EXHIBIT 92

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A COMPARISON OF RECONSTRUCTED LAKE-LEVEL RECORDS SINCE THE MID-1800'S OF SOME GREAT BASIN LAKES

by

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ABSTRACT

The historical record of water-supply variations of closed-basin lakes occupying the Great Basin can be used as analogs in understanding and modeling historical climatic variations in the western United States. However, human influences, such as the consumptive use of water, have altered this natural water-balance in many of the Great Basin closed-basin systems. Therefore, in order to study the response of present-day closed-basin lakes to historical climatic change, the historical record of lake-level changes must be reconstructed to reflect pristine conditions.

The historical variations in lake size, as delineated by lake level, volume and surface area, for Walker, Pyramid, Winnemucca Dry, and Owens Lakes were reconstructed in order to determine if lake responses to climatic variations are synchronous over the Great Basin. The reconstructed records were then compared with similar reconstructions derived previously for Great Salt (Stauffer, 1985) and Mono Lakes (Vorster, 1985).

Lake levels reconstructed for pristine conditions are different than those observed in the historical records. Walker, Pyramid, Winnemucca Dry, Mono, Owens and Great Salt Lakes all experience approximately synchronous variations in

size. However, during the periods 1872-1895 and 1948-1952 opposite changes in lake size in the Walker and Great Salt basins occurred. In addition, variations in lake surface-area and pristine stream discharge were observed to occur simultaneously. Present-day lake levels would be much higher than those observed today (near their historical highstand levels), throughout the period from 1870 to present, if human use was absent.

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INTRODUCTION

Purpose

Variations in the size of a lake occur as a result of changes in the hydrologic balance. Given pristine conditions, these variations are predominantly a function of climatic chhange. The historical record of water-supply variations of present-day closed-basin lakes occupying the northern, western, and eastern Great Basin can be used as analogs in understanding and modeling historical climatic variations in the western United States. However, the historical record of lake-level changes does not reflect natural conditions due to human influences. Consumptive use of water for crops and domestic purposes has altered the natural water balance of the closed-basin systems. Therefore, in order to study successfully the response of present-day closed-basin lakes to climatic variations, the historical record of lake-level changes must be reconstructed to reflect pristine conditions.

The purpose of this study was to reconstruct the natural historical variations in lake size, as delineated by lake level, volume, and surface area, of Pyramid, Winnemucca Dry, Walker and Owens Lakes. The reconstructed lake-level variations were compared with similar reconstructions for Great Salt (Stauffer, 1985) and Mono Lakes (Vorster, 1985) in order to determine if the reconstructed variations are synchronous throughout the Great Basin region. Reconstructed stream discharge for the Truckee, Walker and Owens Rivers were compared to determine if variations in stream discharge occur simultaneously.

Location of study areas

The study areas, located within the internally-draining hydrographic region known as the Great Basin in the western United States, include lakes and streams in California, Nevada, and Utah (figure 1). The region is bordered on the west by the Sierra Nevada Mountains, on the south by the Sonoran desert, on the north by the Columbia Plateau, and on the east by the Wasatch Range. The Great Basin consists of approximately 150 basins separated by north-south-trending mountain ranges. Each of the lakes included in the study occupies a closed drainage basin.

Paleohydrologic setting

Approximately 100 basins of the western United States were occupied by perennial lakes during the Pleistocene epoch (Williams and Bedinger, 1984). In western Nevada and eastern California, Lake Lahontan occupied several subbasins 4364 ft. (figure 1), having a maximum lake-surface altitude of 1,330 meters (m) and surface area of 8600 mi^2 22,300 square kilometers (km^2) during a highstand approximately 14,000 to 12,500 years

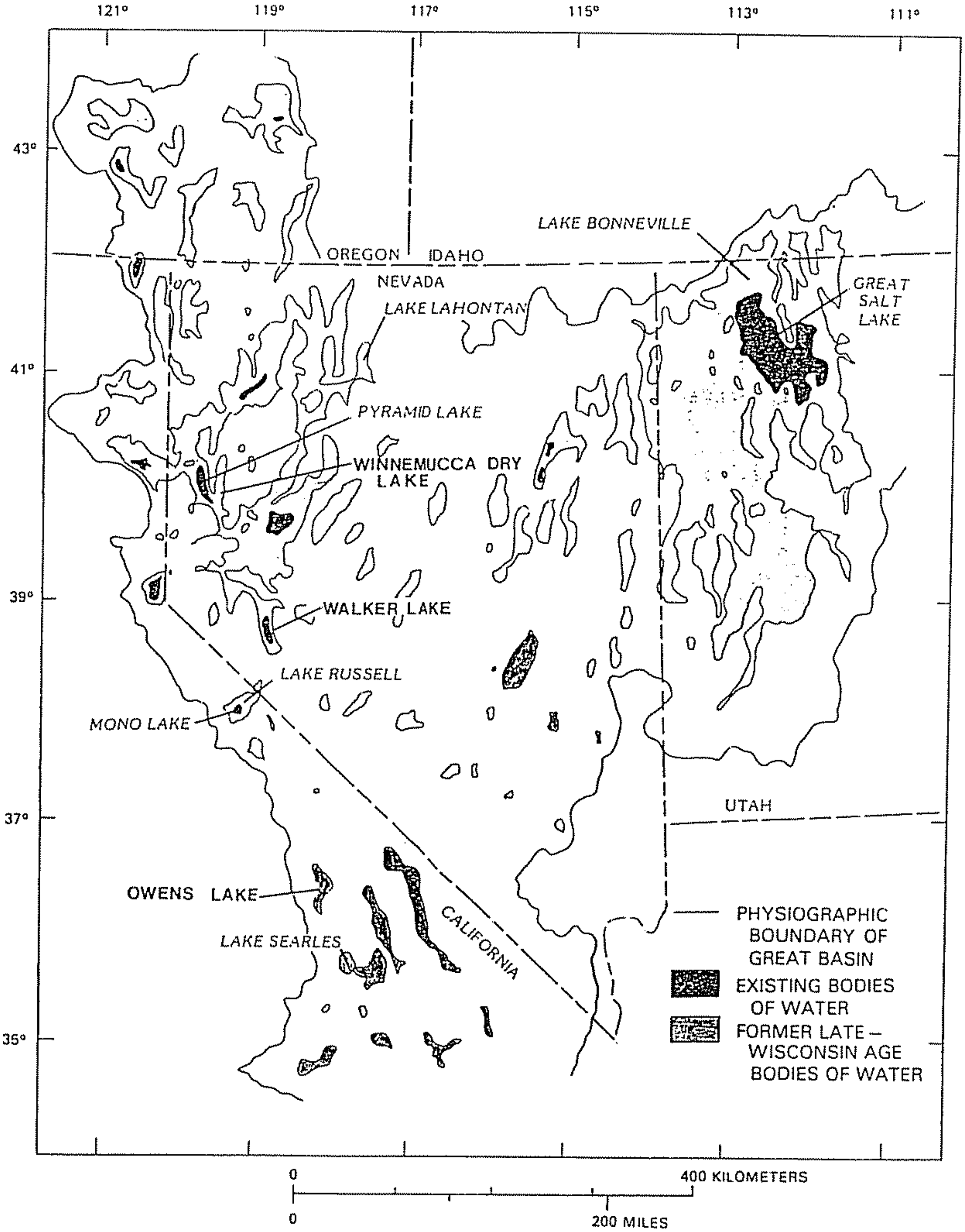


Figure 1.--Location of study areas showing Late Pleistocene lakes of the Great Basin (after Benson, 1986).

before present (yr B.P.) (Benson and Mifflin, 1986). In Utah, Lake Bonneville occupied the Salt Lake and Sevier subbasins (figure 1), reaching a highstand altitude of 1,560 m and a surface area of 51,300 km^2 aproximately 17,000 to 14,000 yr B.P. (Currey and Oviatt, 1985). In the Mono Basin, Lake Russell (figure 1), had a highstand of approximately 2,134 m approximately 14,000 to 12,500 yr B.P (Lajoie, 1968).

The chronologies of lake-level change for Lakes Bonneville, Lahontan, and Russell show that lake-level variations have been approximately synchronous throughout Pleistocene time (Benson and Thompson, 1987). Although a detailed chronologic record for the Owens River system is not available, studies have been conducted for Searles Lake (Stuiver and Smith, 1979), the third in a chain of five permanent lakes receiving water from the Owens River. The chronologic record for Searles lake tends to be diachronous with the chronology for Lake Russell (Benson and Thompson, 1987), indicating that lake-level chronologies may need to be investigated further, or a distinct climatic boundary separates the Lake Russell watershed from the adjoining Owens River watershed.

Numerous workers have attempted to infer the nature of the climatic change that was responsible for the maintenance of such large perennial lakes as Bonneville and Lahontan.

High lake-levels resulted from a change in the water balance that reflected increased runoff, reduced evaporation, increased precipitation, reduced temperatures, or a combination of these or other parameters (Benson, 1986).

Climatic setting

Changes in global air-mass circulation control the regional climate of the Great Basin. In general, three principal precipitation regimes, identified by Houghton (1969), dominate. In the western part of the Great Basin, the principal precipitation occurs between November and April and is derived from North Pacific westerlies that shift southward as subtropical high-pressure cells move toward the equator. During the spring and fall, low-pressure cells develop on the lee side of the Sierra Nevada Mountains. These cells can entrain moisture from the Pacific Ocean, and bring precipitation to the eastern and central regions of the Great Basin that affect Great Salt Lake. The third precipitation source results from monsoonal moisture flow in the summer that brings moisture from the Gulf of California or the Gulf of Mexico and affects Great Salt Lake and eastern and southern regions of the Great Basin. Thus, lakes in the western region of the Great Basin (Pyramid, Winnemucca Dry, Walker and Owens) will receive the majority of their precipitation during the winter months while lakes in the southern and eastern regions (Great Salt) will receive a higher proportion of precipitation during the summer months.

The hydrologic balance of lakes in the Great Basin is strongly dependent upon precipitation in the surrounding mountains. Precipitation directly on the lake surface accounts for very little input, because of the aridity of the basin and orographic effects (rain shadow) associated with westerlies crossing the Sierra Nevada Mountains. For lakes in the Lahontan basin, only 15 percent of the total inflow to the lake results from precipitation on the lake surface (Benson, 1986). In the Owens Lake basin, approximately 6 percent of the total inflow to the lake results from precipitation on the lake surface (LADWP, 1976). In the Mono Lake basin, the contribution due to precipitation is higher, at 17 percent (Mason, 1967), and in Bonneville basin, at 27 percent (Stauffer, 1985). During Pleistocene time, when perennial lakes had larger surface areas, the contribution due to precipitation on the lake surface was higher.

Previous work

A comprehensive study on the water supply of the western U.S. was published by Harding (1965). Harding summarized the water budgets through 1960 for many lakes in the western U.S. including Pyramid, Winnemucca Dry, Walker and Mono Lakes. He concluded that for lakes in the western U.S. the period 1860-1915 showed a rise in water supply, while 1928-1935 was a drought period. Historical variations in water supply were documented, but no corrections for diversion or consumptive use were included.

Pyramid and Winnemucca Dry Lakes

The historical water balance for Pyramid and Winnemucca Dry Lakes was studied by Hardman and Venstrom (1941). From historical lake-levels, estimated evaporation, reconstructed precipitation and estimated diversion, they reconstructed the pristine streamflow of the Truckee River.

Great Salt Lake

The recent rise in the level of Great Salt Lake has resulted in renewed water budget studies. Whitaker (1971) documented changes in the lake level caused by diversion practices. Stauffer (1980, 1985) developed a computer model capable of reconstructing lake-levels for pristine conditions. The general trend of the pristine and historical lake-level variations are similar, however, the pristine lake-levels tend to be 2 meters higher than historical lake-levels (figure 2).

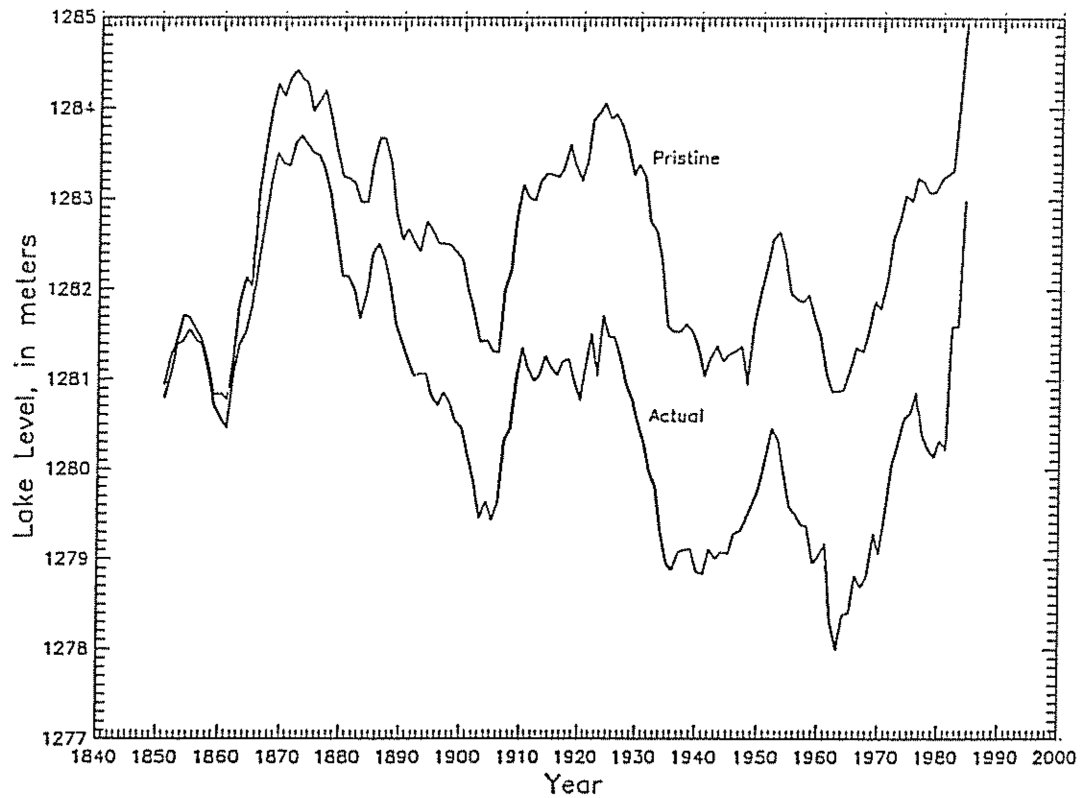


Figure 2.--Historical and pristine lake-level variations for Great Salt Lake (after Stauffer, 1985).

Mono Lake

Mono lake has been studied extensively since the installation in 1941 of diversion tunnels by the Los Angeles Department of Water and Power (LADWP) that export significant amounts of water from the basin. Vorster (1985) estimated all variables in the water budget for the basin, reconstructed lake levels for conditions of no export, and developed stage-area-volume relationships for the lake based on data in Scholl and others (1967). The LADWP (1984) developed a computer model for Mono Lake capable of reconstructing lake levels for no export, and developed stage-area-volume relationships based on data in Russell (1889). The LADWP stage-area-volume relationships differ from those developed by Vorster. LADWP (1987a) refined the stage-area-volume relationships and simulated lake levels based on the new data. The results of the two lake-level models differ. However, both reconstructions indicate the same lake-level variations (figure 3); the Vorster curve has a slightly higher lake level. Both the results of Vorster and LADWP indicate that Mono Lake would have remained near a historical highstand had no water been exported from the basin.

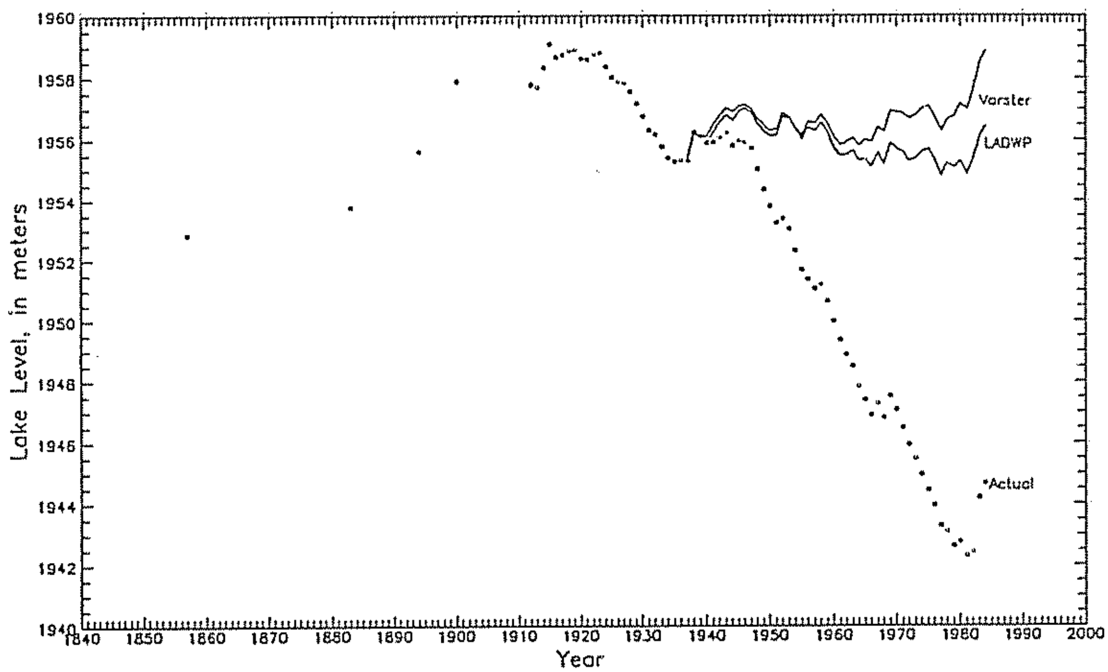


Figure 3.--Historical and pristine lake-level variations for Mono Lake (after LADWP, written comm., 1987; Stine, 1980; Harding, 1965; and Vorster, 1985).

METHODS

Water-balance model

A computer-generated water-balance model was used to calculate the yearly variations in water supply for each lake. The model uses the continuity equation:

$$\Delta S = V_i - V_o$$

where : ΔS = change in storage

V_i = volume input

V_o = volume output

By definition, interbasin ground-water flow and surface outflow do not occur in a closed-basin system, thus, the only output occurs through evaporation. Input comes through direct stream discharge, precipitation on the lake surface, and ground-water inflow. Data required for the lake-level reconstructions include historical lake levels, pristine stream discharge, precipitation directly on the lake, evaporation from the lake surface, and ground-water inflow to the lake. Also, the relationship between lake level and the corresponding volume and surface area (stage-area-volume relationships) must be known.

Water-balance calculations are conducted on an annual basis, assuming all inputs and outputs occur instantaneously. All inflow occurring during a given year is added to an initial volume, then annual precipitation is added, annual evaporation is subtracted, and ground-water inflow is added (figure 4). This annual approach is necessary due to the lack of adequate monthly records for evaporation and historical stream discharge. This approach is valid in that it approximates the natural system where most of the stream discharge occurs in early spring and most evaporation occurs in summer and fall (Benson, 1986).

For each of the lakes, the historical water balance was calculated using the following equations:

$$V_{t-1} + Q = V_{11}$$

$$A_1 = \text{function of } (V_{11} \text{ and } A\text{-}V)$$

$$V_{11} + (A_1 * P) = V_{12}$$

$$A_2 = \text{function of } (V_{12} \text{ and } A\text{-}V)$$

$$V_{12} - [A_2 * (E-G)] = V_t$$

where: V_{t-1} = volume of lake at end of year t-1

Q = total inflow due to stream discharge for year t

V_{11} = volume resulting from input of Q

A-V = area-volume relationship

A_1 = surface area of lake resulting from input of Q, a function of V_{11} and A-V

P = annual precipitation rate for year t

V_{12} = volume of lake resulting from input of P

A_2 = surface area of lake resulting from input of P, a function of V_{12} and A-V

:

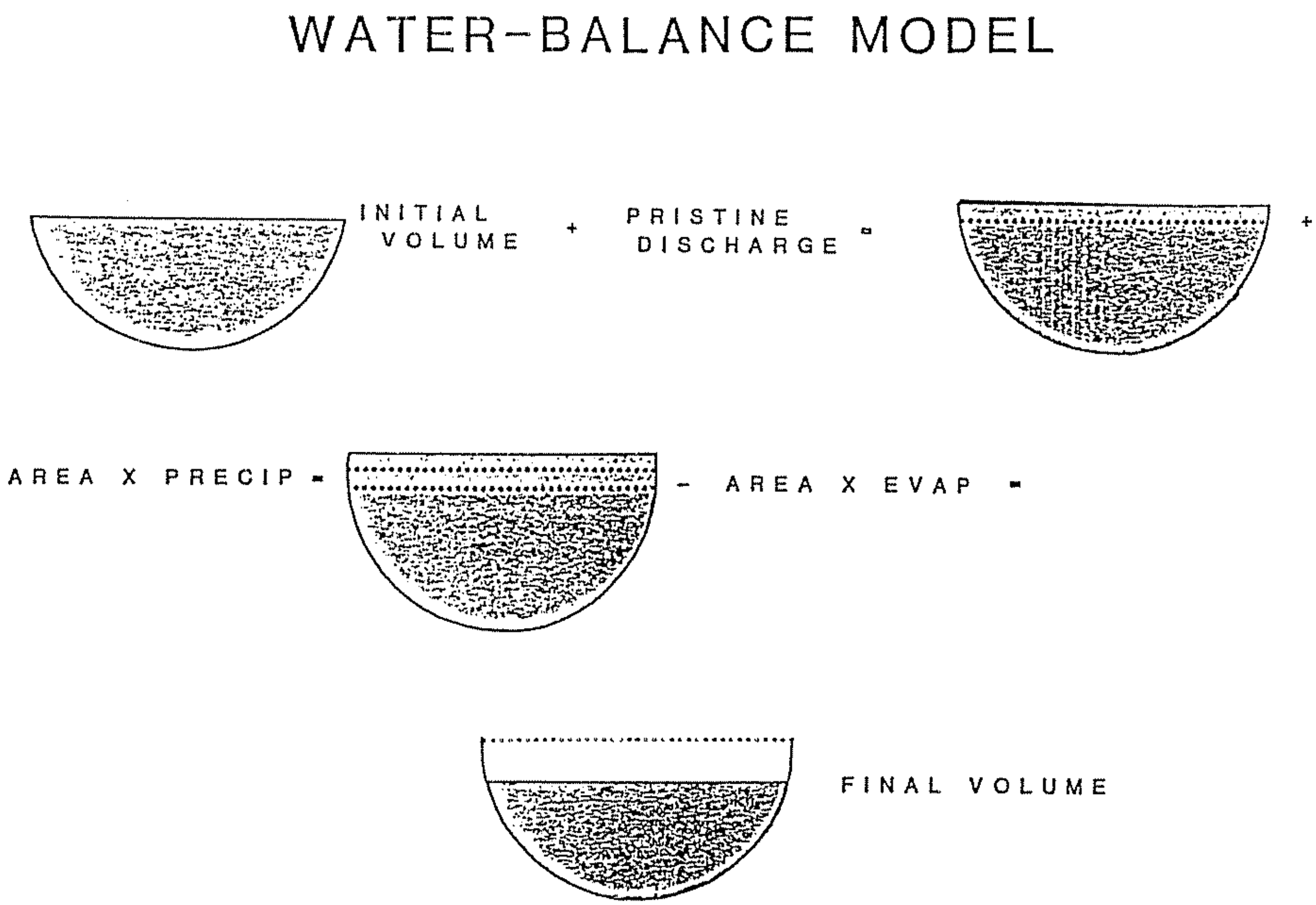


Figure 4.--Schematic diagram showing method of calculating changes in lake level.

