, and result from the variations occurring under these conditions. They cover a part of the time period since Lake Lahontan declined from its former higher stages but do not attempt to derive a date for such past Lahontan stages.

Available records show these enclosed lakes to have been at generally low stages in the 1840's. Such stages indicate below average preceding inflow. There are also the marks of higher stages prior to 1850, such as the white lines on Pyramid and Winnemucca Lakes. The higher stages of these lakes would require inflows above the average such as has occurred during the period of more complete record since 1850. Available information supports the general conclusion that the water supply of these lakes prior to 1850 was subject to extents of variation similar to that shown by the later records. While this general conclusion on the character of the fluctuations prior to 1850 is considered to be sound, there is only limited support for defining the time when excesses of deficiencies prior to 1850 may have occurred and for determining whether earlier periods of shortage or excess were more severe than similar periods which have occurred since 1850.

The conclusions that can be drawn for each enclosed lake have been discussed in the history of each lake for the time period for which information is available. These time periods are variable. The results prior to 1850 do not lend themselves to discussion by selected time periods. The conclusions that can be derived from the available records for each lake are discussed separately. The direct information that is available on the lake stages in the 1840's is used with what can be derived for the prior conditions to reach conclusions regarding the elevations of the enclosed lakes prior to 1850.

On Goose Lake the comments by Work in 1831 indicate a size which would be supported by an inflow of about 90 percent of the 58 year mean from 1902 to 1959.[1] Goose Lake lowered somewhat to 1843 and then lowered to its minimum stage in 1846. Such lowering from 1843 to 1846 would only occur with an average inflow of 31 percent of its 1902-59 mean. The inflow was about 45 percent of the 1902-59 mean until 1852 and the lake remained at a low stage. For the nine year period 1844 to 1852, the mean inflow appears to have been

[1]Alice Bay Maloney, Fur Brigade to the Bonoventure; John Work's California Expedition, 1832-33, 1943.

about 39 percent of the 1902-59 mean.

For the 13 years from 1923 to 1935 the derived runoff, Table 5, was about 30 percent of the 1902-59 mean. This is a greater deficiency than the above results for 1844 to 1852. The actual inflow to Goose Lake from 1923 to 1935 was very small and the derived runoff for this period represents very largely the estimated depletion resulting from diversions for irrigation. Such estimates of depletion may be subject to a probable error of 10 to 20 percent. If the estimated depletion from 1923 to 1935 should be 20 percent too low, the indicated runoff for that period would still be less than that derived for 1844 to 1852.

Some assumptions can be made regarding the inflow prior to 1832 based on reported stumps in the lake bed and Indian legends, but such results are necessarily general. They indicate that Goose Lake has been practically dry at times prior to the depletion of its inflow by diversion for irrigation. The times when such deficiencies may have occurred are not determinable from the available information. It would be within the period that the stumps reported in 1925 would have been preserved. This would require that these stumps had been in water nearly continuously since the time of their growth. Based on C-14 datings on other lakes, such stumps may have been preserved for several hundred years.

It is concluded that, prior to 1850, the inflow had been deficient at times of undefined extent and duration. The available information indicates that such deficiencies may not have been more severe than that during the period 1923 to 1935 but may have lasted longer.

For Eagle Lake the estimated inflow from 1420 to 1850 A. D. has been derived in the preceding portion of this report (Table 9). Based on the C-14 dating of the lowest stump, the inflow from 1420 to 1520 appears to have been 91 percent of the 1902-59 mean. Within this 100 year period the inflow may have been less than the mean for periods of unknown length. From the time of the submergence of the lowest stump until 1860, Eagle Lake could not have had an inflow exceeding its mean since 1902 without rising to submerge other trees. From 1520 to 1860 Eagle Lake may have had periods of deficient inflow. If these had been extended or severe, the lowest stump would have been out of water and would not be expected to have resisted decay and to have been preserved in its present condition.

The available information on Eagle Lake does not disclose any periods of more severe deficiencies in inflow prior to 1850 than have occurred in recent years. Such periods may have occurred but are not determinable from the submerged tree record. The tree records do show that the inflow to Eagle Lake for 250 years prior to 1875 had not been sufficient to raise the lake to the elevations it reach in 1915.

For Pyramid and Winnemucca Lakes the available information shows lake stages in the 1840's that were relatively low and indicate a preceding period of deficient inflow. Winnemucca Lake was dry. There would have been no inflow to Winnemucca Lake for a sufficiently long period so that whatever water may have been in the lake at the beginning of this dry period had been evaporated. If at some earlier time Winnemucca Lake had been at a relatively high stage with a depth of 75 feet, over 20 years would have been required for it to become dry if no inflow occurred in this period.

In the earlier portion of this report, it was assumed that Pyramid Lake lowered from its white line to the elevation of the then submerged beach at its south end in a 30 year period, and that it had remained below the elevation found by Fremont in 1844 and of the trees which grew along the inlet channel of Truckee River for another 30 years. On this basis the inflow from 1780 to 1809 was estimated to have been 57 percent of the 58 year mean from 1902 to 1959, and 70 percent from 1810 to 1839. All other periods of similar length since 1840 (Tables 16 & 18) have had greater runoff of the Truckee River than these results for these two earlier periods.

The preceding results are based on the assumption that Pyramid Lake had lowered from its white line, elevation 3872 feet, to elevation 3852 feet in 30 years. Such a lowering occurred prior to 1844 at some time and in some period of years. The trees along the inlet of Truckee River indicate that Pyramid Lake had been at elevation 3852 long enough prior to 1844 for these trees to have grown, which makes 1810 a reasonable conclusion regarding the date when this occurred. The 30 years prior to 1810 for the lake to lower from its white line to elevation 3852 is also a reasonable assumption but not necessarily the only period during which this lowering may have occurred. It is consistent with the time required to cause Winnemucca to go dry from a stage corresponding to the white line on Pyramid Lake. The minimum time in which Pyramid Lake would lower 20 feet with zero inflow would be about seven years. The time for this assumed lowering could have been longer than 30 years. If it was 60 years, the mean inflow would have been 64 percent of the 58 year mean for 1902-59. This would also be less than the derived runoff of the Truckee River for any 30 year period since 1840.

The available records are adequate to establish the relatively low elevation of Pyramid Lake in 1844 and the absence of a Winnemucca Lake at that time. These results would only occur following a sustained period of deficient inflow. While the conclusions reached regarding the inflow from 1780 to 1840 are subject to uncertainty in their specific results, there is support for the conclusion that the inflow in some extended period prior to 1844 had been less than has occurred during any period of similar length since 1840.

The available records on Lake Tahoe do not cover the period prior to 1850. The submerged trees indicate that there has been some 100 year period in which trees grew on ground below the elevation of the present rim. However the C-14 dating of these stumps places their time of growth outside of the time that has been covered on the other lakes. Prior to the C-14 dating of these stumps it had been assumed that these trees grew at some recent period prior to 1860; this assumption would be consistent with the results for Pyramid and Winnemucca Lakes. Records of the variations in the inflow to Lake Tahoe within recent time are limited to direct records since 1902 and a few results between 1860 and 1900.

For the eight years 1928 to 1935, the derived runoff of the Truckee River was 45 percent of the 58 year mean, 1902 to 1959. This is the most severe eight year shortage within the period of direct records and is more severe than the mean derived for 1780 to 1809. There may have been equally severe eight year shortages within the 30 years from 1780 to 1809, but the available information is not adequate to define such shorter period results.

The elevation of Mono Lake in 1857 enables some conclusions to be drawn regarding its inflow in the period preceding 1857. The lake was about 20 feet lower in 1857 than it was in 1960 although the diversion by Los Angeles during the preceding 20 years represents a depth on the lake of about 20 feet. Under present conditions Mono Lake can be expected to lower to its 1857 elevation in about 1980. After this occurs further lowering can be expected to continue, and an additional area of the lake bed will become exposed. This may disclose clues to the fluctuations of the lake prior to 1857. At present only items now observable can be used.

At its 1857 elevation of 6376 feet, Mono Lake has an area of about 40,000 acres. For present rates of evaporation and mean annual precipitation this area would be maintained by an annual inflow of about 100,000 acre-feet or about two-thirds of the annual mean since 1857. There is no specific basis for assuming any different rates of evaporation for the period prior to 1857 than the present rates. The elevation of Mono Lake in 1857 represents the balance of inflow and evaporation for the preceding years under similar amounts of evaporation and precipitation to those since 1857. On this basis there was a period of undefined length prior to 1857 in which the average inflow had been insufficient to maintain an area of over 40,000 acres in Mono Lake. The mean annual inflow to support this lake elevation is about 15 percent less than occurred in the 19 years (1919-37) of minimum inflow since 1857. It is 72 percent of the mean runoff for the 58 year period 1902-59.

Some conclusions can also be reached regarding the fluctuations of Mono Lake that may have occurred prior to 1857 and resulted in its 1857 elevation. All records in this area since 1857 support the conclusion that the inflow prior to 1857 was not uniform and that Mono Lake probably fluctuated both above and below its 1857 elevation preceding that date.

If Mono Lake had been higher prior to 1856 than it was in that year, the lowering to the 1856 elevation would only have occurred under conditions of deficient inflow. The amount of any such lowering prior to 1857 and how long it may have taken to lower the lake to its 1856 elevation can only be matters of conjecture. The accounts of the submerged cabin and brush indicate that Mono Lake had been below its 1856 elevation prior to that year. Mono Lake may have been rising just prior to 1857.

