Chapter II: THE MONO LAKE WATER BALANCE MODEL

In this chapter a new Mono Lake water balance forecast model is developed by a reproducible, systematic procedure that follows the previously outlined modeling process of formulation, calibration, verification and application.

FORMULATION

The forecast model is formulated through a quantitative assessment of the inflows, (precipitation, runoff, and diversions), outflows (evaporation, evapotranspiration, and diversions), and storage changes within the Mono Groundwater Basin (MGWB), Prior to this analysis the free-body, time interval, and base period must be specified.

FREE-BODY.

The MGWB is the most suitable free-body for a lake level forecast model since most of the inflow to Mono Lake is surface runoff measured at or just upstream from the ground water basin boundary, The boundary of the MGWB is defined by the contact between the unconsolidated sediments of the basin floor and the glacial till or bedrock. This choice of a boundary facilitates a more accurate delineation and estimation of the water balance components because it allows one to assume that all runoff across the water balance boundary consists of measured runoff or an estimated yield (yield which includes surface and subsurface runoff) of the ungaged bedrock and till areas. If the glacial till is assumed to be part of the ground water basin the measured runoff would have to be reduced by the yield of the till between the bedrock boundary and the gaging stations. The lack of reliable information on the runoff characteristics of the till makes such a determination very difficult.

TIME INTERVAL.

Because evaporative outflow cannot be accurately estimated in the Mono Basin for periods shorter than one year, the water balance is developed for an annual time interval. The water year (October 1 through September 30) is an appropriate annual time interval to use since runoff and soil water storage are near a minimum at the beginning of the water year. The beginning of the water year is also close to the start of the winter precipitation season,

BASE PERIOD.

The base period is determined by the availability of reliable measurements of runoff since runoff is the principal inflow to the MGWB. Runoff measurements were made irregularly from 1911 to 1917 on Rush and Lee Vining Creeks by the USGS and again from the mid-1920's to the mid-1930's by the Southern Sierra Power (SSP) Company. Runoff from Mill Creek was presumably measured back to 1904 using the measured output from the power plant. Estimates of total Sierra stream runoff were made from 1872 to 1921 by CADPW (1922) and estimates for the individual streams were made from 1895 to 1947 by the CASWRCB (1951). These estimates were derived by correlation with precipitation and runoff in nearby watersheds (Tuolumne River, Walker River). The natural (unimpaired) runoff from Mill, Lee Vining, and Rush Creeks was estimated back to 1904 by the SSP presumably by extending back through time the correlation of Mill Creek measurements with the available Lee Vining and Rush Creek measurements.[l] The runoff measurements and estimates through 1936 are unsuitable for modeling purposes because the values given by the different agencies for equivalent variables often differ significantly from each other, By 1937 the LADWP, which had taken over the SSP gaging stations and established new ones, was regularly monitoring the principal streams in the Mono Basin. Table 2-l shows the date LADWP established their gaging stations. 1937 is the first year that consistently reliable runoff measurements are available on both Rush and Lee Vining Creeks.

The period from 1937 to 1983 is selected as the base period. The most recent years are included in order to have the longest possible record and to allow the calibration and verification periods to incorporate both wet and dry periods. Although the latest four year (1980-83) period is abnormally wet when referenced to the long term precipitation records at Sacramento or San Francisco, it is not clear what is "normal" in the Mono Basin given that 1980-83 conditions actually occurred and that it appears, according to Stine's (1984) analysis of Mono Lake's pre-historic fluctuations, that for much of the past 4,000 years the

TABLE 2-l. Mono Basin Gaging Stations Used in Calculation of Sierra Nevada Gaged Runoff

Gaging Station	Date LADWP Estab. Station	Measuring Device	Date Automatic Recorder Installed	Remarks
Dechambeau Creek above diversions	5/29/35	1 foot venturi flume	4/28/38	Since 12/l/36, irrigation diversion of .2 cfs above station.
Gibbs Creek @ Lee Vining Cr.	9/3/48	1 foot venturi flume		Not used since 8/77 when Lee Vining Creek station moved downstream.
Gibbs Creek @ diversions	1957?	1 foot venturi flume	None	Measures diversion to Horse Meadow and Farrington Ranch.
"0" ditch	6/25/46	1 foot venturi flume	6/19/75	Measures water diverted from Lee Vining Creek for use on grazing lands.
Lee Vining Creek @ 2.5 M. above USFS R.S.	3/29/34	current meter station	8/7/44	Above all irrigation diversions; occasional current meter measurements made 1923-1935; regular measurements 1935-1977
Lee Vining Creek @ conduit	9/20/72	15 foot parshall flume	9/20/72	Located Just above LADWP conduit and downstream of Gibbs Creek; records used since 8/77

Gaging Station	Date LADWP Estab. Station	Measuring Device	Date Automatic Recorder Installed	Remarks
Parker Creek main stem above diversion	4/l/34	9 foot cippoletti weir	5/12/36	Prior summertime measurements made by SSP.
Parker Creek main stem above diversion	11/18/37	4 foot venturi flume	l/29/38	Switched to down-stream location on 11/18/37,
Parker Creek East, above diversions	5/19/36	2 foot cippoletti weir/ parshall flume	None; frequent gage readings	Parshall flume installed l0/73
Parker Creek South, above diversion	4/29/36	2 foot cippoletti weir/ parshall flume	None; frequent gage readings	Parshall flume installed l0/73
Rush Creek @ damsite	11/3/36	15-foot Venturi flume	11/3/36	Measurements made from 1924 to 1933 two miles upstream.
Walker Creek 300 yds. below lake	3/29/34	3-foot venturi flume	None	Station estab. by SSP 5/2/24,
Walker Creek above conduit	10/6/41	4-foot venturi flume	10/6/41	Moved to present location 10/6/41
Mill Creek Power Plant	N/A	current meter msmts. below plant	N/A	Plant washed out in 1961 - reopened in 1969; sum of measured flow in tailrace and Upper Conway Ditch

Gaging Station	Date LADWP Estab. Station	Measuring Device	Date Automatic Recorder Installed	Remarks
Mill Creek below Lundy Lake	N/A	6-foot parshall flume (replaced by B-foot flume in 1983)	?	Measures seepage, spillage, and releases from from Lundy Lake

Source: Compiled from LADWP "Station Descriptions" (unpublished compilation and SCE personal communication (1982-1983)

N/A - Not Applicable

Mono Basin climate was either wetter or drier than the current climate.

In the following sections each storage, inflow, and outflow process is examined separately and each quantifiable component is identified separately so that independent determinations of each component's annual value in the 1937-83 base period can be made. A discussion and estimate of the errors involved in component quantification is included as a separate section.

PRECIPITATION

Precipitation is examined first because it is the source of all inflows to the MGWB. Over much of the basin the primary source of precipitation is snowfall derived from frontal systems that originate over the Pacific; spring snow storms generated over the Great Basin and summer thunderstorms triggered by moist southerly flow account for the rest of the annual precipitation. As a result, at least 75% of the annual precipitation falls between October and March, except in the eastern portion of the basin where the spring and summer storms may account for a larger percentage of the annual total, Figure 2-l shows the monthly precipitation regime of the Mono Lake, Bodie, and East Side Mono Lake Stations; a shift in the regime as one moves eastward is apparent (see Figure Al-l in Appendix 1 for station locations).

The pattern and amount of precipitation in the Mono Basin can be deduced from the measurements at precipitation stations

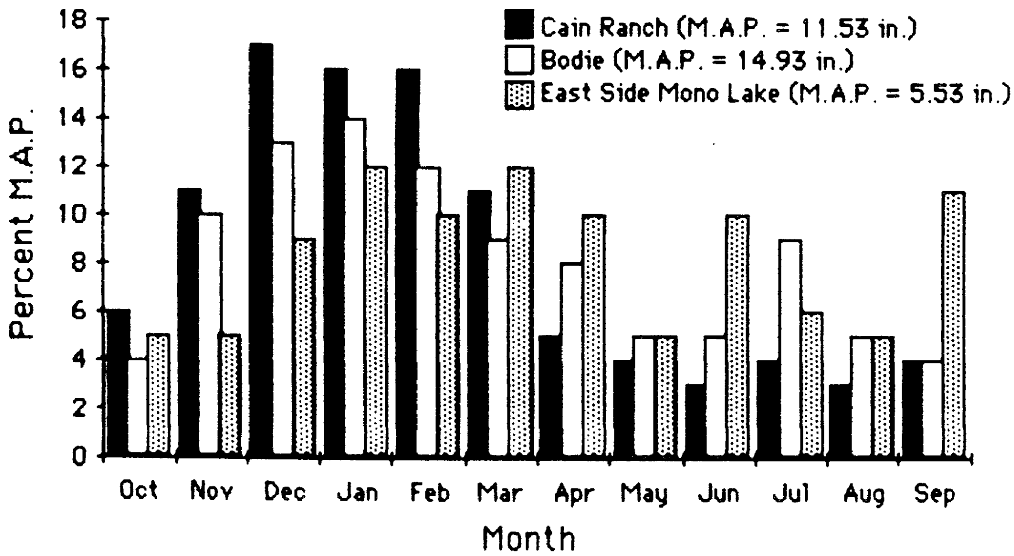


Figure 2-1. Comparision of Monthly Percentage of Mean Annual Precipitation (M.A.P.)

and snow courses within and proximate to the basin. The measurements show that altitude and distance from the Sierra crest explain the large-scale spatial variation of the precipitation over the basin due to orographic effects. Figure 2-2 is a plot of average annual precipitation vs. elevation and distance from the Sierra crest (see also Table A2-1 and Figure A2-1). Spreen (1947) discovered that slope, orientation, exposure, and local topographic barriers can also explain precipitation variation in mountainous regions; in the Mono Basin these latter factors explain more localized spatial variations in precipitation. For example the reduced height of the Sierra Nevada southwest of the Mono Basin allows more winter snowfall at a given altitude in the southwestern portion of the Mono Basin, because Pacific storms retain proportionally more moisture.

A graphic display of the amount and distribution of precipitation over the Mono Basin is portrayed with lines of equal mean annual precipitation in the isohyetal map of Figure 2-3. The isohyetal map is used to estimate the precipitation rate or volume for a region by measuring the area between successive contours (isohyets) and multiplying the area by the average precipitation between the bounding contours. A new isohyetal map is derived for this model because all the isohyetal maps used in the previous models are inadequate portrayals of the amount and distribution of precipitation over the Mono Basin (see Appendix II-A for a discussion of the derivation of this study's map). The problems associated with the other maps include:

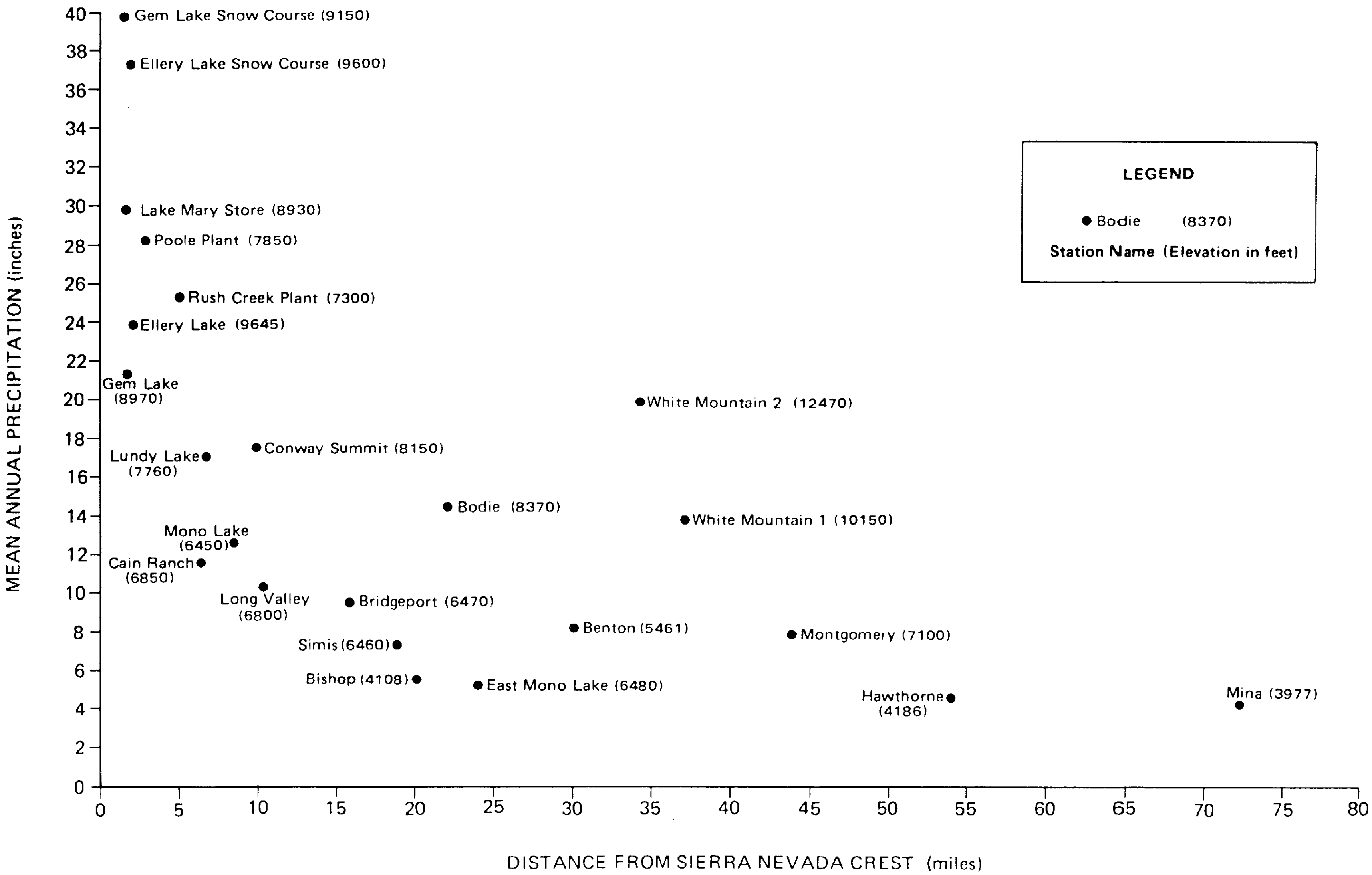


Figure 2-2 **Relationship of Precipitation to Elevation and Distance from the Sierra Nevada Crest**

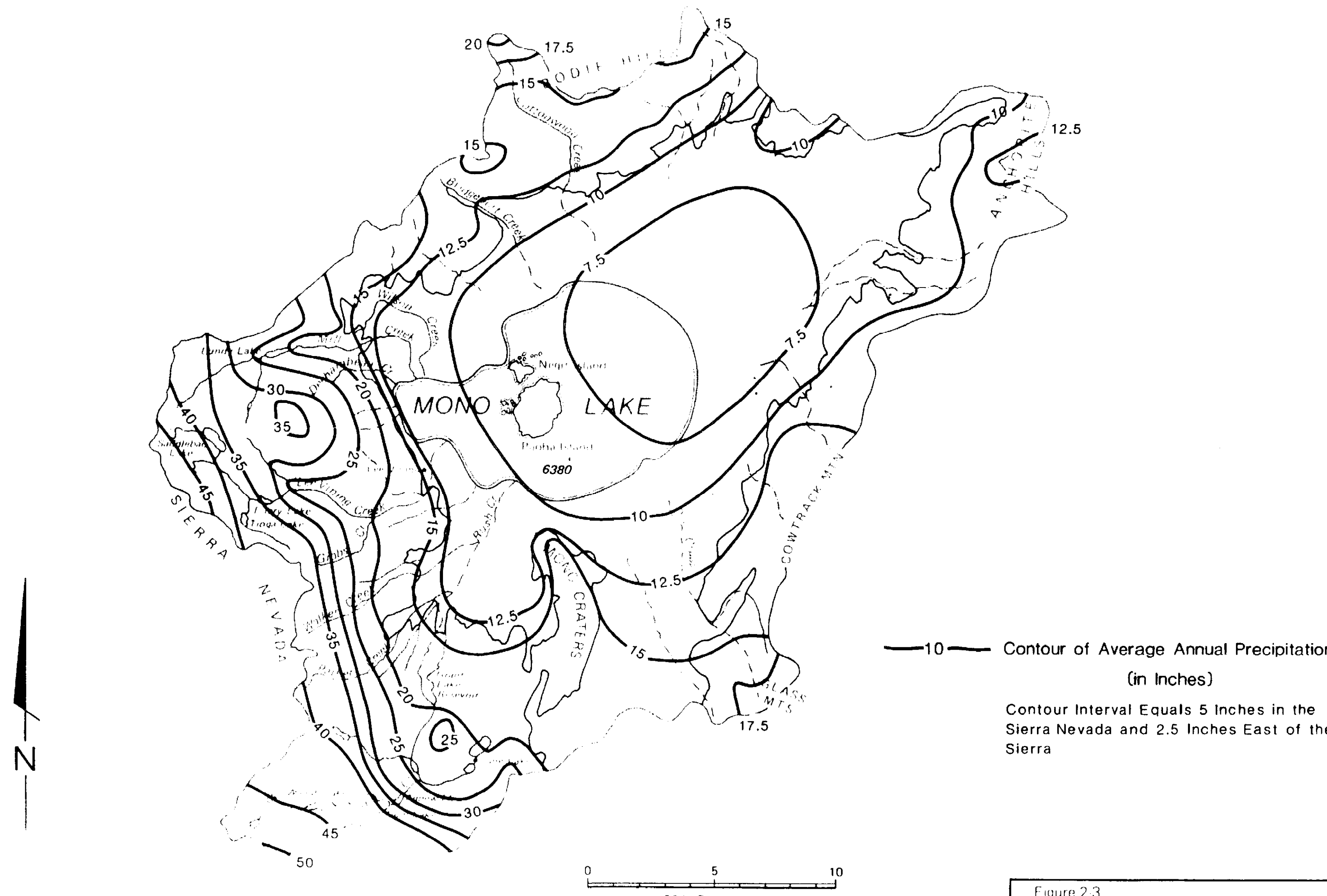


Figure 2.3
Average Annual Precipitation

(a) Precipitation estimates derived from the different maps vary by as much as 20 inches at a given location;

(b) The calculated precipitation volume for the Sierra watersheds derived from the maps used by Lee (1969), Loeffler (1977), LADWP (1984,a,b,c,d) can be shown to be too low given the measured runoff volumes and estimated evapotranspiration; their low estimate of precipitation results from relying on precipitation gages as an estimator of mountain precipitation even though it is widely acknowledged that precipitation gages in mountainous regions substantially undermeasures actual precipitation, especially snowfall, and that snow course measurements are a more reliable guide to precipitation (WMO 1973 and Goodridge pers comm 1980). For example, the average October through March precipitation at the Gem Lake precipitation gage is about 17 inches while the average April 1 snow water content at the nearby Gem Lake snow course is nearly 31 inches;

(c) None of the maps use all of the available precipitation and snow course data that has been collected in and nearby the Mono Basin; and

(d) the period of record upon which the maps are based is no longer representative of this model's base period (1937-83) climate.