E = annual evaporation rate for year t

G = ground-water inflow for year t

V_t = reconstructed volume of lake at end of year t

The volume (V_{t-1}) was determined from historical lake-level records and published stage-area-volume relationships. The amount of inflow (Q) during the next year (t) was added to the initial volume, resulting in a new volume. Because of the increase in volume, the lake achieved a new surface area (A_1). Precipitation on the lake was determined by multiplying the precipitation rate (P) by the surface area (A_1). The volume of water contributed from precipitation ($P*A_1$) was then added to the volume of the lake and a new volume (V_{11}) and surface area (A_2) were determined. Evaporation from the lake and ground-water inflow to the lake was then calculated as the residual term (E-G) multiplied by the surface area (A_2) and subtracted from the lake volume (V_{11}), resulting in the reconstructed lake volume (V_1). Using the final volume (V_1), the reconstructed lake level and area were determined from the stage-area-volume relationships. The final volume becomes the initial volume for the next year.

Model input parameters

Historical lake levels. Historical lake levels documented by Harding (1965) and the U.S. Geological Survey (1884-1950) were used as starting values for calculating lake-level variations. The importance of the starting point for the calculations cannot be overemphasized. In the pristine state, a lake reaches an equilibrium point between input and output. Therefore, if pristine lake-level calculations are begun at a year when human influences have already affected the lake level, it may take up to 200 years of water-balance calculations for the lake to reach a theoretical equilibrium point. Lake-level calculations were started at a time prior to human influence in the basin when possible. However, estimates of starting lake-levels are only as good as the data in historical records. For example, historical lake-levels were determined for Pyramid Lake from a photograph taken of Pyramid Island during the 40th Parallel Survey (Hardman and Venstrom, 1941). The exact date of the photograph is unknown and numerous workers have attempted to determine when the picture was taken. Since the validity of the earliest historical lake-level data may be questioned, the water-balance simulations were conducted using several different starting times.

Pristine stream discharge into the lake. Human influence on stream discharge began in the Great Basin region with the first settlements in 1859 (Houghton, 1986). Therefore, historical stream discharge records do not indicate pristine stream discharge and a value for pristine stream discharge into most lakes must be estimated. If the amount of diversion and consumptive use are known, the amount of water consumed can be accounted for, and a new lake level can be calculated. However, most consumptive-use records, especially for early years of diversion, are estimates. Since the lake level of one year is dependent upon the previous year, the errors associated with such estimates are cumulative.

In order to estimate pristine stream discharge, gaging stations were selected that meet the following criteria:

(a) the station is located below most tributary streams

(b) the station is located above all significant diversions, and

(c) the station records exist for at least 50 years

For example, in order to estimate pristine stream discharge into Pyramid Lake, several stations along the Truckee River may be selected including stations located at Truckee, Farad, Wadsworth or Nixon (figure 10). Both the Nixon and Wadsworth stations are located close to the lake and would represent actual inflow to the lake. However, both of these stations are located below a dam where over one-half of the discharge is diverted out of the basin. Thus, these stations under-estimate pristine stream discharge into the lake. The station at Truckee is located above the diversion in the basin, however, several tributary streams join the river below this station. Therefore, the Truckee station would also under-estimate pristine stream discharge into the lake. The Farad station is located below tributary inputs, yet above the diversions. If the Truckee River flowed without human interference from the Farad station to the lake below, the measured flow at Farad would approximately equal the flow that would reach the lake. This method does not account for ground-water gains or losses occurring in the stream channel below the selected gaging stations. For Pyramid and Walker lakes water input is primarily a function of precipitation in the upper reaches of the drainage system (the Sierra Nevada Mountains) and therefore, negligible amounts of water are contributed to the streams below the selected gaging stations, and losses are minimal when compared to the total flow.

Stream-discharge correlation. For the years that lack stream discharge measurements at the selected stations, flows were estimated by correlation with other gaging-station records. All of the available yearly discharge data (calendar and water year) for U.S. Geological Survey (USGS 1960, 1963, 1961-84) gaging stations on the Truckee, Walker and Carson Rivers were examined. An ordinary least squares linear regression was performed to estimate stream discharge and determine the degree of correlation between discharge at the different gaging stations (tables 1 and 2). For years when data were lacking, the correlation with the highest coefficient of determination (R^2) and lowest standard error of estimate (S) was used to estimate the discharge. The coefficients of determination ranged from 0.57 to 0.99 and standard errors of estimate ranged from 3.5 to 34.5 percent. Linear regression equations are summarized in Appendix B.

For years prior to 1900, no discharge records were available. Therefore, water-year discharge was correlated with water-year precipitation values for three National Oceanographic and Atmospheric Administration (NOAA) (U.S. Weather Bureau, 1870-1965; U.S. Department of Commerce, 1966-86) weather stations located at Truckee, California, Sacramento, California, and Reno, Nevada. The highest correlation between Truckee and Walker River discharge was with precipitation at Truckee, California. Therefore, precipitation at Truckee was used to estimate water-year discharge for years prior to 1900, and the water-year discharge was later converted to calendar-year discharge

Table 1.--Streamflow statistics for gaging stations used in study (USGS, 1884-1950, 1950-1960, 1961-1986).
[$km^3\ yr^{-1}$, cubic kilometers per year]

River/Gage Name	Gage Number	Years of record	Mean Discharge ($km^3\ yr^{-1}$)	Standard deviation ($km^3\ yr^{-1}$)
Truckee River at Farad	346000	86	0.7307	0.3706
Truckee River below Derby Dam, near Wadsworth	351600	68	0.3642	0.4114
Truckee River near Nixon	351700	26	0.5009	0.5404
East Walker River near Bridgeport	293000	61	0.1329	0.0706
West Walker River near Coleville	296500	55	0.2508	0.1132
Walker River near Wabuska	301500	56	0.1543	0.1516
Walker River near Schurz	336	19	0.1407	0.1639
East Fork Carson River near Gardnerville	309000	61	0.3602	0.1581
West Fork Carson River at Woodfords	310000	67	0.1056	0.0460

Table 2.--Linear regression statistics for estimating yearly stream discharge.

[X, station number of independent variable; Y, station number of dependent variable; PPT, water-year precipitation at Truckee, California; R^2, coefficient of determination; N, sample size; S, standard error of estimate; km^3, cubic kilometers; T, Truckee River; W, Walker River; C, Carson River]

X	River	Y	River	N (years)	R^2	S (km^3)	S %	No. Years Estimated
346000[2]	T	346000	T	86	0.95	0.0830	11.4	1
309000	C	346000	T	57	0.79	0.1612	22.1	4
PPT		346000[1,2]	T	20	0.79	0.1579	21.6	26
296000	W	296500	W	26	0.99	0.0088	3.5	19
296500[2]	W	296500	W	55	0.99	0.0093	3.7	2
309000	C	296500	W	34	0.95	0.0231	9.2	8
310000	C	296500	W	36	0.91	0.0364	14.5	5
293000	W	296500	W	41	0.88	0.0348	13.9	1
346000	T	296500	W	55	0.76	0.0550	21.9	1
PPT		296500[1,2]	W	12	0.57	0.0864	34.5	26
293000[2]	W	293000	W	61	0.96	0.0141	10.6	2
296500	W	293000	W	41	0.88	0.0250	18.8	13
309000	C	293000	W	50	0.84	0.0272	20.5	9
310000	C	293000	W	47	0.81	0.0310	23.3	5
346000	T	293000	W	61	0.76	0.0348	26.2	1
PPT		293000[2]	W	49	0.59	0.0441	33.2	2

[1]data set limited to pre-diversion records (1900-30)

[2]water year discharge

using regression methods (table 2). The correlations were improved by using pre-diversion discharge records (1900-1930). The coefficients of determination, standard errors of estimate, and number of years estimated are summarized in table 2.

Precipitation on the lake surface. Precipitation falling directly on the lake was determined by multiplying annual precipitation for a station near the lake by lake surface area. Annual precipitation was determined using NOAA climatological data (U.S. Weather Bureau, 1870-1965; U.S. Department of Commerce, 1966-86). When data were lacking, the long-term mean precipitation was used. In general, precipitation falling directly on the lake is small relative to other input sources and is not variable. Therefore, variations in annual precipitation did not affect the overall results of the model.

Evaporation from the lake surface. Evaporation, the only source of output from closed-basin lakes, is critical in determining an accurate water-balance. The total amount of water evaporated from a lake was determined by multiplying a yearly free-water surface-evaporation rate by the area of the lake.

Annual free-water surface-evaporation data are not available for locations on or near Pyramid, Winnemucca Dry, Walker and Owens Lakes. Therefore, several different sources of evaporation data were used. Class A pan-evaporation data collected at NOAA weather stations were compiled (U.S. Weather Bureau, 1870-1965; U.S. Department of Commerce, 1966-86). Evaporation rates were also determined from the U.S. Weather Bureau evaporation maps for the United States (U.S. Weather Bureau, 1959). Harding (1965) determined evaporation rates from values of historical lake-levels and stream discharge. The year-to-year variability in evaporation rate is small, and, therefore, yearly variations in evaporation rates do not affect the overall results of the model, and use of mean values is valid.

Ground-water discharge. Subsurface inflow to surface-water bodies in the Lahontan basin is estimated to be less than 5 percent of the total water input to a lake (Everett and Rush; 1967 and Van Denburgh and others, 1973) Ground-water inflow to all the lakes was considered minimal for the purpose of the lake-level calculations, but was calculated as a residual term during the model calibration process. Input to and output from a river via ground-water flow below the selected gaging station were not considered.

Stage-area-volume relationships

The relationship between lake level and the corresponding volume and surface area is critical in determining an accurate water balance. Small changes in lake volume can result in large changes in lake level if the topography of the lake basin is steep and narrow. If a lake basin is wide and shallow, large changes in volume are necessary to bring about small lake-level variations.

Model Calibration

The water-balance model was calibrated using historical stream discharge (measured at the station nearest the lake inlet) and historical precipitation data. Differences between predicted and actual lake-level curves are due to improper stage-area-volume relationships, inaccurate estimation of discharge, inaccurate estimation of evaporation, or inaccurate estimation of ground-water inflow. Slight differences in lake levels were recognized during the calibration process. The general trend of the lake-level variations matched, but the curves were slightly offset. The differences are believed to result from a combination of inaccurate estimation of evaporation and ground-water inflow, the two most difficult terms to quantify. To correct the offset between the predicted and actual lake-level curves, the term "evaporation minus ground water" (E-G) was adjusted, resulting in a match between predicted and actual lake-level data. E-G was then used to quantify both evaporation and ground-water inflow during the reconstruction process. Model calibration improves the accuracy of the lake level reconstructions. However, the purpose of this study is to reconstruct relative variations in lake size over an extended period of time. Therefore, the reconstructions represent approximate rather than absolute lake levels.

APPLICATION OF THE WATER-BALANCE MODEL

Walker Lake

Hydrogeologic and Climatic Setting

Hydrogeologic setting. Walker Lake, located in western Nevada, receives inflow from the east and west forks of the Walker River (figures 1 and 5). The Walker River drainage basin is approximately 10,900 km^2 (State of Nevada, 1971) in area; the source of most runoff is from the Sierra Nevada Mountains.

Consumptive use of water within the Walker Lake basin occurred as early as 1859 (Houghton, 1986). In recent years, significant diversion has occurred in the areas of Smith Valley, Mason Valley and Schurz. Based on 1969 figures, approximately 0.38 cubic kilometers (km^3) of water are withdrawn annually for irrigation, and 0.0015 km^3 are withdrawn for domestic use. Approximately 299 km^2 of land is irrigated yearly (State of Nevada, 1971). Flow of the Walker River is regulated by lakes and reservoirs including: Twin Lakes, Bridgeport Reservoir (constructed in 1923), Topaz Lake (constructed in 1922), and Weber Reservoir (constructed in 1935), (USGS, 1884-1950, 1950-1960, 1961-1986).

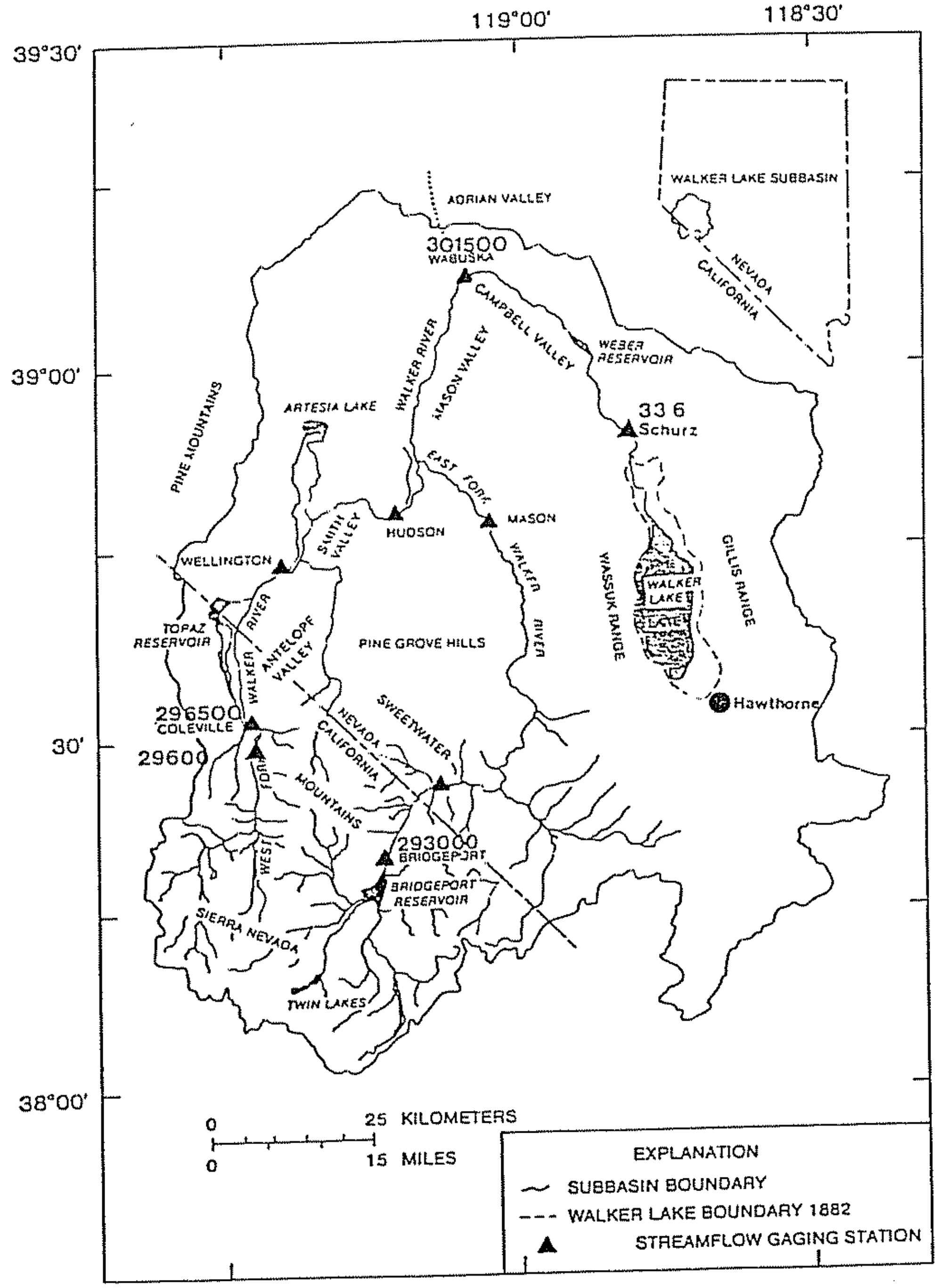


Figure 5.--Location map of the Walker Lake drainage basin (after Benson, 1986).

Climatic setting. Precipitation in the Walker River basin is dependent upon topography. Precipitation varies from a maximum of 66 centimeters (cm) per year at higher altitudes and a minimum of 7 cm per year at lower altitudes (State of Nevada, 1971). Peak discharge occurs during the months of May and June (USGS, 1884-1950, 1950-1960, 1961-1986) due to the snowmelt in the surrounding mountainous regions.

Model input

Pristine stream discharge. In order to reconstruct pristine stream discharge for Walker Lake, available USGS stream discharge records (USGS, 1884-1950, 1950-1960, 1961-1986) for the basin were compiled. The records were studied in order to determine which sections of the stream were gaining or losing water. A gaging station on each fork was selected, according to the criteria discussed previously, to represent pristine flow conditions. Station 293000 (East Walker River near Bridgeport, figure 5) and station 296500 (West Walker River near Coleville, figure 5) were chosen. For years lacking data, linear-regression relationships were used to estimate stream discharge. For years after 1900, coefficients of determination (R^2) range from 0.76 to 0.99, with standard errors ranging from 3.5 to 21.9 percent. Streamflow statistics and a summary of estimated data are listed in tables 1 and 2. Discharge records available for these stations and the equations used for the estimates are included in Appendix B.

Precipitation on the surface of Walker Lake. Precipitation on the surface of Walker Lake was determined using climatological data (U.S. Weather Bureau, 1870-1965; U.S. Department of Commerce, 1966-86) collected at Hawthorne, Nevada (figure 5), the nearest weather station to the lake. For years lacking data, the 38-year mmean annual precipitation value of 13.3 cm (table 3) was used.

Evaporation from Walker Lake. Class A pan-evaporation data (U.S. Weather Bureau, 1870-1965; U.S. Department of Commerce, 1966-86) collected at Fallon and Lahontan Dam (figure 10) were used to estimate evaporation for Walker Lake. These stations are located approximately 100 kilometers (km) north of the lake, and are situated at approximately the same altitude. Monthly temperatures (U.S. Weather Bureau, 1870-1965; U.S. Department of Commerce, 1966-86) at Fallon, Hawthorne and Lahontan Damm were compared in order to determine if one station was more representative of actual evaporative conditions at the lake. The same degree of correlation was found to exist between both northern stations and Hawthorne. Mean annual evaporation rates are quite different at the Fallon and Lahontan Dam stations. This difference may be due to changes in relative

Table 3.--Precipitation statistics for stations used in the study (U.S. Weather Bureau, 1870-1965; U.S. Department of Commerce, 1966-86; LADWP, 1976).

Station	Record length (years)	Mean-annual precipitation (centimeters)	Standard deviation (centimeters)
Hawthorne, NV	38	13.3	4.4
Reno, NV	125	17.8	6.6
Truckee, CA	98	74.9	24.1
Nixon, NV	30	16.5	4.9
Owens Lake	31	12.5	--

humidity resulting from agricultural procedures. Therefore, data from both sites were used during the calibration process, along with evaporation rates from other sources, to determine which evaporation rate could best estimate evaporative conditions at the lake. Evaporation data from all the sources considered are summarized in table 4.

Ground-water discharge. Actual ground-water inflow to Walker Lake has not been quantified, however, no visible spring discharge has been identified near the lake and ground-water discharge is believed to be low (Benson, 1987). Ground-water inflow to the lake was estimated during the calibration process.

Stage-area-volume relationships

Stage-area-volume data are available in 1-meter altitude increments for Walker Lake (Benson and Mifflin, 1986). However, 1-meter altitude increments represent large changes in volume; therefore, interpolations using a spline-fitting algorithm were conducted to develop data points at 10-centimeter altitude increments. The stage-area-volume data for Walker Lake are included in Appendix C.

Table 4.--Summary of evaporation data used during the calibration process.

Data source	Mean annual free-water surface-evaporation rate (meters per year)
Lahontan Dam, (U.S. Weather Bureau, 1870-1965; U.S. Department of Commerce, 1966-86)	1.44
Fallon Experimental station, (U.S. Weather Bureau, 1870-1965; U.S. Department of Commerce, 1966-86)	0.92
Average of Lahontan Dam and Fallon data	1.20
U.S. Weather Bureau Evaporation Map, 1959	1.14 - 1.27
Harding, 1965	1.22 - 1.25
Hardman and Venstrom, 1941	1.32 - 1.37
LADWP, 1976	1.22

Historical lake-level variations

Historical lake-level variations for Walker Lake are summarized in figure 6. The lake was at a low level (approoximately 1230 m) during the period 1840-1860 and reached a historical highstand of 1246.3 m in 1870 (Harding, 1965). Prior to 1,700 yr B.P., it is believed that the lake desiccated on several occasions (Benson, 1987). In recent years, the lake has steadily declined to a historical lowstand of 1204.8 m in 1982. During 1983, the wettest year since 1600 (Smith, 1986), extraordinariily high runoff led to a rise in lake level. Historical lake-level data are included in Appendix D.

Model calibration

The water-balance model for Walker Lake was calibrated using historical stream discharge data (USGS, 1884-1950, 19950-1960, 1961-1986) from Schurz, Nevada (figure 5, station number 336), the gage located nearest the lake. For years lacking data, discharge was estimated using a linear-regression relationship between stream discharge at Walker River near Wabuska (figure 5, station number 301500) and the Schurz station. The coefficient of determination (R^2) is 0.99, with a standard error of 5.5 percent.