The C-14 dating of wood from a stump on the shore of Mono Lake has been previously discussed. The age found was 920 ± 90 years.

The growth of this stump during a recent 50 year period immediately prior to about 1875 when it was submerged would be consistent with the available records on Mono Lake and its preservation to date could be readily understood. It is more difficult to postulate conditions under which this tree could grow 900 years ago and have been preserved to date.

This radio carbon dating places the growth of this tree in some fifty year period at about 1000 A. D. The lake would have been below elevation 6400 feet for its period of growth. The lake may have risen above and fallen below this elevation in a variable pattern of fluctuation during the 900 years since this tree was killed by submergence. Presumably the lake was above elevation 6400 during most of the 900 year period in order that the wood in the stump could be in its present state of preservation.

At elevation 6400 Mono Lake has an area of nearly 50,000 acres. To maintain the lake at this elevation requires a mean annual inflow of about 125,000 acre-feet. These results indicate that in some 50 year period preceding about 1000 A. D., Mono Lake remained below elevation 6400 and had a mean annual inflow of about 125,000 acre-feet. This represents about 90 percent of the mean annual runoff for the 58 years 1902-1959.

Mono Lake probably varied below and above the elevation at which this sampled stump grew. Such fluctuations are normal as shown by the later results on all of the enclosed lakes. In any rising period the inflow would have exceeded that needed to maintain Mono Lake at elevation 6400. In any falling period the inflow would be less than that required to maintain the lake. There is no basis on which conclusions can be reached on the amount and duration of such variation in inflow during the 900 years since the C-14 dated stump was a growing tree.

The elevation of Mono Lake in 1857 represents a more severe deficiency in inflow in the preceding years than are indicated by the conditions under which the C-14 dated stump grew. For Mono Lake a period preceding 1857 appears to have had the greatest deficiency in inflow of any revealed by the available records. This also makes the inflow from 1857 to 1918 the maximum that had occurred during the period of record.

For Walker Lake the only elevation prior to 1860 is that for 1845 derived from Kern's description.[1] This represents a relatively low stage which would be supported by an inflow of about 75 percent of that required to maintain the lake at its general elevation from 1860 to 1890. While fragmentary, the available information relating to Walker Lake indicates a relatively low elevation in the 1840's in which the inflow was about three-fourths of that in more recent years. If Walker Lake had been higher previous to the 1840's, and had lowered to or below its 1845 elevation, its inflow during such periods would probably have been less than two-thirds of its later mean.

The descriptions of Humboldt Lake or Sink in the 1840's indicate a relatively low stage. The uncertainties regarding the conditions of the outflow to the Carson Sink at that time prevent making quantitative estimates of the runoff of Humboldt River. The accounts of the Surprise Valley lakes in the 1840's also indicate that the Upper and Middle Lakes were pracitcally dry. Similar early reports on Honey Lake indicate that there was a lake in this period although the accounts of its size are limited to general terms.

The preceding discussion of the individual lakes prior to 1850 shows them to have been at relatively low stages in the 1840's. On Pyramid and Winnemucca Lakes the inflow for some 30 year period prior to 1840 appears to have been less than has occurred in any period of similar length since 1850. For the other lakes, their elevations in the 1840's appear to have been reached as a result of deficiencies in their inflow which may have been more severe than any since 1850. The available records do not define the duration of this period of early deficiency. If the lake elevations in the 1840's were the result of a relatively short period of extreme deficiency, the inflow may have been less than that for the eight years 1928 to 1935. This later shortage is supported by direct records.

Some indications can be found in these early results of a geographical

[1]Captain J. H. Simpson, "Exploration Across the Great Basin of the Territory of Utah," Appendix Q, p. 480; Reprinted from The Journal of E. M. Kern, 1845.

pattern to the severity of the periods of deficiency prior to 1850. The shortages on Goose Lake prior to 1850 appear to have been less severe than those occurring on lakes further south. A similar pattern has been shown by later years within the period of record. The Oregon lakes, including Goose Lake, had relatively large inflow in the 1850's, while the runoff in the more southern lakes was deficient.

It is concluded that variations in inflow to these enclosed lakes occurred prior to 1850, resulting in fluctuations similar to those that have occurred since 1850. The evidence regarding shortages more severe than those from 1928 to 1935 is insufficient to determine whether more severe eight year shortages occurred prior to 1850. Longer periods of less severe shortage may have occurred.

It is concluded that the available information on these enclosed lakes prior to 1850 indicate a similar character of fluctuation to that which has occurred since 1850. The early records support a conclusion that the 1928 to 1935 runoff may have been the most severe within the period covered in this report, but that equally severe eight year deficiencies and longer less severe shortages probably occurred prior to 1850. Water supply plans for future projects should be based on meeting the demands during a future period similar to 1928-35. This period does not appear to have been unique in the past history of these enclosed lakes, and provision should be made for its possible recurrence in the future.

WATER SUPPLY OF ADJACENT AREAS

The preceding discussion has been confined to the water supply of the western Great Basin as the records of the enclosed lakes in this area enabled the water supply to be derived for a longer period than that covered by the direct records of runoff. The western Great Basin is not an isolated climatic area and the characteristics of its water supply extend into its adjacent areas.

While the writer's work in the western Great Basin has included more investigations than he has made in adjacent areas, he has assembled results in these areas in connection with his own work there. General comparisons can be made between the western Great Basin and these adjacent areas.

EASTERN OREGON

To the north of the western Great Basin, there are the enclosed lakes of Eastern Oregon. Their histories have been discussed in various reports and in litigation over rights in the use of their water supplies. This history, with the results of their own observations, have been assembled by Donald B. and Elizabeth G. Lawrence in an article entitled "Response of Enclosed Lakes to Current Glaciopluvial Climatic Conditions in Middle Latitude Western North America".[1] The Lawrences summarize their results as follows:

A survey of the history of fluctuations of 20 closed basin lakes

[1] Annals of the New York Academy of Sciences, Vol. 95 Art. 1, 1961, pages 341-350.

> from northern California to central British Columbia showed strong growth since 1940 with crests ranging from 1952 to the summer of the survey, 1960. The more recent crests, chiefly in 1957, 1958 and 1960, tended to occur in the more northerly parts of the area.

They also state:

> Several of the lakes studied are not affected by storage, diversion or the works of man. Examples are Crater, Davis, and East Lakes in Oregon, Omak and Granite Lakes in Washington, and Stump and Buse Lakes in British Columbia. These all have followed a definite pattern: high stages in the first decade or two of the 20th century, then a steady drop to about 1935 to 1941, followed by a rapid rise to very high stages in 1958 or 1960. Most of the lakes affected by diversions for irrigation show a parallel response.

These results are in general agreement with those for the more northern lakes in the western Great Basin. The general rise in the first two decades of the 20th century is applicable as far south as Mono Lake; so is the general deficiency to about 1940. There was, generally, an above average water supply into the 1940's but the high stages reached in the lakes studied by the Lawrences in the 1950's were not reflected in the western Great Basin, particularly in its more southerly lakes.

GREAT SALT LAKE

Great Salt Lake is the largest and also the most extensively observed and described of any of the enclosed lakes in the Great Basin. It receives the runoff of the major area of the eastern Great Basin. Being shallow with flatly sloping shores, its area varies relatively widely with changes in its volume and adjusts itself more quickly to variations in its inflow than lakes with steeper shores. Great Salt Lake has fluctuated through a smaller range of elevations than the other enclosed lakes.

Records of the elevation of Salt Lake began in 1848. These enable the fluctuations prior to 1875 to be fairly well established. Since 1875, adequate direct observations have been made. There are earlier descriptive accounts which indicate the extent of the lake. The first survey of the lake was by Stansbury in 1850. Fremont had sailed on the lake in 1843. Trapper accounts began to describe the lake in about 1825.

An account by G. A. Gilbert includes records to 1877.[1] Prior records were derived from indirect observations such as the condition of the bars leading to Antelope and Stansbury Islands. This report includes a chart of the fluctuations of Salt Lake from 1847 to 1878.

Two storm lines on the islands were discussed by Gilbert. The lower or older line was 0.3 feet below the bar to Stansbury Island, and the more recent one was 5.6 feet above this bar. The sage brush grew above the new line and Gilbert concluded that the lake had not reached this elevation for a relatively long period, perhaps over 200 years. Gilbert, in his Monograph 1 of the U. S. Geological Survey on Lake Bonneville adds some further detail to

[1]J. W. Powell, "Lands of the Arid Region of the United States with a More Detailed Account of the Lands of Utah," 1879.

these accounts.

Use of the inflow to Salt Lake is extensive and has resulted in a material depletion of its former supply. This irrigation began in 1847. It occurs on numerous tributaries and only general estimates of the amount of the depletion as it has increased can be made. There have been some importations of water into the basin.

The writer reviewed the available information relating to Salt Lake and reached the following conclusions in 1934.

1 - Great Salt Lake reached higher elevations in the period 1868 to 1878 than it had reached for a long time prior to 1868.

2 - The length of time since the lake had been as high as in 1868 cannot be estimated definitely. Shore lines, brush growth and Indian legends indicate that this period may well have exceeded 100 years.

3 - If there had been no irrigation on its drainage area, Salt Lake would probably have risen as high in the middle 1920's as it did in 1868 to 1878.

4 - From 1902 to 1905 Salt Lake was lower than the previously known low elevations. This was the effect of irrigation. Without irrigation the lake would probably not have lowered below its 1848 elevation.

5 - In 1934 the lake was at its minimum elevation of record.