The new isohyetal map shows that the average precipitation over the Mono Basin varies from near 50 inches in the southwestern extremity of the basin to less than 7.5 inches in the area just east of Mono Lake; about l/2 of the basin receives on the average less than 12.5 inches per year.[2]

In the current model precipitation is a quantified variable in five different components.

These include:

(a) precipitation on the Grant Lake Reservoir surface

(b) precipitation on the Mono Lake surface

(c) net precipitation on the MGWB land surface

(d) ungaged Sierra runoff

(e) non-Sierra runoff

Component (a) has never been quantified as a separate water balance component, In this model it is more conveniently analyzed together with the component net Grant Lake Reservoir evaporation (NGLR), In components (d) and (e) the precipitation is transformed into runoff. These two components are thus discussed in the section that deals with runoff.

Mono Lake Precipitation (MLP). Previous water balance models that include MLP as a separate component compute it as a product of a lake precipitation rate and a lake area. The average annual lake precipitation rate used by the previous models varied from 5.3 inches to 12 inches; a comparison of each model's rate and the method used to calculate it are given in Table 2-2, Five of the models (CADWR 1960, Mason 1967, Moe 1973, CADWR 1974, and CADWR 1979) did not compute MLP as a separate component - it

TABLE 2-2. Comparison of Average Annual Mono Lake Precipitation Rate

Study	Avg Annual Rate (Wyr)	Base Period	Method
Lee (1934)	9.7	1903-33	Not Stated
Black (1958)	5.3	Not stated	Thiessan polygons
CADWR (1960)	Not estimated separately	N/A	Part of net evaporation
Harding (1962)	8.0	N/A	Estimated average rate
Scholl et al(1967)	12.0	Not stated	From Putnam (1949)
Mason (1967)	Not estimated separately	N/A	Does not account for lake precipitation
Lee (1969)	7.3	1954-64	Isohyetal
Corley (1971)	11.2	1937-70	Assumed lake precipitation is equal to Cain Ranch precipi-tation
Moe (1973)	Not estimated separately	N/A	Part of net evaporation; accounted for in measured elevation
CADWR (1974	Not estimated separately	N/A	N/A
Loeffler (1977)	7.8	Not stated	Isohyetal
Cromwell (1979)	7.0	1951-78	Isohyetal
CADWR (1979)	Not estimated separately	N/A	Part of total inflow residual

Study	Avg Annual Rate (in/yr)	Base Period	Method
LADWP (1984 a,b,c,d)	8.0	1941-76	Isohyetal
Vorster (1985)	8.0	1937-83	Isohyetal

N/A - Not applicable

is either part of the net lake evaporation or inflow residual. In the water balances that are derived for successive time intervals (Corley 1970, Loeffler 1977, Cromwell 1979, LADWP 1984 a,d) an annual variation in -the lake precipitation rate is computed by multiplying the average rate by an index of "wetness" or precipitation variability. The lake area used in these models is determined by the relationship of Mono Lake's elevation (stage) to its area; this relationship, in turn, is based on Russell's (1889) lake bathymetry rather than the more accurate bathymetry of Scholl et al. (1967), (Table Al-3 compares the difference between the stage/area relationships using the Russell and Scholl bathymetries.)

For this model the MLP is computed as a product of the average lake precipitation rate, an index of precipitation variability and the average water year lake area, In equation form:

$$MLP = P_A \times PI \times A_L \qquad (11)$$

MLP - Mono Lake Precipitation

P_A - Average Lake Precipitation Rate

PI - Index of Precipitation Variation

A_L - Average Area of Mono Lake

The average annual rate over the lake surface derived from the new isohyetal map equals 8 inches. In regions of large spatial variation of precipitation and/or sparse precipitation networks the isohyetal method reflects the average precipitation rate over a surface more accurately that the other classical methods (Theissan polygons and arithmetic average) of estimating average area1 precipitation (Linsley et al. 1975). The precipitation rate for the lake did not change significantly enough between a high stand of the lake at the beginning of the base period and a low stand of the lake at the end of the base period to warrant having different average precipitation rates for different lake levels.

The annual variation in the lake precipitation rate is represented by a dimensionless index derived from the precipitation variation at Cain Ranch, the only precipitation in the MGWB with measurements for each year in the base period. [3] The annual index equals the ratio of the annual Cain Ranch precipitation to its base period average.

A representative lake area for a given annual period is derived by averaging successive October 1 lake areas. The lake areas are determined from the stage/area relationship derived for this study . The latter relationship updates the one used by the other models.

The annual values for MLP are shown in Table 2-15. This component value generally decreases over the base period due to the reduction in lake surface area.

Net Land Surface Precipitation (NZSP). Except for LADWP (1984 b,c), the land surface precipitation is not quantified by the other models since their free-body does not include any land area. LADWP (1984 b,c) give an annual average land surface precipitation of 157,000 ac-ft for their "Galley-fill" area, which includes the glacial till. They do not state how this figure was derived though it probably is computed as the product of their average land surface precipitation rate and their valley-fill land area.

In this model the average land surface precipitation rate derived from the new isohyetal map is 10.1 inches; when that rate is multiplied by the land area of the MGWB (157,105 ac excluding the till) the land surface precipitation equals 133,233 ac-ft. It is assumed, however, that in most years and in all but the highest portion of the MGWB, the precipitation recharges the soil moisture deficit and is mostly evapotranspired by the basin's vegetation, The assumption is based on the fact that approximately 95% of the vegetation in the MGWB is xerophytic vegetation, i.e., vegetation which satisfies its water requirement from the available soil moisture provided by the meager precipitation. In the very wet years and in the highest portions of the MGWB, some of the precipitation exceeds the soil moisture capacity and either recharges the aquifers directly or becomes surface runoff which eventually recharges the aquifers. Since the unconsolidated sediments of the portion of the MGWB where most of the excess precipitation occurs are extremely permeable, it is assumed that nearly all of the excess will eventually recharge the MGWB as opposed to flowing as surface runoff directly into Mono Lake. The excess soil moisture can be quantified by a Thomthwaite soil moisture balance that is modified using Shelton's (1978) corrections to more accurately reflect potential evapotranspiration (PET) in semi-arid regions, Appendix II-2 gives a detailed explanation of the assumptions and data used in the Thomthwaite balance, Table A2-4 in Appendix II-B gives the results of the computation. The resulting average excess soil moisture net land surface precipitation is about 9,000 ac-ft/yr. An annual variation of NLSP cannot be computed at this time because of the lack of data. The annual variation of the NLSP would be dampened (i.e. closer to a constant amount than the actual year-to-year variation of the precipitation would suggest) because most of the soil moisture excess occurs in the higher elevations of the MGWB where the water table is often one hundred feet or more below the surface (e.g. Cain Ranch well and the domestic well in T3N R26E near the Bodie Road),

RUNOFF.

Precipitation on the mountain watersheds that is not consumptively used eventually runs off into the MGWB. The runoff either (a) recharges the MGWB through lateral underflow, (b) flows directly into the MGWB in stream channels, (c) is diverted into in-basin Irrigation or hydroelectric facilities or (d) is diverted into LADWP aqueduct export facilities, The Sierra Nevada contributes most of the runoff since it receives the most precipitation, Sierra runoff occurs primarily as streamflow and is sustained mainly by the melting winter snows and to a much lesser extent by rainfall and springflow. Consequently, streamflow is highly seasonal, with one half to two thirds of it occurring in the peak snow melt months of May, June, and July. Peak flows on Rush, Lee Vining, and Mill Creeks, however, are dampened by reservoirs that regulate stream flow for hydropower production. Although most of the reservoirs are enlargements of previously existing lakes (see Table 2-3), they can reduce the peak flows in May, June, and July by 40% and augment low flows in other months by 400% of the natural (unimpaired) runoff. Figure 2-4 shows the average monthly actual and natural runoff regime of selected creeks, On an annual basis, the total actual runoff can differ from the total natural runoff by up to 14%.

The runoff from about two-thirds (about 127 mi^2) of the total Sierra watershed area of 195 mi^2 is measured at gaging stations and can be quantified as the component "Sierra Nevada Gaged Runoff" (SNGR), The runoff from the remainder of the Sierra is quantified as the component "Ungaged Sierra Runoff" (USR) and the runoff from the rest of the basin's bedrock area is quantified. as the component "Non-Sierra Runoff" (NSR). Figure 2-5 differentiates these runoff areas.

<u>Sierra Nevada Gaged Runoff (SNGR)</u>. The principal streams in the Sierra Nevada (Rush, Lee Vining, Mill, Walker, and Parker Creeks) as well as small streams that provide aqueduct or irrigation supply (East Parker, South Parker, Bohler, Gibbs, and

TABLE 2-3. Reservoirs in the Mono Basin

Name of Reservoir	Drainage	Owner	Area (ac)	Spillway Elev. (ft)	Usable Capacity (ac-ft)	Dam Height (ft)	Year Completed	Previous Lake
Gem	Rush	SCE	275	9052	17604	75	1917	yes
Waugh (Rush Cr. Meadows)	Rush	SCE	176	9424	4970	50	1925	no*
Agnew	Rush	SCE	40	8508	851	30	1916	yes
Ellery (Rhine-dollar)	Lee Vining	SCE	68	9489	745	17	1927	yes
Tioga	Lee Vining	SCE	81	9651	1386	15	1928	yes
Saddlebag	Lee Vining	SCE	325	10087	11138	33	1921	yes
Walker	Walker	LADWP	87	7935	540	10	1925	yes
Sardine	Walker	LADWP	19	9895	385	9	1920	yes
Lundy	Mill	SCE	130	7808	3820	45	1911	yes
Grant	Rush	LADWP	1095	7130	47525	87	1940	yes

Source: CADWR (1976) also LADWP Reservoir data

* numerous small ponds existed previously

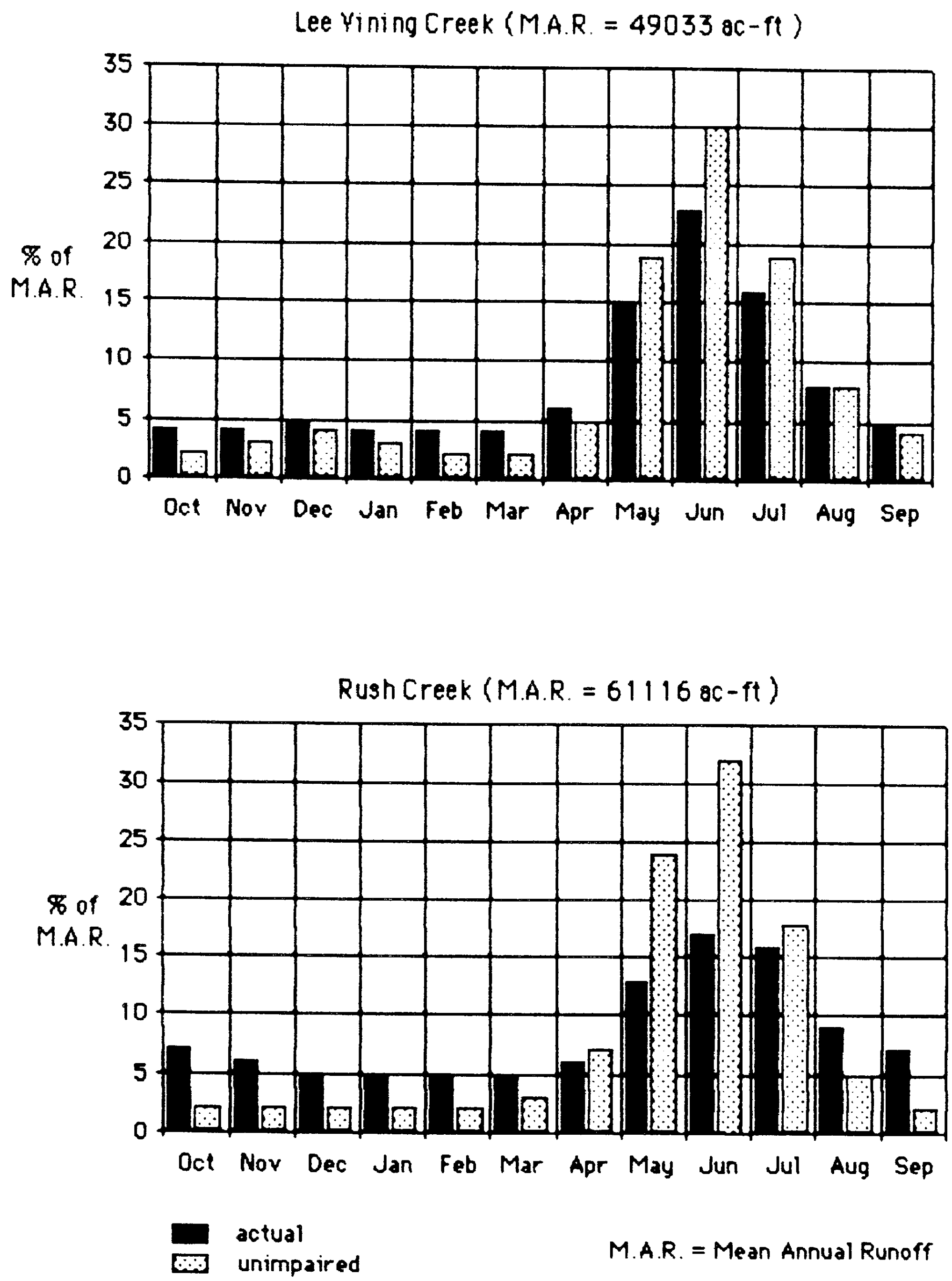


Figure 2-4. Comparisxon of Average Monthly Actual and Unimpaired Runoff

Station Names

1. Rush Creek at Damsite
2. Parker Creek East above Diversions
3. Parker Creek South above Diversions
4. Parker Creek Main Stem above Diversions
5. Walker Creek above Conduit
6. Gibbs Creek at Diversions
7. Lee Vining Creek at 2.5 miles above Diversions
8. Gibbs Creek at Lee Vining Creek
9. "O" Ditch
10. Lee Vining Creek at Conduit
11. Dechambeau Creek above Diversions
12. Mill Creek Power Plant
13. Mill Creek below Lundy Lake