Table 5.--Summary of model input data for Walker Lake calibration and pristine reconstructions. [m/yr, meters per year; C, calibration; P, pristine; Sim., simulation; Avg L+F, average of Lahontan Dam and Fallon; 2930+2965, total flow at 293000 and 296500]

Sim. number	Type of Sim.	Starting year	Evaporation data set (or rate, m/yr)	Discharge data set	Precipitation data set
1	C	1927	Lahontan Dam	estimated 336	Hawthorne
2	C	1927	Fallon	estimated 336	Hawthorne
3	C	1927	Avg btw L+F	estimated 336	Hawthorne
4	C	1927	1.25	estimated 336	Hawthorne
5	C	1919	1.25	estimated 336	Hawthorne
6	C	1919	1.30	estimated 336	Hawthorne
7	C	1927	1.30	estimated 336	Hawthorne
8	C	1927	1.35	estimated 336	Hawthorne
9	P	1871	1.35	estimated 2930+2965	Hawthorne
10	P	1927	1.35	actual 2930+2965	Hawthorne
11	P	1903	1.35	estimated 2930+2965	Hawthorne

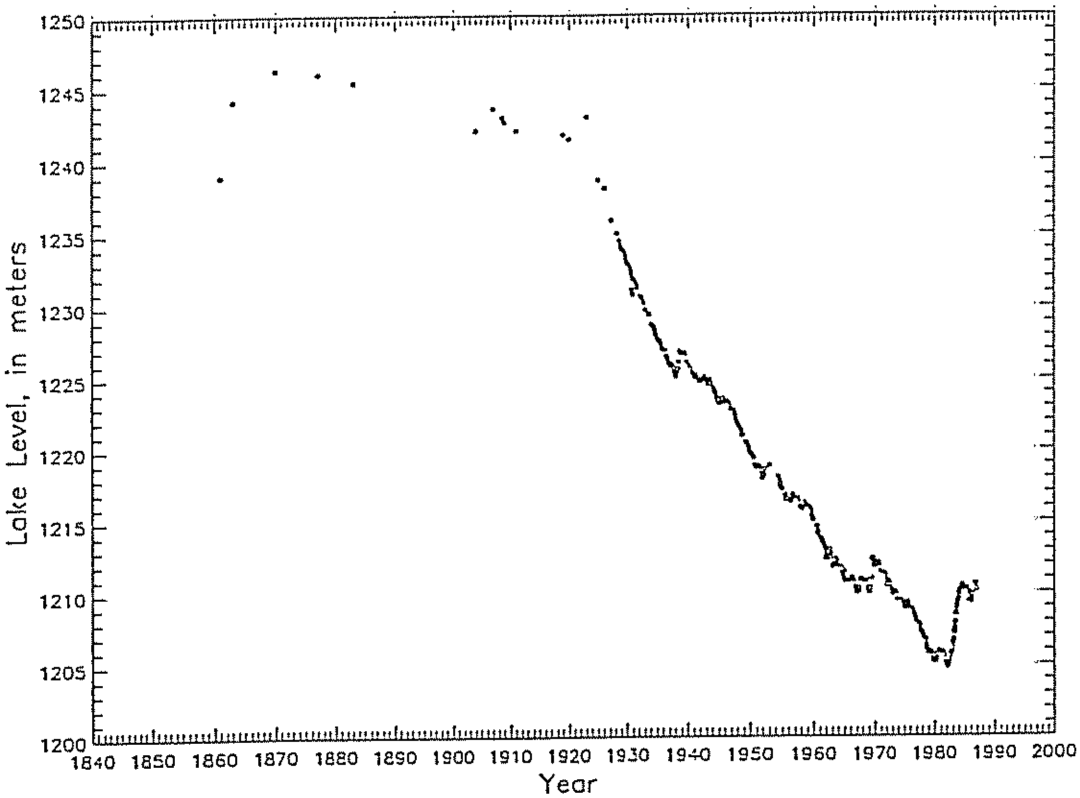


Figure 6.--Historical lake-level variations for Walker Lake (after Harding, 1965 and USGS, 1884-1950, 1950-1960, 1961-1986).

The model was used several times incorporating the historical stream discharge data and historical precipitation data, with varying evaporation rate from the data sources discussed previously (table 4). The general lake-level trend was always duplicated; however, the use of different evaporation rates resulted in an offset of the lake-level curves (figure 7). Table 5 summarizes the input parameters used during the calibration process. An evaporation rate of 1.35 m per year was determined (Simulation 8) to provide the best match between actual and estimated lake-level curves (figure 8). This value of 1.35 m actually represents a residual term that incorporates both evaporation and ground-water inflow (E-G). The model lake-levels, calculated during Simulation 8 using an E-G of 1.35 m, correlated well with the actual lake-level (figure 8, $R^2 = 0.99$). The E-G of 1.35 m per year was then used in the lake-level reconstructions.

Simulations 1-3 use Class A pan-evaporation data from Fallon and Lahontan Dam. These data sets incorporate year-to-year variability in evaporation. However, the reconstructions show that this variability tends to be masked by the year-to-year variability in stream discharge when compared to the results of Simulations 4-8 that use a mean evaporation rate with no year-to-year variability.

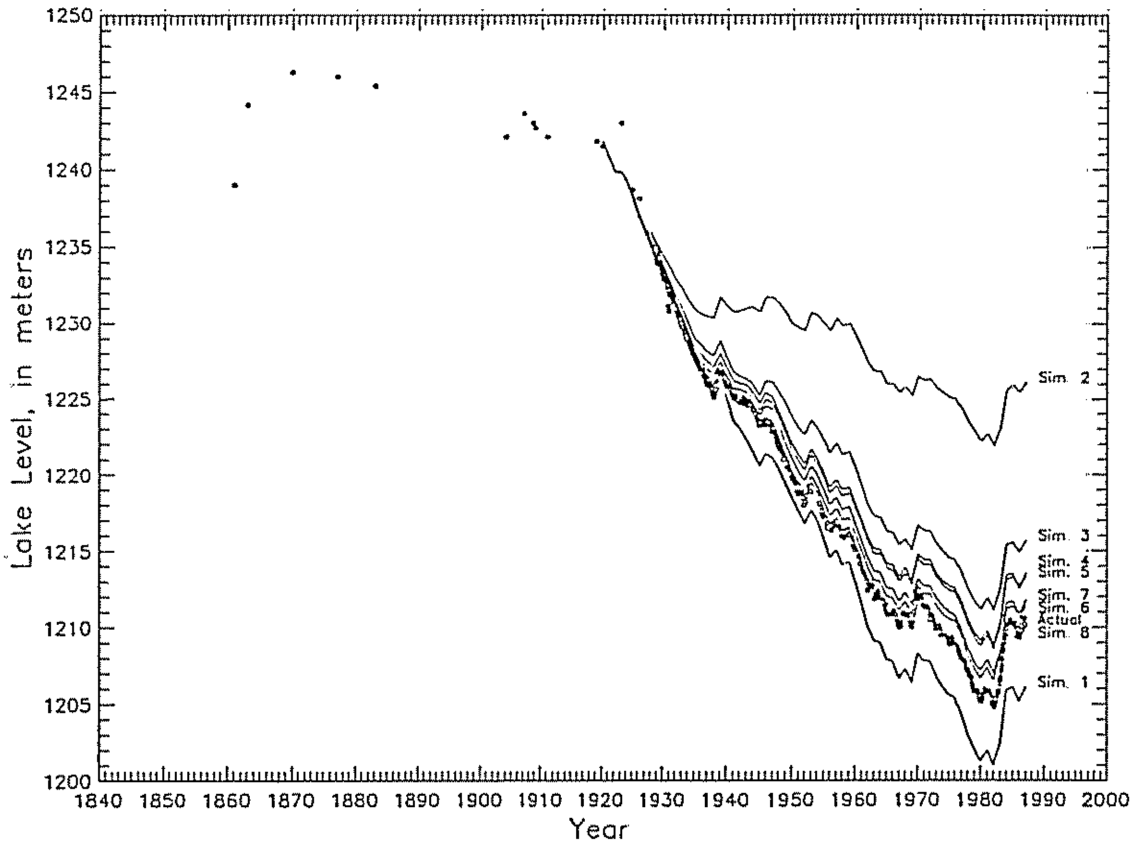


Figure 7.--Model-calibration results for Walker Lake (refer to Table 5 for summary of model input data).

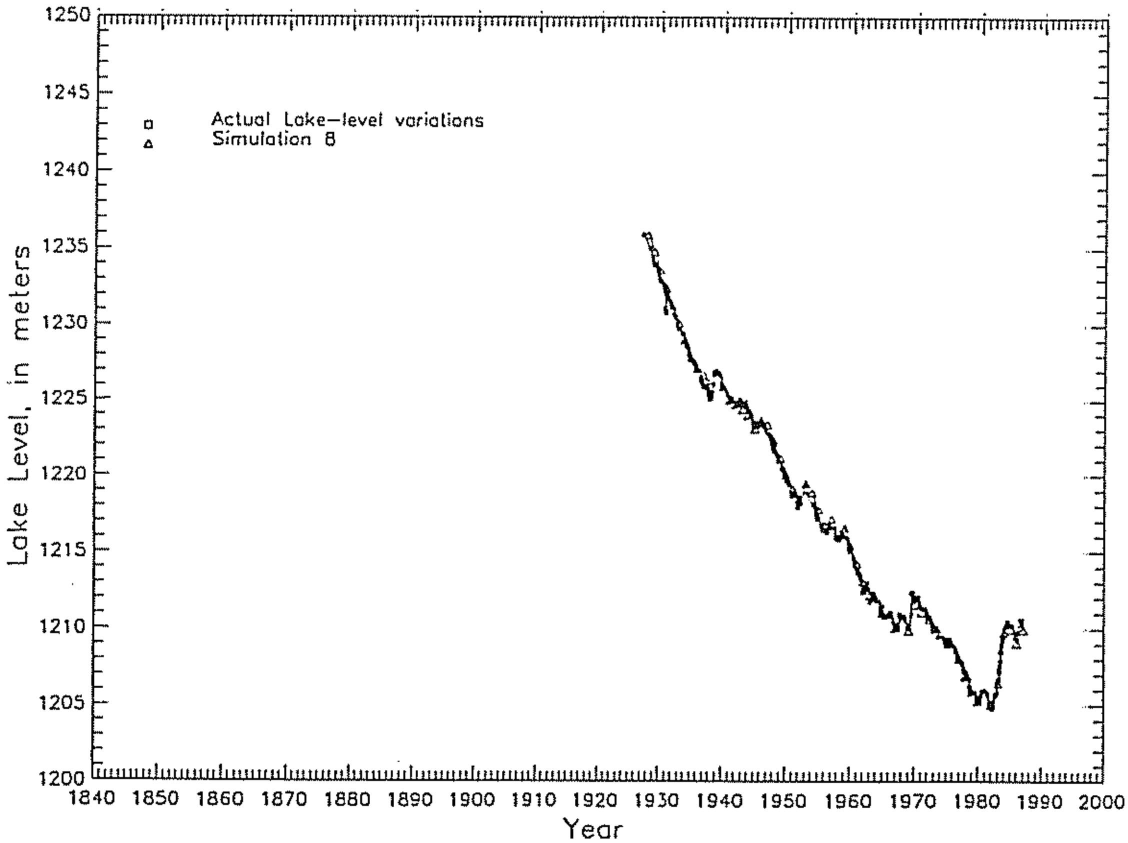


Figure 8.--Comparison of model-calibration results with historical lake-level variations for Walker Lake.

Pristine Lake-level reconstructions for Walker Lake

Pristine lake-level reconstructions were conducted using different sets of input data. Input parameters that were varied included starting year and discharge data (estimated versus actual). The input parameters for each of the simulations are summarized in table 5. Reconstructed lake-levels for each of the simulations are illustrated in figure 9. Simulation 9 (figure 9, dashed line) represents the best approximation of pristine conditions. Simulations 10 and 11 use the same input data as Simulation 9, however, these simulations began during years after the lake had been affected by human influences. The results of Simulations 10 and 11 indicate the same variations in lake level, however the curves are offset by 2 to 20 meters because the lake has not equilibrated (illustrating the importance of the starting year for the lake-level calculations). Each reconstruction indicates that Walker Lake would have risen above the historical highstand if pristine conditions prevailed. The resulting lake-levels from Simulation 9 are included in Appendix E.

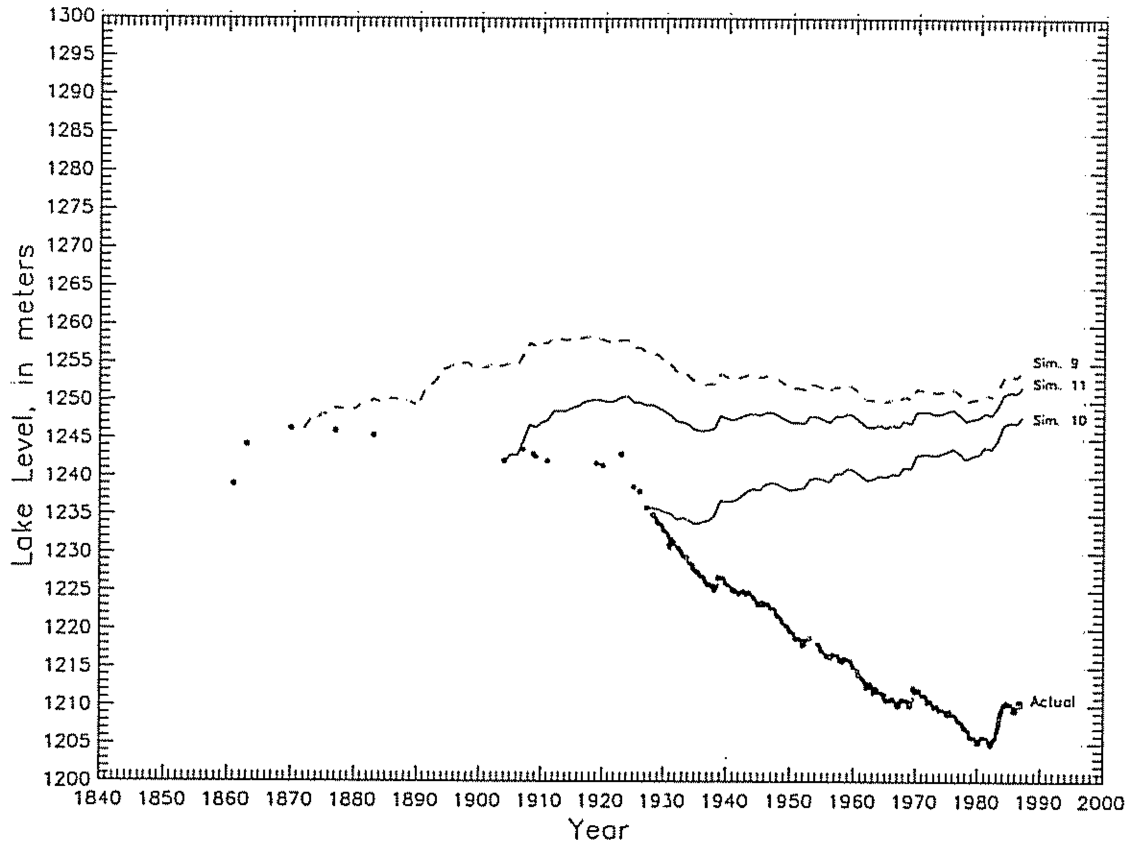


Figure 9.--Pristine lake-level reconstructions for Walker Lake (refer to Table 5 for summary of model input data).

Pyramid and Winnemucca Dry Lakes

Hydrogeologic and Climatic Setting

Hydrogeologic setting. The Pyramid and Winnemucca Dry Lakes drainage system (figure 10) is located in north eastern California and west-central Nevada and encompasses an area of approximately 7,040 km^2 (State of Nevada, 1971). The lakes receive inflow from the Truckee River, which receives runoff from the Sierra Nevada Mountains and originates at Lake Tahoe. The Truckee River has a reach of approximately 130 km from the headwaters at Lake Tahoe to Pyramid Lake. When flow was sufficient, the Truckee River bifurcated at Marble Bluff (3 km northwest of Nixon) and discharged in part into a lateral channel called the Mud Lake Slough (figure 11), to fill Winnemucca Dry Lake. The division of water through the slough was unequal because the slough has a bedrock threshold altitude of 1177 m and the river, flowing into Pyramid Lake, has an altitude of 1174 m (Hattori, 1982). Winnemucca Dry Lake only received water from the Truckee River when the river rose above the 1177 m $\times$ 3.281 = 3862 ft. threshold by increased stream discharge, blockage of the Truckee downstream from the slough entrance, or filling and overflow from Pyramid Lake. Once Pyramid Lake reached an altitude of 1177 m, the two lakes merged into one large lake. Below the sill level of 1177 m, the lakes received different volumes of water.

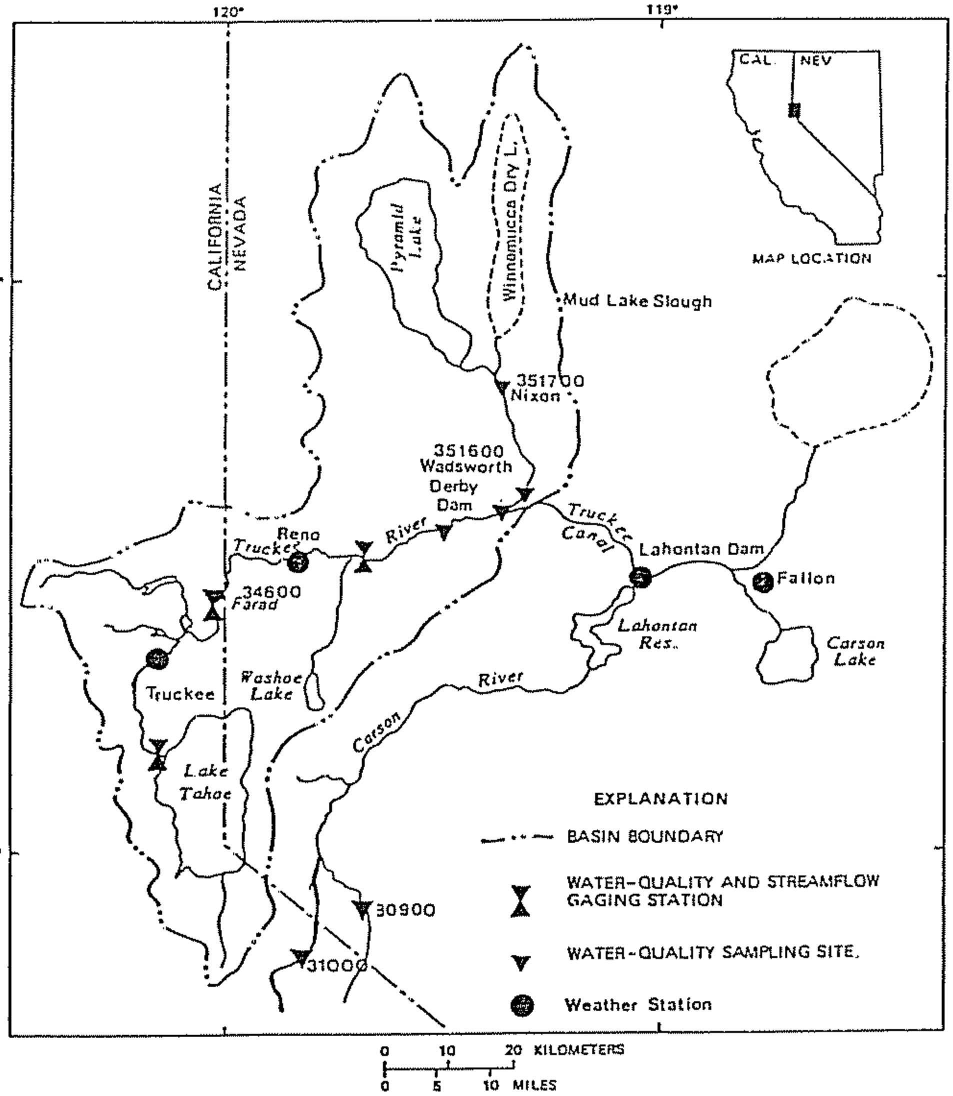


Figure 10.--Location map of the Pyramid and Winnemucca Dry Lakes drainage basin (after Benson, 1984).

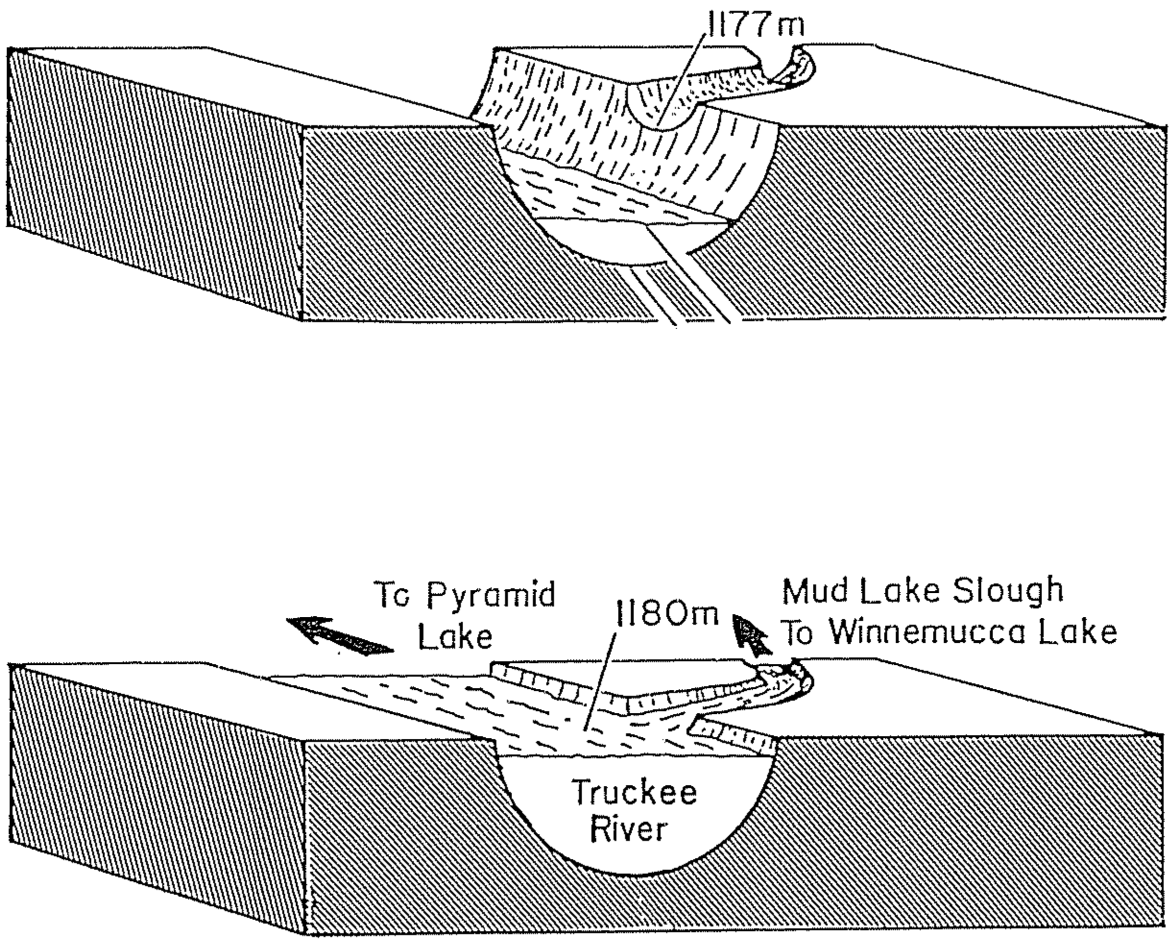


Figure 11.--Cross-sections of the Truckee River channel at the Mud Lake Slough (after Hattori, 1982).

Historically, Pyramid Lake received most of the Truckee River flow. However, in the summer of 1876, a gravel bar formed across the Truckee River and permitted water to flow exclusively into Winnemucca Dry Lake until spring runoff flushed the bar away (Hattori, 1982). In the late 1880's, a debris dam across the Truckee River blocked the water flow into Pyramid Lake; the dam was removed artificially (Hattori, 1982). In 1888 or 1889, the Indian Service constructed a tight brush and rock dam across the mouth of the slough to prevent water from entering Winnemucca Dry Lake. The dam deteriorated about 1891 (Hardman and Venstrom, 1941). A highway was constructed across the slough, in recent years, preventing all flow from the Truckee River into Winnemucca Dry Lake (Harding, 1965). $\times \frac{10^9 m^3}{km^3} \times \frac{1 AF}{1233 m^3} = 43 KAF/yr$

that's not what prevented inflow to W.L.