The deficiency in 1934 continued to 1935. Utah Lake became practically dry in 1935. In the succeeding 20 years the runoff refilled Utah Lake and raised Salt Lake. The 1960's to date have been a period of deficiency.

The record of Great Salt Lake shows an extent of variation in the runoff of its drainage area similar to that shown by the lakes of the western Great Basin. The time of these variations in some cases are in harmony and in others are at variance. The rise in the 1860's and 1870's on Salt Lake is in agreement with that in the western Great Basin. The lowering of Salt Lake in the period 1902 to 1905 is not matched in the western Great Basin; both areas had record deficiencies ending in about 1935. These comparisons are most directly applicable to Pyramid and Winnemucca Lakes. The variations between these two lakes and Great Salt Lake on an east west direction is similar to the variations between Goose and Mono Lakes in the western Great Basin on a north south direction.

COLORADO RIVER AT LEE FERRY

In the Congressional Hearings on S. 1658, Central Arizona Project, 1963 (88 Cong. 1st Sess.), a chart was introduced (p. 74) showing the 10 year moving average of the flow of the Colorado River at Lee Ferry both actual and virgin from 1896 to 1963. The runoff was above the mean for the period until 1930 and has been below the mean since. From 1930 to 1940 only two years had above average runoff. From 1940 to 1950 the runoff was larger than in the 1930's; in the 1950's it was again deficient.

These results show a pattern of wide variation similar to that found for the enclosed lakes of the western Great Basin. The same general deficiency in the 1930's is shown; this started and lasted later than the 1928-1935 deficient period in the western Great Basin. The excess period continuing to 1930 on the Colorado River is similar to that in the western Great Basin which ended in about 1917.

LAKES IN EASTERN GREAT BASIN

There are shallow enclosed lakes in northeastern Nevada which become dry at times. The record on these lakes (Ruby, Franklin, Goshoot, Snow Water, and Diamond) is fragmentary. The reports of Beckwith and Simpson indicate that these lakes were at lower stages in the 1850's than those that occurred after 1860. Use of the runoff of their drainage areas has reduced these lakes to playas. The deficiency in runoff extending into the 1850's in the western Great Basin appears to have extended into northeastern Nevada.

OWENS LAKE

Owens Lake formerly received the runoff of the Owens River and fluctuated with its variations. By the 1870's and 1880's diversions for irrigation began to deplete the inflow. The diversions by Los Angeles beginning in 1914 has resulted in the former lake becoming dry except for occasional flood inflows. Based on Fremont's account, Owens Lake appears to have been relatively low in the 1840's, although there was a large shallow body of water. This report is consistent with the record at Mono Lake to the north.

SOUTHERN CALIFORNIA

H. B. Lynch made a study of water supply conditions for the Metropolitan Water District in 1931. His results were published in a report entitled Rainfall and Stream Runoff in Southern California since 1769. Among the sources used by Lynch were th mission records extending back to 1769. As a result of these studies Lynch reached the following conclusions regarding this 162 year period.

1 - There has been no material change in the mean climatic conditions of Southern California in the past 162 years.

2 - There were, however, earlier fluctuations from average rainfall conditions, both excesses and deficiencies, of greater magnitude than any which have occurred in the past forty years.

3 - The twenty-eight year period of rainfall deficiency which ended in 1810 was about as severe as has been the present one to date, and much more protracted.

4 - The period of rainfall surplus from 1810 to 1821 was more intense than anything in the past forty years. It seems to have been about as intense as was that between 1883 and 1893.

5 - The period of rainfall deficiency which lasted from about 1822 to 1832 was more severe than has been any occurring since.

6 - The period of rainfall deficiency which commenced in 1842 and lasted until 1883 was much longer than any other of which we have record. It was not so acute, however, as some others, both earlier and later. It was broken by a period of normal rainfall, but was without any period of excess rainfall to balance the deficiency.

7 - In comparison with several periods of rainfall shortages which have occurred in past years, the present rainfall deficiency

to date cannot be considered a major shortage.

8 - For all practical purposes the useful water yield of the areas under consideration closely approximate the runoff from the principal streams of these areas, except in times of heavy floods.

9 - The runoff from Southern California streams has in general shown fluctuations from the normal similar in character to those of the rainfall, but larger in relative percentage.

10 - By reason of these fluctuations, the useful water yield has at various times been reduced from the average by considerably more than one-half for a period of ten years, and by thirty per cent for a period of twenty-eight years.

Lynch's study was made in 1931 during a period of deficiency which has extended beyond the date of his report. He found a similar extent and character of variation in Southern California to that which has been found for the western Great Basin. The periods of deficiency and excess in Southern California prior to 1931 agree in time in some cases with those in the western Great Basin and differ at other times. The 28 years of deficiency in Southern California ending in 1810 predated any similarly identifiable period in the western Great Basin. The period of deficiency from 1842 to 1883 in Southern California includes both the below average 1840's and 1850's of the western Great Basin but also includes the period of excess supply from 1862 to beyond 1883.

In the 30 odd years since Lynch made his report, Southern California has experienced both excesses and deficiencies in its water supply. Bringing Lynch's 1931 report to date by the inclusion of the records which have become available since his report was prepared would enable the recent period of deficiency to be compared with those in earlier periods.

Records are available of the stream flow of the Santa Ana River at Mentone, the San Gabriel near Azusa and the Sweetwater at the dam for the same 58 year period from 1902 to 1959 that has been derived for the drainage areas of the enclosed lakes in the western Great Basin. The accumulated departures from their means are shown in Figure 56. The Santa Ana and San Gabriel show runoff above the mean from 1905 to 1927, deficiencies to 1936, excesses to 1943 and deficiencies to 1959. The Sweetwater had deficiencies to 1913 and then followed the general pattern of the other two streams.

The Sweetwater for the three years from 1914 to 1916 had a runoff of 450 per cent of the mean, and from 1942 to 1959, 67 per cent. The variations of the Santa Ana and San Gabriel were less in amount than those on the Sweetwater. For the 13 years 1924 to 1936 the Santa Ana had a runoff of 69 per cent of the mean, and for the 16 years 1944 to 1959, 62 per cent of the mean. The San Gabriel for the 13 years 1924 to 1936 had a runoff of 56 per cent of the mean and the 16 years 1944 to 1959, 62 per cent of the mean. For the 11 years 1906 to 1916, the Santa Ana had an average runoff of 165 per cent of its mean, and the San Gabriel 162 per cent.

For the eight years 1928 to 1935, the runoff of the Santa Ana was 57 per cent, of the San Gabriel 54 per cent, and of the Sweetwater 40 per cent of the 58 year mean. These results are similar to those for the same years for the enclosed lakes.

These three streams were selected as one for which changes in the conditions of their drainage areas above the points of measurement have been

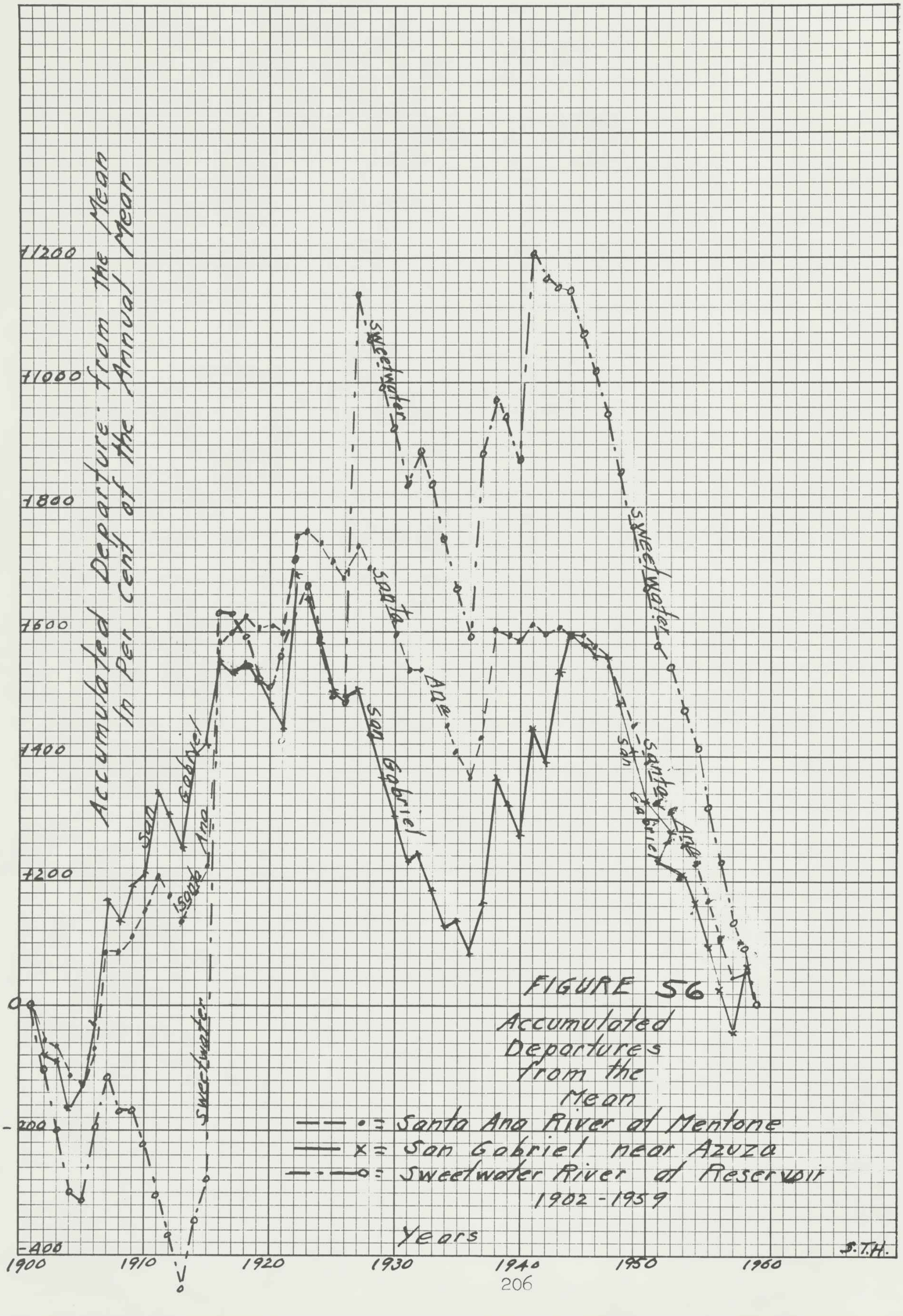


FIGURE 56
Accumulated Departures from the Mean

relatively small. The results shown extend only through 1959. The extension of these results through 1964 would show continuation of the period of deficiency that had preceded 1959.