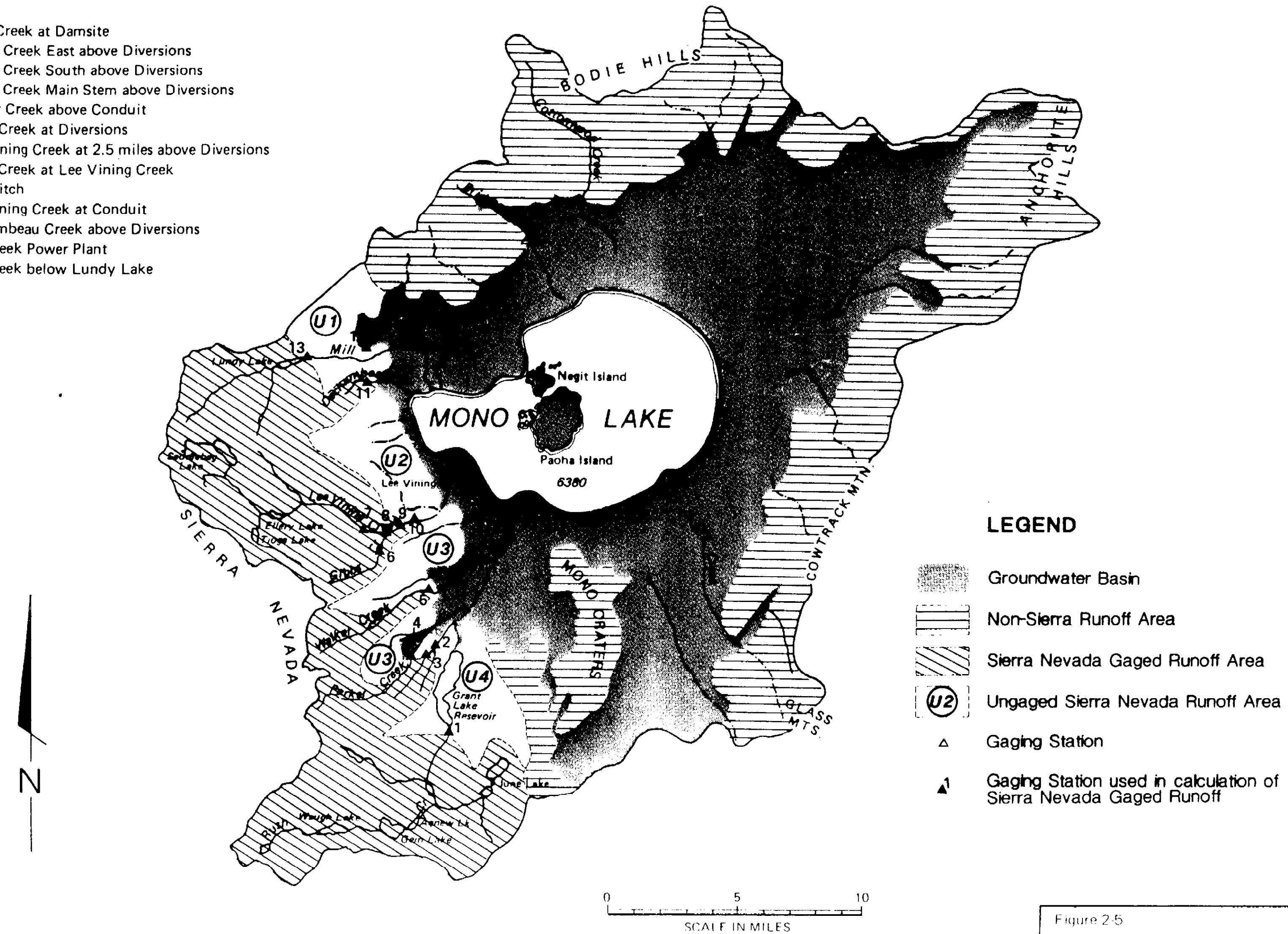


Figure 2-5
Runoff Areas and Gaging Stations

Dechambeau Creeks) are gaged. All of the streams except Mill Creek are measured by LADWP at the sites listed in Table 2-l and shown on Figure 2-5; Mill Creek is currently measured by Southern California Edison (SCE). SCE measures Mill Creek flows as the sum of the measured flow from the Mill Creek Power Plant and the releases/spill/leakage from Lundy Lake, The average runoff from each of these watersheds varies with its area and precipitation, which itself is a function of the watershed elevation and crest exposure (Table 2-41, Table 2-4 also shows that the proportion of precipitation that becomes runoff is related to the amount of exposed bedrock within the watershed.

With the exception of Harding (1962) all of the previous water balances computed the annual surface runoff from the principal streams in the Sierra Nevada with the gaging station measurements and/or the estimates made prior to the gaging station installation, A comparison of the different models' average annual runoff values is given in Table 2-5. The differences in the values are due to (a) use of different base periods, some of which include the period prior to 1937 when few reliable measurements were made and (b) exclusion of non-aqueduct streams such as Mill and Dechambeau Creeks. For this model the annual SNGR value represents the total actual flow of Rush, Lee Vining, Mill, Parker, Walker, Gibbs (including diversions), Dechambeau, South Parker, and East Parker Creeks.[4]

The SNGR is the largest inflow component to the MGWB. The 1937-83 average SNGR of 149,696 AF represents about 80% of the

TABLE 2-4. Runoff Characteristics of the Gaged Watersheds

Watershed	1937-83 Average Natural Runoff (ac-ft)	Area (ac)	Unit Precip (ft)	Unit Runoff (ft)	Elevation Average (ft)	Elevation Above 10,000 (%)	Exposed Bedrock* (%)	Crest Exposure** (%)
Rush (total)	61116	33471	2.92	1.83	9800	45	35	45
Rush above Agnew Lake	45801	14880	3.62	3.07	10500	65	50	60
Lee Vining	49033	22168	2.91	2.21	10275	60	50	40
Mill	21971	11604	2.67	1.89	10300	60	45	20
Parker	8201	4045	2.92	2.03	10775	60	60	20
Walker	5465	4961	2.64	1.10	10125	55	25	20
Gibbs	2073	1862	2.57	1.11	10000	50	25	10
Dechambeau	945	1511	2.20	0.63	9850	40	10	0
S. Parker	947	1125	2.20	0.84	8800	5	10	0
E. Parker	286	736	1.55	0.39	8500	0	0	0
Total	150047	81483	2.84	1.84	10000	50	35	40

* the percentage of the total watershed area with exposed bedrock and/or thin colluvium; estimated from topographic maps and aerial photos.

** the percentage of the watershed boundary along the Sierra crest; estimated from topographic maps.

TABLE 2-5. Comparison of Average Annual Runoff from Currently Gaged Sierra Nevada Watersheds

Study	Average Annual Measurement or Estimate ac-ft/yr	Base Period	Methodology
Lee (1934)	165,000	1903-1933	EST
Black (1958)	116,000 [l]	not given	EST
CADWR (1960)	144,300 [2]	1895-1959	1895-1947: EST 1948-59: MSMT
Harding (1962)	not given separately	1857-1960	Part of total inflow computed as residual value,
Scholl _et al_. (1967)	128,558	Mill Cr. 1904-62; all other: 1940-64	EST AND MSMT
Mason (1967)	121,824	Lee Vining Cr: 1904-63 ; Mill Cr: 1904-62; Rush, Parker, Walker: 1935-59	EST and MSMT
Lee (1969)	121,824	Lee Vining Cr: 1904-63; Mill Cr: 1904-62; Rush, Parker, Walker: 1935-59	EST and MSMT

Study	Average Annual Measurement or Estimate (ac-ft/yr)	Base Period	Methodology
Corley (1971)	146,228	19374970	MSMT [3]
Moe (1973)	144,300 [2]	1895-1959	EST [4]
CADWR (1974)	N/A	N/A	N/A
Loeffler (1977)	137,135	1921-1975	1935-1975: MSMT & EST 1921-1935: EST & MSMT [5]
Cromwell (1979)	142,300	1951-1978	MSMT [3]
CADWR (1979)	108,000 [1]	1941-1964	MsMT [3]
LADWP (1984a, b)	141,934 [6]	1941-1976	MSMT [3]
Vorster (1985)	149,696	1937-83	MSMT [3]

EST - Estimate designated if more than 50% of the total annual runoff and/or 50% of the years are estimated. Estimates are usually based on intermittent measurements or correlation with gaged watershed
MSMT - Measurement at stream gaging station or hydroelectric facility
N/A - Not Applicable

l - Aqueduct streams only (excludes Dechambeau and Mill Creeks)

2 - Does not include Dechambeau or South and East Parker Creeks.
3 - The total Gibbs Creek runoff (including the Farrington diversion) is estimated through 1956.
4 - Used CADWR (1960) value.
5 - Lee Vining and Rush Creeks are correlated to Mill Creek measurement.
6 - Does not include Dechambeau Creek

total average runoff into the MGWB estimated by this model. The annual SNGR, shown in Table 2-15, varied from about 43% to 193% of the base-period average.

The sequence of SNGR is a time series that is best represented by the dimensionless index of runoff variation which is equal to ratio of the annual SNGR to the average SNGR.

$$\text{Runoff Index (RX)} = \frac{\text{annual SNGR}}{\text{average SNGR}} \qquad (12)$$

The annual runoff index, both actual and natural, is shown in Table 2-15.

Table 2-6 shows quartiles and extreme values of the annual runoff index, Runoff in approximately two-thirds of the years ranged from 69% to 131% of the average, In slightly more than 10% of the years, runoff was less than 61% or greater than 140% of average, Runoff values are skewed so that only 45% of the years have greater than average runoff, The statistical distribution of the runoff index is shown in Appendix I-D,

Ungaged Sierra Runoff (USR). The runoff from the remaining 68 mi^2 of the Sierra is ungaged. Most of the ungaged area lies in between and to the east of the gaged watersheds (see Figure 2-5) and consists primarily of small watersheds whose surface runoff is normally intermittent,[5] Glacial till makes up a portion of

TABLE 2-6. Quartiles and Extreme Values of the 1937-83 Annual Sierra Nevada Runoff Index

	Gaged Runoff (ac-ft)	Index 1.0=149,696 (ac-ft)	Unimpaired Runoff (ac-ft)	Index 1,0=150,047 (ac-ft)
Driest Year	64,685	,432	62,001	.413
First Quartile	113,120	.756	109,890	.732
Second Quartile	146,223	,977	148,472	,989
Third Quartile	171,591	1,146	183,751	1.224
Wettest Year	288,644	1.928	287,936	1.918

Notes: 47 total values
first quartile value exceeded 35 times (74.4%)
second quartile value exceeded 23 times (48.9%)
third quartile value exceeded 12 times (25.5%)

the area. Much of the land, however, is not glaciated and is covered with a weathered mantle that is underlain by bedrock, some of which is extensively fractured because it is proximate to the eastern Sierra fault zone. As a consequence a portion of the ungaged runoff occurs as subsurface flow into the MGWB. Since the available data does not permit the surface and subsurface runoff from the ungaged area to be distinguished, the two are quantified together in the USR.

A few of the previous models (Lee 1934; CADWR 1960, Lee 1969, Cromwell 1979, LADWP 1984 b,c) quantify the USR separately, although most models quantify it as part of an inflow residual. Table 2-7 compares the USR value of the other models and the method used to compute it, The independently derived values are of little use because the method of computation is insufficiently documented,

For this model the USR in each year of the base period is computed as the product of the average annual yield and an index of the variation in the annual yield, Thus,

$$USR = \text{Avg. Annual Yield} \times \text{Index of Annual Variation} \quad (13)$$

The average annual yield is estimated by a commonly used analogue method (Ferguson et al. 1981, Winter 1981, Sorey et al. 1978) that uses the relationship between mean annual runoff and mean annual precipitation for the gaged watersheds (Figure 2-6). [6] By computing the mean annual precipitation for the ungaged area

TABLE 2-7. Comparison of Estimates of Average Annual Runoff From Ungaged Sierra Nevada and Non-Sierra Watersheds

Study	Avg. Annual Sierra (ac-ft/yr)	Avg. Annual Non-Sierra (ac-ft/yr)	Avg. Annual Combined if not given separately (ac-ft/yr)	Methodology
Lee (1934)	24,000	11,000		Sum of estimated average yield of each watershed draining into Mono Lake. No explanation how value is derived.
Black (1958)			77,468 includes Mill Cr.	Water balance residual
CADWR (1960)	45,500	26,200		Estimates taken from CASWRCB (1951) which used analogue method.
Harding (1962)	Not calculated separately			Part of total inflow computed as residual value.
Scholl et al. (1967)	9,180 [a]		113,000[6]	[a]Estimate apparently provided by LADWP [b]Water balance residual computed as ground water inflow from rest of basin.

Study	Avg. Annual Sierra (ac-ft/yr)	Avg. Annual Non-Sierra (ac-ft/yr)	Avg. Annual Combined if not given separately (ac-ft/yr)	Methodology
Mason (1967)			8,100	Given as maximum combined flow of Dechambeau Wilson, Bridgeport Horse Meadow, and several unnamed streams along the west shore but no explanation of how value is derived; an additional 24000 ac-ft/yr of springflows was estimated some of which must be derived from ungaged runoff
Lee (1969)	1,900[a]	29,000[b]		[a]Estimate from intermittent measurements; restricted to ungaged area between Mill and Lee Vining Creeks. [b]Minimum amount of precipitation available for ground-water recharge in the non-Sierra bedrock estimated as difference between precip and ET.
Corley (1971)	Not calculated separately			Part of larger residual value

Study	Avg. Annual Sierra (ac-ft/yr)	Avg. Annual Non-Sierra (ac-ft/yr)	Avg. Annual Combined if not given separately (ac-ft/yr)	Methodology
Moe (1973)	45,500	26,200		Derived from CADWR (1960)
CADWR (1974)	N/A	N/A		
Loeffler (1977)			0-47,000	Constant in calibration equation interpreted as ungaged runoff; quantity depends on estimate for Mono Lake evaporation precipitation
Cromwell (1979)	8,200[a]		0[b]	[a]Derived from precip/runoff relationship for gaged watersheds, [b]Water balance residual;acknowledged possibility of subsurface runoff.
CADWR (1979)	Not calculated separately			Part of total inflow computed as residual value.
LADWP (1984b)	4,700	19,900		Based on precip/runoff relationships for unspecified watersheds

Study	Avg. Annual Sierra (ac-ft/yr)	Avg. Annual Non-Sierra (ac-ft/yr)	Avg. Annual Combined if not given separately (ac-ft/yr)	Methodology
Vorster (1985)	l7,646[a] (16,646 after 1977)	19,673[b]		[a]Derived from precipitation runoff relationship for gaged watersheds, [b]Precipitation surplus computed by modified Thornthwaite soil moisture balance.

N/A - Not Applicable

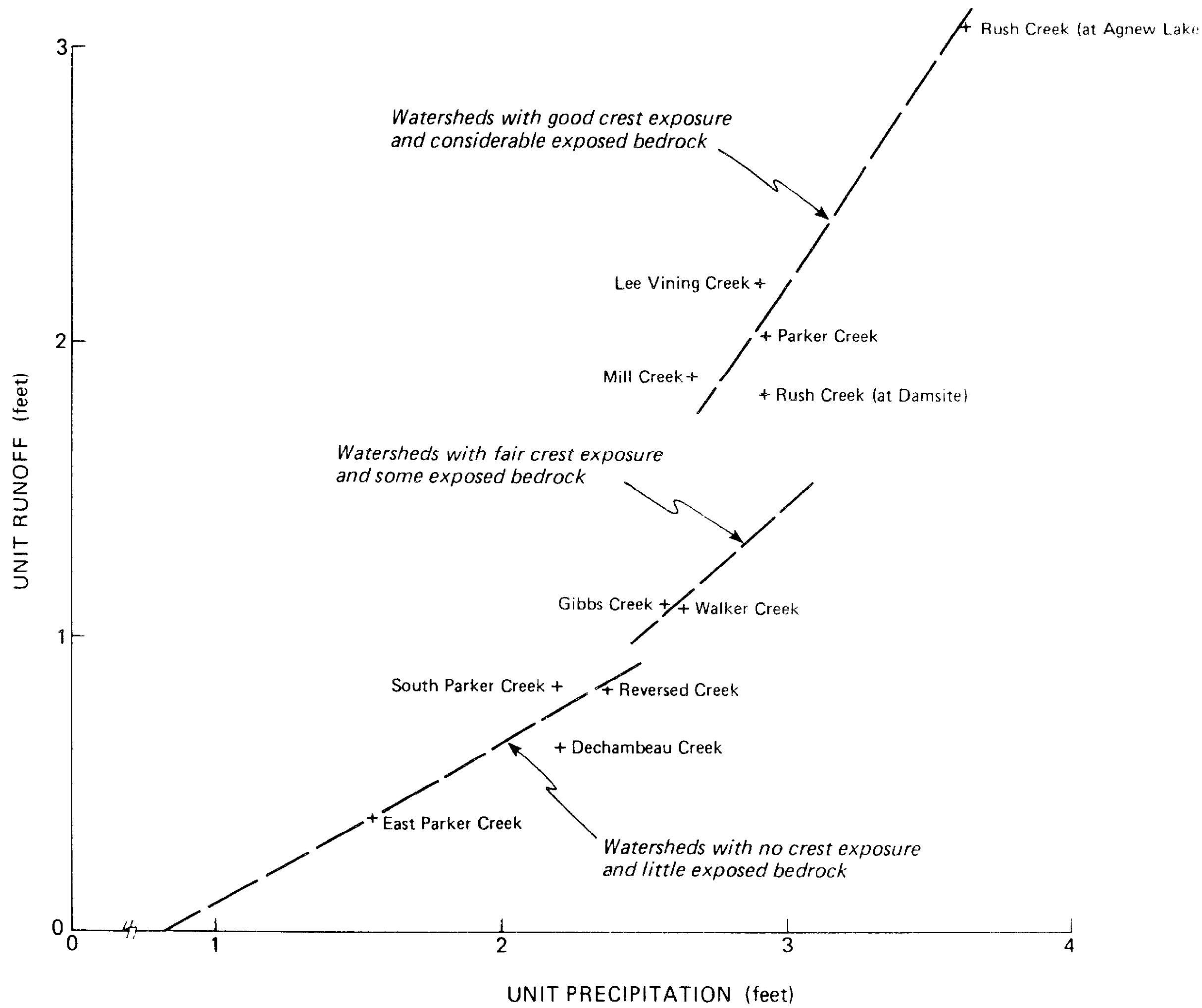


Figure 2-6 Approximate Relationships of Precipitation and Runoff for Gaged Watersheds

and using the relationship for watersheds with no crest exposure and little exposed bedrock, a mean annual runoff for the ungaged area is computed. Because of its disjunction, the ungaged area is partitioned into four "provinces" (see Figure 2-5) for purposes of analysis. The results of the computation are shown in Table 2-8.[7] The 17,646 ac-ft/yr, amount decreases by about 1000 ac-ft/yr after 1977 because the new Lee Vining Creek gaging station incorporates about 1900 acres of previously ungaged area. Since a portion of the ungaged runoff flows through the subsurface it is assumed that the year-to-year variation in the annual yield would be dampened somewhat in the same manner that reservoir regulation dampens the runoff from the gaged watershed, The index of actual runoff variation derived from the SNGR component (RI) is therefore used as the index of the annual variation in the ungaged yield.[8] The annual USR is shown in Table 2-15,