Approximately 0.053 km^3 of water is withdrawn from the Truckee River basin for domestic, public-supply and industrial use (based on 1969 figures, Van Denburgh and others, 1973); 0.037 km^3 is obtained from the Truckee River. The remaining 0.016 0.009 km^3 is obtained from alluvial wells. The greatest ground-water withdrawal, of approximately 0.009 km^3 annually, supplies the Reno-Sparks municipal system (Van Denburgh and others, 1973), the second-largest population center in Nevada. Water is also used in a non-consumptive capacity for electric-power generation, totaling 0.926 km^3 annually (Van Denburgh and others, 1973).

Irrigation withdrawals are mostly from the Truckee Rivver, and much ~1/3? of the water is returned to the system after use. Consumptive use of water above the gaging station at Farad, California is approximately 0.020 km^3 16 KAF ?? per year (Van Denburgh and otherss, 1973). Irrigated acreage within the lower reach of the Truckee River (below Farad) is estimated at 113 km^2, with approximately 0.073 km^3 59 KAF ?? of water consumed annually for crop irrigation (State of Nevada, 1971). Since 1905, approximately 0.309 km^3 251 KAF of water has been diverted annually through the Truckee Canal at Derby Dam for irrigation use outside the Truckee River basin.

Regulation of the Truckee River began in 1870 when a timber dam was constructed at the outlet of Lake Tahoe. The present concrete dam was built in 1909 and allows storage of water approximately 1.83 m above the natural sill level. Additional dams have been constructed on Donner Creek, Prosser Creek and the Little Truckee River. Thus, reservoirs regulate approximately 70 percent of the Truckee River flow (Fordham and Butcher, 1970). Steamboat Creek, the only main tributary below Farad, joins the Truckee River upstream of Vista, Nevada (figure 10). All tributary streams below Vista are ephemeral.

<u>Climatic setting</u>. Precipitation patterns in the Truckee River basin are affected strongly by the presence of the Sierra Nevada Mountains Mountains flanking the western

edge of the basin. Orographic lifting of air masses moving eastward across the Sierra Nevada Mountains cause most of the precipitation to occur at the higher altitudes, resulting in a "rain shadow" in the areas to the east. Average annual-precipitation values vary from a minimum of 12 cm at lower altitudes to 100 cm in the higher areas (Van Denburgh and others, 1973). Maximum flows in the Truckee River ordinarily occur during the months of May and June (USGS, 1884-1950, 1950-1960, 1961-1986) as a result of snowmelt runoff.

Model input

Pristine stream discharge. In order to reconstruct pristine stream discharge for Pyramid Lake, available USGS stream discharge records (USGS, 1884-1950, 1950-1960, 1961-1986) for the basin were compiled. The records were studied to determine which sections of stream were gaining or losing water. The gaging station 346000 (Truckee River at Farad, figure 10) was selected to represent pristine conditions according to the criteria discussed previously.

Linear-regression relationships were used to estimate incompplete data. For years prior to 1900, data were estimated using a relationship with an R^2 of 0.79 and a standard error of 21.6 percent. These estimated data were then compared with similar data estimated by Hardman and

Venstrom (1941) (figure 12). The two data sets were found to correlate with an R^2 of 0.74 and when analyzed by a statistical t-test, the two data sets were determined not to be significantly different (the null hypothesis was accepted). Streamflow statistics and a summary of estimated data are summarized in tables 1 and 2. Discharge records and the equations used for the estimations are included in Appendix B.

Precipitation on the Surface of Pyramid and Winnemucca Dry Lakes. Climatological data collected at Nixon, Nevada (figure 10) the closest weather station to the lakes (U.S. Weather Bureau, 1870-1965; U.S. Department of Commerce, 1966-86) was used to estimate precipitation on the surface of Pyramid and Winnemucca Dry Lakes. The 30-year mean annual precipitation rate at Nixon is 16.5 cm, with a standard deviation of 4.9 cm (table 3).

Evaporation from Pyramid and Winnemucca Dry Lakes. Class A pan-evaporation data (U.S. Weather Bureau, 1870-1965; U.S. Department of Commerce, 1966-86) collected at Fallon and Lahontan Dam (figure 10) were used to estimate evaporation for Pyramid and Winnemucca Dry Lakes. These stations are located within 100 km of the lakes, and are at approximately the same altitude. Evaporation data from both sites, along with evaporation rates obtained from other sources (table 4) were used during the calibration process.

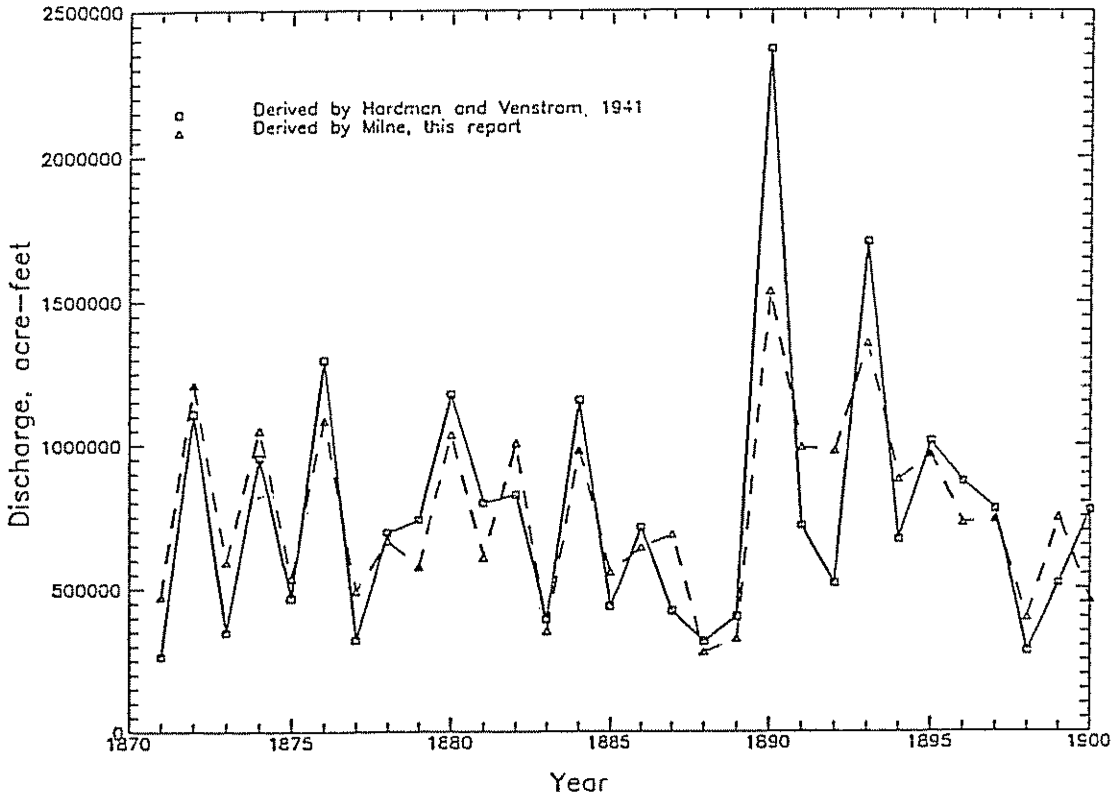


Figure 12.--Comparison of estimated pristine discharges for the Truckee River (after Hardman and Venstrom, 1941).

Ground-water discharge. Ground-water inflow to the Truckee River channel between the gages at Wadsworth and Nixon (figure 10) has been estimated by Van Denburgh and others (1973) as 5 KAF 0.0062 km^3. For a 51-year base period, the estimated inflow to Pyramid Lake via the Truckee River was 250 KAF 0.3083 km^3. Additional surface- and ground-water inflow from Warm Springs Valley and from within the local valley area adds approximately 10 KAF 0.0123 km^3 yearly, or an addition of 4 percent of the mean-annual discharge (Van Denburgh and others, 1973). Total ground-water inflow to Pyramid and Winnemucca Dry Lakes has not been quantified. However, ground-water inflow was estimated during the calibration process.

Stage-area-volume relationships

Stage-area-volume data are available in 1-meter altitude increments for Pyramid Lake (Benson and Mifflin, 1986) and in 1-foot increments from Harris (1970). Although differences do exist between the two data sources, the data from Benson and Mifflin were used because Harris did not present data for Winnemucca Dry Lake, or for lake-levels above the 1177-m threshold. Since 1-meter altitude increments are associated with large changes in volume, interpolations using a spline-fitting algorithm were conducted to develop data points at 10-centimeter altitude increments. Stage-area-volume data are included in Appendix C.

Historical lake-level variations

Historical lake-level variations for Pyramid and Winnemucca Dry Lakes are summarized in figures 13 and 14. Pyramid Lake reached a historical highstand of 1184.1 m in 1871 (Harding, 1965). Prior to that time, it is believed that the lake has not desiccated, and represents one of the few "remnant Pleistocene" lakes in the Great Basin (Benson and Thompson, 1987). During the period 1840-1860, the lake was at a relatively low level of approximately 1176 m. The lake has steadily declined in recent years to a historical lowstand of 1153.3 m in 1967. During the year 1983, extraordinarily high runoff resulted in a rise in the lake level.

Winnemucca Dry Lake reached a historical highstand of 1174.9 m in 1882 (Harding, 1965). Prior to that time, the lake was dry during the period 1840-1856 (Harding, 1965). Human influences affecting the Mud Lake Slough offset the natural water balance of the lake, and in 1940 Winnemucca Dry Lake went dry. Since that time no inflow has occurred through the slough because the slough is currently blocked by the highway, and inflow comes only through ground-water discharge, surface runoff and irrigation return flow within the immediate area of the lake. Historical lake-level data for Pyramid and Winnemucca Dry Lakes are included in Appendix D.

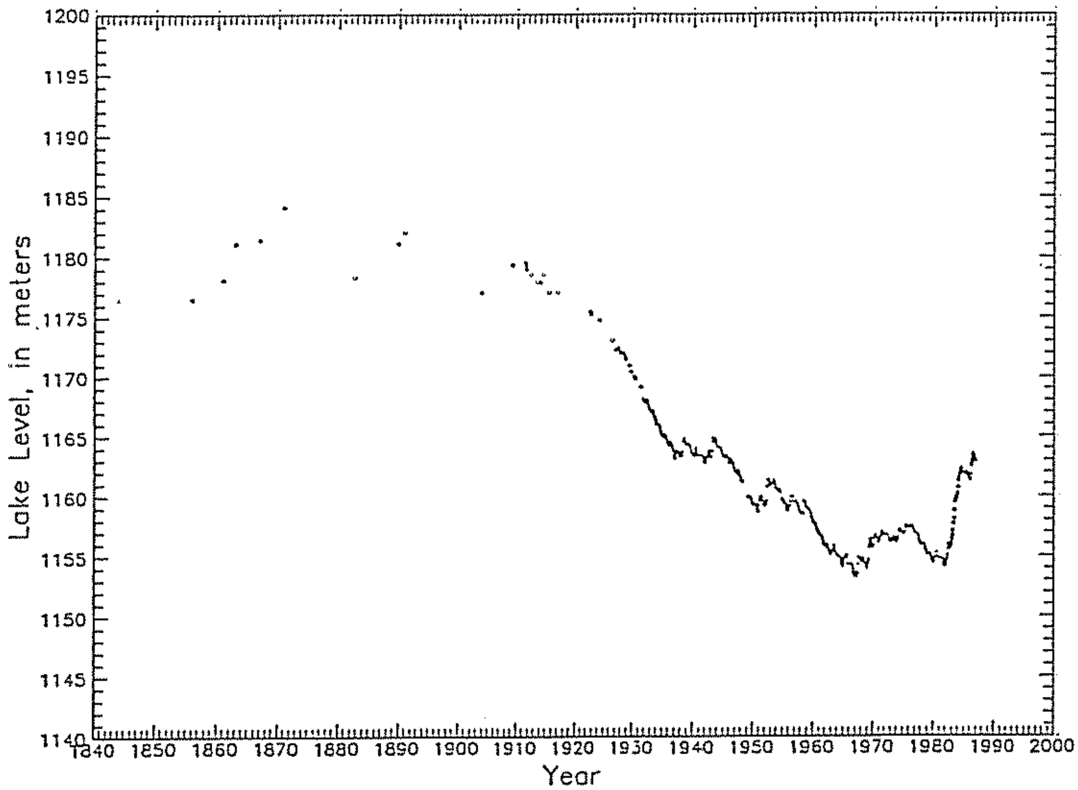


Figure 13.--Historical lake-level variations for Pyramid Lake (after Harding, 1965 and USGS, 1884-1950, 1950-1960, 1961-1986).

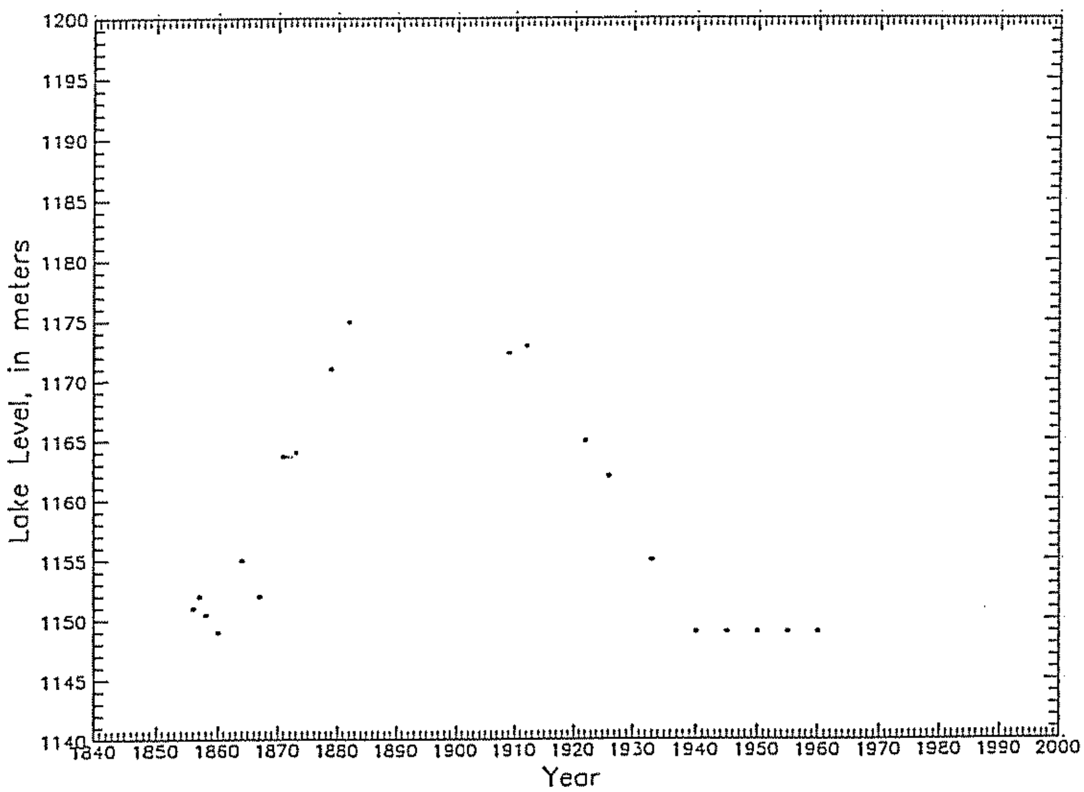


Figure 14.--Historical lake-level variations for Winnemucca Lake (after Harding, 1965).

Model calibration

The water-balance model for Pyramid and Winnemucca Dry Lakes is complicated since the two lakes are hydrologically connected. Instantaneous discharge through the slough cannot be modeled due to the lack of adequate monthly discharge data and because human influences interrupted the natural flow through the slough. The lakes coalesce to form one large lake when the combined volumes of Pyramid and Winnemucca Dry Lakes are greater than 41.63 km^3. The volume of Pyramid Lake, when filled to the sill level, is 36.51 km^3. Therefore, the water-balance model was modified for this two-lake system using the following guidelines.

1 - The volume in Pyramid and Winnemucca Dry Lakes are summed, and yearly discharge is added.

2 - The lakes become one large lake when the total volume is greater than 41.63 km^3. The corresponding surface area for the large lake is determined, and evaporation is subtracted and precipitation on the lake is added. If the new volume is large enough to persist as one lake, the lake level is reported for the combined lake. If the new volume drops below the 41.63 km^3 threshold, the lake level is reduced simultaneously for both lakes by evaporation minus precipitation and ground-water inflow.

3 - The lakes are separated if the total volume is less than 36.51 km^3, and no flow to Winnemucca Dry Lake occurs. The area for each lake is determined and evaporation, precipitation and ground-water are accounted for, and new lake-levels are determined.

4 - Some inflow to Winnemucca Dry Lake will occur if the combined volume is between the two threshold values. In order to quantify the amount reaching Winnemucca Dry Lake, Pyramid Lake is filled to the sill level (a volume of 36.51 km^3) and the remaining volume is spilled to Winnemucca Dry Lake. The level of Pyramid Lake will be dependent on the amounts of evaporation, precipitation, and ground-water inflow, and will be lowered below the sill level. The final volume in Winnemucca Dry Lake is used to determine the final lake level for Winnemucca Dry Lake.

This method of reconstructing lake levels for Pyramid and Winnemucca Dry Lakes causes actual lake level variations to be divided between the two lakes, masking the climatic variations. Therefore, a combined surface area for the two lakes was also calculated to more accurately reflect climatic variations.

The water-balance model for Pyramid and Winnemucca Dry Lakes was calibrated using historical stream discharge into Pyramid Lake (USGS, 1884-1950, 1950-1960, 1961-1986) measured at Nixon (figure 10, station number 351700), the last stream gage before the stream discharges into the lakes. Pyramid Lake was used to calibrate the model due to the lack of discharge data through the slough. Discharge was estimated, for years lacking data, using a linear-regression relationship between stream discharge at the Truckee River near Wadsworth (figure 10, station number 351600) and the Nixon station. The coefficient of determination (R^2) is 0.99, with a standard error of 4.9 percent.

The model was used several times incorporating the historical stream discharge data into Pyramid Lake and historical precipitation data; evaporation rates were varied. Table 6 summarizes the input parameters used during the calibration process. The general trend of the lake-level variations was always duplicated; however, the use of different evaporation rates resulted in an offset of the lake-level curves (figure 15). An evaporation rate of
= 41 ft
= 49 in
1.25 m per year was determined (Simulation 2) to provide the best match between actual and estimated lake-level curves (figure 15). This value of 1.25 m actually represents a residual term that incorporates both evaporation and

Table 6.--Summary of model input data for Pyramid and Winnemucca Dry Lakes calibration and pristine reconstructions. [m/yr, meters per year; C, calibration; P, pristine; Sim., simulation; Avg L+F, average of Lahontan Dam and Fallon data]

Sim. number	Type of Sim.	Starting year	Evaporation data set (or rate, m/yr)	Discharge data set	Precipitation data set
2	C	1917	1.25	estimated 351700	Nixon
3	P	1871	1.25	estimated 346000	Nixon
4	C	1917	1.35	estimated 351700	Nixon
5	C	1917	Lahontan	estimated 351700	Nixon
6	C	1917	Fallon	estimated 351700	Nixon
7	C	1917	Avg L+F	estimated 351700	Nixon
11	P	1904	1.25	actual 346000	Nixon

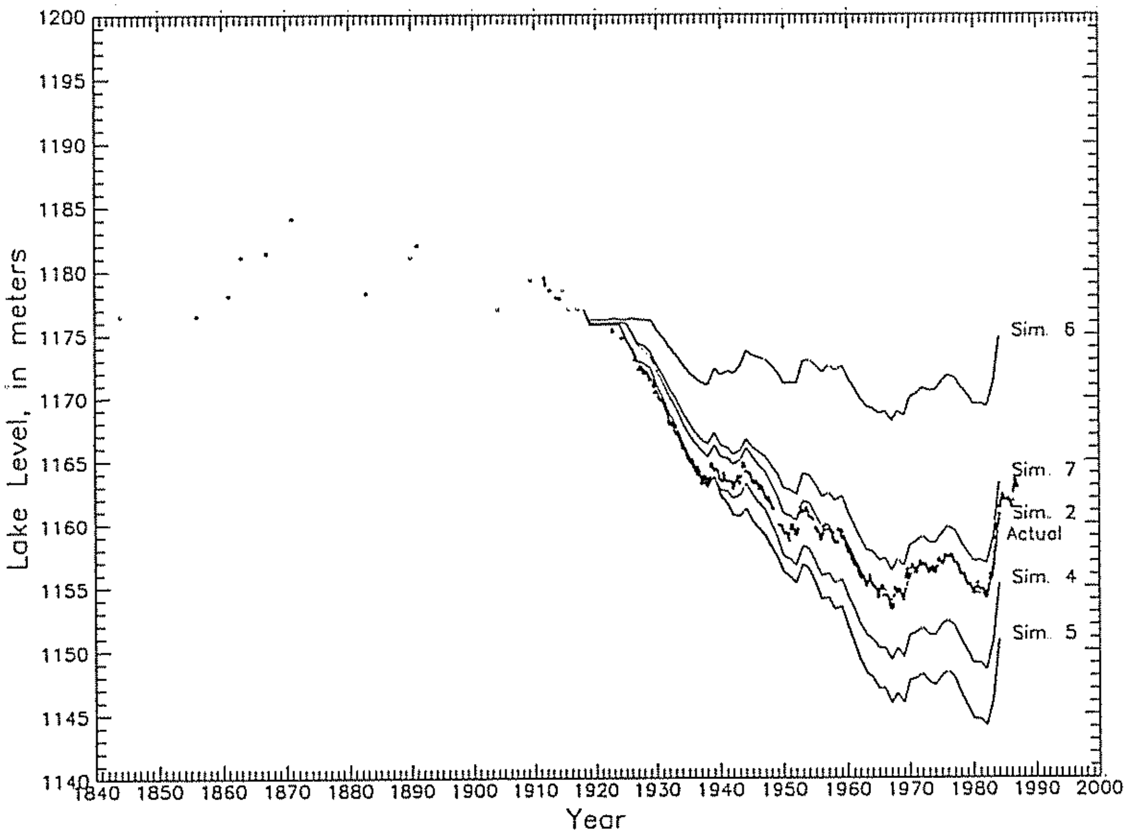


Figure 15.--Model-calibration results for Pyramid Lake (refer to Table 7 for summary of model input data).

ground-water inflow (E-G). The model lake-levels, calculated during Simulation 2 using an E-G of 1.25 m, correlated well with the actual lake-levels (R^2=0.84). The E-G of 1.25 m per year was then used in the lake-level reconstructions. This value of E-G is 10 cm per year lower than that determined for Walker Lake. This difference is believed to result from greater ground-water flow to Pyramid Lake, as Harding (1965) suggests that evaporation rates for both lakes are equal.

Simulations 5-6 use actual Class A pan-evaporation data from Fallon and Lahontan Dam. These data sets incorporate year-to-year variability in evaporation. However, the reconstructions show that this variability tends to be masked by the year-to-year variability in stream discharge when compared to the results of Simulations 2-4 which utilize a mean evaporation rate with no year-to-year variability.