CENTRAL VALLEY OF CALIFORNIA

The runoff of the western slope of the Sierra Nevada results mainly from the same storms which produce the runoff of the western Great Basin. Three streams of the Central Valley having relatively long discharge records which have had only limited changes in the use of their stream flow above the gaging stations have been used for comparison with the results derived from the enclosed lakes of the western Great Basin. These streams are Kern River at Bakersfield, the Feather River at Oroville and the Sacramento River near Red Bluff. These three streams represent the southern end of the Central Valley, its north central area and its northern end. The accumulated departures from the mean for the 58 year period 1901-02 to 1958-59 for these three streams have been plotted in Figure 57. These three streams have a generally similar pattern of accumulated departures from their means. Above average runoff for the 58 year period occurred from 1902 to about 1917, below average to about 1935, a smaller excess to about 1944, and a deficiency to about 1950. In the 1950's the runoff of the Feather and Sacramento Rivers was above the mean, with Kern River averaging about the mean. For the seven years 1928 to 1934, the average runoff of the Kern River was 53 per cent, of the Sacramento River was 59 per cent and of the Feather River was 57 per cent of the 58 year mean.

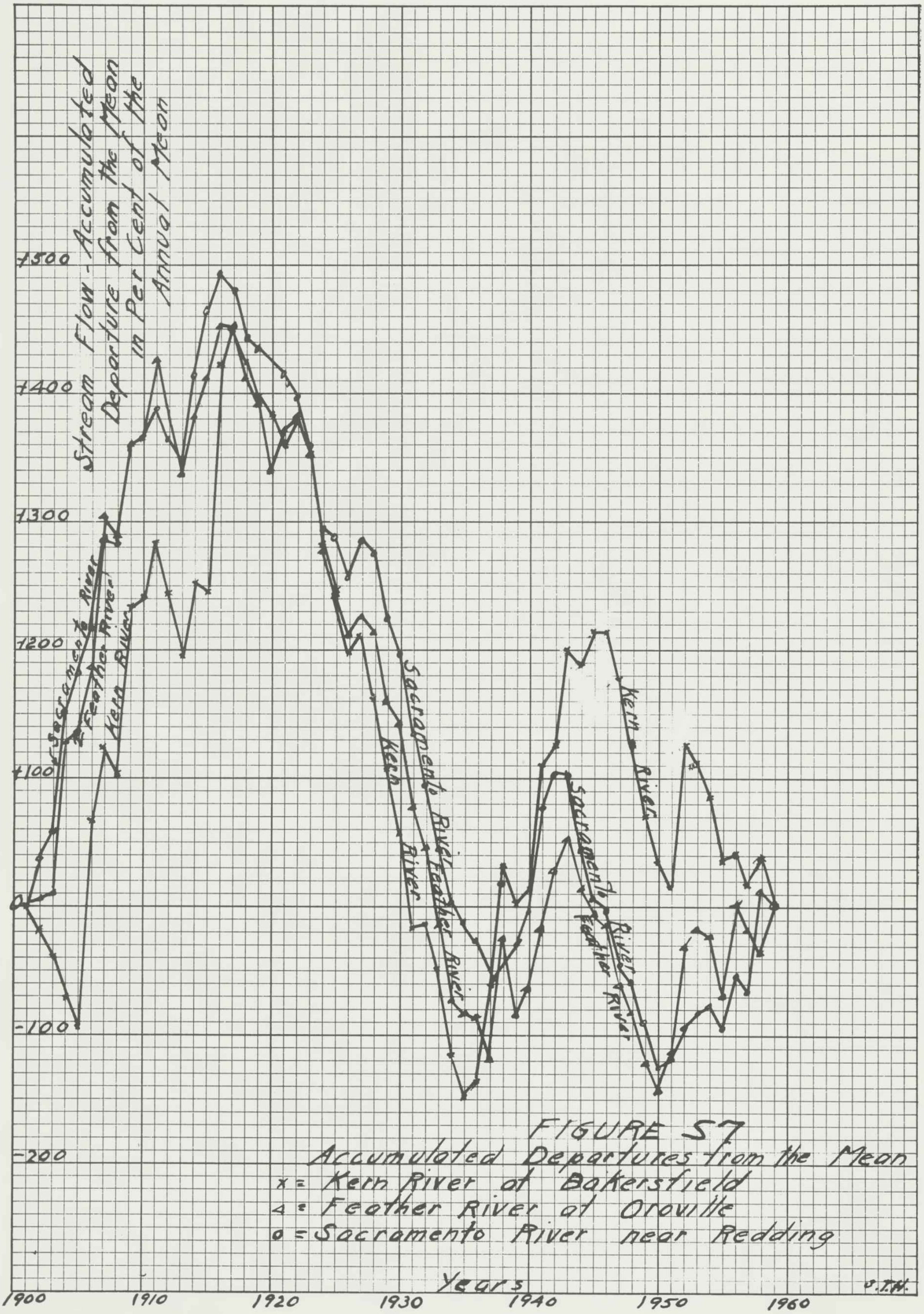
For the 15 years 1902 to 1916, the average runoff of the Kern River was 128 per cent, of the Sacramento 133 per cent and of the Feather River 130 per cent of the 58 year mean. For the same period the enclosed lakes varied from 116 to 142 per cent of their 58 year means.

There is an agreement in the general character of the variations in runoff in the Central Valley with those in the western Great Basin, with the differences that would be expected in their amounts and times of occurrence.

LAKE LAHONTAN WATER SUPPLY

While it is outside of the scope covered by this report, the results regarding the water supply of the western Great Basin during its recent past raise the question of how much change in the present supply would be required to restore another Lake Lahontan. This question can only be answered on the basis of several assumptions. It can be approximated if the rate of evaporation at the time of the higher stages of Lake Lahontan is assumed to have been similar to that at present. Some general conclusions can be reached regarding the precipitation that would be needed to provide runoff which would maintain a Lake Lahontan.

Russell, in Monograph 11 of the U. S. Geological Survey, found that Lake Lahontan covered 21 per cent of its total basin equivalent to 26 per cent of its tributary drainage area. Jones in Carnegie Publication 352 derived a lake


Stream Flow - Accumulated Departure from the Mean in Per Cent of the Annual Mean
+500
+400
+300
+200
+100
0
-100
-200
Sacramento River
Feather River
Kern River
Sacramento River
Feather River
Kern River
Kern River
Sacramento River
Feather River
Kern River
FIGURE 57
Accumulated Departures from the Mean
x = Kern River at Bakersfield
△ = Feather River at Oroville
o = Sacramento River near Redding
Years
1900
1910
1920
1930
1940
1950
1960
S.T.H.

area of 16 per cent of the basin.[1] Russell also found that the remaining lake areas in the Lahontan basin in 1882 were about 18 per cent of the area of Lake Lahontan; this represents less than 5 per cent of their tributary drainage areas. Walker Lake has had a recent area equal to 3 per cent of is drainage area. Honey Lake, which has had an area of 5 per cent of its drainage area at some recent times, has also gone dry at other times. Eagle Lake has supported a water area representing 12 per cent of its tributary area. The Humboldt River, draining 15,000 square miles representing the eastern one-third of the Lahontan basin supplied only limited runoff to Humboldt Lake and Carson Sink from the precipitation of 10 inches or less on much of its drainage area. Lake Tahoe has an area equal to 59 per cent of its tributary area. It has maintained an outflow except in some periods of large deficiency in precipitation. The drainage area of Lake Tahoe receives precipitation of greater amount than nearly all of the Lake Lahontan basin. Prior to the extensive diversion of their inflow for irrigation, the combined areas of Pyramid and Winnemucca Lakes has been as great as nine per cent of their tributary area.

Mono Lake is not within the Lake Lahontan basin. Its maximum stage had an area about four times its recent area. The recent area of Mono Lake has been about 15 per cent of its tributary area. Conditions on the entire Lahontan Drainage area would not need to be much more humid than the present conditions in the Mono basin in order to maintain Lake Lahontan at its higher stage. Mono Lake receives its water supply from the higher mountains to the west, but two-thirds of its basin includes desert areas to the east. Its higher altitude results in an evaporation rate equal to about 80 per cent of that on Pyramid and Walker Lakes. There are still remnants of glaciers on the higher peaks of Mono Basin. There were probably at least equivalent glaciers in the Lahontan basin when Lake Lahontan was at its higher stages.