Non-Sierra Runoff (NSR). Most of the 178 mi^2 of the non-Sierra watershed areas north, east, and south of the MGWB is also ungaged, Bridgeport and Cottonwood Creeks are gaged but only on an intermittent basis with portable weirs or a current meter. The surface flow in the latter two creeks is usually small or non-existent and not representative of the yield of non-Sierra watersheds because most of the runoff into the MGWB from non-Sierra watersheds occurs in the subsurface. This is based on observations that precipitation and snowmelt infiltrate into the numerous fractures, joints, and cracks of the volcanic

TABLE 2-8. Estimated Runoff From Ungaged Sierra Nevada Watersheds Using Precip/Runoff Method

Precip Zone (in)	Average Precip (in)	Mill-Conway (U1) Area (ac)	Mill-Conway (U1) Precip (ac-ft)	Warren (U2) Area (ac)	Warren (U2) Precip (ac-ft)	Walker-Gibbs (U3) Area (ac)	Walker-Gibbs (U3) Precip (ac-ft)	Fore-Rush (U4) Area (ac)	Fore-Rush (U4) Precip (ac-ft)	Total Area (ac)	Total Precip (ac-ft)
12.5-15	13.75	550	630	0	0	623	716	2324	2673	3497	4019
15-20	17.5	2976	4340	2600	3792	5812	8485	4441	6476	15829	23093
20-25	22.5	2573	4824	3452	6473	2560	4800	1665	3122	10250	19219
25-30	27.5	1152	2640	1966	4505	1312	3004	545	1249	4975	11398
30-35	32.5	0	0	924	2503	678	1837	200	542	1802	4882
35-40	37.5	0	0	257	803	250	781	19	59	526	1643
Total		7251	12434	9199	18076	11235	19623	9194	14121	36879	64254
Unit Precip (ft)		1.71		1.96		1.75		1.54		1.74	
Unit Runoff (ft) (from Figure 2-6)		0.46		0.61		0.48		0.36		0.47	
Total Runoff (ac-ft)		3336		5611		5388		3310		17646	

bedrock and eventually percolate into the MGWB by a process that Feth (1964) describes as "hidden recharge." Patrick Glancey, hydrologist for the USGS in Carson City (pers comm 1984), states that hidden recharge from consolidated rocks into alluvial basins is routinely assumed to be an important process in Great Basin hydrologic studies,

The NSR is difficult to compute because of the lack of data. Most of the models quantify the NSR as a residual (see Table 2-7). Two of the four previous models that quantify NSR independently (CADWR 1960 and Lee 1934) do not explain their method of computation and thus are of little applicability. Lee (1969) made a rough estimate of the minimum amount of precipitation in the non-Sierra bedrock area available for groundwater recharge by subtracting a roughly estimated volume of evapotranspiration from the estimated volume of precipitation, Lee (1969), however, incorrectly included a portion of the unconsolidated sediments east of the Mono Craters that are part of the MGWB in his non-Sierra bedrock "recharge'! area. LADWP (1984 b) estimate the runoff from the non-Sierra areas as a product of watershed area, average precipitation, and a runoff factor based on a precipitation/runoff relationship for unspecified Sierra watersheds. The precip/runoff relationship for the gaged Sierra watersheds is not applicable because the climatic and geologic characteristics of the non-Sierra watersheds are so different from the Sierra watersheds,

For this model the NSR is computed to be 90% of the soil moisture surplus calculated by a modified (Shelton 1978) Thornthwaite soil moisture balance. The methodology is explained in Appendix II-B. The results are shown in Table A2-4, in Appendix II. The 10% reduction from the 21,859 ac-ft/yr total surplus is an arbitrary reduction to account for losses that would occur between the point where the surplus occurs and the MGWB boundary. The losses would include evapotranspiration from phreatophytes found along stream channels and around springs, An annual variation in the NSR cannot be calculated at this time because of the lack of data. The annual NSR, however, is dampened since most of it percolates very slowly by way of hidden recharge into the MGWB.

EVAPORATION.

The only natural water loss from the MGWB is by evaporation, a process defined as the transfer of water vapor from a surface on the Earth into the atmosphere at a temperature below the boiling point of water (Hounam 1971), A distinction is made between the vapor transfer from a free water surface, from a bare soil surface, and from transpiring vegetation because the rate of evaporation is influenced by the nature of the surface. The vapor transfer from transpiring vegetation and the intervening soil surface is usually designated as evapotranspiration (ET) and is examined separately in the next section.

Evaporation is a complex process that is very difficult to estimate accurately because many factors directly influence it, including solar radiation, differences in vapor pressure, water temperature, air temperature, wind, salinity, and wave action. The evaporation from bare ground is additionally influenced by the soil moisture content, depth to water table, and soil texture and composition,

Techniques for estimating evaporation include (a) water budget, (b) energy budget, (c) turbulent diffusion (eddy correlation), (d) mass transfer, (e) evaporation pan. These and other techniques are summarized in USGS (1954), WMO (1966), Hounam (1971), Winter (198l), and Ferguson et al, (1981). The applicability and accuracy of each technique largely depends on the available data, The water budget technique requires a complete and accurate accounting of all. the other terms in the budget, which is usually not possible, and thus is limited in its practical application, Energy budget and turbulent diffusion techniques require relatively sophisticated instrumentation in order to quantify a number of complex variables. With proper measurements these techniques are considered the most accurate and are especially useful for short-term (day or week) estimates. The mass transfer technique requires observations of wind speed, air and water temperature, and humidity; it can be used to make relatively accurate estimates of monthly evaporation if the mass-transfer coefficient can be accurately estimated. The evaporation pan is the most commonly used technique to estimate evaporation because of the relative simplicity of directly measuring evaporation from a pan. A number of problems are associated with the pan technique, however; these problems restrict its accuracy and applicability to lakes. First, geographically and seasonably variable pan coefficients are required to convert pan to lake evaporation; second, pan measurements are limited to summer months in climates where the pan water freezes; third, within an annual cycle, advection and heat storage changes may occur within a lake that will cause the evaporation from it to be out of phase with pan evaporation (i.e. the lake evaporation will lag behind pan evaporation) and thus the pan technique is usually restricted to making annual estimates of lake evaporation by assuming that the annual advection and heat storage changes are negligible. The evaporation pan (as well as the turbulent diffusion and mass transfer) technique estimates evaporation from a point and must be spatially extrapolated for water balance applications,

In the following sub-sections the evaporation from Mono Lake (MLE) and Grant Lake Reservoir (GLE), the only two water bodies of significance in the MGWB, are examined as two separate water balance components, In addition the evaporation from the bare ground (BGE) that is exposed as Mono Lake recedes is examined as a separate component,

Mono Lake Evaporation (MLE).

The annual volume of MLE is the product of the annual evaporation rate and a specified lake area. Previous estimates of Mono Lake's evaporation rate varied widely reflecting the variety of techniques used. Table 2-9 compares the estimated average annual rate and the techniques used in previous models. All of these estimates rely on limited data bases, and require assumptions, extrapolations, and regionalizations that are not warranted for Mono Lake, For example, the energy budget and mass transfer estimates are considered by their authors (Black 1958 and Mason 1967) to be crude because of the lack of measurements of the necessary variables at Mono Lake, Water budget estimates by Lee (1934) and Harding (1962) are not reliable because other components (such as ungaged runoff) in the water budget have to be grossly estimated, Harding's use of the water budget technique contradicts his earlier (1935) observation that "the conditions of inflow [to Mono Lake] do not permit sufficiently close measurement to enable [the] fluctuations to be used as a measure of evaporation." Despite this cogent observation, Harding's later estimate of 39 inches is used directly or as the confirmation for the evaporation estimates by a number of the other models (Cromwell 1979, Lee 1969, Loeffler 1977, LADWP 1984 a,b,c,d, CADWR 1979, CADWR 1974), The estimates by Lee (1969) and Cromwell (1979) using the Grant Lake Reservoir evaporation pan are not reliable because (1) the land pan that Lee (1969) incorrectly referred to as a Class A pan is a Colorado square pan whose pan-to-lake coefficient is not reliably known, and (2) the pan site is over 700 feet higher than the surface of Mono Lake and is located in a topographic trough that receives significantly less Insolation than Mono Lake and that fills with relatively cool katabatic flow from the surrounding highlands. The estimate by LADWP (1984 a,b,c,d) using the floating pan that

TABLE 2-9. Comparison of Estimated Mono Lake Evaporation Rates

Study	Avg. Annual Rate (in/yr)	Salinity Adjustment	Index of Annual Variation	Technique
Lee (1934)	45	Yes	No	Water budget; also estimated 46" by extrapolating msmts from Walker Lake,
Black (1958)	51	Not Necessary	No	Energy budget; stated that pan msmts at Grant Lake and Long Valley are not applicable to Mono Lake
CADWR (1960)	40.8(Net)	No	No	Technique not stated; Net rate incorporates precip on lake
Harding (1962)	39	Not	NO Necessary	Water budget and extrapolation of evap/ altitude relationship from other Great Basin Lakes
Scholl et al, (1967)	72	No	No	Pan msmts from Haiwee Resv in Owens Valley.
Mason (1967)	37.4[a]	Not Necessary	No	[a]Water budget residual.
	43.3[b]	Not		[b]Water budget residual with expected "cryptic" inflow,
	51.2[c]	Not Necessary		[c]Mass transfer
	78.8[d]	Not		[d]Energy budget
Lee (1969)	39.4	No	No	Evaporation pan; Incorrectly assumed Grant Lake was Class A pan.

Study	Avg. Annual Rate (in/yr)	Salinity Adjustment	Annual Index of Variation	Technique
Corley (1971)	Not calcu- lated separately	No	No	Part of larger residual.
Moe (1973)	45.6(net)	No	NO	Based on CADWR (1960) estimated evaporation volume; incorporates precipitation on lake.
CADWR (1974)	39	Not Necessary	No	Used Harding (1962) estimate.
Loeffler (1977)	41.3-44.4	Yes	No	Based on Lee (1969) value and on analysis of regression equation residual to indicate "correct" rate. Corresponds to saline water evaporation rate in 1976 of 39"-42"
Cromwell (1979)	39.5	Not Necessary	No	Pan msmts from Grant Lake; also derived as water balance residual,
CADWR (1979)	39	Not Necessary	No	Used Harding (1962) estimate,
LADWP (1984a,b,c,d)	40.8	Yes	Yes	Freshwater rate neces- sary to give Mono Lake saline rate of 39" as derived by Harding (1962), and calculated from Mono Lake floating pan measurements.
Vorster (1985)	45	Yes	Yes	Class A pan measurements and evaporation/altitude relationship.

LADWP maintained on the west shore of Mono Lake from 1949-1959 must be questioned because of the pan's susceptibility to wind and wave splash.[9] Indeed in a letter to S.T. Harding dated July 26, 1959, Mr. Samual R. Nelson, the Chief Engineer of Water Works and Assistant Manager of the LADWP, noted that "due to frequent high winds on the Lake, causing water to splash in and out of the pan, the record is very incomplete and such short portions as we have seen are unreliable, so that it would be unwise to publish any of the record we have from this station" (cited by Harding 1962), The estimate by Scholl. et al. (1967) using Haiwee Reservoir pan measurements are totally unacceptable because no pan coefficient was used nor was an adjustment made for the significantly cooler climate at Mono Lake.[l0]

An estimate of about 40 inches of annual free-water surface evaporation for the Mono Lake region is obtainable from the large-scale evaporation maps of the United States prepared by Kohler et al, (1959) and updated by Farnsworth et al. (1982). The maps are based on Class A pan evaporation from meterological data at sites scattered throughout the United States, None of the sites are located in the Mono Basin or in environments similar to Mono Lake; thus the map must be used with caution in estimating Mono Lake's evaporation rate. In fact, the map of annual free water surface evaporation prepared by Farnsworth et al. (1982) contradicts the evaporation/altitude relationship for eastern California that they also present.

Estimates of Mono Lake's evaporation rate by other than the water and energy budget techniques represent the annual rate from an equivalent freshwater body. Mono Lake's salinity, which has ranged from about 45,000 to 90,000 parts per million (ppm) over the base period, reduces the evaporation rate by decreasing the vapor pressure difference between the water surface and overlying air. Only three of the previous water balance models (Lee 1934, Loeffler 1977, Blevins and Mann 1983) adjust their evaporation estimates to reflect Mono Lake's salinity. The adjustment is based on knowing Mono Lake's specific gravity and using a specific gravity/evaporation relationship that Lee (1934) developed for Mono Lake's water.

All of the previous evaporation estimates with the exception of Blevins and Mann (1983) assume that the evaporation rate is the same in each year even though the climatic factors that influence the evaporation rate do vary year to year, Blevins and Mann (1983a) vary the evaporation rate using an index derived from the ratio of the annual June through September evaporation measurements to the average June through September measurements at the Grant Lake Reservoir pans. The Grant Lake pan measurements consist of two essentially non-overlapping records with different averages: one for a floating pan from 1942-69 and the other for a land pan from 1968 to the present. Another problem with the Grant Lake pan index is that the average of the last five years (1979 through 1983) of June-September data from the land pan is 19% higher than the average of the first 11 years of land pan data even though other climatic parameters have not shifted so dramatically. The Grant Lake pan site also has the additional problems discussed on P.88.

It is not surprising that there is a. wide variation in the estimated Mono Lake evaporation rate given the limited and relatively unreliable date base, When the range in the plausible Mono Lake evaporation rates (12 inches, based on estimates from 39 to 51 inches, if one ignores the implausible estimates by Scholl et al, 1967 and Mason 1967) is translated into a volume of MLE, the quantity of water can be greater than all the other water balance components except the SNGR.

In attempting to compute the MLE for this model one obvious way of grappling with the lack of reliable estimates on Mono Lake's evaporation rate is to collect more evaporation data. Cost and instrument monitoring requirements limited the additional. data collection this author could undertake to the seasonal (May-October) monitoring of a Class A pan at the Simis climate station located just north of Mono Lake and the monitoring of a Class A pan at the south shore of Mono Lake (see Figure Al-l for site locations). Measurements have been made since June 1980 at the Simis site and since July 1983 at the south shore site; additional climatic data, including wind speed, humidity, precipitation and temperature, are collected at the Simis site,

The monthly pan data from the Simis site are given in Tables A3-1 in Appendix III. It must be emphasized that these measurements cannot be used to estimate Mono Lake's monthly evaporation rate because the actual lake evaporation lags behind the cycle of solar radiation -- which pan measurements reflect -- by some unknown period of time. The maximum lake evaporation probably occurs in the August-October period and continues at some unknown rate through the winter as evidenced by the commonly occurring lake fog in December and January.

Assuming that the pan site at the Simis station is in a "representative" location [ll] and that Mono Lake's annual net advected energy and heat storage change is close to zero, an annual fresh water evaporation rate of 45 inches is computed with the following equation:

$$E_A = \frac{50 \text{ inches}}{0.79} \times 0.71 = 45 \text{ in} \qquad (14)$$

E_A = Average Annual Fresh Water Evaporation Rate

50 inches is the 1980 - 1983 average May through October Class A evaporation pan measurement at the Simis site.

0.79 is the percentage of annual pan evaporation in the May through October period from Kohler et al. (1959).

0.71 is the pan coefficient from Kohler et al. (1959) for the Mono Lake region for converting Class A pan measurements into the fresh water evaporation.

A 45 inch annual rate is also estimated with the following regional data compiled in Farnsworth et al. (1982):

$$E_A = 50 \text{ inches} \times 0.74 + 8 \text{ inches} = 45 \text{ inches} \qquad (15)$$

50 inches is the average May through October pan evaporation rate for the elevation of Mono Lake from the evaporation/altitude relationship for eastern California developed by Peck in Farnsworth et al. (1982).

0.74 is the May through October pan coefficient from Map 4 in Farnsworth et al. (1982)

Eight inches is the difference between the May through October lake evaporation rate and the annual fresh water evaporation rate for the Mono Lake region given by Farnsworth (pers comm 1982).