Pristine Lake-level reconstructions for Pyramid and Winnemucca Dry Lakes

Pristine lake-level reconstructions were conducted using different sets of input data. Input parameters that were varied included starting year and discharge data (estimated versus actual). The input parameters for each of the simulations are summarized in table 6. Reconstructed lake-levels for each of the simulations are illustrated in figures 16, 17 and 18. Simulation 3 (figure 18) represents the best approximation of pristine conditions. Simulation 11 utilizes the same input data as Simulation 3, however, this simulation has a starting date of 1904 when historical stream discharge data became available and after the lake had been affected by human influences. The results of Simulations 3 and 11 indicate the same variations in lake level, however the lake levels are offset by approximately 2 meters because the lakes are not in equilibrium (illustrating the importance of the starting point). The Simulation 3 reconstruction shows that Pyramid and Winnemucca Dry Lakes would have coalesced into one large lake during 1872 and remained as one lake until 1930 when Pyramid would have remained near the sill level and Winnemucca would have fluctuated. In addition, Winnemucca Dry Lake would have desiccated during the periods 1949-52, 1961-1967 and 1979-82. The resulting lake-levels from Simulation 3 are included in Appendix E.

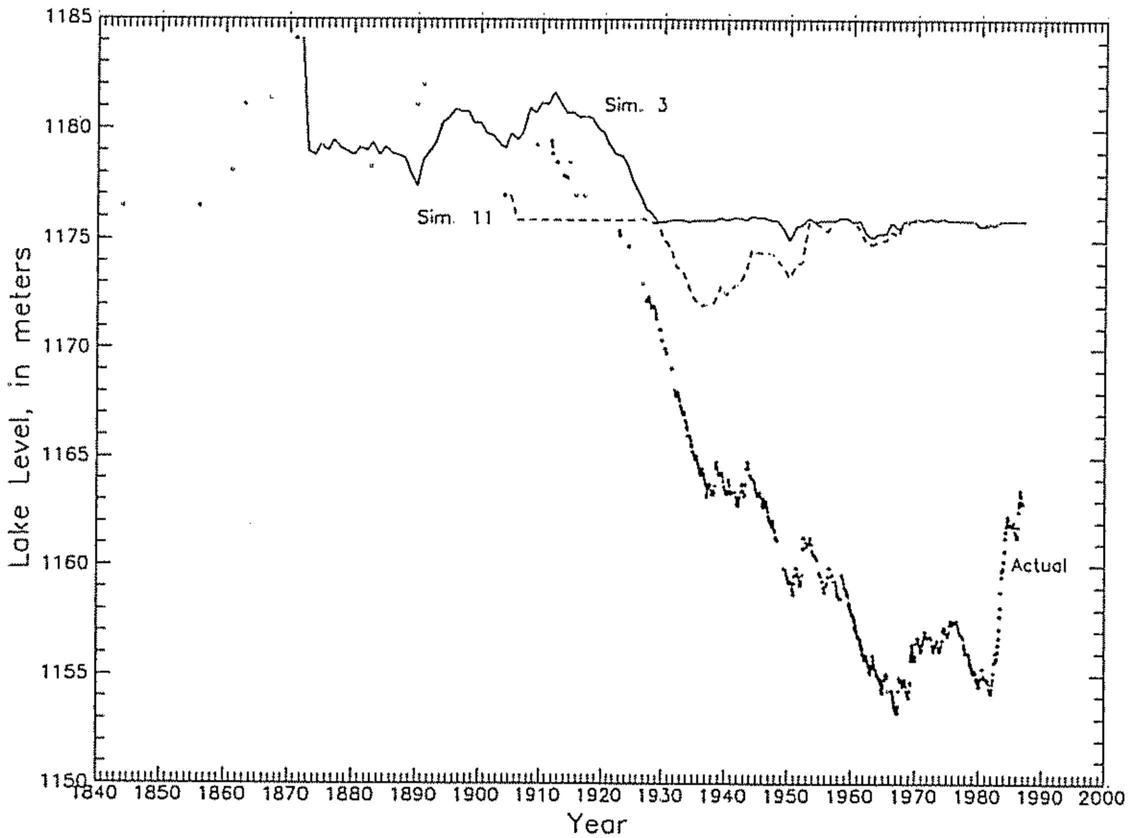


Figure 16.--Pristine lake-level reconstructions for Pyramid Lake (refer to Table 6 for summary of model input data).

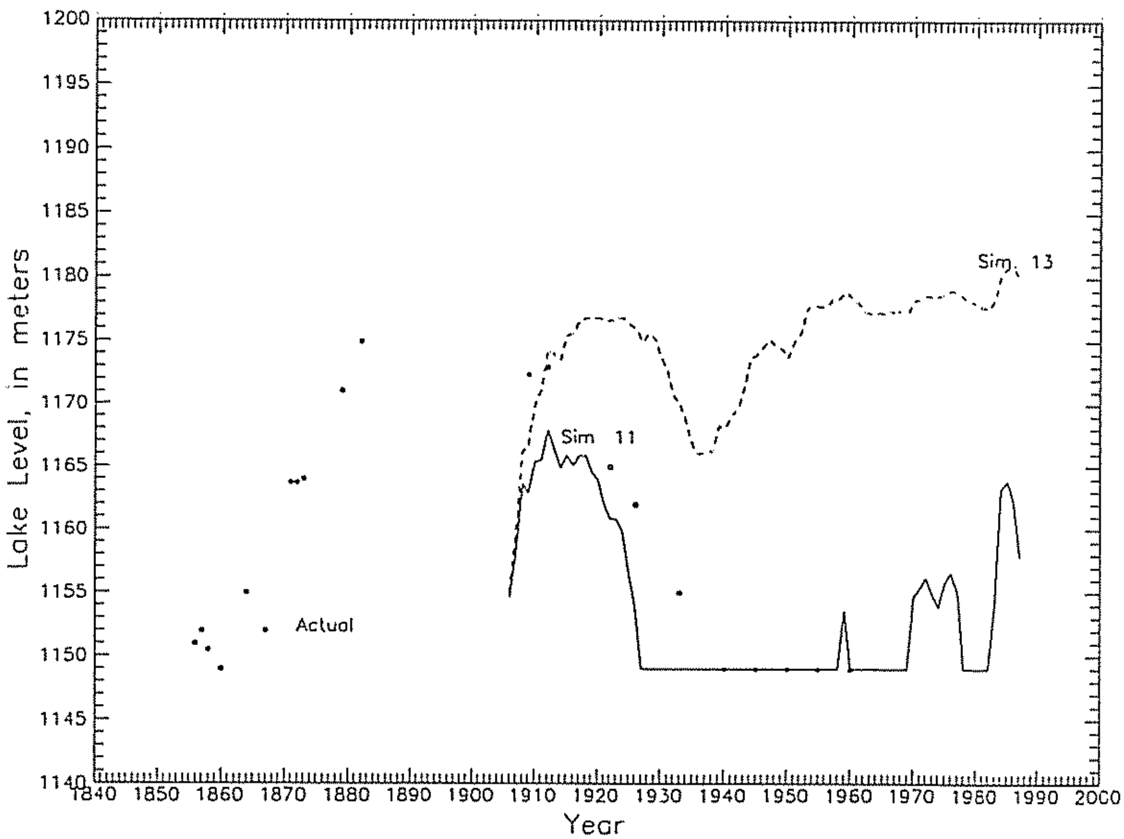


Figure 17.--Pristine lake-level reconstructions for Winnemucca Lake (refer to Table 6 for summary of model input data).

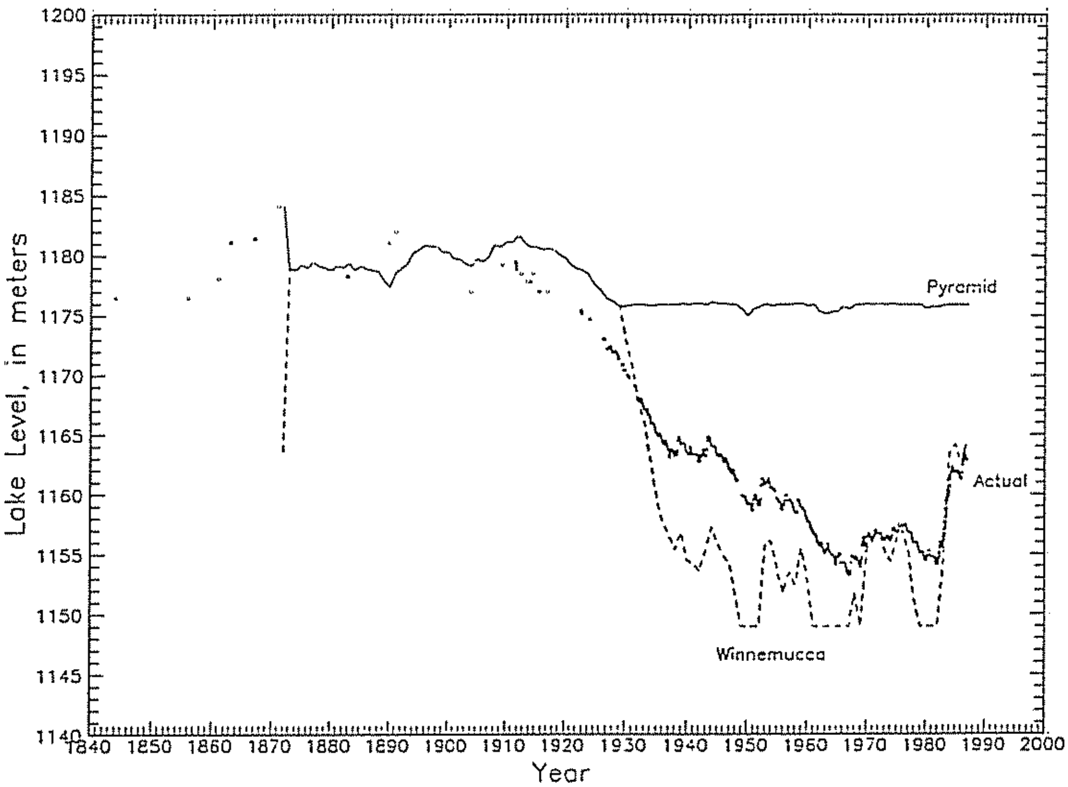


Figure 18.--Pristine lake-level reconstructions for Pyramid and Winnemucca Lakes (refer to Table 6 for summary of model input data).

Owens Lake

Hydrogeologic and Climatic Setting

Hydrogeologic setting. Owens Lake is located in a north-south-trending structural basin on the eastern flank of the Sierra Nevada Mountains (figure 19). The Owens Lake Basin is bordered on the east by the White and Inyo Mountains, and encompasses a drainage area of approximately 8,300 km^2 (State of California, 1981). The Owens River flows from near Mount Lyell, southward a distance of approximately 193 kilometers (State of California, 1981). Tributary streams, including South Branch, Rock, Pine, Bishop, Coyote, Big Pine, Tinemaha, Taboose, Oak, Shepherd and Lone Pine Creeks, originate in the Sierra Nevada Mountains.

Consumptive use of water by farmers in the Owens Valley began about 1870 (Lee, 1912). In 1913 the Los Angeles Department of Water and Power completed a 402 km long aqueduct to transport water from the Owens Valley to the city of Los Angeles (Los Angeles Department of Public Service, 1916). Most of the Owens River flow enters the aqueduct however, some water is left to flow in the Owens River channel and reaches the lake during wetter years. The 18.2 km long Mono Craters tunnel was constructed in 1941 to transport additional water from the adjacent Mono Basin to the aqueduct intake (LADWP, 1984). Also, water is extracted

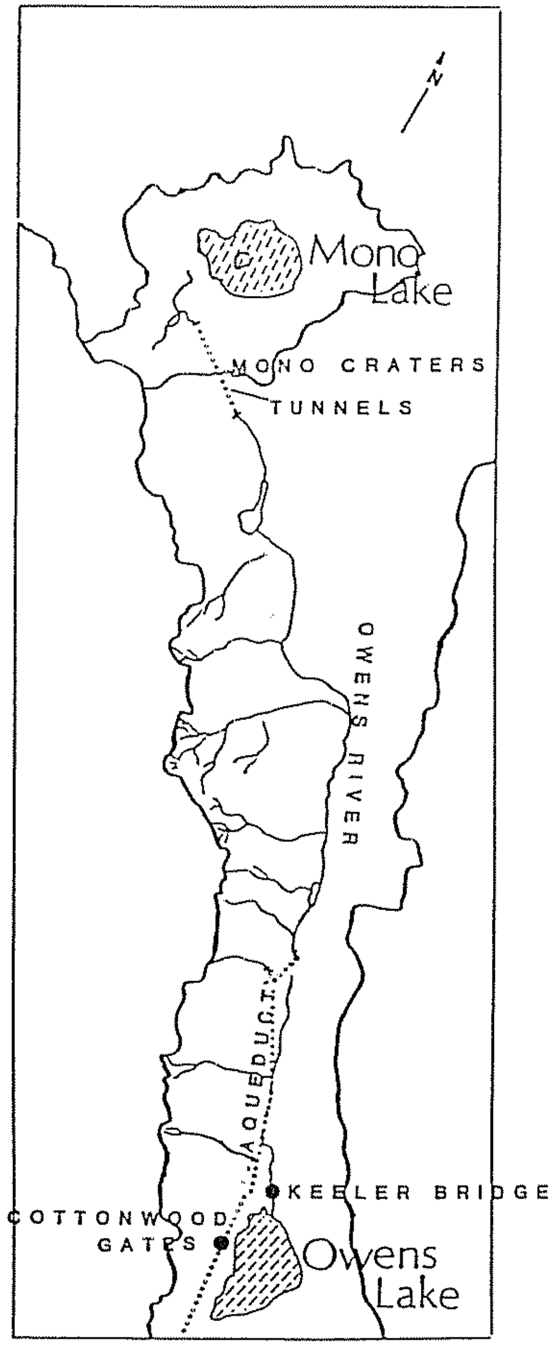


Figure 19.--Location map of the Owens Lake drainage basin (after LADWP, 1966).

from well fields in the Owens Basin to supplement flow in the aqueduct during dry years (LADWP, 1966). In 1960, for example, approximately 0.12 km^3 of water was pumped into the aqueduct from the LADWP well fields, accounting for over 50 percent of the flow in the aqueduct that year.

Climatic setting. Precipitation in the Owens Basin ranges from a maximum of 89 cm per year in the high altitude regions to a minimum of 3.6 cm at the lower altitudes (State of California, 1981). The amount of precipitation on the surface of the lake is small because the Sierra Nevada Mountains create a rain shadow over the lake.

Model input

Pristine stream discharge. Pristine stream discharge for the Owens River system was reconstructed using LADWP aqueduct flow records that were corrected for import from Mono Basin, import from ground-water sources, and for overflow to the lake measured at Keeler bridge (figure 19). Corrected flow in the aqueduct, measured at Cottonwood Gates (figure 19, the last gage before the aqueduct leaves the Owens Valley), represents the discharge that would reach Owens Lake if the stream were allowed to flow naturally. Corrected aqueduct flow records are available for the years 1927-1976. However, ground-water pumping data are available only for years 1933-34 and 1959-61 (LADWP, 1966).

mentioned previously, during dry years ground-water pumping can increase the flow in the aqueduct by as much as 50 percent, introducing significant error into the water-balance calculations.

Precipitation on the surface of Owens Lake. Annual precipitation on the Owens Lake bed, as reported by LADWP (1976) was used for the reconstructions (table 3).

Evaporation from Owens Lake. Evaporation from the lake surface was estimated using the data presented by LADWP (1976) (table 4)

Ground-water discharge. Ground-water discharge into Owens Lake has not quantified and springs are present in the lake basin.

Stage-area-volume relationships

Stage-area-volume relationships were developed by LADWP (1976) and Lee (1912) (Appendix C). The LADWP relationships, available in 0.3 m increments were used for lake levels below 1021 m. The LADWP relationships do not include data above 1021 m, and, therefore, for points above 1021 m, the relationships developed by Lee were used.

Historical lake-level variations

Owens lake presently is dry due to LADWP diversion in the basin. Historical lake levels (figure 20 and Appendix D) were reported by LADWP (1976). Measurements did not begin until 1905 after the lake had already been affected by human influences. Owens Lake reached a historical highstand of 1090.6 m in 1912.

Model calibration

The water-balance model for Owens Lake could not be calibrated using the methods previously described because of data limitations. Historical stream discharge and evaporation data sets are limited, and do not provide the necessary data base for calibration. Because calibration could not be conducted, the residual term E-G could not be estimated, and therefore, an additional source of error was introduced into the calculations.

Pristine lake-level reconstructions for Owens Lake

Lake levels were reconstructed for Owens Lake using a precipitation rate of 12.5 cm per year and an evaporation rate of 1.22 m per year. Reconstructed lake levels are illustrated in figure 21. The reconstruction indicates that the lake would have risen to a stage above the 1912 historical highstand. Ground-water pumping during dry years was not quantified for years when data were unavailable,

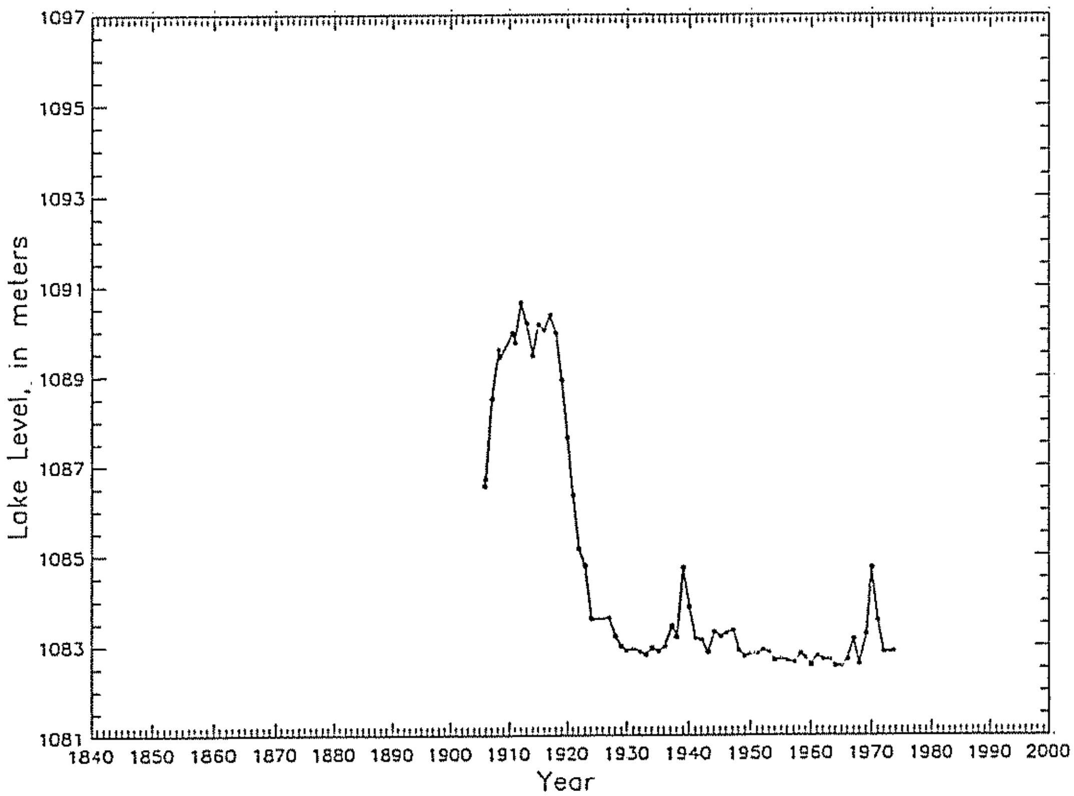


Figure 20.--Historical lake-level variations for Owens Lake (after LADWP, 1976).

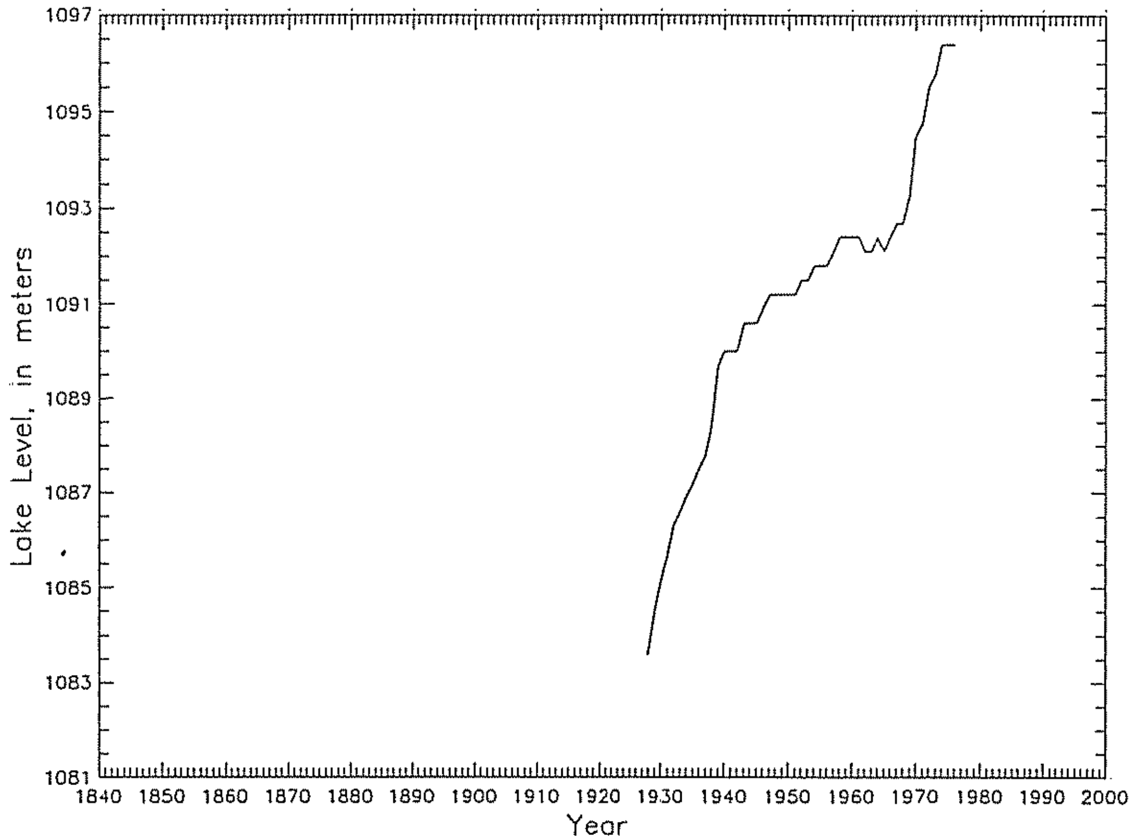


Figure 21.--Pristine lake-level reconstructions for Owens Lake

therefore, the estimated lake levels are too high. Another effect of not correcting for the ground-water pumping is a tendency to mask the year-to-year variability in stream discharge. The reconstructions could only be conducted for the period 1927-1976, due to lack of data, after the starting lake-level had already been affected by human influences; the lake is unable to achieve equilibrium. The predicted pristine lake-levels are included in Appendix E.