When Goose Lake is at its overflow elevation its area is about 17 per cent of its tributary area. Its average area has been much less than its overflow area; the lake was relatively low in the 1840's before its inflow was affected by diversions from its tributaries. During the more favorable recent periods Goose Lake has maintained nearly as large a percentage of its drainage area in lake surface as Lake Lahontan maintained at its high stage. The present mean annual precipitation in Goose Lake basin varies on the different parts from 10 to 30 inches. As the drainage area of Goose Lake does not include extensive deserts, the average precipitation on the productive portions of the Lahontan drainage would need to have been larger than these amounts in order to maintain an equivalent lake area.

The high stages of Lake Lahontan are generally placed as having occurred within the last 25,000 years. Similar general topography existed at that time and the relative distribution of precipitation and runoff was also probably similar to the present. Then, as now, much of the drainage area was probably relatively arid, the increased inflow from the increased precipitation coming mainly from the western mountain areas. The same climatic conditions that produced the increased precipitation in Lahontan times also probably resulted

[1] J. Claude Jones, "Geologic History of Lake Lahontan," Quaternary Climates, Carnegie Institute Publications 352, 1925.

in some decrease in summer temperatures and evaporation.

The recent water areas of the enclosed lakes are from one-fifth to one-third of that at the higher stages of Lake Lahontan. However an increase in precipitation of three to five times would not be needed to produce the runoff which would restore Lake Lahontan. The runoff resulting from increased precipitation increases more rapidly than the rate of increase in precipitation. With the probable decrease in evaporation that would occur under conditions that would produce an increase in precipitation, it is considered that Lake Lahontan would be restored with an increase of about 100 percent in the present mean annual precipitation. Such an increase would result in the mean annual precipitation being about the equivalent of the present individual years of maximum supply.

In general it appears that an average annual precipitation equal to that now received in the present maximum years would restore Lake Lahontan. Much of the drainage area of Lake Lahontan which now receives about six inches of mean annual precipitation was also arid or perhaps semiarid when Lake Lahontan was at its higher stages. Then, as now, the major portion of the runoff probably came from the higher western portion of the drainage area.

GENERAL CONCLUSIONS

The direct records and other pertinent information relating to the water supply of the western Great Basin have been presented and discussed in the preceding portions of this report. The conclusions which are considered to be supported by this record now need to be presented.

These conclusions apply directly to the area of the western Great Basin. While as previously discussed the general conditions in adjacent areas may follow those in the western Great Basin, there may be differences in the time and extent of the fluctuations from those that have occurred in the western Great Basin. Similar variations may also occur within the western Great Basin.

A historical record of the water supply of the western Great Basin includes much of general interest relating to conditions during the earlier years of the present settlement of this area. This would justify an effort to assemble such a record even if it was useful only as a history of this area. However, the importance of its water supply to this arid area makes it essential that an attempt be made to find answers in its past water supply conditions applicable to its future water resource development. Adequate programming of water projects requires an understanding of the variations to which the water supplies to be used are subject. While this is essential in all areas, it is of particular importance in arid areas such as the western Great Basin.

Records are now available for deriving the annual runoff of most of the streams on which this area depends. The direct records cover the past 50 to 60 years and reasonably adequate indirect records extend back to about 1850. These records disclose the variations which have occurred within this period.

In earlier years it was necessary to plan projects on the basis of shorter periods of record. Expectations have not been realized in some cases where later years were ones of lesser water supply. One hundred years is a length of record that would usually be considered to be long enough to include the full range of variation that would be expected to occur. However, the wide variations that occur over periods of several years in the water supply of the enclosed lakes of the western Great Basin make it essential that an effort be made to determine whether there may have been periods of more severe and extended deficiency in water supply prior to 1850 than any which have occurred since. A principal purpose of the investigations on which this report is based was the search for an answer to this question.

The best basis on which to forecast the future water supply of this area is to assume that what has occurred in the past will recur in the future. This does not mean an exact repetition, but that the general character of the runoff in its mean annual amounts and its departures from the mean will be similar in the future to those which have occurred in the past.

It is well established that major climatic changes have occurred in the past over periods of time represented by the geological schedule. Such time periods are too long to be used as the basis for present projects in which the costs will be repaid within a period of time too short to be affected by such long time trends. The water supply of the past 200 years should be a reliable basis on which to forecast the supply expected to occur in the next 200 years. It is to such a general period that the conclusions reached in this report are applicable.

In analysing the past records of these enclosed lakes, the major interest is in determining their periods and extent of the deficiencies below their long time annual means. The periods of deficiency have continued too long to enable the mean annual stream flow to be regulated for full use by any present or prospective storage on their drainage areas. Major attention has been given to deficiencies rather than to excesses in the water supply.

From all of the material which has been presented in the preceding portions of this report certain conclusions which are considered to have adequate support can be drawn. These include the following.

The general period from about 1860 to 1915 had a larger runoff than that of the preceding 50 years or of the years since 1915.

This conclusion is supported by the results for all of the enclosed lakes extending from Goose Lake to Mono Lake. While similar periods can be expected to recur in the future, the plans for water supply projects in this area should not be based on the 1860 to 1915 supply. The records both before and after this period are a more reliable guide on which to base project plans.

The years since 1915 have included about an average supply to 1924, a generally severe shortage to 1935, an above average supply into the 1940's, a generally average supply to the late 1950's, and a period of shortage in the early 1960's. 1928 to 1935 appears to have been the most deficient period of equal length occurring within the past 200 years. This period was preceded by less severe shortages from 1924 to 1927.

The elevations of the enclosed lakes in the 1840's represent a preceding mean annual inflow for some undefined period that was essentially less than the mean annual inflow since 1901 and in some areas may have represented a more severe shortage than that for the period 1924 to 1935. The available information indicates that the deficiency of the 1840's was more severe in the southern part of the western Great Basin than in its northern part. The shortage in the 1840's on Mono Lake appears to have exceeded any that has occurred since; on Goose Lake the shortage ending in 1935 appears to have been more severe than that in the 1840's. For Truckee River the total deficiency which produced the 1844 dryness of Winnemucca Lake and the relatively low elevation of Pyramid Lake represents a smaller runoff than any that has occurred in any 30 years since, but no continuous eight years in such a 30 year period may have had as severe a deficiency as that which occurred from 1928 to 1935.

The present use of the streams tributary to the enclosed lakes in the western Great Basin is generally as extensive as can be supported by the existing amounts of storage. Much of the mean annual supply continues to reach the enclosed lakes. Storage sites of large capacity and low cost are generally lacking on the upper drainage areas of the enclosed lakes. No means of fully using these variable water supplies can be foreseen and sufficient water will continue to reach the enclosed lakes to maintain substantial lake areas. Shallow lakes such as Goose Lake can be expected to go dry again in the future during periods of deficient runoff. Adequate but reduced areas will be maintained in Pyramid, Walker, and Mono Lakes. Further diversion from Eagle Lake is not improbable and its fluctuations can be expected to reflect the variations in its inflow. Humboldt Lake is already a playa.

The lowering of these enclosed lakes now occurring will continue until they reach an area in balance with their reduced inflow resulting from the diversions on their tributaries. Such further lowering will vary for the different lakes. The full lowering will not be reached quickly as the rate of lowering will diminish as the new equilibrium is approached. Fluctuations above and below this equilibrium will occur as the annual inflow varies.

The probable future status of each lake has been discussed in the preceding portions of this report. Eagle Lake is the only one of these enclosed lakes which has not been materially affected by the past diversion of its inflow; Eagle Lake is also the only one of these lakes in which the natural conditions may be maintained.

As the lakes lower, the total solubles in their water will increase. The degree to which such concentration may go will vary with each lake depending on the percentage of reduction in the present volume which will occur and the present quality of the water. In the lakes now suitable for fish, the present types of fish may not be adapted to the future quality of the water. Any such changes will occur gradually over a considerable period of years. All of the enclosed lakes in the western Great Basin presently have a quality of water that is much less salty than Great Salt Lake. Only the water of Mono Lake is now too salty to contain fish.

The water supply of future projects in the western Great Basin should be planned on the basis of expecting to have to meet stream flow conditions such as those that were experienced from 1924 to 1935. For irrigation use considerable shortages can be endured if they do not occur too frequently. As 1928 to 1935 appears to have been the most deficient period in over 100 years, irrigation use can be planned on the basis of the largest endurable shortage during such a period. For municipal use the ability to endure shortages is more limited and water supplies for such use will need to be based on smaller shortages than those permissible for irrigation.

Similar deficiencies to that in 1924 to 1935 occurred in the 1840's. This represents about 75 years between such periods. No cyclic variation has been found in the water supplies in this area and there is no presently known basis on which to forecast when the next similar period of deficiency may occur. The record of the past indicates that such periods of shortage can be expected to recur. Project plans should be based on this expectation.

If a single general conclusion can be drawn from all of the material that has been presented regarding the water supply of the western Great Basin, it would be that there is no regularity in the variations from the mean; that the variations follow no determinable pattern; and that the time when future periods of deficiency may occur cannot be forecast.

In planning future water supply projects in this area, all available information and records on the source of supply to be used should be assembled. This information should be combined with the proposed amount of storage and the endurable shortages for the proposed uses of water to determine the amount of new water supply that can be secured without exceeding the shortages that can be endured.

APPENDIX

VARIATIONS IN THE RUNOFF OF THE WESTERN GREAT BASIN BASED ON TREE RING RECORDS.