The adjustment to the freshwater rate to account for Mono Lake's salinity is determined in a two-step process. First, the specific gravity (S.G.) in each year of the base period is calculated with an empirical equation developed by LADWP (Blevins pers comm 1982; also given in LADWP 1984a) that assumes the total tonnage of solids in Mono Lake remains constant.

$$S.G. = \frac{\text{Lake Vol.(ac-ft)} \times 1359 \text{ (tons/ac-ft)} + 230 \times 10^{6} \text{ tons of solids}}{\text{Lake Volume} \times 1359}$$

Second, the adjustment coefficient for evaporation rate (ADJ) is determined by the specific gravity/evaporation relationship developed for Mono Lake water by Lee (1934) and updated by Loeffler (1977).

$$\text{if } S.G. < 1.121 \quad ADJ = -.744 \times S.G. + 1.744 \qquad (17)$$

$$\text{if } S.G. > 1.121 \quad ADJ = -.968 \times S.G. + 1{,}995 \qquad (18)$$

The relationship corresponds relatively well to the specific gravity/evaporation relationship developed for the Great Salt Lake by Waddell and Bolke (1973). When Mono Lake's salinity is 90,000 ppm (the 1980 value) its specific gravity is 1.075 and the evaporation rate is 5.4% less than the fresh water rate.

The annual variation In the evaporation rate over the base period is represented by an index calculated as the ratio of the annual June through September measurements from the Long Valley Reservoir land pan to the period of record average of those measurements. The annual index, given in Table 2-15; varies from 0.89 to 1.13. An index derived from the Long Valley pan is used because of the unreliability of the index derived from the Grant Lake Reservoir pan measurements as discussed on P. 92. The Long Valley land pan record should correlate better than the Grant Lake pan with Mono Lake conditions because (a) the Long valley pan elevation is closer to Mono Lake's elevation, (b) the Long Valley pan -- which is about 28 miles from Mono Lake-- is not located in a topographic trough and is not as close to the Sierra crest. Indeed, a regression of the monthly Long Valley pan measurements for the 1980 through 1982 period with the Class A pan measurements from the Simis climate station has a R^2 value of 0.91; the regression of Grant Lake pan measurements with the Class A pan has a R^2 of 0.83. Since the Long Valley land pan record begins only in 1944, the index for the prior seven years of the base period (1937-43) is derived from the ratio of the annual to average June-September measurements at Tinemaha

Reservoir in the Owens Valley, the closest (about 75 miles from Mono Lake) land pan with a record for the 1937-43 period.

In this model the annual rate of Mono bake evaporation is thus the product of three variables: (a) the average annual freshwater rate (45 inches), (b) the adjustment for Mono Lake's salinity (ADJ), (c) the index of annual evaporation variation (EI), The volume of MLE is the product of the annual evaporation rate and lake area. In equation form:

$$MLE = 45 \text{ inches} \times ADJ \times EI \times \text{Lake Area} \qquad (19)$$

The lake area in a given year is the average of the beginning and end of water year lake area. The average lake area is equivalent to the actual lake area in the summer when the lake exhibits a net water year decline. In water years of net lake level rise, the average area is equivalent to the actual lake area in the spring.

The MLE for each year of the base period is shown in Table 2-15. Its decline over the base period is a direct result of the reduction in Mono Lake's surface area. It is the largest component of outflow quantified in this model and represents from 45% (1979) to 92% (1937) of the quantified -total annual outflow from the MGWB.

Net Grant Lake Evaporation (NGLE). Because Grant Lake Reservoir lies downstream from the gaged and ungaged watersheds of the Sierra Nevada, the evaporation from its surface reduces the runoff available to into the MGWB; precipitation on the surface of Grant Lake Reservoir, on the other hand, adds to the runoff. Over an annual time interval the evaporation is usually greater than the precipitation and the net result is an outflow from the MGWB that is quantified as the net GLE or NGLE.

Prior to 1915 Grant Lake was a small natural lake of about 200 ac, A marsh area of equal size existed just upstream from it, In 1915 the Cain Irrigation District constructed a small (ten-foot high) dam at the lake mouth for irrigation storage. In 1925 the dam was raised to about 25 feet, enlarging the surface area of the lake to about 700 acres at capacity (Lee 1934). The LADWP completed a third dam in November 1940 about one-third of a mile downstream from the old dam. The third dam increased the surface area by almost 60% to 1095 acres at capacity.

CADWR (1960) and LADWP (1984 b,c) are the only previous water balances to quantify a NGLE. CADWR (1960) estimates an average NGLE of 2400 ac-ft/yr based on a net evaporation rate of 2.5 ft/yr and an average surface area of 960 acres. LADWP (1984 b,c) estimate an average NGLE of 1000 ac-ft/yr although no basis for this estimate is given and it is unexplainedly lower than the average NGLE value of 1500 ac-ft given in LADWP's data compilation entitled "Recapped Aqueduct Operations".

This model uses the annual NGLE values reported in the "Recapped Aqueduct Operations". Although there is no indication of how these values are derived, LADWP did maintain a Colorado floating and land pan at Grant Lake Reservoir. The first year for the "Recapped Aqueduct Operations" is 1945 so the NGLE for years prior to that must be estimated separately. The values for 1941-44 are assumed to be equal to the average NGLE in the 1945-83 period (1500 ac-ft). Prior to the reservoir enlargement in water year 1941, the NGLE values are calculated as the product of the estimated average 1937-1940 reservoir surface area (approximately 600 ac or 100 ac less than its size at capacity) and the net evaporation rate of 1.67 ft/yr. This net evaporation rate is calculated in two different ways: 1) it is a balance of a gross evaporation rate of 36 in/yr derived from the land pan evaporation measurements and the gross precipitation of 16 in/yr derived from the isohyetal map; 2) it is the result of the average net evaporation given in the Recapped Aqueduct Operation (1500 ac-ft/yr) divided by an approximate average 1945-83 lake surface area (approximately 900 ac).

The NGLE in each year of the base period is shown in Table 2-15. The evaporation is greater than the precipitation in all the years except 1967. A wet spring and summer in 1967 caused the annual precipitation to be greater than the annual evaporation and is thus shown as a negative NGLE value in Table 2-15, The current reservoir's average NGLE of 1500 ac-ft is less than 1% of the estimated total average outflow from the MGWB quantified in this study.

Bare Ground Evaporation (BGE). As Mono Lake recedes from its historical high stand of 6428 ft, much of the exposed lake bottom is left bare, uncolonized by vegetation. In many areas - especially north and east of the lake margin - the bare ground becomes overlain by a salt crust, not unlike the playa surfaces found in valley bottoms throughout the Great Basin. The evaporation from the bare ground exposed by the receding lake can be very high, because:

a) from much of the exposed area the water table is close enough to the land surface that capillary action is able to bring water up to the surface to be evaporated.[l2]

b) wave run-up and seiches saturate land immediately above the shoreline.

d) residual pools of water are left stranded by the receding lake.

None of the previous water balances estimated the BGE as an independent component, The exposed lake bottom is not within the free-body of previous water balances except CADWR (1960) and LADWP (1984 b,c), CADWR (1960) may have ignored the water loss from the bare ground because the exposed acreage in 1960 was less than one-third of the exposed, acreage in 1983. LADWP (1984 b,c) presumably include the water loss from the exposed lake bottom in their residual determination of their component "valley-fill evapotranspiration".

The annual volume of evaporation from the bare ground can be conceptually formulated as the product of the annual bare ground surface area and the evaporation rate (Hounam 1971, Rantz and Eakin 1971), The bare ground area in any year is equal to the exposed lake bottom area (calculated as the difference between the lake area at 6428 ft and the average lake area in the given water year) minus the area colonized by phreatophyte vegetation, which is calculated by equation 24 on P. 123.

The bare ground evaporation rate is highly dependent on water table depths. Generalized observations on bare ground evaporation rates and water table depths by Houk (1951), Rantz and Eakin (1971), and Harrill (pers comm 1984) indicate that when the water table or capillary fringe is high enough to maintain a moist surface, the evaporation rate will be equivalent to the free-water surface or potential evaporation rate (i.e. the rate is limited only by climatic conditions). With increasing water table depths, rates of bare ground evaporation decrease rapidly and depending on the soil texture, evaporation rates become extremely low when the water table falls below 4 to 8 feet. The coarser the soil particle size, the more rapidly the rate drops off.

Because information concerning depth to water in the MGWB over time and space is deficient, only very rough estimates of annual bare ground evaporation rates can be made. The available information [13] consists of the following:

a) Five seismic profile transects starting at the 1976 shoreline, conducted by Loeffler (1977).

b) Ten shallow bore holes dug by Lee (1969) in 1968 mainly east and south of the lake,

c) 25 shallow pits dug by this author at various locations around the lake shore - including a transect from elevation 6402 ft to the lake margin on the north shore of the lake in March 1981 and July 1984,

d) Large scale aerial photography (less than 1:30,000 scale) taken in 1940, 1964, 1978, 1980, and 1982 that indicate areas of shallow water table and moist ground.

The usefulness of the foregoing information is limited because water table depths at any one point will vary as the lake fluctuates, The air photos and water table measurements do indicate that most of the BGE occurs from the eastern two-thirds of the exposed lake bottom. The exposed lake bottom on the western side of the lake Is usually colonized by vegetation or has depths-to-water that exceed four feet.

Bare ground evaporation rates from areas with similar water table depths are estimated in water budget studies of neighboring basins (Alkali Valley, Long Valley, Fish Lake Valley, Lower Walker

Lake Valley), The rates vary from O.l ft/yr (Van Denburgh and Glencey 1970) to 1.8 ft/yr (Schaeffer 1980), This wide range in the estimates reflects the fact that very few evaporation measurements from bare ground (especially playa surfaces) have been made. Thus the estimates are rough guesses based on the hydrologist's judgement (Van Denburgh pers comm 1984) or are calculated as a parameter in a model (Schaeffer 1980),

From the available data base, assumptions are made about the relationship of Mono Lake levels to water table depth and consequently to bare ground evaporation rates, These are detailed in Appendix 11-C. The volume of bare ground evaporation is calculated in each year as the product of the bare ground acreage and the assumed evaporation rates, both of which are determined by the average lake level in the given year. The volume of BGE in each year of the base period is shown in Table 2-15, The BGE represents from 1% to almost 8% of the quantified total annual outflow from the MGWB.[15]

EVAPOTRANSPIRATION.

Evapotranspiration (ET) by vegetation in the MGWB consumes a portion of the precipitation and runoff. Most of the plants in the MGWB are xerophytes since they satisfy their water requirements from soil moisture provided by the meager precipitation. Plants such as big sagebrush (Artemisia tridentata) and bitterbrush (Purshia tridentata) are adapted to the less than 12 inches of annual precipitation and long periods of seasonal drought. Young and Blaney (1947) and Rantz and Eakin (1971) suggest that there is an approximate balance between the precipitation and xerophytic ET in semi-arid areas. In this model, therefore, the xerophytic ET is not separately quantified and is assumed to be equivalent to the land surface precipitation, Any precipitation not consumed by the xerophytes is quantified as the component NLSP.

In addition to the predominantly xerophytic vegetation there are plants in the MGWB designated as phreatophytes that obtain their water supply from sources supplemental to the precipitation, such as stream flow, irrigation water, or groundwater.[16] Phreatophytes in the MGWB occur in a) the riparian zone along stream courses and irrigation ditches, b) the artificially irrigated lands, c) areas of higher water table and spring discharge above Mono Lake's historic high stand of 6428 ft, and d) areas of high water table and spring discharge around the exposed Mono Lake bottom in which the soil is sufficiently flushed of alkaline salts. These areas of phreatophytic vegetation are shown in Figure 2-7.

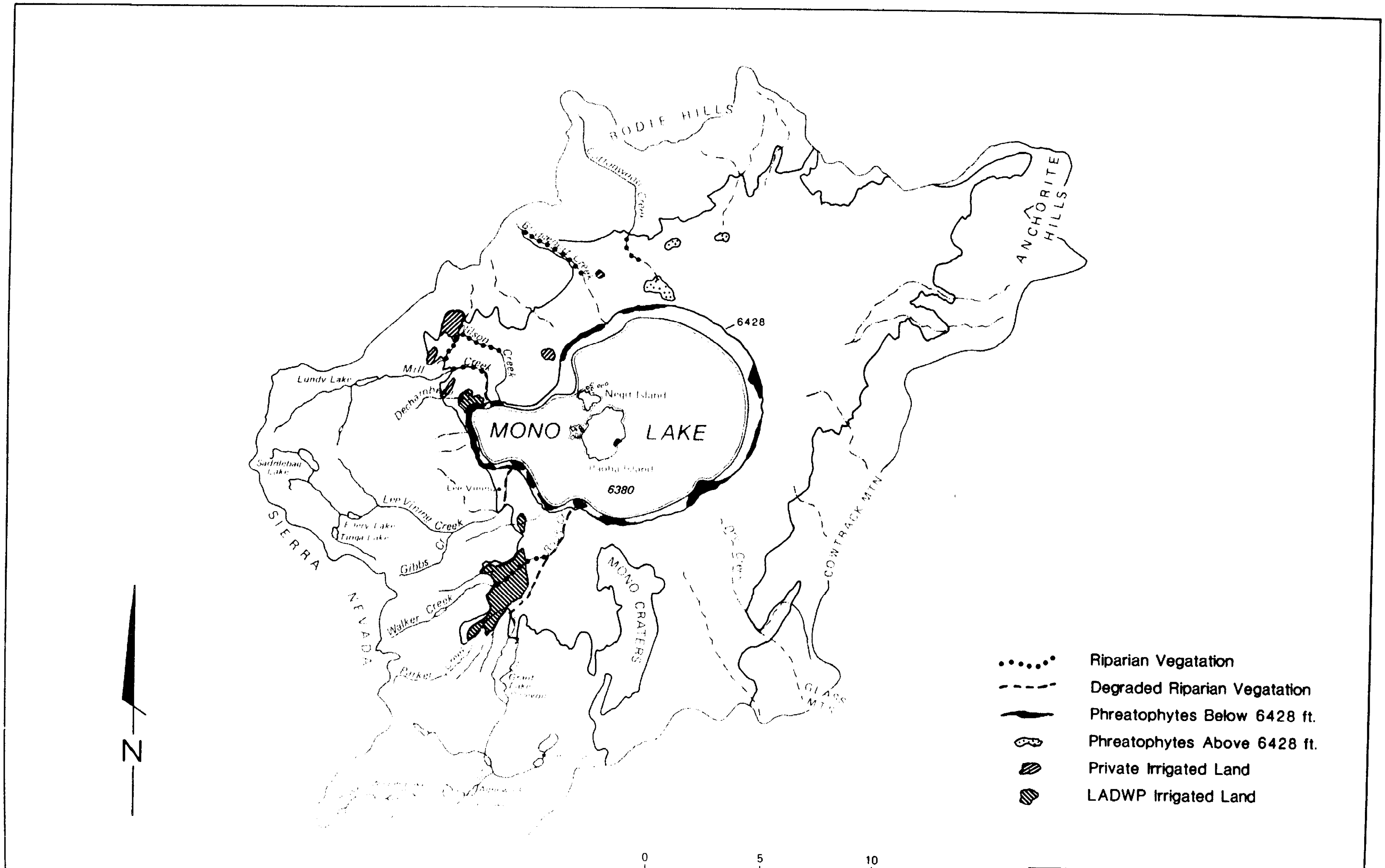


Figure 2-7
Phreatophyte Distribution

According to Rantz and Eakin (1971) and Robinson (1952) the annual water consumption by phreatophytes can be roughly estimated as the product of the acreage of phreatophyte *vegetation* in a given year and the annual rate of ET. The rate of ET, which ideally should be estimated for each vegetal species, is dependent upon access to water, climatic conditions, and soil and vegetative factors. It is assumed that the ET rate from phreatophytes is close to the potential ET (PET) rate -- a rate of water loss not limited by water deficiencies and largely controlled by climate -- since access to an abundant water supply and therefore ample soil moisture is a necessary prerequisite for phreatophyte growth.[l7] The actual ET from phreatophytes is usually somewhat lower than the PET because natural phreatophyte ecosystems deviate from the PET ideal of an infinite surface and unlimited water supply. Lysimeters can measure the actual ET from phreatophytes. In their absence phreatophyte ET is estimated by methods that use empirically derived equations which express the relation between PET (or the equivalent reference ET rate or consumptive water requirement) and climatic parameters.[l8]

Using the climatic data from the Simis and Cain Ranch climate station, the PET rate in the MGWB is estimated by five methods, including: (a) Blaney-Criddle (Rantz 1974), (b) modified Blaney-Criddle (Doorenbos and Pruit 1974), (c) Thornthwaite (Thornthwaite 1957), (d) modified Thornthwaite (Shelton 1978), (e) evaporation pan (Doorenbos and Pruit l974), Table 2-10 shows the PET in the April through September period -- assumed to

TABLE 2-10. Potential Evapotranspiration (PET) in the Mono Grondwater Basin

Method	Climate Station	Period	PET April - Sept	PET Oct - March	Total
Blaney - Criddle*	Cain Ranch	1982	29.7	13.5	43.2
	Cain Ranch	1981	32	14.6	46.6
	Simis	1982	29	13.6	42.6
	Simis	1981	31	13.8	44.8
Modified Blaney Criddle*	Simis	1982	25.3	7.2	32.5
	Simis	1981	29.9	4.6	34.5
Thornthwaite	Simis	1982	16.61	1.1	17.7
	Simis	1981	19	2.3	21.3
	Mono Lake	1965-79	19.8	3.1	22.9
Modified Thornthwaite	Simis	1982	27.9	2	29.9
	Simis	1981	31.7	4.1	35.8
Evaporation Pan	Simis	1982	32.2**	N.M.	N.M.
	Simis	1981	37.8***	N.M.	N.M.