DISCUSSION

Comparison of changes in lake size

The reconstructed data were compared in order to determine if lake size variations occur simultaneously between the lakes in the Great Basin region.

Lake levels

The best-approximation of pristine lake-level variations made in this study and those by Stauffer (1985) and Vorster (1985) were compared by overlaying the reconstructed curves on a graph with a relative scale. The comparison is illustrated in figure 22. The variations in lake level tend to occur simultaneously. For example, during the periods 1906-1920 and 1967-1974 lake levels were rising in the Mono, Great Salt, Walker, Pyramid, and Winnemucca Dry Lake basins. However, during the periods 1872-1895 and 1948-1952, Great Salt Lake was declining while the other lakes were rising. The Owens Lake reconstruction is different from the other lakes because the lake level continues to rise. This continued rise is believed to be a result of inaccurate correction for ground-water pumping and does not reflect a climatological difference. Therefore, Owens Lake levels were not considered in the lake level comparisons.

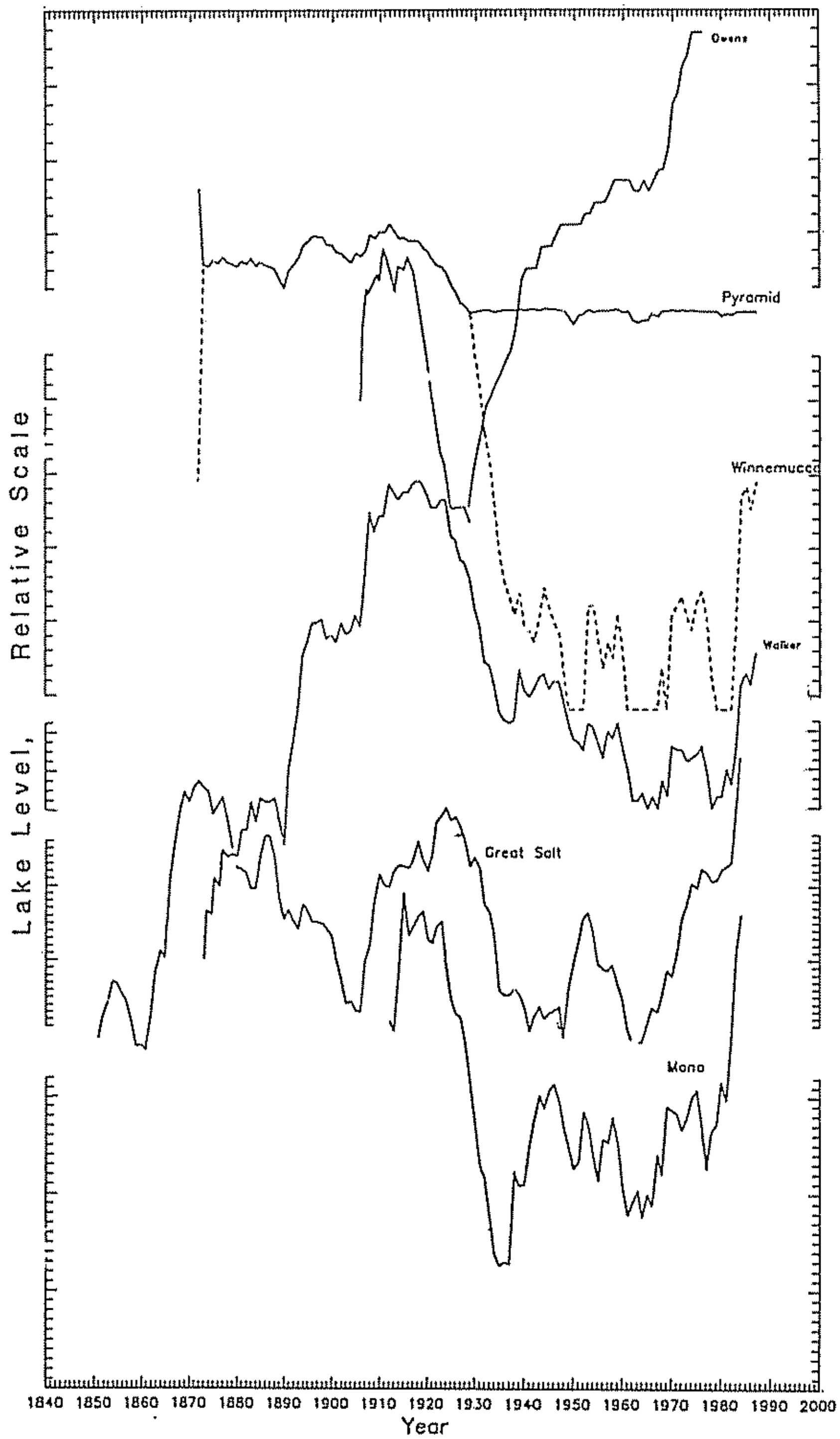


Figure 22.--Comparison of pristine lake-level variations (Great Salt Lake after Stauffer, 1985; Mono Lake after Vorster, 1985).

Areas

Lake surface area is more sensitive to climatic changes than lake level because a close relationship exists between evaporation and surface area. A comparison of lake surface area variations is useful especially for the Pyramid and Winnemucca Dry Lake system because the surface areas for these two lakes can be added, thus integrating the observed variations in these sometimes connected subbasins fed by a single stream. Therefore, variations in surface area were compared as shown in figure 23. This comparison indicates that variations in surface area occur simultaneously except for the periods 1872-1895 and 1948-1952 when Great Salt Lake was declining and the other lakes were increasing.

Stream discharge

A comparison of pristine stream discharge for the Walker, Truckee and Owens Rivers is shown in figures 24 and 25. The pristine discharge for each fork of the Walker River was added and plotted as combined flow. The pristine stream discharge data were normalized by dividing by the mean discharge and plotted in figure 25. The year-to-year variability in discharge is high; however, the variations occur simultaneously between all three rivers. The Owens River system varies synchronously with both the Truckee and Walker Rivers despite the errors associated with inaccurate correction for ground-water pumping. This comparison is

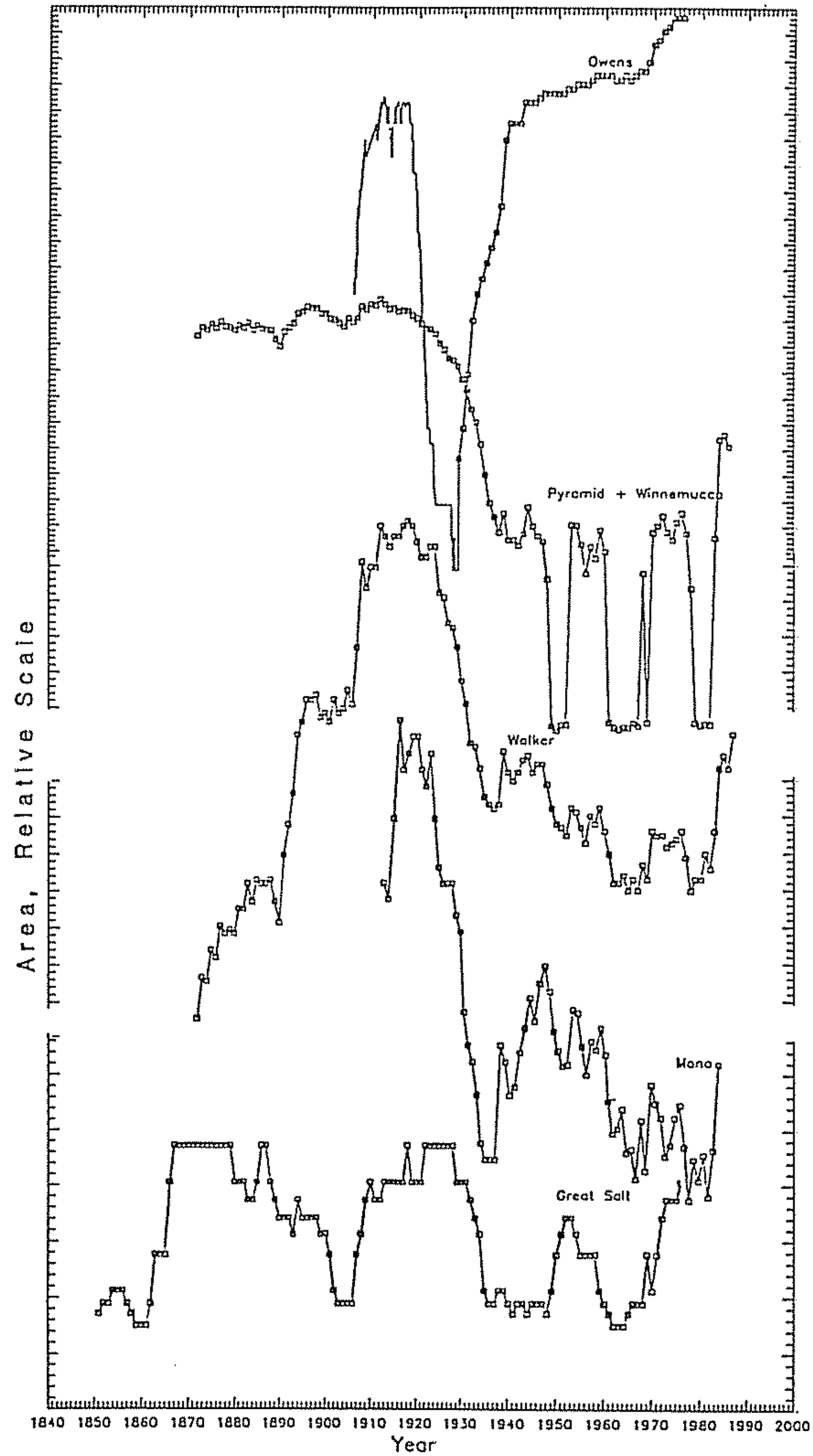
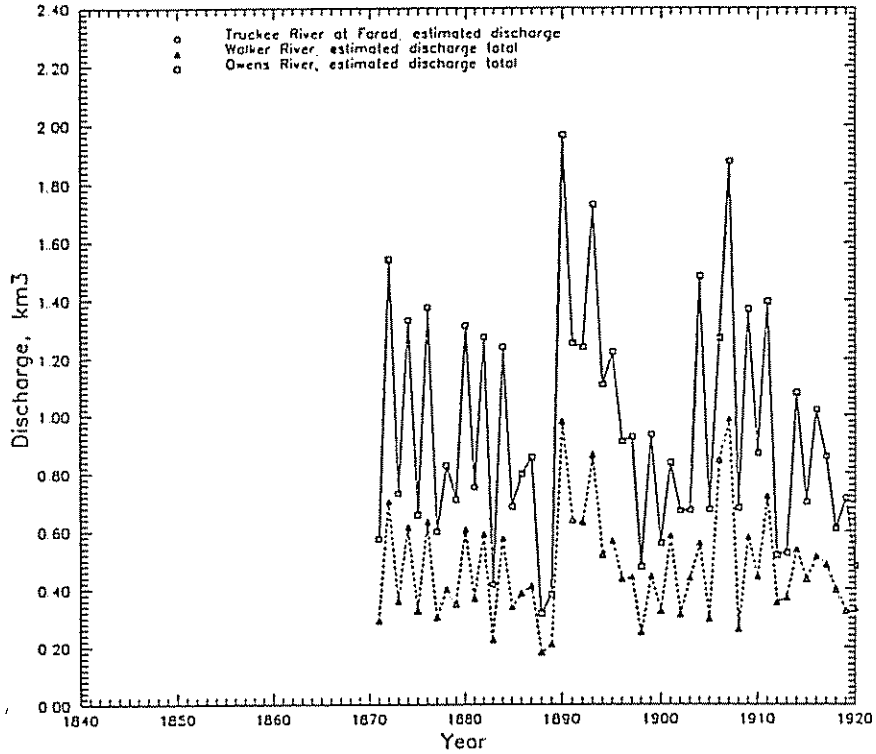


Figure 23.--Comparison of pristine lake surface-area variations (Great Salt Lake after Stauffer, 1985; Mono Lake after Vorster, 1985).



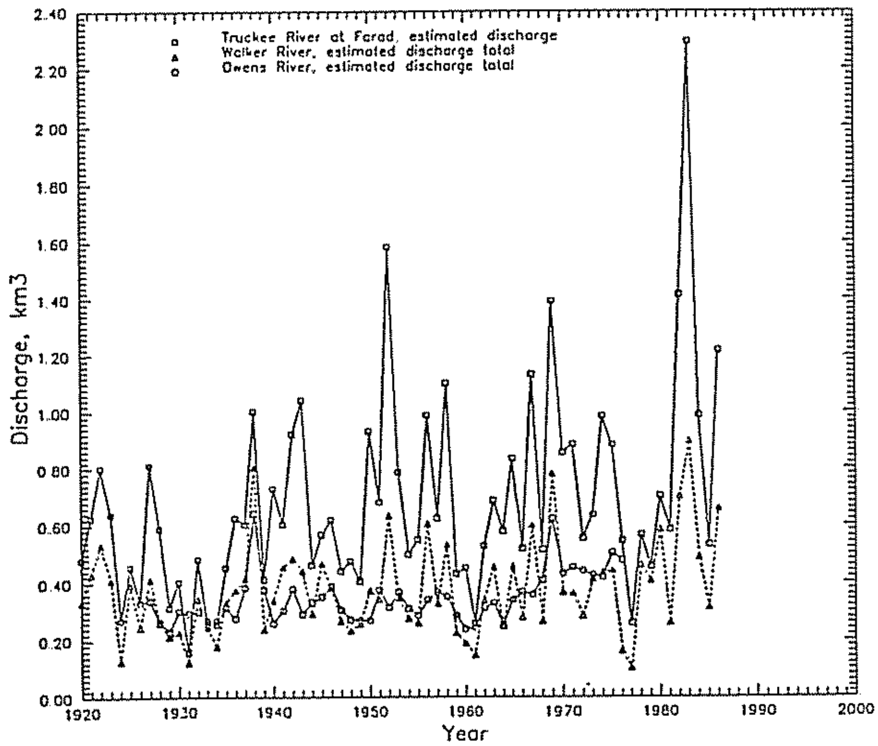


Figure 24.--Comparison of pristine stream-discharge variations.

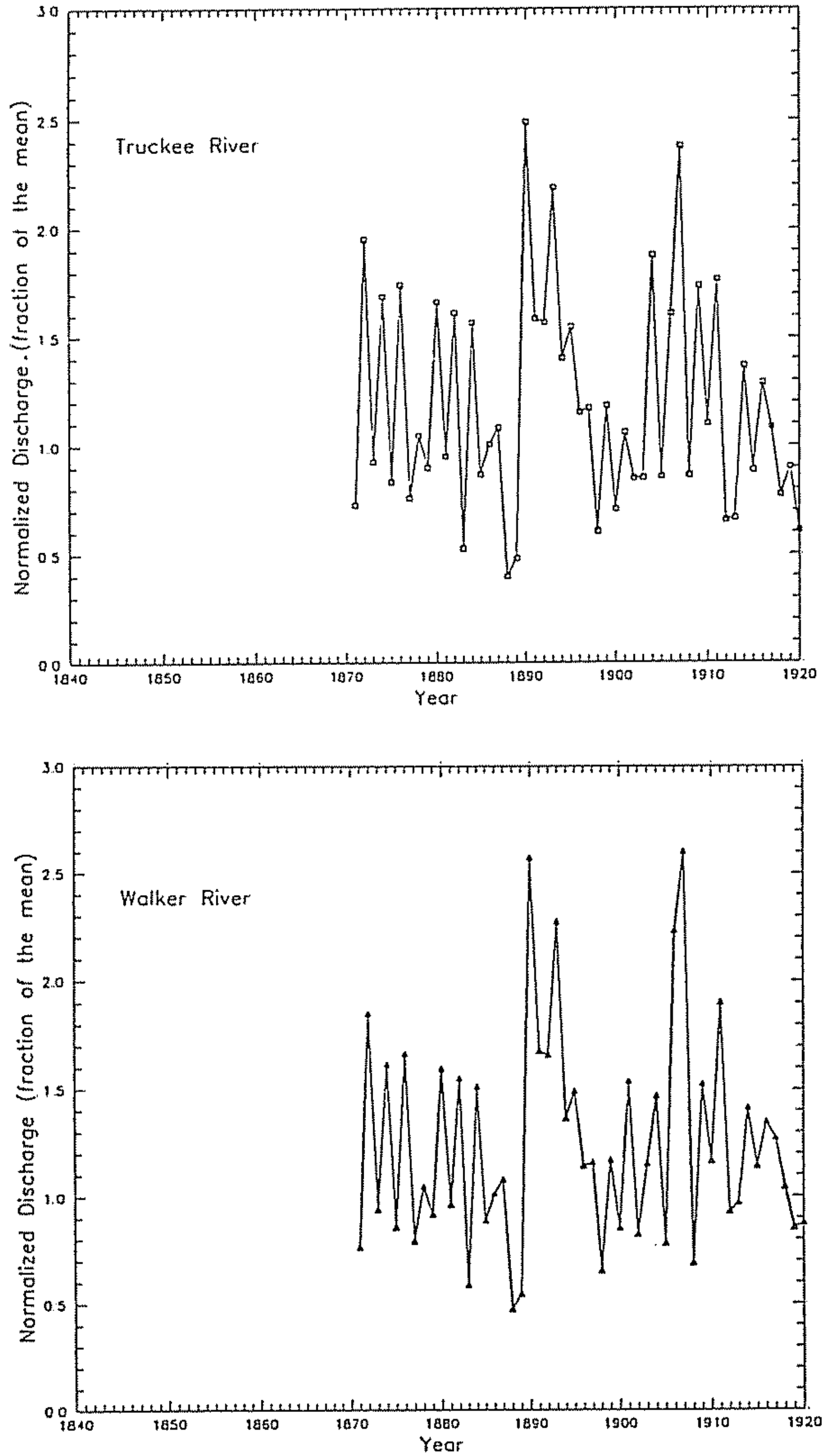


Figure 25.--Comparison of normalized pristine stream-discharge variations for the period 1871-1920.

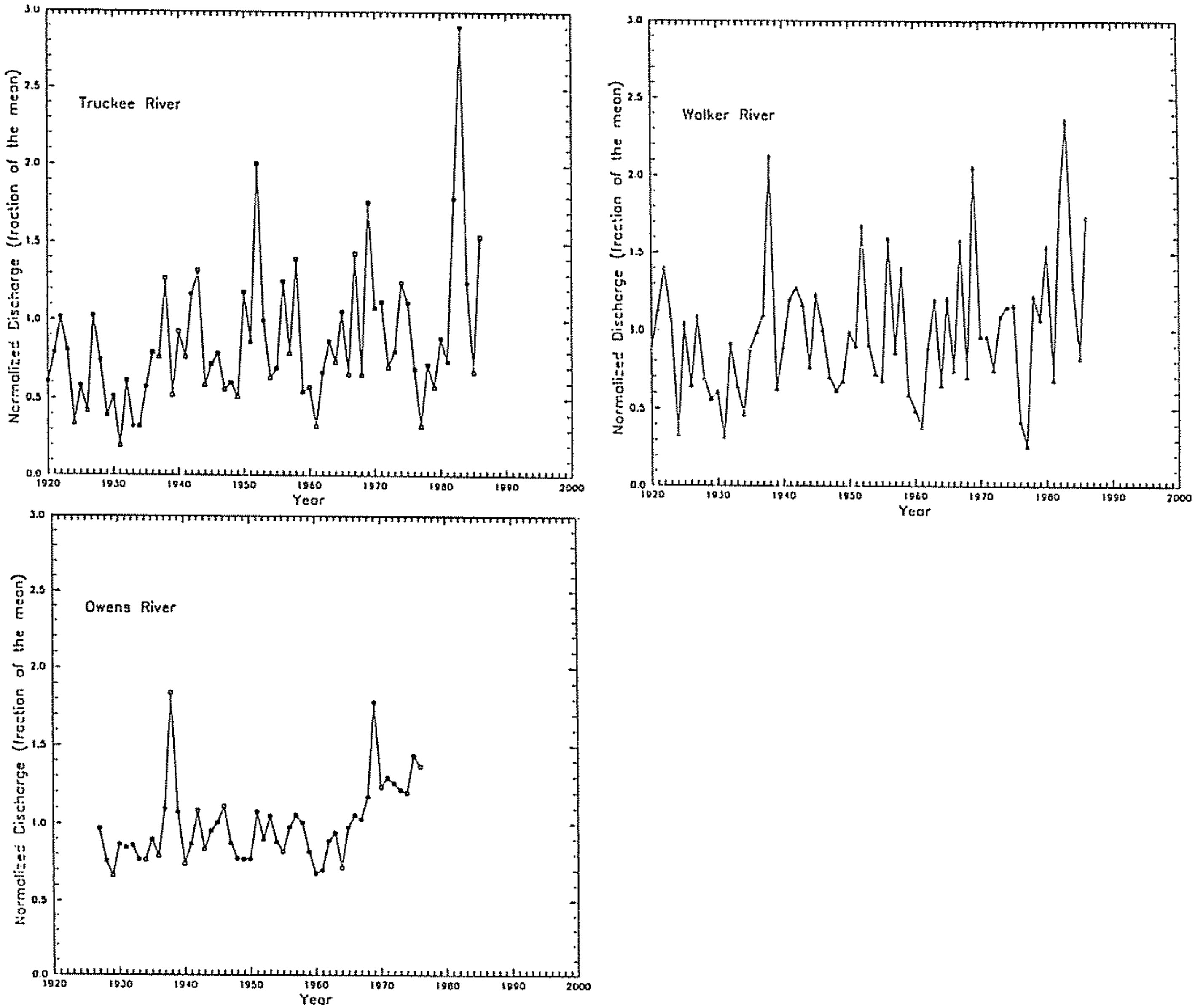


Figure 26.--Comparison of normalized pristine stream-discharge variations for the period 1920-1985.

especially important with regards to the Owens River watershed; the rivers draining the Sierra Nevada Mountains all change similarly and, correspondingly, the terminal lakes fed by these river systems should also respond similarly.

El Nino and stream discharge variations

Because of the close physical connection between the oceans and the atmosphere, global climatic changes can occur when sea-surface temperature changes occur. Therefore, stream discharge variations were compared with the occurrence of El Nino/Southern Oscillation (ENSO) events. During the 116 years of pristine streamflow data, abnormally high discharge occurred (mean plus 1 standard deviation) during 24 years. Of these 24 high discharge years, an El Nino of intensity 3 or 4 (as reported by Rasmusson, 1984) occurred 15 times. Conversely, 11 El Nino events occurred that were not accompanied by increases in stream discharge. This seems to indicate that a connection between ENSO events may exist, however the effects of such a connection and its physical causes are unknown at this time.