The results that can be derived for the runoff of the western Great Basin from the observations on its enclosed lakes have been discussed, and conclusions regarding variations that have occurred that can be derived from these lake records have been presented. Another source of information which has been used to indicate the past water supply of this area is the thickness of the annual growth of trees. Such tree ring records are available in this area on an annual basis for periods of 400 years.

In the following discussion an attempt is made to use available tree ring observations to supplement the conclusions regarding the past water supply of the western Great Basin derived from the history of the enclosed lakes.

Trees, like other vegetation, respond to their available water supplies. The amount of wood growth, as measured by the thickness of the annual ring, may be a measure of the water supply available in the year of its growth. In humid areas where an adequate water supply may be available in all years, the amount of tree growth may be controlled by other factors. In arid areas the amount of the water supply in any year may be the controlling factor in the growth.

Trees 4000 years old are still growing in some areas. The sequoias in California are over 3000 years old; the bristle cone pines in some parts of the Great Basin are over 4000 years old. Some junipers also have a relatively long life.

If tree rings are an index of the water supply, they offer a means by which one may derive the variations that have occurred during the life of the tree. If this can be done the tree rigns provide a basis for determining the variations in precipitation and runoff that have occurred over periods longer than those covered by other forms of record.

Several series of tree ring observations are available for areas within the western Great Basin. These results have been compared with the available water supply records for the period when both are available in an effort to determine the extent to which the tree ring records may be useful in deriving the water supply for periods prior to other records. Trees having the length of life of the sequoia and bristle cone pine are not found in the area of the enclosed lakes discussed in this report. However, tree ring records have been secured from trees of over 400 years old in the lake areas.

One conclusion can be drawn from the age of the trees now growing in any area. The climate during the life of the tree must have been within the limits of tolerance of the tree. If drouths so severe that the tree could not survive had occurred, present trees would have a life limited by the time since the occurrence of such a drouth. On this basis there is assurance that the water supply in the areas of the longer growing trees has been within the general range under which these trees can exist. As these trees are still adding annual rings this past climate must have been similar to that of the past period covered by other forms of record.

The use of tree rings to date historic events and as an indicator of variations in water supply has become widespread since the technique of their measurement was developed by Douglas and his associates. While this dating practice is now widely recognized as having usefulness, the use of tree rings as a climatic indicator is less extensively accepted. Quantitative relationships between the variations in the width of annual tree rings and the resulting amount of variation in the annual water supply have not, as yet, been established.

The thickness of an annual ring of a tree is the composite result of several factors affecting the growth of the tree. Tree rings are usable as an indicator of water supply only where the moisture available to the tree is the controlling factor in its growth. Trees growing where no shortages occur in their water supply show limited variation in the thickness of their annual rings. Such "complacent" records do not reflect variations in the general water supply of their area. Tree rings are most useful as an indicator of water supply where the trees grow under conditions of marginal moisture supply and the rate of growth may be materially reduced in years of water shortage. These conditions are met in arid areas for trees growing away from stream and ground water influences and receiving only their local precipitation.

Like other practices, the technique of tree ring determination has improved as its use has become more extensive. Recent work has been based on more careful selection of the trees used and greater care in determining double or missing rings. At present, experienced investigators can be relied upon to secure a tree ring record which correctly represents the actual growth of the trees used.

The result of tree ring measurements are usually reduced to terms of the percentage of the mean for the width of the tree ring for each year for the period covered by the record. This is a convenient form for use in comparing different results. It is usual to combine the results of all of the trees which have been measured in an area. As the individual tree records have varying lengths the resulting means may not be in terms of the mean for the entire period covered. In comparing results for different areas or different groups of trees, the same time periods need to be used for each group.

The comparison between precipitation and runoff previously discussed in this report shows that this relationship is variable. Qualitatively runoff increases with an increase in precipitation, but quantitatively the rate of increase depends on additional factors. A given amount of annual precipitation occurring in a larger number of well distributed storms will produce less runoff than an equal amount of precipitation occurring in a few larger storms. Figure 1 is an illustration of the variability of this relationship.

Similar conditions are applicable to the usefulness of a given amount of annual precipitation in supplying soil moisture to trees. A close quantitative relationship would not be expected and has not been found. Generally an increase in precipitation, up to the limit that may be retained as soil moisture, would be expected to result in an increase in tree growth. In arid areas such a soil moisture limit may seldom be reached.

An examination of tree ring records shows a smaller range of annual fluctuation than that for either precipitation or runoff. As shown in the preceding portions of this report, both the annual precipitation and the runoff may vary from over 200 percent of the mean to less than 50 percent of the mean. Such wide variations seldom occur in the tree rings.

Several results of tree ring measurements in the western Great Basin have been published. These were made in the 1920's or early 1930's. They cover different ages of trees but all but one have a common period of about 450 years beginning in 1480 and extending to 1929. These are located from eastern Oregon to Mono Lake. Except for two results by Antevs and by Davis and Sampson, they were made by separate investigators.

The results which have been compared by the writer in this report are those of (1) Keen for eastern Oregon which includes Goose Lake, (2) Group A of Davis and Sampson west of Lakeview, (3) Group B of Davis and Sampson in Fort Bidwell Canyon, (4) Antevs for southeastern Oregon, (5) Antevs for northeastern California, (6) Hardman and Reil for the Truckee River drainage area, (7) Schulman for the Mono-Owens area.

These results are distributed over the western Great Basin with enough work in the Goose Lake area to enable the results of different investigators to be compared.

Results of F. P. Keen

F. P. Keen published his results in the monthly Weather Review for May 1937 in an article entitled "Climate Cycles in Eastern Oregon as Indicated by Tree Rings." Keen's work was done while he was employed by the Division of Forest Insect Investigations, Bureau of Entomology and Plant Quarantine of the U. S. Department of Agriculture. His work began at Klamath Falls in 1923 and continued intermittently until the article cited was prepared. Keen used methods of sampling and analysing the records based on the results of Huntington, Antevs, and Douglas. As Keen was working on bark beetle damage to Pondorosa pine, his results were on this tree. Only trees growing on well drained slopes were used. Altogether tree-ring sections were secured on 1140 trees in 44 localities in eastern Oregon and northeastern California. The most sensitive trees were found on the edge of the desert. Trees at the higher elevations receiving more rainfall were more complacent.

Keen found a similarity in fluctuations in annual growth not only between neighboring trees but also from different areas. Keen concluded that the climatic influences were more or less general throughout the northern Great Basin region with only slight modification by more local weather conditions.

Keen's Tree Ring Calendar is shown in his Figure 7. This covers from A.D. 1268 to 1935. The number of trees used to derive the mean in the different portions of this calendar increase from two in the beginning to 14 in 1480 and 296 in 1929. Both the annual results and the smoothed five year averages are plotted on Keen's Figure 7.

Keen's article does not include the annual results except as plotted to the scale of his Figure 7. These annual results were scaled from Figure 7 from 1480 to 1929. This scaling introduces probable errors in the results for individual years but should not result in any overall errors of consequence. These scaled results have been used in this writers' comparisons with other work.

Keen's work represents an extensive field investigation and office analysis, both conducted in accordance with the recognized practice in this field. His calendar is a thorough effort to produce results applicable to the generally arid area of eastern Oregon. Keen summarized his conclusions as follows:

> The tree-ring record for eastern Oregon indicates that during the past 650 years there has been no general trend toward drier or wetter years. If such a trend exists, the change over a 650 year period is so slight that it is obscured by other fluctuations. Average growth for the 20 year period 1900-19 was found to be identical with the average growth during the past 650 years. There have been important fluctuations in growth throughout the entire period, however, with alternate periods of good and poor growth.
>
> All tree-ring measurements agree in showing that a very critical subnormal growth period has existed since 1917. This slowing down of the growth rate is undoubtedly the result of deficient precipitation and lowered water tables. As compared with other drought periods, the present one is the most severe and critical that the present forests have experienced in the last 650 years. Several other periods have exceeded the present one in duration of subnormal growth, but none has approached it for severity. Growth in 1931, the poorest year, was 68 percent below normal.
>
> The tree-ring record indicates that the last period of 19 years of drought and poor tree growth represents a major fluctuation in a broad climatic cycle which eventually will be followed by a wet period of better than average growth. No rhythmic cycle has been formed which would permit a prediction as to when this reversal in trend will occur.

Keen's results include tree rings through 1935. His prediction that the drought since 1917 would end and be followed by a period of larger water supply began to be verified in 1936 and continued for eastern Oregon area to 1960.

While Keen's results were applicable mainly to eastern Oregon they include the area tributary to Goose Lake.

Results of Davis and Sampson

In 1931 tree rings on 90 stumps in the vicinity of Lakeview, Oregon were measured in an effort to correlate tree growth and precipitation in that area. The results were published by Wendell E. Davis and Arthur W. Sampson in the Transactions of the American Geophysical Union for 1936, Part II, p. 493, under the title "Experiment in Correlation of the Tree-Growth and Precipitation Cycles." These trees were in three groups from locations adjacent to the available precipitation records. The authors found only limited correlation between tree growth and precipitation. For multiple correlation using precipitation, temperature, and length of growing season, the results were somewhat better giving a correlation factor of 0.37. Precipitation ceased to be determining at 29 inches per year and the length of season at 180 days. The authors concluded that the annual precipitation and growth as measured by these annual rings were not related to each other; that the yearly trend of the precipitation explained only an average of 14 percent of the trend of growth so that a precipitation curve based on tree growth records would not be dependable; and that while tree growth fluctuations are fundamentally climatic the relationship was complex.