* K factor equals one
** May-October measurement
*** June-October measurement, May is estimated
N.M. No measurement

roughly correspond to the growing season [19] -- and the October through March period estimated by the different methods.

Nearly all of the ET from phreatophytes in the MGWB is in the growing season, when precipitation is minimal, ET at other times is limited by the lack of plant transpiration and frozen soils, Therefore the annual ET of water supplementary to precipitation (i.e. groundwater or stream flow) is assumed to be represented by the growing season value in Table 2-10.

The average growing season ET, excluding the Thomthwaite method is 28.8 in for 1982 (a cool, wet growing season) and 32.6 in for 1981 (a warm, dry growing season), The Thomthwaite method traditionally under-estimates PET in arid and subhumid climates up to 50% (Cruff and Thompson 1967). Pennington (1980) found that in western Nevada the different methods resulted in similar variations in the ET rate,

In this report the Blaney-Criddle method is favored for estimating phreatophyte ET because of its relative accuracy in semi-arid areas (Jenson 1973), its simplicity, and because it is able to differentiate between different plant species.[20] The Blaney-Criddle formula is given as:

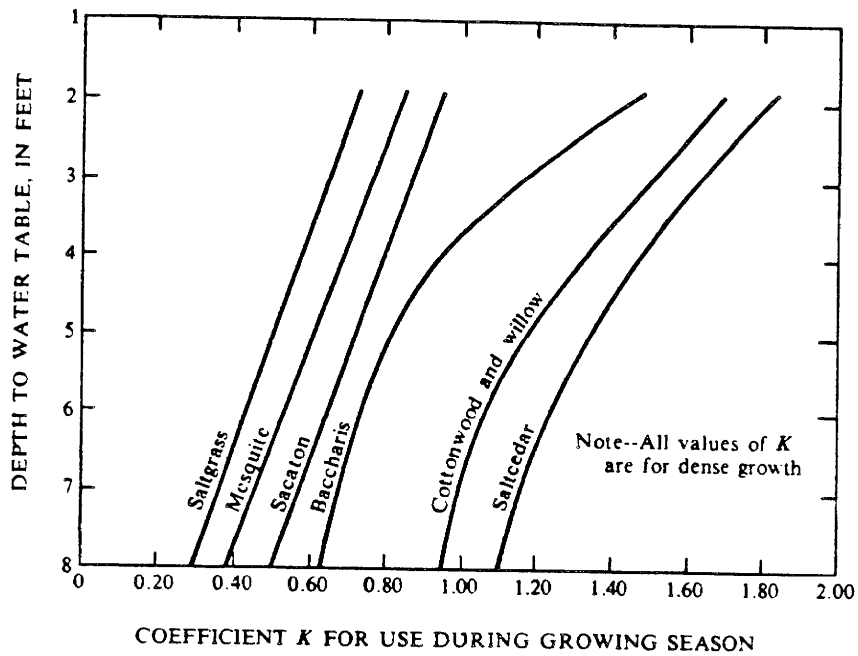
$$U = K \times F$$

U = estimated ET for the growing season

K = empirical consumptive use coefficient, dependent on species, density of growth, and depth to water table

F = consumptive use factor dependent on day length and temperature

A major difficulty presented by the Blaney-Criddle formula is the selection of the proper value of the all-important "K" coefficient. This coefficient depends not only on the vegetal species, but also on the depth to the water table and on the vigor and density of growth. In addition, "K" has a regional variation because mean monthly temperature is only an index to the many climatic factors that affect ET, Rantz (1968), after examining the available literature, prepared a graph, reproduced here as Figure 2-8, which gives values of "K" for the growing season, for dense growths of various phreatophytes, and shows the variation of "K" with depth to water table (a "K" value of 1.30 is recommended for dense growths of tule and sedge that live with roots wholly or partly submerged in water or in saturated soil that is intermittently submerged). Blaney (1954) derived factors for adjusting "K" values for the effect of density of growth of phreatophytes; these are given in the tabulation of Figure 2-8. Rantz states that subjective reasoning was used in constructing the graph from the welter of conflicting data for phreatophytes. He advocates use of the graph only in the absence of measurements at sites where time and expense required for a quantitative study are not warranted. Rantz warns that the available literature does not allow the curves to be extended below water table depths of eight feet, Although most phreatophytes cannot survive if water table depths are much below eight feet, some phreatophytes -- such as greasewood -- can extend their roots to as deep as 129 feet to obtain their water supply (Robinson 1958), Rantz also observes



Growth	*Factor by which to multiply* K *value for density of growth*
Dense----------------	1.00
Medium---------------	.85
Light----------------	.70

Figure 2-8. Graph and table for determining Blaney-Criddle "K" coefficient (To be used only in absence of quantitative data at a site. Graph from Rantz 1968; table from Blaney 1954b.)

that phreatophyte ET decreases with increasing salinity of the moisture supply but that quantitative values of general applicability in defining the effect of salinity are not available.

Most of the previous water balances did not quantify the phreatophyte ET, since their free-body is are confined to the lake surface area. CADWR (1960) and LADWP (1984 b,c) quantify the ET from irrigated lands as a separate component. Both studies are mean value water balances and thus quantify it as a product of a constant irrigated acreage and ET rate, Neither study, however, explain the methodology for their ET estimate. Lee's (1934) model separately quantifies the water consumption from a number of vegetation associations that are recognized as phreatophytic including a) meadow land, b) willow, cottonwood, and aspen, c) salt grass, d) rabbitbrush and e) alfalfa. The water consumption from each type is calculated as a product of the vegetated acreage and estimated ET rate, Lee determined the acreage from vegetation maps ostensibly prepared by the USGS.[21] Lee did not state the methodology for his ET estimates although it is likely he drew upon his work on phreatophyte water consumption in nearby Owens Valley (Lee 1912).

In this water balance the phreatophyte water consumption from each of the type-localities where phreatophophytes occur is quantified as a separate component because the factors that determine the acreage and ET rate for each locality are different. The four components are:

1. Riparian Evapotranspiration (RET)

2, Irrigated Land Evapotranspiration (ILET)

3. Phreatophyte Evapotranspiration above 6428 ft (PETA)

4. Phreatophyte Evapotranspiration below 6428 ft (PETB)

Riparian Evapotranspiration (RET). The riparian vegetation varies from thin strands of willow along the irrigation ditches and minor creeks to extensive stands of Jeffrey pine, cottonwood, and aspen interspersed with meadow and cattail marshes along the major creeks, The riparian vegetation is dependent upon stream flow which recharges the alluvium along the streams, When stream flow and/or groundwater is reduced there is a reduction in the acreage of riparian vegetation (Taylor 1982).

i. Acreage. There has been a significant reduction in riparian acreage in the MGWB over the 47 year study period because LADWP diversions reduced or eliminated the stream flow along lower Lee Vining and Rush Creeks, The present total riparian acreage in the MGWB is estimated from aerial photographs and reconnaissance ground surveys to be approximately 260 ac, compared to 732 ac measured from June 1940 aerial photographs. It is assumed that the 1937-39 riparian acreage is also 732 ac. Lee (1934) measured 710 ac of cottonwood, willow, and aspen from the USGS vegetation maps.[22]

It is assumed that the reduction in riparian acreage along lower Rush and Lee Vining Creeks between 1940 and 1983 is related to the reduction in the surface flow in these creeks. The available flow measurements for lower Lee Vining and Rush Creeks indicate a greater and more rapid reduction in flow on lower Lee Vining Creek as compared to Power Rush Creek. Not surprisingly, aerial photographs in 1956, 1964, 1968, 1972, 1976, and 1979 and the observations of local residents indicate that a more rapid decline in riparian acreage occurred along Lee Vining Creek as compared to Rush Creek. After May 1947 lower Lee Vining was essentially dry except in the high runoff periods of 1952-53, 1956-58, 1967, 1969, 1978, 1980, 1982-83. By the early 1950's the riparian vegetation along lower Lee Vining Creek was so dessicated that 100 ac of it was destroyed in a fire (Banta pers comm 1980) and never regenerated, A continuous but highly variable flow in lower Rush Creek below Highway 395 was sustained until 1970 by a combination of springs and releases from Mono Gate No. 1. After the completion of the second barrel of the Los Angeles Aqueduct in 1970, the releases from Mono Gate No. 1 were curtailed to only the very wet years (1978, 1980, 1982, 1983), As a result of the latter operational change and the reduction in upstream irrigated acreage, continuous flow in lower Rush Creek was eliminated, Thus after 1970 the acreage of Rush Creek riparian vegetation rapidly declined (Johnson per comm 1980). The rough correlation between the estimated riparian acreage and the estimated and/or measured flows in lower Rush Creek and Lee Vining Creeks allows an estimate of the reduction in riparian acreage to be made in each year of the study period.

A small reduction in riparian acreage also occurred along the irrigation ditches because the amount of irrigation water released was reduced. The riparian acreage reductions along the irrigation ditches is assumed to be proportional to the overall reduction in irrigated acreage. It is assumed that the non-aqueduct streams including Mill, Wilson, Bridgeport, and Cottonwood Creeks and the irrigation ditches north of Mono Lake have maintained relatively constant riparian acreage throughout the study period.

ii. Rate, Because the deep roots of many riparian species guarantee an ample moisture supply and the thick foliage presents a large transpiring area, Rantz (1971) suggests that riparian vegetation will have a high ET rate and thus can have a Blaney-Criddle "K" value higher than 1.0. Assuming a growing season PET rate of approximately 2.5 ft and a "K" value of 1.10 (1.30 average value for cottonwood and willow x 0.85 density adjustment) a Blaney-Criddle ET value of 2.75 ft is estimated for the riparian vegetation in the MGWB.

Although the ET rate probably changed as the riparian vegetation became stressed along lower Lee Vining and Rush Creeks, a changing ET rate cannot be estimated with the available data, By estimating the reduction in riparian acreage and assuming the remaining riparian acreage evapotranspired at a constant rate, the gradual reduction in the total RET is estimated. In the first few years of the study period over 2200 ac-ft/year is consumed by the riparian vegetation, or about 1% of the total quantified outflow from the MGWB. By 1983 the estimated RET is about 700 ac-ft or less than 0.3% of the total outflow. The annual values of RET are shown in Table 2-15.

Irrigated Land Evapotranspiration (ILET), The largest areas of phreatophytic vegetation in the MBWB are irrigated parcels of land. Most of the irrigated land is located in the southwest and northwest portions of the MGWB proximate to the streams that debouch from the Sierra Nevada (see Figure 2-7). A few parcels of irrigated land are also located between the Bodie Hills and the north shore of Mono Lake. LADWP owns most of the irrigated land; their land is principally located in the vicinity of Cain Ranch, while the privately owned land is located primarily north of Mono Lake.

The irrigated land supports native phreatophytes, including *Carex* and *Juncus* although occasionally some land is seeded with tall fescue, bird's foot, clover, rye grass, orchard grass, and redtop (Novak pers comm 1983). Prior to the advent of Irrigation, the land around Cain Ranch and Conway Ranch probably experienced seasonally high water tables and supported native phreatophytes.

Most of the irrigated land is leased to sheep grazing operators, The land is cleared and ditched for spreading irrigation water but it is not contoured or levelled. Water is applied to the land by wild flooding severed times each growing season. Much of the land is then intentionally dried out between irrigations in order to minimize hoof rot In the sheep.

LADWP reports the annual amount of irrigation deliveries to their Mono Basin land in their Recapped Aqueduct Operation (LADWP no date), Analysis of these records, however, suggests that they are not a reliable indicator of actual deliveries, and therefore of irrigated acreage or water consumption, Until 1965, for instance, they reported the exact same amount of irrigation deliveries in every year, despite the variability in the available Irrigation water supply.

i. Acreage. The privately owned irrigated acreage appears to have remained relatively constant at about 1,000 ac throughout the entire study period. The acreage of irrigated land owned by LADWP fluctuated during the study period depending on the available water supply and LADWP's irrigation policy, A rough estimate of the acreage annually irrigated by LADWP can be determined from a combination of sources, including aerial photographs, stream diversion records, and published and unpublished reports indicating the general irrigation management policy of the LADWP. Within a few years after their purchase of the irrigated land in the 1930's, LADWP reduced or eliminated irrigation on about 500 acres of land in the MGWB, principally in the vicinity of Lee Vining. For about the next 20 years LADWP irrigated about 3,500 acres of their land except when low runoff and export needs reduced the available irrigation water supply. In the 1960's LADWP implemented a new irrigation policy as part of planning for the second barrel of the Los Angeles Aqueduct, That policy was designed to eliminate irrigation of land with low forage yields and extremely high water requirements in Pumice Valley and included much of the land previously irrigated from Rush Creek (LADWP 1966). After 1966, Rush Creek irrigation facilities were only used to spread excess runoff in very wet years, such as 1967, 1969, 1978, 1980, 1982, and 1983. Currently only the most suitable pasture land is irrigated, including about 2,000 ac around Cain Ranch, about 150 ac in Lee Vining Canyon and around Horse Meadow, and about 200 ac on the north shore of Mono Lake.

ii, ET Rate. An estimated average annual ET rate for irrigated land in the Mono Basin is provided in several references. These include 1.4 ft (applied water rate,, 2.3 ft total ET, CADWR 1960); 2.5 to 3 ft (CADPW 1948); 2.5 ft (Lee 1934). None of these references, however, explain the derivation of their ET rates. An average growing season ET rate of approximately 2 ft is estimated by this author, using the calculated Blaney-Criddle consumptive use factor of 2.5 ft and a suggested "K" value of 0.80 for native pasture (Blaney 1954). This estimate is close to the measured growing season ET rate for native pasture at high altitudes in Colorado (Kruse and Haise 1974). The annual ET rate from the irrigated land will vary considerable because of the variation in water supply, climate, and species. The available data, however, do not permit variations in the ET rate to be estimated.

The annual ILET is shown in Table 2-15, The ILET has decreased by about 25% during the study period because of the reduction in irrigated acreage, The current average water consumption of 7,000 ac-ft per year represents about 3% of the current quantified outflow from the MGWB.

Phreatophyte Evapotranspiration Above 6428 Ft (PETA). The non-irrigated, non-riparian phreatophyte vegetation that occurs in areas of high water table and spring flow above Mono Lake's historic high stand of 6428 ft consists mostly of salt grass, sedge, and rabbitbrush with clumps of willows around the springs. Robinson (1958) classified rabbitbrush as a phreatophyte. It appears that rabbitbrush is an opportunistic species, i.e., it will survive in conditions associated with xerophytes as well as in conditions where it can obtain a supplemental water supply, Areas of high water table are commonly found near the bottom of the coalescing alluvial fans created by the streams that emit from the Bodie Hills. The numerous springs, including Waford, Burkham, Coyote, Moore, Kirkwood, and Villette are usually associated with fault zones that probably bring water up from deeper confined aquifers.

i. Acreage. Aerial photographs from 1929 to the present indicate the acreage of these phreatophytes has remained relatively constant over the study period. Excluding the rabbitbrush, approximately 700 ac is measured from these photos. Lee (1934) estimated a similar acreage for non-irrigated salt grass and meadow vegetation in the MGWB. Lee estimated that another 3,000 ac of rabbitbrush occurred around the north shore. The latter figure (3,000 ac) will be used by this report since the rabbitbrush acreage cannot be easily measured on the available aerial photographs.

ii. Rate. Because a high proportion of the phreatophyte acreage consists of salt grass, the estimated Blaney-Criddle "K" value would be lower than the irrigated native pasture. A growing season ET rate of 1.5 ft for the 700 ac of non-rabbitbrush phreatophytes is calculated as a product of the Blaney-Criddle consumptive use factor of 2.5 ft and an average Blaney-Criddle "K" value of .60. An ET rate of 0.2 ft/yr is estimated for the rabbitbrush areas using the rate Van Denburgh and Glancey (1970) estimated for groundwater ET from rabbitbrush in nearby Alkali Valley.

The average annual PETA by both saltgrass-dominated phreatophytes and the rabbitbrush is as follows:

$$\begin{aligned} PETA &= 700 \text{ ac} \times 1.5 \text{ ft/yr} + 3000 \text{ ac} \times 0.2 \text{ ft/yr} \\ &= 1{,}700 \text{ ac-ft/yr} \end{aligned} \tag{21}$$

This is less than 1% of the annual quantified outflow from the MGWB, The PETA would be about 600 ac-ft lower if rabbitbrush was not considered a phreatophyte.

Phreatophyte Evapotranspiration Below 6428 Ft. In the past 64 years new vegetation associations dominated by phreatophytes have established themselves on land around Mono Lake that has been exposed since the lake reached its historic high stand of 6428 ft in 1919. All of the previously established vegetation was killed by the rise to 6428 ft, so that any vegetation currently existing below that level has colonized since 1919.