Differences between historical and reconstructed lake-levels

In all cases, reconstructed lake-level curves indicate that observed, present-day low lake-levels are the result of human intervention in the basins. Walker Lake would have risen above the historical highstand and remained at such a level until the present is pristine conditions prevailed. Winnemucca Dry Lake would have contained water for much of the period, and the Pyramid/Winnemucca Dry Lakes system would have been at a level above the sill as one large lake until 1930. Owens Lake would have risen above the 1912 historical highstand, although the error incorporated with ground-water pumping does not allow for the accurate prediction of maximum pristine lake levels.

Paleoclimatic significance

The results of this study indicate that all the lakes studied react similarly to climatic variations. Because changes in lake level, and surface area occurred synchronously between Walker, Pyramid, Winnemucca Dry and Mono Lakes, it is believed that the paleolakes occupying these basins would also behave similarly. Variations in stream discharge occur synchronously between the Truckee, Walker and Owens Rivers, all draining the Sierra Nevada Mountains. Therefore, the lakes fed by these river systems should respond synchronously to the same climatic changes.

Great Salt Lake, however, is fed by a different river system and receives a higher amount of monsoonal precipitation. Therefore, lake-level variations for Great Salt Lake differ from the lake-level variations for lakes in the western regions of the Great Basin. Thus, the levels of paleolakes Lahontan, Russell and Searles should have changed similarly, while Lake Bonneville should have changed differently. The similarity in stream discharge between the Owens, Truckee and Walker Rivers indicates that a distinct climatic boundary does not separate the Owens River watershed from the Mono Lake watershed, and does not account for the differences between the Lake Searles and Lake Russell paleolake level variations.

SUMMARY

The purpose of this study was to reconstruct the natural historical variations in lake size, as delineated by lake level, volume, and surface area, of Pyramid, Winnemucca Dry, Walker and Owens Lakes. The significance of this study is that the chronologies of lake-level change for Lakes Bonneville, Lahontan, and Russell show that lake-level variations have been approximately synchronous throughout Pleistocene time (Benson and Thompson, 1987). The chronologic record for Searles lake, however, tends to be diachronous with the chronology for Lake Russell (Benson and Thompson, 1987), indicating that a climatic boundary may separate the Lake Russell watershed from the adjoining Owens River watershed. Variations in these present-day closed-basin lakes will reveal information about past lake-level variations.

The water-balance of lakes in the Great Basin is strongly dependent upon regional climatic factors. Lakes in the western region of the Great Basin (Pyramid, Winnemucca Dry, Walker and Owens) receive precipitation mostly during the winter months while lakes in the southern and eastern regions (Great Salt) receive a higher proportion of precipitation during the summer months. The amount of surface-water inflow reaching the lakes is greatly dependent upon precipitation in the surrounding mountains; precipitation in the Sierra Nevada Mountains affects lakes in the western regions, while precipitation in the Wasatch Mountains affect Great Salt Lake. Precipitation directly on the lake surface accounts for very little input; precipitation accounts for less than 17 percent of the total water input to lakes in the western regions of the Great Basin, and 27 percent for Great Salt Lake.

A water-balance computer model was used to reconstruct the lake size variations. Water-balance calculations were conducted on an annual basis, using the continuity equation, and assuming all inputs and outputs occur instantaneously. All inflow occurring during a given year was added to an initial volume, then annual precipitation was added, annual evaporation was subtracted and ground-water inflow was added. Pristine stream discharge was reconstructed by selecting a gaging station on the inflowing stream that was located above diversions, below tributary inputs and had a period of record of at least 50 years. For years without stream discharge data, discharge was estimated using linear-regression methods. Precipitation data were obtained from historical records. Ground-water inflow to all the lakes was considered minimal for the purpose of the lake-level calculations, but was calculated as a residual term during the model-calibration process. Input to and output from a river by ground-water flow below the selected gaging station were not considered. Stage-area-volume data, available in 1-meter altitude increments for Walker, Pyramid, and Winnemucca Dry Lakes were interpolated using a spline-fitting algorithm to develop data points at 10-centimeter altitude increments.

The water-balance model was calibrated using historical stream discharge (measured at the station nearest the lake inlet) and historical precipitation data. The general trend of the lake-level variations matched during calibration, but the curves were slightly offset. The differences were believed to result from a combination of inaccurate estimation of evaporation and ground-water inflow, the two most difficult terms to quantify. To correct the offset between the predicted and actual lake-level curves, the residual term "evaporation minus ground water" (E-G) was adjusted, resulting in a match between predicted and actual lake-level data; E-G was then used during the reconstruction process. E-G was determined to equal 1.35 m per year for Walker Lake and 1.25 m per year for Pyramid Lake. The difference between these two values is believed to result from greater ground-water inflow to Pyramid Lake.

The water-balance model, when calibrated, was highly sensitive to evaporation rate. However, the year-to-year variations in lake size were dependent mostly upon the year-to-year variability in discharge, rather than similar variability in precipitation or evaporation.

The water-balance model for Pyramid and Winnemucca Dry Lakes was complicated since the two lakes are connected hydrologically. Therefore, the water-balance model was modified for this two-lake system. Pristine discharge was added to the initial volume. If the resulting volume was sufficient to raise Pyramid Lake above the sill level, a part of the flow was spilled to Winnemucca Dry Lake. This method of reconstructing lake levels for Pyramid and Winnemucca Dry Lakes caused actual lake-level variations to be divided between the two lakes, masking the climatic variations. Therefore, a combined surface area for the two lakes was calculated to reflect more accurately climatic variations.

The water-balance model for the Owens Lake system was complicated by the withdrawals of water in the LADWP aqueduct. Pristine stream discharge for the Owens River system was reconstructed using LADWP aqueduct flow records that were corrected for import from Mono Basin, import from ground-water sources, and for aqueduct overflow. Ground-water pumping can increase the flow in the aqueduct by as much as 50 percent, introducing significant error into the water-balance calculations, especially since pumping data were only available for 4 years. The reconstructions for Owens Lake should be refined as more data become available. The estimated pristine lake levels are too high because of the inability to correct for ground-water pumping. The inability to correct for ground-water pumping has a tendency to mask the year-to-year variability in discharge and in corresponding lake levels. Also, the volume of inflow to Owens Lake was over-estimated, especially during dry years.

The reconstructions were then compared in order to determine if lake size variations occur simultaneously between the lakes in the Great Basin region. The lake-level comparison, indicates that during the periods 1906-1920 and 1967-1974 lake levels were rising in the Mono, Great Salt, Walker, Pyramid, and Winnemucca Dry Lake basins. However, during the periods 1872-1895 and 1948-1952, Great Salt Lake was declining while the other lakes were rising. The Owens Lake reconstruction is different from the other lakes because the lake level continues to rise, a result of inaccurate correction for ground-water pumping.

Lake surface-area variations were also compared because surface area is more sensitive to climatic changes than lake level. The comparison of lake surface-area variations is useful especially for the Pyramid and Winnemucca Dry Lake system because the surface areas for these two lakes can be added, thus integrating the observed variations in these occasionally connected subbasins. The surface-area comparison (figure 23) indicates that variations in this parameter occur similarly to the variations in lake level.

The comparison of pristine stream discharge for the Walker, Truckee and Owens Rivers (figures 24 and 25) shows that although the year-to-year variability in discharge is high, variations occur simultaneously between all three rivers. The Owens River system varies synchronously with both the Truckee and Walker Rivers despite the errors associated with inaccurate correction for ground-water pumping. Stream-discharge variations were also compared with the occurrence of El Nino/Southern Oscillation events. The comparison indicates that a relation between El Nino/Southern Oscillation events and stream discharge may exist, however the effects and physical causes are unknown currently.

In all cases, reconstructed lake-level curves indicate that observed, present-day low lake-levels are the result of human intervention in the basins. Walker Lake would have risen above the historical highstand and remained at such a level currently. Winnemucca Dry Lake would have contained water for much of the period, and the Pyramid/Winnemucca Dry Lakes system would have been one large lake until 1930. Owens Lake would have risen above the historical highstand, although the error incorporated with ground-water pumping does not allow for the accurate prediction of maximum pristine lake levels.

The results of this work indicate that all the lakes studied react similarly to climatic variations. Because changes in lake level and surface area occurred synchronously between Walker, Pyramid, Winnemucca Dry and Mono Lakes, the paleolakes occupying these basins may also change similarly. Variations in stream discharge occur synchronously between the rivers draining the Sierra Nevada Mountains and therefore, the lakes fed by these river systems should change synchronously to the same climatic changes. Great Salt Lake, however, supplied by a different river system, differs from the lakes in the western regions of the Great Basin. Thus, the levels of paleolakes Lahontan, Russell and Searles should have changed similarly, while Lake Bonneville should have changed slightly differently. A distinct climatic boundary does not separate the Owens River watershed from the Mono Lake watershed, and does not account for the differences between the Lake Searles and Lake Russell paleolake level variations.

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APPENDIX A - WATER-BALANCE COMPUTER MODEL

```
* Program: Wlklklv.prg
* Purpose: Interactive Reconstruction of lake levels
* Author:  Wendy Milne
* Date:    6/11/87
* Lake:    Walker
select 1
use wlkdat index wlkdat
select 2
use wlk10 index wlk10
clear
text
                 THIS PROGRAM WILL CALCULATE HISTORIC
                      LAKE LEVELS FOR WALKER LAKE ENDTEXT ?
accept "DO YOU WANT A PRINT-OUT OF THE RUN PARAMETERS? " to
choice
input "ENTER YEAR TO BEGIN CALCULATIONS: " TO YR
ACCEPT "ENTER THE RUN NUMBER (as RUN1):  " TO N
?
clear
SELECT 1
DISPLAY STRUC
?
accept "ENTER FIELD NAME OR VALUE FOR DISCH(1)  " TO disch1
ACCEPT "ENTER FIELD NAME OR VALUE FOR DISCH(2)  " TO disch2
ACCEPT "ENTER FIELD NAME OR VALUE FOR PRECIP    " TO precip
ACCEPT "ENTER FIELD NAME OR VALUE FOR EVAP      " TO evap
clear
@ 6,10 say "WALKER LAKE RECONSTRUCTION PROGRAM RUN IN
PROGRESS"
SET TALK OFF
*calculate 1st incremental vol (virgin inflow to *lake)
select 1
seek YR
REPLACE CSTAGE_M WITH HEIGHT_M
STORE HIST_VOL TO MVOLUME1
SKIP 1
do while .not. eof()
REPLACE VOLUME_KM3 WITH MVOLUME1
STORE &disch1 to Q1
STORE &disch2 to Q2
Q=Q1+Q2
STORE mvolume1+Q TO VOL_I1
*Look-up the incremental area related to the new volume
mvolume = 0
marea = 0
lookup = '0'
mdiff = 0
mdiff1 = 0
mvolume1 = 0
   lookup = str(100*vol_I1,4)
   lookup = substr(lookup,1,3)
   mvolume1 = vol_I1
```

```
   select 2
   seek lookup
   skip -2
   mdiff1 = volume_km3 - mvolume1
   skip
   mdiff2 = volume_km3 - mvolume1
   if abs(mdiff2) < abs(mdiff1)
      do while abs(mdiff2) < abs(mdiff1)
         mdiff1 = mdiff2
         skip
         mdiff2 = volume_km3 - mvolume1
      enddo
      if abs(mdiff2) > abs(mdiff1)
         skip -1
      endif
      marea = area_km2
      select 1
      store marea to area_I1
   else
      marea = area_km2
      select 1
      store marea to area_I1
   endif
**2nd Sub-routine to calculate 2nd incremental volume
*calculate precip on the lake
select 1
STORE &PRECIP TO PPT
 ppt_LAKE=PPT*area_I1*10E-6
 store vol_I1+ppt_lake to vol_I2
*Look-up the incremental area related to the new volume
   lookup = '0'
   mdiff1 = 0
   mdiff2 = 0
   mvolume = 0
   marea = 0
   mvolume1 = 0
   lookup = str(100*vol_I2,4)
   lookup = substr(lookup,1,3)
   mvolume1 = vol_I2
   select 2
   seek lookup
   skip -2
   mdiff1 = volume_km3 - mvolume1
   skip
   mdiff2 = volume_km3 - mvolume1
   if abs(mdiff2) < abs(mdiff1)

      do while abs(mdiff2) < abs(mdiff1)
         mdiff1 = mdiff2
         skip
         mdiff2 = volume_km3 - mvolume1
      enddo
      if abs(mdiff2) > abs(mdiff1)
         skip -1
```

```
      endif
      marea = area_km2
      select 1
      store marea to area_I2
   else
      marea = area_km2
      select 1
      store marea to area_I2
   endif
**3rd Sub-routine to calculate final volume
*calculate evap from the lakes
select 1
 store &evap to ev
 store area_I2*ev*10E-6 to evap_total
 store vol_I2-evap_total to cvolumekm3
*Look-up the final area and height related to the new volume
   lookup = '0'
   mdiff1 = 0
   mdiff2 = 0
   mvolume = 0
   mheight = 0
   marea = 0
   mvolume1 = 0
   lookup = str(100*cvolumekm3,4)
   lookup = substr(lookup,1,3)
   mvolume1 = cvolumekm3
   select 2
   seek lookup
   skip -2
   mdiff1 = volume_km3 - mvolume1
   skip
   mdiff2 = volume_km3 - mvolume1
   if abs(mdiff2) < abs(mdiff1)
      do while abs(mdiff2) < abs(mdiff1)
         mdiff1 = mdiff2
         skip
         mdiff2 = volume_km3 - mvolume1
      enddo
      if abs(mdiff2) > abs(mdiff1)
         skip -1
      endif

      marea = area_km2
      mheight = height_m
      select 1
      store marea to carea_km2
      replace wlkdat->cstage_m with mheight
   else
      marea = area_km2
      mheight = height_m
      select 1
      store marea to carea_km2
      replace wlkdat->cstage_m with mheight
endif
```

```
skip
mvolume1 = cvolumekm3
enddo
SELECT 3
USE WLKREC INDEX WLKREC
select 1
seek YR
do while .not. eof()
store year to y
store cstage_m to q

select 3
 seek y
skip 1
replace &n with q
select 1
skip 1
enddo
close databases
clear
if choice='y' .or. choice='Y' set device to print
endif

clear @ 3, 15 say "WALKER LAKE: LAKE-LEVEL RECONSTRUCTION
PARAMETERS"
@ 7, 10 say "MODEL RUN NUMBER:                       "+N
@ 8, 10 say "BEGINNING YEAR:                       "+STR(YR,4,0)
@ 10, 10 say "FIRST DISCHARGE VALUE:                    "+DISCH1
@ 11, 10 say "SECOND DISCHARGE VALUE:                   "+DISCH2
@ 13, 10 say "PRECIPITATION:                          "+PRECIP
@ 15, 10 say "EVAPORATION:                           "+EVAP

set device to screen
SET TALK ON
```

```
* Program: Pyrwinn.prg
* Purpose: Interactive Reconstruction of lake levels
* Author:  Wendy Milne
* Date:    7/9/87
* Lake:    Pyramid and Winnemucca

select 1
use pyrdat index pyrdat
select 2
use pyr10 index pyr10
select 3 use winn10 index winn10
select 4 use pyrwinn index pyrwinn
clear

text
                    THIS PROGRAM WILL RECONSTRUCT
             LAKE LEVELS FOR PYRAMID AND WINNEMUCCA LAKES
 ENDTEXT
?
accept "DO YOU WANT A PRINT-OUT OF THE RUN PARAMETERS? " to
choice
input "ENTER YEAR TO BEGIN CALCULATIONS: " TO YR
ACCEPT "ENTER THE RUN NUMBER (as RUN1):  " TO N
ACCEPT "ENTER THE RUN NUMBER FOR WINNEMUCCA (as WRUN1): "TO
O
?
clear

SELECT 1
DISPLAY STRUC
?
accept "ENTER FIELD NAME OR VALUE FOR TOTAL DISCH  " TO
disch1
ACCEPT "ENTER FIELD NAME OR VALUE FOR PRECIP     " TO precip
ACCEPT "ENTER FIELD NAME OR VALUE FOR EVAP       " TO evap

set talk off
CLEAR
@10,10 say "PYRAMID LAKE RECONSTRUCTION RUN IN PROGRESS"

*calculate 1st incremental vol (virgin inflow to lake)
select 1
seek YR
REPLACE CSTAGE_M WITH PHIST_M
replace wstage_m with whist_m
STORE PHISTVOL TO MVOLUME1
STORE WHISTvol TO WVOL_1
STORE WHISTAREA TO WAREA_KM2
SKIP 1

do while .not. eof()
REPLACE PVOLUME1 WITH MVOLUME1
REPLACE WVOLUME1 WITH WVOL_1
STORE &disch1 to Q
```

```
STORE mvolume1+Q+wvol_1 TO VOL_I1

*Look-up the incremental area related to the new volume
mvolume = 0
marea = 0
lookup = '0'
mdiff = 0
mdiff1 = 0
mvolume1 = 0
DO CASE

**1ST CASE - IF ONE BIG LAKE CASE VOL_I1>=41.6287
 *look-up area for the combined lake
   lookup = str(100*vol_I1,4)
   lookup = substr(lookup,1,3)
   mvolume1 = vol_I1
   select 4
   seek lookup
   skip -2
   mdiff1 = combvol - mvolume1
   skip
   mdiff2 = combvol - mvolume1
   if abs(mdiff2) < abs(mdiff1)
      do while abs(mdiff2) < abs(mdiff1)
         mdiff1 = mdiff2
         skip
         mdiff2 = combvol - mvolume1
      enddo
      if abs(mdiff2) > abs(mdiff1)
         skip -1
      endif
      marea = combarea
      cheight = height_m
      select 1
      store marea to Parea_I1
      store cheight to cheight_m
   else
      marea = combarea
      cheight = height_m
      select 1
      store marea to Parea_I1
      store cheight to cheight_m
   endif pvol=vol_i1 wvol_1=0 wvol_i2=0

**2ND CASE - EACH LAKE IS SEPARATE CASE VOL_I1<=36.5062
 *look-up area for Pyramid
   pvol=vol_i1-wvol_1
   lookup = str(100*pvol,4)
   lookup = substr(lookup,1,3)
   mvolume1 = pvol
   select 2
   seek lookup
   skip -2
   mdiff1 = volume_km3 - mvolume1
   skip
```

```
   mdiff2 = volume_km3 - mvolume1
   if abs(mdiff2) < abs(mdiff1)
      do while abs(mdiff2) < abs(mdiff1)
         mdiff1 = mdiff2
         skip
         mdiff2 = volume_km3 - mvolume1
      enddo
      if abs(mdiff2) > abs(mdiff1)
         skip -1
      endif
      marea = area_km2
      select 1
      store marea to Parea_I1
   else
      marea = area_km2
      select 1
      store marea to Parea_I1
   endif
 *look-up area for Winnemucca
   WINNVOL=WVOL_1
   do case
    case wvol_1<=0.1
     select 1
    case wvol_1>0
     lookup = str(100*WINNVOL,4)
     lookup = substr(lookup,1,3)
     mvolume1 = WINNVOL
     select 3
     seek lookup
     skip -2
     mdiff1 = volume_km3 - mvolume1
     skip
     mdiff2 = volume_km3 - mvolume1
     if abs(mdiff2) < abs(mdiff1)
       do while abs(mdiff2) < abs(mdiff1)
         mdiff1 = mdiff2
         skip
         mdiff2 = volume_km3 - mvolume1
       enddo
       if abs(mdiff2) > abs(mdiff1)
         skip -1
       endif
       marea = area_km2
       select 1
       store marea to Warea_KM2
     else
       marea = area_km2
       select 1
       store marea to Warea_KM2
     endif
   endcase

**3RD CASE - PYRAMID SPILLS TO WINNEMUCCA, PYRAMID IS
CONSTANT,
**WINNEMUCCA FLUCTUATES CASE VOL_I1>36.5062 .and.
```

```
vol_i1<41.6287
 *look-up Winnemucca
  WINNVOL=VOL_I1-36.5062
   lookup = str(100*WINNVOL,4)
   lookup = substr(lookup,1,3)
   mvolume1 = WINNVOL
   select 3
   seek lookup
   skip -2
   mdiff1 = volume_km3 - mvolume1
   skip
   mdiff2 = volume_km3 - mvolume1
   if abs(mdiff2) < abs(mdiff1)
      do while abs(mdiff2) < abs(mdiff1)
         mdiff1 = mdiff2
         skip
         mdiff2 = volume_km3 - mvolume1
      enddo
      if abs(mdiff2) > abs(mdiff1)
         skip -1
      endif
      marea = area_km2
      select 1
      store marea to Warea_KM2
   else
      marea = area_km2
      select 1
      store marea to Warea_KM2
   endif
PAREA_I1=569.45
pvol=36.5062
wvol_1=winnvol
wvol_i2=0
endcase


**CALCULATE PRECIP AND EVAPORATION
select 1
STORE &PRECIP TO PPT
store &evap to ev

do case
 case vol_I1>=41.6287
  PEVAP_PPT=(EV-ppt)*Parea_I1*10E-6
  store pvol-PEVAP_PPT to Pvol_I2
   if pvol_I2>41.6287
    wvol_i2=0
    wevap_ppt=0
    wvol_1=0
   endif
 case vol_i1<41.6287
  PEVAP_PPT=(ev-PPT)*Parea_I1*10E-6
  store pvol-PEVAP_PPT to Pvol_I2
  WEVAP_PPT=(ev-PPT)*Warea_KM2*10E-6
  store Winnvol-WEVAP_PPT to Wvol_I2
```

```
   if wvol_i2<=0
   store 0 to wvol_i2
   endif     endcase

*FINAL LAKE-LEVELS
   lookup = '0'
   mdiff1 = 0
   mdiff2 = 0
   mvolume = 0
   marea = 0
   mvolume1 = 0

DO CASE

**1ST CASE - ONE BIG LAKE CASE pVOL_I2>=41.6287
 *look-up Pyramid
   lookup = str(100*pvol_I2,4)
   lookup = substr(lookup,1,3)
   mvolume1 = pvol_I2
   select 4
   seek lookup
   skip -2
   mdiff1 = combvol - mvolume1
   skip
   mdiff2 = combvol - mvolume1
   if abs(mdiff2) < abs(mdiff1)
      do while abs(mdiff2) < abs(mdiff1)
         mdiff1 = mdiff2
         skip
         mdiff2 = combvol - mvolume1
      enddo
      if abs(mdiff2) > abs(mdiff1)
         skip -1
      endif
      mheight = height_m
      select 1
      replace pyrdat->Cstage_m with mheight
      replace pyrdat->wstage_m with mheight
   else
      mheight = height_m
      select 1
      replace pyrdat->Cstage_m with mheight
      replace pyrdat->wstage_m with mheight
   endif wvol_i2=0 wvol_1=0

**2ND CASE - BIG LAKE EVAPORATES TO TWO LAKES AT SAME LEVEL
 case pvol_i2>36.5062 .and. pvol_i2<41.6287 .and.
vol_i1>=41.6287
      mheight = cheight_m - (ev-ppt)/100
      replace pyrdat->cstage_m with mheight
      replace pyrdat->wstage_m with mheight
       wvol_i2=0
       wvol_1=0
 **3RD CASE - TWO SEPARATE LAKES Case pvol_i2<41.6287
 *look-up Pyramid
```

```
   lookup = str(100*pvol_I2,4)
   lookup = substr(lookup,1,3)
   mvolume1 = pvol_I2
   select 2
   seek lookup
   skip -2
   mdiff1 = volume_km3 - mvolume1
   skip
   mdiff2 = volume_km3 - mvolume1
   if abs(mdiff2) < abs(mdiff1)
      do while abs(mdiff2) < abs(mdiff1)
         mdiff1 = mdiff2
         skip
         mdiff2 = volume_km3 - mvolume1
      enddo
      if abs(mdiff2) > abs(mdiff1)
         skip -1
      endif
      mHEIGHT = HEIGHT_m
      select 1
      replace pyrdat->Cstage_m with mheight
   else
      marea = area_km2
      mheight = height_m
      select 1
      replace pyrdat->Cstage_m with mheight
   endif *look-up Winnemucca
   lookup = '0'
   mdiff1 = 0
   mdiff2 = 0
   mvolume = 0
   mheight = 0
   marea = 0
   mvolume1 = 0 do case
  case wvol_i2<=0.1
    wvol_i2=0
    replace pyrdat->wstage_m with 1149
  case wvol_i2>0
   lookup = str(100*wvol_i2,4)
   lookup = substr(lookup,1,3)
   mvolume1 = wvol_i2
   select 3
   seek lookup
   skip -2
   mdiff1 = volume_km3 - mvolume1
   skip
   mdiff2 = volume_km3 - mvolume1
   if abs(mdiff2) < abs(mdiff1)
      do while abs(mdiff2) < abs(mdiff1)
         mdiff1 = mdiff2
         skip
         mdiff2 = volume_km3 - mvolume1
      enddo
      if abs(mdiff2) > abs(mdiff1)
         skip -1
```

```
      endif
      marea = area_km2
      mheight = height_m
      select 1
      store marea to warea_km2
      replace pyrdat->wstage_m with mheight
   else
      marea = area_km2
      mheight = height_m
      select 1
      store marea to warea_km2
      replace pyrdat->wstage_m with mheight
   endif
  endcase
 if pvol_i2>36.5063
 wvol_i2=0
endif
endcase

skip
mvolume1 = PVOL_I2
wvol_1=wvol_I2
enddo

*WRITE RESULTS TO FINAL DATABASE
SELECT 5
USE pyrREC INDEX pyrREC
select 1
seek YR
do while .not. eof()
store year to y
store cstage_m to q
STORE WSTAGE_M TO R

select 5
 seek y
skip 1
replace &n with q
replace &o with r
select 1
skip 1
enddo

*PRINT SEQUENCE
close databases
clear
if choice='y' .or. choice='Y'
set device to print
endif
clear

@ 3, 15 say "PYRAMID LAKE: LAKE-LEVEL RECONSTRUCTION
PARAMETERS"
@ 7, 10 say "MODEL RUN NUMBER:                    "+N
```

```
@ 8, 10 say "BEGINNING YEAR:
"+STR(YR,4,0)
@ 10, 10 say "VALUE FOR TOTAL DISCHARGE                "+DISCH1
@ 13, 10 say "PRECIPITATION:
"+PRECIP
@ 15, 10 say "EVAPORATION:                           "+EVAP

set device to screen
SET TALK ON
```

```
* Program: Owenlklv.prg
* Purpose: Interactive Reconstruction of lake levels
* Author:  Wendy Milne
* Date:    7/15/87
* Lake:    Owens

select 1
use owendat index owendat
select 2
use owenhyp index owenhyp
select 3
use owenrec index owenrec
clear

text
                      THIS PROGRAM WILL RECONSTRUCT
                        LAKE LEVELS FOR OWENS LAKE ENDTEXT ?
accept "DO YOU WANT A PRINT-OUT OF THE RUN PARAMETERS? " to
choice
input "ENTER YEAR TO BEGIN CALCULATIONS: " TO YR
ACCEPT "ENTER THE RUN NUMBER (as RUN1):  " TO N
accept "ENTER FIELD NAME FOR AREA (as R3AREA): " TO AR
ACCEPT "ENTER FIELD NAME FOR VOLUME (as R3VOL): " TO VL
ACCEPT "ENTER VALUE FOR PRECIP    " TO precip
ACCEPT "ENTER VALUE FOR EVAP      " TO evap

set talk off
CLEAR
@10,10 say "OWENS LAKE RECONSTRUCTION RUN IN PROGRESS"

*calculate 1st incremental vol (virgin inflow to lake)
select 1
seek YR
REPLACE CSTAGE_M WITH HEIGHT_M
MVOLUME1=CVOLUME_KM
SKIP 1

do while .not. eof()
REPLACE VOLUME1 WITH MVOLUME1
STORE TOT_FLOWKM to Q
STORE mvolume1+Q TO VOL_I1

*Look-up the incremental area related to the new volume
mvolume = 0
marea = 0
lookup = '0'
mdiff = 0
mdiff1 = 0
mvolume1 = 0

 *look-up area for the combined lake
   lookup = str(100*vol_I1,4)
   lookup = substr(lookup,1,3)
   mvolume1 = vol_I1
   select 2
```

```
   seek lookup
   skip -2
   mdiff1 = volume_km3 - mvolume1
   skip
   mdiff2 = volume_km3 - mvolume1
   if abs(mdiff2) < abs(mdiff1)
      do while abs(mdiff2) < abs(mdiff1)
         mdiff1 = mdiff2
         skip
         mdiff2 = volume_km3 - mvolume1
      enddo
      if abs(mdiff2) > abs(mdiff1)
         skip -1
      endif
      marea = area_km2
      cheight = height_m
      select 1
      store marea to area_I1
      store cheight to cheight_m
   else
      marea = area_km2
      cheight = height_m
      select 1
      store marea to area_I1
      store cheight to cheight_m
   endif

**CALCULATE PRECIP AND EVAPORATION
select 1
STORE &PRECIP TO PPT
store &evap to ev

 EVAP_PPT=(EV-ppt)*area_I1*10E-6
 store mvolume1-EVAP_PPT to vol_I2
 *FINAL LAKE-LEVELS
   lookup = '0'
   mdiff1 = 0
   mdiff2 = 0
   mvolume = 0
   marea = 0
   mvolume1 = 0

   lookup = str(100*vol_I2,4)
   lookup = substr(lookup,1,3)
   mvolume1 = vol_I2
   select 2
   seek lookup
   skip -2
   mdiff1 = volume_km3 - mvolume1
   skip
   mdiff2 = volume_km3 - mvolume1
   if abs(mdiff2) < abs(mdiff1)
      do while abs(mdiff2) < abs(mdiff1)
         mdiff1 = mdiff2
         skip
```

```
          mdiff2 = volume_km3 - mvolume1
       enddo
       if abs(mdiff2) ) abs(mdiff1)
          skip -1
       endif
       mHEIGHT = HEIGHT_m
       marea=area_km2
       select 1
       replace owendat->Cstage_m with mheight
       replace owendat->cvolume_km with mvolume1
       replace owendat->carea_km2 with marea
    else
       marea = area_km2
       mheight = height_m
       select 1
       replace owendat->Cstage_m with mheight
       replace owendat->cvolume_km with mvolume1
       replace owendat->carea_km2 with marea
     endif
SKIP 1
ENDDO
*WRITE RESULTS TO FINAL DATABASE
select 1
seek YR
do while .not. eof()
store year to y
store cstage_m to s
store carea_km2 to a
store cvolume_km to v
select 3
 seek y
skip 1
replace &n with s
replace &ar with a
replace &vl with v
select 1
skip 1
enddo
*PRINT SEQUENCE
close databases
clear
if choice='y' .or. choice='Y'
set device to print
endif
clear
@ 3, 15 say "OWENS LAKE: LAKE-LEVEL RECONSTRUCTION
PARAMETERS"
@ 7, 10 say "MODEL RUN NUMBER:                    "+N
@ 8, 10 say "BEGINNING YEAR:
"+STR(YR,4,0)
@ 13, 10 say "PRECIPITATION:                        "+PRECIP
@ 15, 10 say "EVAPORATION:                         "+EVAP
set device to screen
SET TALK ON
```