The preceding paper did not include the annual tree ring measurements made by the authors. Hearing that this work had been done, the writer in 1933 secured from Dr. Sampson the numerical results for the annual growth for two of the groups of trees. These were expressed in terms of the percentage of the mean for the period covered. Group A was for trees 14 miles west of Lakeview covering years from 1413 to 1920. From one to nine trees were used to 1748, and from nine to 30 trees thereafter. These results were compared with the precipitation at Lakeview. Group B included a similar number of trees from Bidwell Canyon above Fort Bidwell for comparison with the precipitation record at Fort Bidwell.

The results for Group A have been used for comparison with other results relating to Goose Lake. A separate comparison has also been made between the results of Davis and Sampson's Groups A & B.

Results of Ernst Antevs

Ernst Antevs reports the results of his tree ring studies in this area in Rainfall and Tree Growth in the Great Basin, published jointly by the Carnegie Institution of Washington (Publication no. 469) and the American Geographical Society (Special Publication no. 21) in 1938.

Antevs discussed the rainfall fluctuations during the past hundred years for five areas, namely Lake County in South-Central Oregon, the Great Basin Region of northeastern California, Modoc and Lassen Counties, the Truckee-Carson-Walker Region, Western Nevada, the Humboldt Region, northern Nevada and the Great Salt Lake Region, Utah. As the title indicates, this report was concerned mainly with the relationship between rainfall and tree growth during the past 100 years for which both records were available. Earlier tree-ring results were also discussed.

Antevs secured tree-ring cores covering more than 100 years. These were sent to the Laboratory of Tree-Ring Research, University of Arizona in Tucson. They were individually standardized there by Edmund Schulman in 1932. Schulman's results were published in 1956 in a special publication of the University of Arizona Press titled Dendroclimatic Changes in Semiarid America. In this report Schulman included tables showing the indices of the annual tree rings for the Southeastern Oregon Ponerosa Pine (Table 75), and the Northeastern California Ponderosa Pine (Table 76) based on the cores collected by Antevs. Schulman did not include similar results for Antevs' Truckee-Carson-Walker or Humboldt areas. These results extend to 1931. For Southeastern Oregon they start in 1453, for Northeastern California in 1485, and for East-Central California in 1353. The results are expressed in terms of the mean for the trees used in each group. For Southeastern Oregon, called the Lakeview area by Schulman, from one to seven trees were available from 1453 to 1565, and eight to 15 trees for the remainder. For Northeastern California, called the Susanville area by Schulman, the trees used numbered one tree to 1622, and two to five for the remainder. Extracts from Antevs' conclusions include the following:

> From 1801 to 1828 wide tree rings indicate ample precipitation in the northeastern part of the Great Basin.... Also, judging from the

> tree growth the precipitation was exceedingly small in 1829 and then increased to a fair maximum in 1836-38. Then followed, during the 1840's, a wide spread and persistent drought, in severity comparable to that of 1924-34. (p. 59)

Using the tree-ring results Antevs concluded that prior to 1850 the precipitation had been about the average of that since for the Susanville area. For the Lakeview area the rainfall since 1850 was above that in the remainder of the tree-ring record.(p. 60)

> Since the 1924-34 drought was surely the only one of its severity since the 1840's, its equal may not recur for several decades. (p. 62)

Results of Hardman and Reil

Hardman and Reil worked on tree rings in the upper drainage of Truckee River. They derived annual indices for several areas. The most composite result was for 46 trees from 1732 to 1930. These results were published in The Relationship between Tree Growth and Stream Runoff in the Truckee River Basin, California-Nevada, Bulletin 141, Nevada Agricultural Experiment Station, 1936. The results for the 46 tree group are in Table 9, p. 35. The actual measurements of tree ring thicknesses were standardized for age. Smoothing was also used by moving average of five or three years, placing the smoothed result in the middle of the period used. The smoothed values were used in Table 9.

Results of Edmund Schulman

In the Dendroclimatic Changes in Semiarid America Schulman included results secured in the Mono-Owens area (Table 77). These indices were based on one tree from 1353 to 1490, four trees 1491 to 1527, five to seven trees 1528 to 1699, 13 trees 1700 to 1941. These results have been compared with the inflow to Mono Lake.

Comparison of Results

Of the results which have been used, four cover the 450 years 1480 to 1929. Each is reported in terms of the annual percentage of the mean. These results are the means of the annual percentage of the mean of each tree entering into the mean for each area. As the individual trees have variable periods of record, this procedure gives results which may not be in terms of the percentage of the mean for all results. The available mean indices for each area were first used for the 450 years 1480 to 1929, and the total reconciled to a total of 45,000. The original sums used varied from this total by one to five percent. While this adjustment is small and within the probable error of the results used, it places all areas on a comparable basis.

A general inspection of the different annual indices for these different areas showed much variation. To reduce the detail involved in comparing the different areas for each year of the common 450 year period, the results were computed by decades with the means for each decade used in the comparisons. This gave 45 decades for which comparisons were made.

The decade results also showed much variation between the different areas. These variations were large in amount and many were in opposite directions. It did not appear that statistical forms of comparison would be useful for such wide variability.

To secure a general picture of the variations of these tree-ring indices for these different areas, the accumulated departures from the mean were computed for each area. These results also showed relatively wide variations between the different areas. This indicates that the area from Goose Lake to Mono Lake is itself subject to variation in its water supply within its own area.

Three of the five results for which the accumulated departures of the tree-ring indices had been computed are applicable to Goose Lake. Keen's results are for trees over a larger area in eastern Oregon, including Goose Lake. Sampson's Group A and Antevs' Goose Lake are within the drainage basin of the lake. These three results show material variation in their accumulated departures. If tree-ring indices in an area are to be used to derive the past variations in its water supply, the first requirement appears to be to secure tree-ring observations that are representative of the water supply variations of the area. The technique of tree-ring determinations has been materially improved as more experience with its use has been secured.

The results since about 1800 for these areas are more nearly in agreement for all areas, except Mono Lake, than those for the previous 320 years. This may be coincidence or it may be the result of using the rings for the more mature portions of the life of the trees.

The departures from the mean give the following results.

Observations	Maximum Accumulated Excess	Maximum Accumulated Deficiency	Total Accumulated Departure from Mean
	In Percent of the Annual Mean		
Keen	390	600	990
Davis & Sampson Group A	650	810	1460
Antevs-Goose Lake	340	130	470
Antevs-Eagle Lake	620	620	1240
Schulman-Mono Lake	170	860	1030

These results indicate that there has been an accumulated departure from the mean rate of growth for these trees varying from five to 15 years for the different areas. Over this 450 year period the tree growth in these areas has been subject to variations in its yield similar to those affecting annual crops.

Davis and Sampson's Group A & B represent trees within two areas close enough together to represent the same climatic influences. If the variations in the width of the tree rings in these two groups represent the variation in the precipitation in this area, the result for the two groups of trees should agree with each other. Group A represents 30 trees growing in the mountains 15 miles west of Lakeview. Group B represents 30 trees growing in the area of Bidwell Creek near Fort Bidwell. These areas were selected because of their nearness to the available precipitation records at Lakeview and Fort Bidwell respectively. Group B trees were about 15 miles south of Lakeview. Group A were on the eastern slope of the mountains west of Goose Lake and Group B were on the eastern slope of the Warner Range.

These two results had a common period of record from 1480 to 1928. Their annual differences in percent of their mean for this period were computed disregarding the direction of the difference. For the period the average annual variation was 21 percent. For individual decades in this period the accumulated differences were as large as 664 percent of the annual mean or an average difference of 66 percent. In 41 decades the average annual differences exceeded 10 percent; in 19 it exceeded 20 percent; and in seven it exceeded 30 percent.

If either of these groups of trees should be used in preference to the other to derive the precipitation, the annual results would have an average difference of about 20 percent.

These results indicate that the tree ring growth is itself variable within comparatively close areas. Whatever effects may influence such growth appear to have varied over the past 450 years in the areas of these two groups of trees.

The accumulated departures from the mean were also computed by decades for these two groups. These accumulated departures are widely variable. From 1480 to 1560 Group A had ring widths much below the average and then recovered until 1630. Group B followed the mean fairly closely in this period. From 1630 to 1720 the results were reversed. Group A had a growth well above the average and Group B was well below. Both groups had no wide departures from the mean from 1720 to 1840. From 1840 to 1900, Group B was well above the mean while Group A remained close to the mean. Widely different conclusions regarding the variations in the water supply to be expected would be reached from the separate use of the results for these two groups of trees.

Davis and Sampson attempted to correlate these tree ring results with the precipitation for the years when precipitation records were available. They concluded that their results did not indicate any significant association between annual precipitation and tree growth. They also concluded, (1) that annual precipitation and growth of trees as measured by their annual rings are not related to each other in this area; (2) as the yearly trend of precipitation explains an average of only 14 percent of the trend of growth a precipitation curve based on tree growth records would not be dependable; and (3) tree growth fluctuations are fundamentally climatic and are complex.

In the preceding portions of this report results have been derived for the runoff of the drainage areas of some of the enclosed lakes in the western Great Basin for varying periods based on the available information. These results have been compared with the tree ring records in their area in an effort to estimate the extent to which tree ring records may be an index of the runoff. This has been done for Goose, Eagle, and Mono Lakes and for the Truckee River. Each area is discussed separately.

Goose Lake Area

The runoff from the drainage area of Goose Lake has been previously derived for the period 1832 to 1960. Tree ring records are available for this period to 1929. The results for the 98 years covered by both inflow and tree rings have been compared.