In a 1976 botanical survey of the vegetation of the exposed lake bottom (Winkler 1977), the following plants which Robinson **(1958)** recognized as phreatophytes were found: tule (Scirpus), rush (Juncus), cattail (Typha), salt grass (Distichlis), willows (Salix), greasewood (Sarcobatus), rabbitbrush (Chrysothamnus). Other plants that may be phreatophytes were identified, including monkey flower (Mimulus), alkaline grass (Puccinellia), desert crowfoot (Ranunculus), scratch grass (Muhlambergia), and willowherb (Epilobium). A reconnaissance botanical survey by this author in 1982 indicated that the phreatophytes are generally limited to locations where either water in the uppermost aquifer or water from springs can adequately flush the soil of alkaline salts, These ground surveys and recent (1978 to 1982) infra-red imagery distinguished 15 major sites (see Figure A2-2 in Appendix II-D) of phreatophyte vegetation on the exposed lake bottom. The acreage of these sites are given in Table A2-5 in Appendix II-D, A zonation of phreatophytes species is observed in most of these sites, corresponding to changes in alkalinity and water table depth as one moves upslope from the shoreline.

i. Acreage. As the level of Mono bake has dropped and exposed increasing amounts of lake bottom, the area of phreatophyte vegetation has increased. Downslope colonization by phreatophytes has occurred in the areas where the high water table and springs have followed the receding shoreline. In the upslope areas where the springs continue to discharge or where the roots of the plants have been able to grow down to the lowering water table, the phreatophytes have been able to survive. Where recharge is insufficient and the water table lowered beyond the reach of the phreatophytes, a few xerophytes such as sagebrush have colonized,

An evaluation of the changing acreage of phreatophyte vegetation over the study period is made by comparing the phreatophyte area on 1940 aerial photographs with the area of phreatophytes on 1978, 1979, and 1980 aerial photographs. Qualitative assessment of the changes in the area of phreatophyte vegetation in the intervening years are made using imagery from 1951, 1956, 1964, 1968, and 1976. More detailed information on the methodology employed in determining the current and 1940 area of phreatophyte vegetation is given in the technical appendix.

The area of phreatophyte vegetation in June 1940 was approximately 170 acres; by July 1978 the area had increased by 1190 acres to a total acreage of 1360 acres.[23] The 1940 acreage represented about 12% of the exposed lake bottom area; the 1978 acreage represented about 8% of the exposed lake bottom area.

Part of the higher percentage in 1940 can be explained by the fact that proportionately more of the exposed lake bottom was flushed by ground water and springs because of the greater recharge from the pre-diversion flow in Lee Vining and Rush Creeks and the more widespread irrigation that occurred immediately upslope.

Aerial imagery shows a gradual increase in the area of phreatophyte vegetation from 1940 to 1978, suggesting a relationship between the Increasing acreage of exposed lake bottom and acreage of phreatophyte vegetation, The acreage of relicted lake bottom is controlled by the lake level which also influences the groundwater conditions around the lake. In the absence of data and for the sake of simplicity a linear relationship between the phreatophyte acreage and the exposed lake bottom acreage is assumed. Using the historic high stand as a zero level, the relationship can be formulated as follows:

$$\frac{1978\ PA - 1919\ PA}{1978\ AE - 1919\ AE} = \frac{1359 - 0}{17000 - 0} = 0.079 \text{ acres of phreatophyte vegetation per acre of exposed lake bottom} \tag{22}$$

$$\frac{1940\ PA - 1919\ PA}{1940\ AE - 1919\ AE} = \frac{170 - 0}{1400 - 0} = 0.121 \text{ acres of phreatophyte vegetation per acre of exposed lake bottom} \tag{23}$$

PA - Phreatophyte acreage

AE - Exposed lake bottom acreage

As explained previously, the 1940 phreatophyte acreage was proportionally higher and one expects equation 22 to be somewhat less than equation 23. Taking the average of the two relationships, the area of phreatophyte vegetation in any year can be calculated with the equation:

$$PA = 0.10 \times AE \qquad (24)$$

ii. Rate. The Blaney-Criddle "K" values for these phreatophytes could range from about 0.35 for light density salt grass areas with lower water table depths to 1.5 for dense growth of tules and sedges in standing water. An average "K" value of 0.8 is estimated, based upon a very rough qualitative evaluation of the vegetation types and water table depths, The growing season ET rate is thus calculated to be approximately 2 ft (0.8 times 2.5 ft consumptive use factor),

The annual PETB is calculated with the following equation as the product of the area of the phreatophyte vegetation (PA) and the ET rate of 2 ft, or:

$$\text{PETB in ac-ft} = 0.10 \times AE \times 2 \text{ ft} \qquad (25)$$

The water consumption in any year therefore can be calculated knowing only the level of Mono Lake, since the lake level will determine the area of exposed lake bottom. The annual values of the PETB are given in Table 2-15. The 1983 PETB of approximately 3800 ac-ft represents about 1.5% of the estimated total annual outflow from the MGWB.

DIVERSIONS

The municipal and agricultural use of water within the Mono Basin and by the City of Los Angeles results in the diversion of water into and out of the MGWB, The water that is brought into the MGWB for agricultural and municipal use is quantified into two components: (1) Virginia Creek Inflow (VCI), and (2) Net Municipal Inflow (NMI). Surface and subsurface runoff that LADWP removes or prevents from flowing into the MGWB is quantified as two components: (1) LADWP Surface Water Export (SWEX), and (2) LADWP Ground Water Export (GWEX).

Virginia Creek Inflow (VCI), Virginia Creek, a tributary of the East Walker River, is diverted into the northern part of the MGWB in order to augment the irrigation of approximately 600 acres of meadow band at Conway Ranch (See Figure 2-9), This diversion, commonly called the Conway Summit diversion, is made under water rights adjudicated and confirmed by Federal Court Decree C-125, The Court Decree set the diversion right at 6 cfs during the period from March 1 to October 31 in each year (CADWR 1960). The maximum diversion thus permitted would be slightly more than 2,900 ac-ft/yr. No records of the quantity actually diverted are available, so annual diversion amounts must be grossly estimated,

Two of the previous water balance studies quantify this diversion. C.H. Lee (1934), citing a letter from the Office of Indian Affairs, estimated an average of 3 cfs diversion for six months for an annual total of about 1,100 ac-ft/yr.

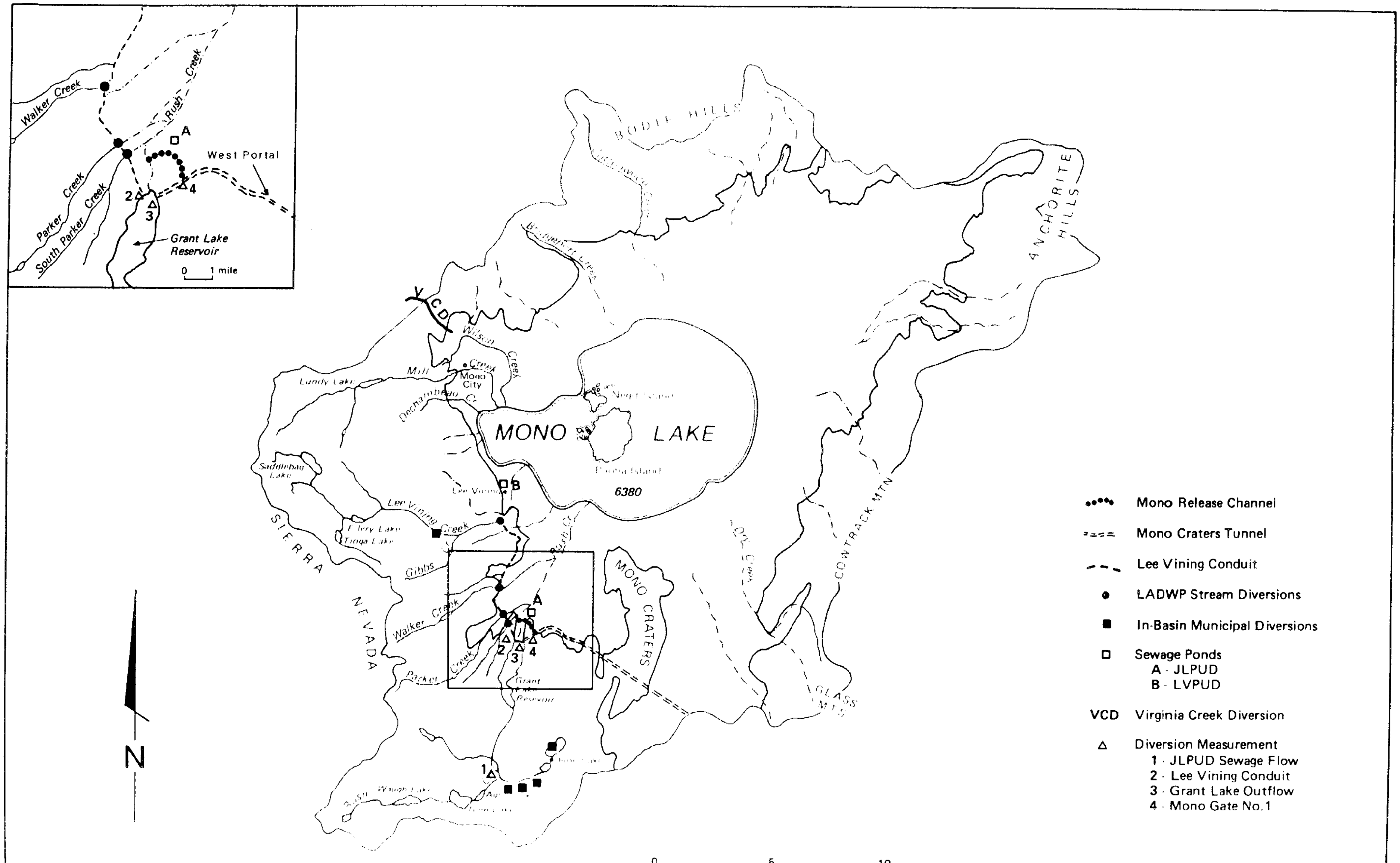


Figure 2-9
Diversions

LADWP (1984 b,c) estimate a diversion of 2,500 to 3,000 AF per year but do not explain the basis for that estimate.

Any estimate of VCI must take into account the following considerations:

(a) the Conway Ranch, which has the right to the Virginia Creek water, also has a "first right" to about 13,000 ac-ft/yr of Mill Creek water (Brown pers comm 1984). In many years the Mill Creek right satisfies a major portion of the irrigation needs and relatively little Virginia Creek water is needed.

(b) in wet years, 6 cfs of water is not needed for the whole period because the growing season is generally no more than six months long (approximately from April 15 to October 15).

(c) in dry years, 6 cfs of water is not available for the whole period because of natural runoff limitations and/or downstream Virginia Creek users' demand for the water.

(d) no more than approximately 3 cfs of flow in the diversion ditch has ever been observed by this author; a local resident (McPherson pers comm 1980) usually observed about 1 cfs in the ditch,

Based on these aforementioned considerations the annual VCI is estimated to be a constant 1100 ac-ft or less than 1% of the quantified average annual inflow to the MGWB. This estimate is somewhat arbitrary although it is equivalent to Lee's (1934) estimate, It is slightly more than an 8 month average of the most observed at any one time (3 cfs) and the amount most commonly observed (1 cfs).

Net Municipal Inflow (NMI). Residents of the June Lake Loop area and Lee Vining procure their municipal water supply upstream of the MGWB boundary and discharge it below the boundary resulting in a diversion inflow to the MGWB (see Figure 2-0). Municipal water use outside of Lee Vining and the June Lake Loop area but within the MGWB results in a diversion outflow, It will be shown that the balance of the municipal inflow and outflow results in a net diversion inflow to the MGWB. Thus for simplicity's sake, the inflow and outflow from municipal water use will be quantified together as the NMI.

LADWP (1984 b,c) estimate a total municipal outflow of 1000 ac-ft/yr. It is an outflow because their valley-fill boundary is upstream from the water-using areas of the Mono Basin, It is not explained how they arrived at the 1000 ac-ft/yr outflow figure. CADWR (1960) estimates the urban consumptive use for the entire Mono Basin to be close to 400 ac-ft/yr, The latter number is based on a 1958 reconnaissance land use survey of urban/suburban water using areas in the Mono Basin and the CASWRCB (1951) estimates of urban consumptive use of 0.8 feet per acre. None of the other water balances made estimates of the municipal water consumption.

The lack of historic municipal water use data makes it virtually impossible to estimate the municipal inflows and outflows in each year of the study period. By extrapolating backwards from the current water use, approximations of the past inflows and outflows can be made. The current water use is analyzed by examining the current supply, use, and disposal of water in the four water using area of the Mono Basin. These four areas are delimited as the a) June Lake Loop, b) Lee Vining, c) Mono City, and d) other residents.

i. June Lake Loop. The water supply for the June Lake Loop, a year-round recreational center outside of the MGWB which includes the June Lake "village" and "down canyon" area, is derived from sources that are upstream of the MGWB boundary. Specifically, the water supply for the June Lake village area is procured from June Lake and Twin Springs Creek and is distributed by the June Lake Public Utilities District (JLPUD). The water supply for most of the "down canyon" area of the June Lake Loop is procured from Fern Creek, Yost Creek, and springs and is distributed by several small water companies associated with individual housing tracts including the Clark tract, Williams tract, and Peterson tract, The United States Forest Service campgrounds, the June Mountain Ski Area, and a few other private establishments in the June Lake Loop supply their own water from wells and springs.

A substantial portion of the total water use in the June Lake Loop area is by tourists and seasonal residents during the winter and summer seasons. Most of the water Es used indoors for commercial and domestic purposes. Outdoor use (i.e. landscape irrigation) is limited because of the short growing season and the small amount of landscaped acreage. The most outdoor water use occurs at the June Mountain Ski area for snow making and erosion control and in the various public and private campgrounds, Leaks in the distribution system and the use of bleeder lines also account for some non-indoor water use. The current total use is estimated to be approximately 385 ac-ft/yr (see Table 2-11).

Prior to about 1974, water used indoors in the June Lake Loop area was disposed of in the immediate surrounding area through septic tank leach fields or, in the case of the June Lake Village area, through on-site post-treatment spray irrigation. Water that was not consumptively used flowed into Rush Creek and became part of the gaged runoff into the MGWB. In the mid-1970's a program to sewer the entire June Lake Loop area was instituted. By 1976 nearly the entire June Lake Loop including the campgrounds was connected to sewers. The effluent is routed into the JLPUD Water Treatment Plant located in Pumice Valley, which is within the MGWB (see Figure 2-9). The treated water is released into percolation ponds and infiltrates into the aquifers of the ground water basin.

ii, Lee Vining. The water supply for Lee Vining, a summer recreational center within the MGWB, is derived from a spring in Lee Vining Canyon upstream from the MGWB boundary. The supply is distributed by the Lee Vining Public Utilities District (LVPUD).

During the summer months tourists and seasonal residents account for a major portion of the total Lee Vining water use. It is assumed that a greater proportion of Lee Vining supply is used outdoors in comparison to the June Lake Loop area because of the extensive grass landscaping that occurs at the high school, county park, and trailer parks. The current total use is estimated to be approximately 232 ac-ft/yr.

Most water used indoors in Lee Vining is collected in sewers and disposed of in settling ponds maintained by the LVPUD. Water percolates from the ponds into the MGWB,

iii. Mono City. Mono City, a small development of about 30 private residences within the MGWB, obtains its water from a deep well near Mill Creek that is maintained by the Lundy Mutual Water Company (a new well is being drilled in 1985 farther away from Mill Creek).

The use of water in Mono City is entirely for the indoor and outdoor domestic needs of the residents. A substantial portion is used outdoors for landscaping. The current total use is estimated to be approximately 27 ac-ft/yr.

Each resident in Mono City has an individual septic tank that disposes of water through a leach field into the MGWB, Since the water for Mono City is procured from within the MGWB, any consumptive use (mainly evapotranspiration from outdoor landscaping) results in an outflow of water from the MGWB.

iv. Other Residents. There are about 30 homes scattered throughout the MGWB who obtain water from wells, springs, or streams. The water is assumed to be used entirely for indoor domestic and outdoor landscaping purposes. The current total use is estimated to be approximately 27 ac-ft/yr. Water is disposed of in individual septic tanks and into the MGWB, Any consumptive use of water, principally evapotranspiration, results in an outflow of water from the MGWB.