APPENDIX B - ACTUAL AND ESTIMATED DISCHARGE DATA

Walker River
(km3)

YEAR	Actual 296500	Estimated 296500	Actual 293000	Estimated 293000
1871	0.0000	0.2280	0.0000	0.0629
1872	0.0000	0.4993	0.0000	0.2037
1873	0.0000	0.2723	0.0000	0.0859
1874	0.0000	0.4406	0.0000	0.1733
1875	0.0000	0.2515	0.0000	0.0752
1876	0.0000	0.4529	0.0000	0.1796
1877	0.0000	0.2351	0.0000	0.0666
1878	0.0000	0.2990	0.0000	0.0998
1879	0.0000	0.2664	0.0000	0.0828
1880	0.0000	0.4353	0.0000	0.1705
1881	0.0000	0.2780	0.0000	0.0889
1882	0.0000	0.4243	0.0000	0.1647
1883	0.0000	0.1838	0.0000	0.0400
1884	0.0000	0.4145	0.0000	0.1597
1885	0.0000	0.2593	0.0000	0.0791
1886	0.0000	0.2906	0.0000	0.0954
1887	0.0000	0.3068	0.0000	0.1039
1888	0.0000	0.1556	0.0000	0.0254
1889	0.0000	0.1737	0.0000	0.0348
1890	0.0000	0.5987	0.0000	0.3788
1891	0.0000	0.3970	0.0000	0.2403
1892	0.0000	0.3928	0.0000	0.2374
1893	0.0000	0.5312	0.0000	0.3324
1894	0.0000	0.3778	0.0000	0.1407
1895	0.0000	0.4095	0.0000	0.1571
1896	0.0000	0.3226	0.0000	0.1120
1897	0.0000	0.3267	0.0000	0.1142
1898	0.0000	0.2008	0.0000	0.0489
1899	0.0000	0.3289	0.0000	0.1153
1900	0.0000	0.2127	0.0000	0.1111
1901	0.0000	0.3651	0.0000	0.2184
1902	0.0000	0.2048	0.0000	0.1083
1903	0.2778	0.2778	0.0000	0.1607
1904	0.3491	0.3491	0.0000	0.2089
1905	0.1932	0.1932	0.0000	0.1035
1906	0.5220	0.5220	0.0000	0.3257
1907	0.6059	0.6059	0.0000	0.3823
1908	0.0000	0.1743	0.0000	0.0874
1909	0.0000	0.3625	0.0000	0.2166
1910	0.0000	0.2969	0.0000	0.1463
1911	0.0000	0.4438	0.0000	0.2784
1912	0.0000	0.2273	0.0000	0.1262
1913	0.0000	0.2371	0.0000	0.1330
1914	0.0000	0.3349	0.0000	0.2018
1915	0.0000	0.2746	0.0000	0.1594
1916	0.3221	0.3221	0.0000	0.1906

1917	0.3048	0.3048	0.0000	0.1789
1918	0.2530	0.2530	0.0000	0.1439
1919	0.2098	0.2098	0.0000	0.1147
1920	0.2147	0.2147	0.0000	0.1181
1921	0.2727	0.2727	0.0000	0.1572
1922	0.3332	0.3332	0.0000	0.1981
1923	0.2715	0.2715	0.1382	0.1382
1924	0.0765	0.0765	0.0000	0.0506
1925	0.2517	0.2517	0.0000	0.1430
1926	0.1567	0.1567	0.0887	0.0887
1927	0.2949	0.2949	0.1183	0.1183
1928	0.1629	0.1629	0.0996	0.0996
1929	0.1468	0.1468	0.0666	0.0666
1930	0.1666	0.1666	0.0627	0.0627
1931	0.0866	0.0866	0.0357	0.0357
1932	0.2507	0.2507	0.0958	0.0958
1933	0.1477	0.1477	0.0972	0.0972
1934	0.1196	0.1196	0.0574	0.0574
1935	0.2403	0.2403	0.0925	0.0925
1936	0.2496	0.2496	0.1257	0.1257
1937	0.2684	0.2684	0.1489	0.1489
1938	0.0000	0.4845	0.3224	0.3224
1939	0.0000	0.1481	0.0899	0.0899
1940	0.0000	0.2468	0.0930	0.0930
1941	0.0000	0.3011	0.1542	0.1542
1942	0.0000	0.3044	0.1789	0.1789
1943	0.0000	0.2791	0.1641	0.1641
1944	0.0000	0.1791	0.1114	0.1114
1945	0.0000	0.3070	0.1599	0.1599
1946	0.0000	0.2423	0.1398	0.1398
1947	0.0000	0.1725	0.0940	0.0940
1948	0.0000	0.1640	0.0696	0.0696
1949	0.0000	0.1794	0.0774	0.0774
1950	0.0000	0.2872	0.0876	0.0876
1951	0.0000	0.2348	0.1089	0.1089
1952	0.0000	0.3806	0.2548	0.2548
1953	0.0000	0.2269	0.1188	0.1188
1954	0.0000	0.1759	0.0988	0.0988
1955	0.0000	0.1922	0.0664	0.0664
1956	0.0000	0.3899	0.2160	0.2160
1957	0.0000	0.2084	0.1194	0.1194
1958	0.3359	0.3359	0.1961	0.1961
1959	0.1366	0.1366	0.0879	0.0879
1960	0.1288	0.1288	0.0588	0.0588
1961	0.1099	0.1099	0.0381	0.0381
1962	0.2317	0.2317	0.1069	0.1069
1963	0.2854	0.2854	0.1687	0.1687
1964	0.1625	0.1625	0.0850	0.0850
1965	0.2975	0.2975	0.1597	0.1597
1966	0.1715	0.1715	0.1091	0.1091
1967	0.3816	0.3816	0.2179	0.2179
1968	0.1661	0.1661	0.1010	0.1010
1969	0.4693	0.4693	0.3118	0.3118
1970	0.2268	0.2268	0.1391	0.1391
1971	0.2378	0.2378	0.1262	0.1262

1972	0.1866	0.1866	0.0979	0.0979
1973	0.2759	0.2759	0.1376	0.1376
1974	0.2881	0.2881	0.1497	0.1497
1975	0.2883	0.2883	0.1529	0.1529
1976	0.0976	0.0976	0.0639	0.0639
1977	0.0632	0.0632	0.0376	0.0376
1978	0.3157	0.3157	0.1472	0.1472
1979	0.2468	0.2468	0.1604	0.1604
1980	0.3624	0.3624	0.2227	0.2227
1981	0.1567	0.1567	0.1038	0.1038
1982	0.4247	0.4247	0.2772	0.2772
1983	0.5003	0.5003	0.3956	0.3956
1984	0.3111	0.3111	0.1768	0.1768
1985	0.1861	0.1861	0.1272	0.1272
1986	0.0000	0.4001	0.0000	0.2573

Actual and Estimated Discharge Data
Truckee River
(km3)

YEAR	Actual 346000	Estimated 346000
1871	0.0000	0.5745
1872	0.0000	1.5403
1873	0.0000	0.7319
1874	0.0000	1.3314
1875	0.0000	0.6582
1876	0.0000	1.3750
1877	0.0000	0.5996
1878	0.0000	0.8272
1879	0.0000	0.7111
1880	0.0000	1.3124
1881	0.0000	0.7525
1882	0.0000	1.2732
1883	0.0000	0.4170
1884	0.0000	1.2383
1885	0.0000	0.6857
1886	0.0000	0.7971
1887	0.0000	0.8550
1888	0.0000	0.3166
1889	0.0000	0.3810
1890	0.0000	1.9642
1891	0.0000	1.2533
1892	0.0000	1.2384
1893	0.0000	1.7262
1894	0.0000	1.1077
1895	0.0000	1.2207
1896	0.0000	0.9110
1897	0.0000	0.9258
1898	0.0000	0.4777
1899	0.0000	0.9337
1900	0.5578	0.5578
1901	0.8367	0.8367
1902	0.6701	0.6701
1903	0.6725	0.6725
1904	1.4808	1.4808
1905	0.6750	0.6750
1906	1.2710	1.2710
1907	1.8757	1.8757
1908	0.6812	0.6812
1909	1.3697	1.3697
1910	0.8700	0.8700
1911	1.3944	1.3944
1912	0.5183	0.5183
1913	0.5257	0.5257
1914	1.0785	1.0785
1915	0.6997	0.6997
1916	1.0180	1.0180
1917	0.8564	0.8564

1918	0.6096	0.6096
1919	0.7120	0.7120
1920	0.4800	0.4800
1921	0.6256	0.6256
1922	0.8021	0.8021
1923	0.6380	0.6380
1924	0.2702	0.2702
1925	0.4553	0.4553
1926	0.3332	0.3332
1927	0.8120	0.8120
1928	0.5886	0.5886
1929	0.3147	0.3147
1930	0.4047	0.4047
1931	0.1567	0.1567
1932	0.4825	0.4825
1933	0.2579	0.2579
1934	0.2564	0.2564
1935	0.4542	0.4542
1936	0.6259	0.6259
1937	0.6036	0.6036
1938	1.0035	1.0035
1939	0.4128	0.4128
1940	0.7302	0.7302
1941	0.6040	0.6040
1942	0.9238	0.9238
1943	1.0425	1.0425
1944	0.4629	0.4629
1945	0.5684	0.5684
1946	0.6205	0.6205
1947	0.4411	0.4411
1948	0.4751	0.4751
1949	0.4055	0.4055
1950	0.9328	0.9328
1951	0.6818	0.6818
1952	1.5832	1.5832
1953	0.7867	0.7867
1954	0.5003	0.5003
1955	0.5500	0.5500
1956	0.9888	0.9888
1957	0.6255	0.6255
1958	1.1020	1.1020
1959	0.4312	0.4312
1960	0.4508	0.4508
1961	0.2590	0.2590
1962	0.5277	0.5277
1963	0.6847	0.6847
1964	0.5797	0.5797
1965	0.8354	0.8354
1966	0.5188	0.5188
1967	1.1306	1.1306
1968	0.5164	0.5164
1969	1.3907	1.3907
1970	0.8570	0.8570
1971	0.8860	0.8860
1972	0.5554	0.5554

1973	0.6356	0.6356
1974	0.9837	0.9837
1975	0.8828	0.8828
1976	0.5453	0.5453
1977	0.2595	0.2595
1978	0.5666	0.5666
1979	0.4557	0.4557
1980	0.7008	0.7008
1981	0.5850	0.5850
1982	1.4129	1.4129
1983	2.2928	2.2928
1984	0.9876	0.9876
1985	0.5317	0.5317
1986	0.0000	1.2166
1987	0.0000	0.0000

Actual and Estimated Discharge Data
Owens River
(km3)

YEAR	Estimated Discharge into Owens Lake
1927	0.3386
1928	0.2656
1929	0.2331
1930	0.3020
1931	0.2959
1932	0.3002
1933	0.2692
1934	0.2685
1935	0.3142
1936	0.2770
1937	0.3841
1938	0.6431
1939	0.3768
1940	0.2599
1941	0.3043
1942	0.3788
1943	0.2925
1944	0.3336
1945	0.3533
1946	0.3888
1947	0.3069
1948	0.2716
1949	0.2693
1950	0.2706
1951	0.3766
1952	0.3151
1953	0.3678
1954	0.3106
1955	0.2864
1956	0.3418
1957	0.3690
1958	0.3520
1959	0.2864
1960	0.2386
1961	0.2457
1962	0.3113
1963	0.3294
1964	0.2511
1965	0.3415
1966	0.3693
1967	0.3617
1968	0.4103
1969	0.6222
1970	0.4332
1971	0.4528
1972	0.4415
1973	0.4264
1974	0.4204
1975	0.5027
1976	0.4791

Linear regression formulae for estimating yearly stream discharge in km^3.
[WTY, water year; Q, discharge; PPT, precipitation at Truckee California]

Formula		Years derived
Q_{3460}	$=-0.0078 + 1.0112Q_{3460WTY}$	1986
Q_{3460}	$=-0.0529 + 2.3586Q_{3090}$	1890-1893
$Q_{3460WTY}$[1]	$=-0.0390 + 0.0140PPT$	1870-1889, 1894-1899
$Q_{3460WTY}$	$= 0.0140 + 0.0097PPT$	–
Q_{2965}	$= 0.0038 + 1.0300Q_{2960}$	1939-1957
Q_{2965}	$=-0.0037 + 1.0196Q_{2965WTY}$	1910, 1986
Q_{2965}	$= 0.0265 + 0.6691Q_{3090}$	
1890-93, 1901-02, 1908-09		
Q_{2965}	$= 0.0312 + 2.2747Q_{3100}$	1911-15
Q_{2965}	$= 0.0624 + 1.3091Q_{2930}$	1938
Q_{2965}	$= 0.0768 + 0.2436Q_{3460}$	1900
$Q_{2965WTY}$[1]	$= 0.0560 + 0.0039PPT$	1870-89, 1894-99
Q_{2965}	$= 0.0357 + 0.0030_{PPT}$	–
Q_{2930}	$=-0.0041 + 1.0313Q_{2930WTY}$	1924, 1986
Q_{2930}	$=-0.0270 + 0.6756Q_{2965}$	
1903-07, 1916-22, 1925		
Q_{2930}	$=-0.0141 + 0.4594Q_{3090}$	
1890-93, 1901-02, 1908-10		
Q_{2930}	$=-0.0117 + 1.5994Q_{3100}$	1911-15
Q_{2930}	$= 0.0158 + 0.1708Q_{3460}$	1900
$Q_{2930WTY}$	$=-0.0228 + 0.0020_{PPT}$	1870-89, 1894-99

[1]data set limited to pre-diversion records (1900-30)

APPENDIX C - STAGE-AREA-VOLUME RELATIONSHIPS

Stage-area-volume relationship
Walker Lake

HEIGHT METERS	AREA KM2	VOLUME KM3
1172.00	0.00	0.00
1172.10	0.01	0.00
1172.20	0.03	0.00
1172.30	0.05	0.00
1172.40	0.06	0.00
1172.50	0.07	0.00
1172.60	0.08	0.00
1172.70	0.10	0.00
1172.80	0.12	0.00
1172.90	0.20	0.00
1173.00	0.35	0.00
1173.10	0.54	0.00
1173.20	0.77	0.00
1173.30	1.03	0.00
1173.40	1.33	0.00
1173.50	1.66	0.00
1173.60	2.02	0.00
1173.70	2.42	0.00
1173.80	2.84	0.00
1173.90	3.29	0.00
1174.00	3.76	0.00
1174.10	4.26	0.00
1174.20	4.78	0.00
1174.30	5.33	0.00
1174.40	5.90	0.00
1174.50	6.51	0.00
1174.60	7.14	0.01
1174.70	7.80	0.01
1174.80	8.50	0.01
1174.90	9.23	0.01
1175.00	10.00	0.01
1175.10	10.80	0.01
1175.20	11.64	0.01
1175.30	12.51	0.01
1175.40	13.42	0.01
1175.50	14.35	0.01
1175.60	15.32	0.02
1175.70	16.31	0.02
1175.80	17.32	0.02
1175.90	18.37	0.02
1176.00	19.43	0.02
1176.10	20.52	0.03
1176.20	21.62	0.03
1176.30	22.75	0.03
1176.40	23.89	0.03
1176.50	25.05	0.03