The runoff record is based on the fluctuations of Goose Lake and its evaporation. As the records of lake elevation are intermittent, the inflow was derived in terms of the average for the periods between times of record of the lake elevation. The tree ring records are available annually; they were computed in terms of the annual average for the same periods used in deriving the inflow. Twenty-three periods were used for the total period of 98 years.

There are four tree ring results applicable to the area of Goose Lake. These are Keen's for eastern Oregon, Davis and Sampson's Groups A & B, and Antevs'. All inflow and tree ring results were computed in terms of their percentage of their 98 year mean.

When these percentages were tabulated, relatively large variations between the different results were apparent. The extent of the variations in the runoff was much larger than that in the tree rings. Here again these variations were too large to justify attempts to derive relationships by statistical analysis. The accumulated departures from the means for the periods were computed and plotted to provide a visual comparison of the extent to which the tree ring results might be usable as a basis for deriving the runoff.

The four tree ring results show much departure from each other. The results of Davis and Sampson's Group B and Antevs' show fairly good agreement with each other for this 98 year period, and the results of Keen and of Davis and Sampson's Group A are also in general agreement, but the two pairs of results differ from each other.

The accumulated departures for the runoff show much greater variations from the mean than of the tree ring results and follow a different pattern. From 1832 to 1859 there was an accumulated deficiency in runoff of 815 percent where two tree ring results were about the mean and the other two had a difficiency of about 240 percent. From 1859 to 1914 the runoff exceeded the annual mean by 1700 percent while the different tree rings varied from the mean by an excess of from about 400 to 500 percent. The runoff of the Goose Lake drainage area from 1914 to 1929 was only 40 percent of the 98 year mean while the four tree ring results averaged about 80 percent of their annual mean.

From these results it was concluded that none of these measured tree rings' thicknesses were usable as a practical basis for estimating the runoff of the drainage area of Goose Lake on an annual basis.

Eagle Lake

While interpretations of the elevations above which Eagle Lake did not rise have been made, based on the elevations at which present tree stumps grew, what may be considered to be the direct records of the elevation of Eagle Lake begin in 1875. The period from 1875 to 1931 is also within the results of

Antevs for his Susanville trees. These trees grew in an area adjacent to Eagle Lake and may have been, at least partially, within its drainage area. The annual results for this 57 year period year compared.

The percentage of the annual tree rings and the runoff showed no consistent relationships. Only two of the 57 annual tree rings were less than 60 per cent of the annual mean; 16 of the annual inflows were less than 60 per cent of their annual mean. Four of the annual tree ring results were over 140 per cent of their mean compared with 10 of the inflow results. Tree ring percentages between 60 and 120 per cent were distributed over inflow percentages from less than 20 to over 140 with no consistent relationship. For such scattering no statistical analysis of any correlation was considered to be worth attempting.

The accumulated departures of the Eagle Lake inflow and Antevs' tree rings were also computed. No correlation is shown that would be useful in deriving the inflow although the two results move in the same direction in some parts of this 57 year period.

These results indicate that Antevs' Susanville tree ring results do not supply a basis for estimating either the amount or the variations in the annual runoff of the drainage area in which Antevs' trees grew.

Truckee River

In Bulletin 141 of the Nevada Agricultural Experiment Station Hardman and Reil compared the tree growth and stream runoff in the Truckee River Basin for the period 1904 to 1930 for which records of both items were available. A similar comparison between tree growth and precipitation was made for the period 1871 to 1930. They found a general similarity between the curves for tree growth and precipitation although the agreement was not complete. They also found a correlation factor of 0.88 between tree growth and runoff for the Truckee River. The authors state "These facts lead to the assumption that precipitation has a similar effect upon both tree growth and stream runoff, and that runoff can be estimated from tree growth."

In the writer's work on the runoff of Truckee River based on fluctuations of Pyramid and Winnemucca Lakes, an estimated runoff was derived for the period 1780 to 1960. Hardman and Reil's tree ring results are available for the same period to 1930. These two results have been compared for the common period of 151 years.

For the tree rings the percentage of the smoothed values of the annual group for the 46 tree group at five different sites in the upper drainage area of Truckee River was used. In their work Hardman and Reil used moving averages of five and three with the resultant placed in the middle year of the group. The writers' results for stream flow have not been smoothed.

The runoff of Truckee River since 1780 was necessarily derived for periods between the times when information regarding the elevation of Pyramid and Winnemucca Lakes was available. Since 1922 annual records are available. For the preceding 142 years the results were derived for 29 periods varying from 30 to one years in individual length. The tree ring results were derived for the same periods.

An inspection of these results for the tree rings and runoff for the periods used show wide variations. To illustrate the relationship of these two items, their accumulated departures from their means were computed expressing each item in terms of its percentage of its annual mean.

These results show little correlation between the tree rings and the runoff. Somewhat closer agreement is shown from 1900 to 1930 when the results for the runoff rest on a greater amount of observations. For the 60 years from 1780 to 1840 the average tree ring results show normal growth while the runoff averaged nearly 30 per cent below its 151 year mean. After 1840 there is closer agreement between the accumulated departure of the tree rings and runoff, but for some periods they vary in opposite directions.

Mono Lake

Schulman has derived results for the thickness of tree rings for trees in what he calls the Mono-Owens area. These extend to 1941. The annual results were published in Dendroclimatic Changes in Semiarid America in 1956 (Table 77). Previously in this report the inflow to Mono Lake from 1857 to 1960 has been derived. These two results have a common period of 85 years. For the 55 years from 1857 to 1911 the runoff was derived in terms of the means for five periods varying from four to 15 years based on the availability of records of the elevation of Mono Lake.

The results for the tree rings and the runoff of the drainage area of Mono Lake were compared. A greater consistency was shown than had been found for the other drainage areas in the western Great Basin for which similar comparisons had been made. The accumulated departures from the mean in terms of the percentage of the annual mean were computed. For the infrequent observations on Mono Lake prior to 1912 there are divergences between the tree rings and runoff. From 1911 to 1941 there is as close agreement as would be expected between two items having a common relationship to the water supply but also affected by other factors.

The closer agreement of the tree rings and the runoff for Mono Lake may reflect the more critical moisture control over vegetative growth in its area. For the common period of annual records, the tree ring results would have usefulness in indicating the variations in runoff if runoff records were lacking.

General Comparisons

The preceding results that have been presented show that the thickness of the annual tree rings in the western Great Basin area is not a direct guide to the annual precipitation or runoff. Some agreements are shown such as that found on Mono Lake. Disagreements were shown between different tree ring results in the same area as for Goose Lake.

If specific relationships between tree rings and water supply do not exist in this area on an annual basis, usefulness can still be secured from tree ring results if they reflect general water supply variations. If no water supply records were available in an area, tree ring results might have usefulness in determining periods of excess or deficiency as to time of occurrence, duration and at least generally as to amount. The available tree ring

Table 32 Summary of Variations in Annual Width of Tree Rings.
For Different Results in Western Great Basin
In Terms of Percentage of the Annual Mean Width

Item	Keen in Eastern Oregon	Sampson & Davis Trees West of Lakeview	Sampson & Davis Trees near Fort Bidwell	Antevs for Southeast Oregon	Antevs for Northeast California	Antevs for Mono-Owens Area
Number of Years, Total	450	515	438	479	447	589
Maximum Year	135	204	168	179	211	162
Minimum Year	47	32	50	34	23	15
Years over 150 %	0	11	1	3	22	14
Years over 120 %	11	101	52	74	140	107
Years under 50 %	1	12	0	4	18	4
Years under 80 %	31	84	45	84	88	149
Mean for 1860-1919	100	106	116	104	104	116
Mean for 1830-1849	91	103	86	82	96	82
10 Year Minimum	1918-39 = 70 1842-51 = 81	1920-28 = 70 1847-56 = 89	1916-25 = 78 1830-39 = 80 1888-97 = 75	1919-32 69 1846-1850 74	1920-32 = 89 1840-48 = 85	1924-35 81 1840-49 79
10 Year Maximum	1860-67 112 1668-77 115	1860-69 = 113 1903-14 = 119 1860-1915 = 108 1679-1700 = 133	1860-69 = 120 1899-10 = 132 1851-1908 = 120	1860-69 = 111 1901-10 = 103 1860-1919 = 104	1860-69 = 105 1900-09 = 126 1860-1919 = 104 1660-79 = 144	1870-79 129 1901-09 122 1860-1919 116 1859-69 131

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results were examined to determine the periods of excess or deficiency which they might show in comparison with the similar periods shown by the water supply records. These results are shown in Table 32.

The results in Table 32 show a generally smaller variation from the mean for the tree ring measurements than is shown by the inflow to the enclosed lakes. For the three enclosed lakes represented in Table 32, the comparisons are as follows:

Percent of the Annual Mean

	Goose Lake		Eagle Lake		Mono Lake	
	Runoff	Tree rings	Runoff	Tree rings	Runoff	Tree rings
Minimum Year	27	32-50	6	23	45	15
Maximum Year	238	135-204	315	211	191	162
10 Year Minimum Period	29	70-80	50	96	72	82
10 Year Maximum Period	153	111-132	157	126	120	129

The 10 year minimum and maximum periods for runoff and for tree rings were in general agreement as to the time of their occurrence.

The tree rings show variations from year to year and for series of years which represent a generally similar irregular pattern to that shown by the annual runoff. However the tree ring results do not furnish a basis on which the variations in runoff can be derived in quantitative terms. The tree ring results for the 450 years that are available add support to the conclusion derived from the enclosed lakes that the water supply conditions in the western Great Basin have not varied essentially for the past 500 years.