The current municipal water use in the four water using areas is shown in Table 2-11. The resulting amount of inflow and/or outflow are derived from estimates of effluent discharge and consumptive water use. Water that is used indoors in the Lee Vining area and since 1976 in the June Lake Loop area flows into their respective sewage ponds and is available for inflow, Most of this sewage water percolates into the MGWB except for a small portion that evaporates. It is also assumed that about 50% of the outdoor water use in Lee Vining is also available for inflow. Currently water use in the Lee Vining and June Lake Loop Area results in an annual inflow to the MGWB of around 482 ac-ft and the water use of Mono City and other residents in the MGWB results in an annual outflow of about 27 ac-ft. (see Table 2-11). The current net inflow to the MGWB is close to 500 ac-ft or less than l/3 of 1 percent of the quantified total average annual Inflow. The net inflow has not changed significantly since 1976 when the June Lake Loop became completely sewered and its indoor

TABLE 2-11. Current Municipal Water Use

Location of Use	Total Use (ac-ft)	Avg. Population	GPCD[7]	Indoor Use (ac-ft)	Outdoor Use (ac-ft)	Total Consumptive Use (ac-ft)	Available for Inflow (ac-ft)
June Lake Loop	385[1]	1217[4]	283	354[8]	31	61[12]	308[14]
Lee Vining	232[2]	650[5]	319	116[9]	116	78[12]	174[15]
Mono City	27[3]	75[6]	319	13.5[10]	13.5	13.5[13]	N/A
Rest of Basin	27[3]	75[6]	319	13.5[10]	13.5	13.5[13]	N/A

Notes

1. Actual deliveries by JLPUD plus estimates for Down Canyon area
2. assumed total use was double the indoor use
3. avg. population X GPCD.
4. avg. year round includes permanent and visitors from Colwell (1980)
5. avg. year round includes permanent and vistors from Hardstrom (1980)
6. 32 residences X 2.3 persons/resident
7. gallons per capita per day (GPCD) = $\frac{\text{total use (ac-ft/yr)} \times 325{,}900 \text{ gal/ac-ft}}{\text{avg. pop.} \times 365 \text{ days/yr}}$
8. measured sewage flows by JLPUD + 10% for indoor consumptive use
9. estimated sewage flow by LVPUD + 10% for indoor consumptive use
10. 50% of total use
11. total use - indoor use
12 10% of indoor use + 50% outdoor use + evaporation from sewage ponds
13. 50% of total use
14. sewage flow - evaporation from sewage ponds
15. sewage flow - evaporation from sewage ponds + 50% outdoor use

N/A - Not Applicable

use became an inflow to the groundwater basin. Prior to 1976 only the water use in Lee Vining resulted in an inflow but the outflow from the water use by Mono City and other residents was so small that a net inflow still occurred. The net inflow prior to 1976 could not have been any greater than 147 ac-ft (current Lee Vining inflow minus current Mono City and other residents outflow). Since the population of the Mono Basin has changed slowly in absolute numbers over the study period (the percentage increase Is great; the absolute increase is not), it is assumed that a constant 100 ac-ft net inflow (rounding to the nearest 100 ac-ft) occurred in the 1937 to the 1974 period.[24]

<u>Surface Water Export (SWEX)</u>. The LADWP diverts the surface water of Lee Vining, Rush, Walker, and South Parker Creeks for export to Los Angeles. Diversion facilities are located very close to the groundwater basin boundary, just downstream from the stream-gaging stations. The diversion facilities on Lee Vining, Walker, and Parker Creeks consists of small checkdams that divert the creek flow into the Lee Vining conduit; the conduit in turn empties into the northwest corner of Grant Lake Reservoir, on Rush Creek (see Figure 2-9).

All of the previous water balances accounted for LADWP's surface water export. Only the "total. watershed" water balance of LADWP (1984 c), however, treats the export as an outflow component, All of the other water balances treat the export as a quantity that reduces the inflow of runoff into Mono Lake.

The water diverted out of Grant Lake Reservoir minus any releases back to Rush Creek at Mono Gate No. 1 are quantified as SWEX. The SWEX is reported by LADWP as "flow to West Portal" in their Recapped Aqueduct Operations, The SWEX is also equivalent to the measured outflow from the Mono Craters tunnel at the East Portal, minus the calculated "tunnel-make" (see next page) both of which are reported in LADWP's Summary of Runoff.

LADWP exported the first surface water from the Mono Basin in April 1940 for a limited test period (Harding 1962); the "official" commencement of exports was in April 1941. Because of an abnormally wet period from 1941 to 1947, Los Angeles water demand was satisfied from their Owens River supply and so the SWEX in the first 7 years (1941 - 1947) averaged only 17,000 ac-ft/yr. SWEX since 1948 has averaged approximately 78,000 ac-ft/yr, Since the completion of the second barrel of the Los Angeles Aqueduct (LAA) in 1970, SWEX has averaged close to 93,000 ac-ft/yr, although there was zero export in 1983. The annual SWEX export amount is determined by (1) the runoff in the Mono Basin, (2) the Owens River Basin surface and sub-surfacse supplies, (3) the available reservoir storage in the Los Angeles Aqueduct System (including the San Fernando Valley Groundwater Basin "reservoir"), (4) physical and legal restrictions in the Los Angeles Aqueduct, (5) the demand for water and power in Los Angeles. Since 1970, the coordinated operations of SCE and LADWP allow nearly the entire flow of the four creeks to be exported in all but the very wet years. SCE reservoirs regulate the stream flows above the LADWP diversion facilities for hydropower production and LADWP uses Grant Lake Reservoir to store the runoff that cannot be immediately exported. In the very wet years (1978, 1980, 1982, 1983) the runoff exceeds the aqueduct diversion and storage facilities and LADWP must release water into Mono Lake. Table 2-15 shows the annual SWEX in the base period.

Groundwater Export (GWEX). The underground conduit that transports the Mono Basin surface water from Grant bake Reservoir through the Mono Craters and into the Owens River watershed intercepts groundwater like a giant horizontal well. A portion of this intercepted water, or "tunnel--make" would flow into the MGWB under natural conditions.[25]

None of the previous water balances, except CADWR (1960) and LADWP (1984c) include tunnel-make as a separate water balance component, although some of the other water balances (Loeffler 1977 and Lee 1934) acknowledge the existence of the tunnel-make. CADWR (1960) reports the Mono Basin tunnel-make is 61% of the total tunnel-make, an estimate ascribed to figures provided by the LADWP.

The total annual tunnel-make is equal to the difference between the measured discharge at the East Portal of the Mono Craters Tunnel and the measured LADWP surface water export. It is assumed that about 60% of the total tunnel make would have flowed into the MGWB because according to the groundwater profiles in Greswell (1940), approximately 60% of the total tunnel length is within the MGWB, The distance to the Mono-Owens surface water divide from the West Portal is also about 60% of the total tunnel length. The annual GWEX is thus calculated as 60% of the total measured tunnel-make that LADWP reports in the Summary of Runoff. LADWP (1984 c) assumes that half (50%) of the total tunnel-make is water that is exported from the MGWB.

The GWEX in each year of the study period is shown in Table 2-15. The tunnel was not completed until April 1939; prior to that time, it cannot be ascertained what portion of the approximately 12,000 ac-ft of total tunnel-make for the period October 1936 to April 1939 should be credited to the MGWB. The 60% credit will be used until additional information is acquired.

GWEX was high for several years after the tunnel was completed because of above normal precipitation and the "draining" of the intercepted formations. GWEX presumably reached a steady-state condition in which the quantity is a function of recharge. It is hard to say when a steady-state condition was achieved because 1937-46 was a wet period, The 1940-79 average GWEX is about 7500 ac-ft/yr; the 1947-83 average is about 7270 ac-ft/yr. The latter will be the assumed steady-state average GWEX.

STORAGE CHANGES

Within the MGWB water is stored in Grant Lake Reservoir, Mono Lake, the aquifers, and the soil, On an annual time interval, the storage will change if the inflows and outflows are not equal. The storage changes are quantified as:

1) Soil Water Storage Change
2) Grant Lake Reservoir Storage Change
3) Groundwater Storage Change
4) Mono Lake Storage Change

Soil Water Storage Change (SWSC). Not enough data are available to quantify an annual change in soil water storage change., It is assumed, however, that this change is relatively small because: (1) the maximum total soil water storage in the MGWB is roughly 55,OOOO ac-ft assuming 4 inches (100 mm,) storage in a 60 in soil column; Dan Vaughn (pers comm 1980), soil scientist for the USBLM, estimated a 4 inch storage for the alluvial soils of the MGWB; (2) the beginning and end of the water balance time interval (October 1 - September 30) is when soil water storage would normally be close to its annual minimum. SWSC is therefore assumed to be zero.

Grant Lake Reservoir Storage Change (GLSC). The storage capacity of the existing Grant Lake Reservoir at the spillway elevation of 7130 ft is 47170 ac-ft. Storage can exceed this amount by up to 1900 ac-ft when the lake level rises above the spillway elevation, The storage capacity of the previous reservoir --

enlarged in 1940 when LADWP moved the dam downstream - was approximately 10,000 ac-ft.[26]

Only the LADWP (1984b) valley-fill water balance acknowledges the GLSC as a separate water balance component, although Corley (1971) adjusted the measured inflow with the reservoir storage change, The mean-value water balances assume that GLSC over a base period is equal to zero. The other water balances that evaluate the historic inflows and outflows on an annual basis - Loeffler (1979), Cromwell (1979), CADWR (1979), LADWP (1984a,d) - give no reason for not accounting for the GLSC.

The amount of water in storage at Grant Lake Reservoir has been recorded by LADWP since it began filling the existing reservoir in November 1940. Daily measurements of water levels are converted to an equivalent storage amount based on the elevation, area, and volume relationship developed for the existing reservoir. The difference in the October 1 storage amount in each year is equal to the annual GLSC.

The annual storage change for water years 1937-1940 must be estimated because records of storage in the previous Grant Lake Reservoir are not available. The balance of the estimated annual inflow to the reservoir (equal to the Rush Creek measurements and ungaged runoff estimates) and the estimated annual outflow from the reservoir (equal to the Rush Creek at

Highway 395 measurements, irrigation diversion measurements, estimates of inflow between the dam and Highway 395, and estimates of net reservoir evaporation) gives an estimated annual storage change in each year of the 1937-1940 period,

The annual GLSC in each year of the study period is shown in Table 2-15. A "plus" value is a gain in storage, and a "minus" value is a release from storage. The annual storage change varies from the 26,000 ac-ft released from the reservoir during a dry year (1959) to the 34,000 ac-ft added to the reservoir during the wet year (1978) that followed the 1976-77 drought.

Groundwater Storage Change (GWSC), GWSC occurs in the permeable littoral, riverine, and volcanic sediments that overlie the impermeable lake sediments, Most of it probably occurs in the deltas of the major Sierran streams, The available flow records for lower Rush Creek suggest that the stream may "lose" water to the aquifer in wet years and "gain" water from the aquifer in dry years. There are not enough data, however, to indicate the quantity of the storage change in the delta areas for each year of the study period,

Upon examination of the few long-term records from wells and springs near Mono Lake that tap the uppermost (unconfined and semi-confined) aquifers, It appears that the aquifers have drained as the level of Mono Lake has dropped.[27] The level of the lake appears to influence the depth to the water table in a portion of the uppermost aquifers around the lake in a manner analogous to the bank storage of a reservoir. The water table can be no lower than the lake level and in many places, depending on upstream recharge and thickness of the aquifer, the water table is close to the land surface for a considerable distance above the shoreline, The influence of the lake on water table fluctuations diminishes as one moves further away from the lake,

None of the previous water balances estimated the GWSC. To accurately determine the groundwater storage change would require comprehensive modeling of the aquifer characteristics and an extensive data collection program well beyond the means of this study. A rough estimate, however, of the GWSC in the portion of the aquifer influenced by Mono Lake can be made as follows:

(1) A zone of lake influence, i.e. the area in which the water table lowered as the lake lowered, is delineated by analysis of non-artesian wells. The non-artesian wells around the north and east shore were analyzed for net water table drops from October 1, 1936 to October 1, 1979 (data was not available after 10/l/79). The zone of influence is extrapolated around the rest of the basin using Lee (1969) and Loeffler (1977) hydrogeologic data. The falling water table was assumed to follow the drop in lake level, so that a triangular "wedge" of sediments is drained. (Figure 2-10)

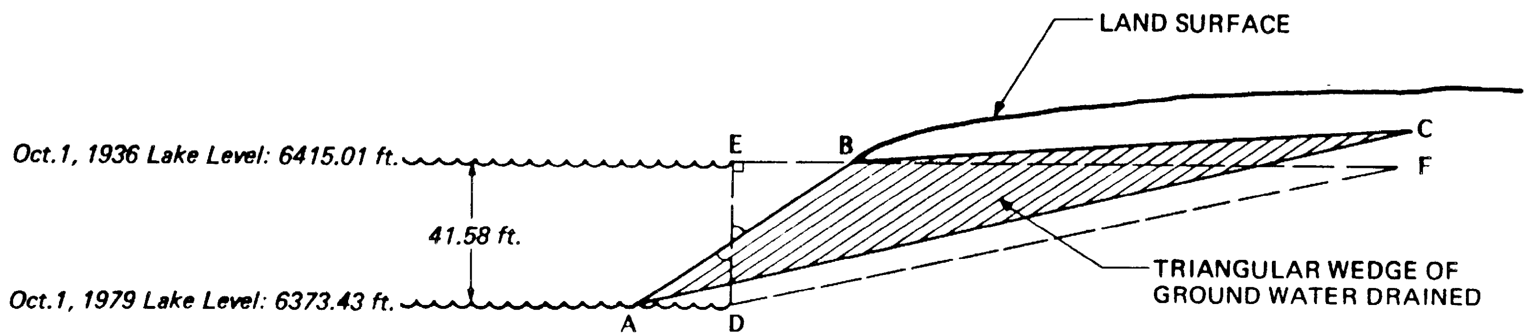
(2) The volume of water drained from this triangular "wedge" over the data period is calculated. The volume of this triangular "wedge" is nearly equal to the right triangular "wedge" in Figure 2-10 (the water table slopes upwards so gently that a right triangle is assumed) whose base is equal to the zone of influence and whose height is equal to the change in lake level. The volume drained is equal to the volume of the right triangular wedge (i.e. volume of sediments times the specific yield)

$$\text{Groundwater storage change from 10/1/36 to 10/1/79} = \frac{\text{Surface Acreage} \times \text{change in lake level} \times \text{specific yield}}{2} \qquad (26)$$

$$= \frac{(34{,}580 \text{ ac}) \times (-41.58 \text{ ft}) \times (.1)}{2}$$

$$= 72272 \text{ Ac-ft}$$

The specific yield, which is equal to the storage coefficient of the unconfined aquifer, is the volume of drainable pore space expressed as a percentage of aquifer volume. There are no published calculations of the specific yield of the aquifers in the MGWB. According the A.S. Van Denburgh (pers comm 1982), hydrologist with the USGS in Carson City, 0.l or 10% is a specific yield value that is a reasonable average for aquifers in this region. Van Denburgh et al, (1973) calculated the groundwater storage change in Pyramid Lake Valley water balance as the volume of saturated sediments times a specific yield value of 0.l.



$\Delta ABC \approx \Delta DEF$ for gently sloping water table

NOT TO SCALE

Figure 2-10 **Ground Water Storage Change Near Mono Lake**

(3) The ratio of the volume drained to the total Mono Lake storage change over the study period is calculated. This results in a dimensionless figure that is the average unit loss or gain of groundwater from storage per unit lake storage change.

$$\frac{\text{Volume drained from 10/1/36 to 10/1/79}}{\text{Mono Lake storage change over same period}} = \frac{72272 \text{ ac-ft}}{2{,}053{,}736 \text{ ac-ft}} = .035 \qquad (27)$$

(4) The annual groundwater or bank storage change is then calculated as .035 times the annual lake storage change. Kraeger and Linsley (1975) assumed that the bank storage at Pyramid Lake is also a percentage of the total lake volume. The GWSC in each year of the study period is given in Table 2-15, A "plus" figure represents the gain in aquifer storage as the lake goes up; a "minus" figure represents the draining of the aquifer as the lake goes down, The greatest amount of GWSC due to lake level fluctuations occurred in 1983 when the lake rose 5.81 ft and an estimated 8,069 ac-ft of water was added to the uppermost aquifer,

Mono Lake Storage Change (MLSC). In this model the annual Mono Lake storage change (MLSC) Is the calculated sum of all the other inflows, outflows and storage changes in MGWB. In order to calibrate the model and use it for forecasting purposes it is required to know the value of the Mono Lake storage change that results from lake level fluctuations. A discussion of how this storage change is determined follows.

The amount of water stored in Mono Lake is a function of the Lake's morphometric characteristics. These characteristics determine the relationship between the lake's stage, area, and volume. All the previous water balances except for Scholl et al. (1967) use the stage/volume and stage/area relationships developed by LADWP. LADWP's relationships are based upon the Russell (1889) bathymetric survey and the LADWP topographic sheets for elevations 6419 and 6428, Scholl et al. (1967) developed a hypsometric curve (stage/volume and stage/area curves) using their bathymetric map; it is only applicable, however, to elevations below 6392 ft, For this report, LADWP's stage/area/volume relationship is updated by planimetering the more accurate Scholl et al, (1967) bathymetry, The relationship for this study is also extended up to elevation 6480 ft. An explanation of how the relationship is derived is presented in Appendix I-B along with the table of stage/area/volume values.

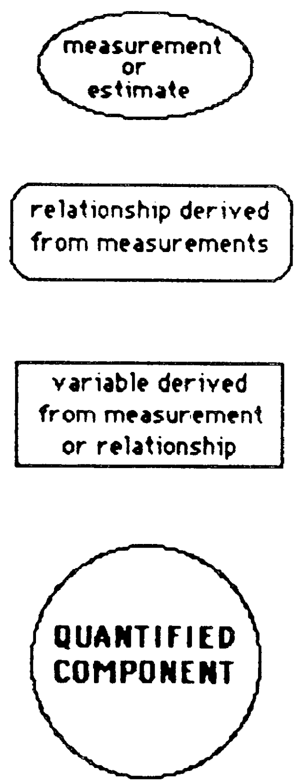
ERROR ANALYSIS

The quantification of the component values in the preceding sections involve measurements, approximations, regionalizations, and assumptions that result in random and systematic error. Analysis of how component values are derived will identify where error occurs and allow an educated guess of the component error magnitude. Figures 2-11 a-f on the following pages are flow diagrams showing how relationships, variables and components are quantified and estimated. Random error results from the measurements and estimates -- the basic data -- and the regionalization of it to larger areas in, for example, the isohyetal map, the precipitation/runoff relationship, or the evaporation estimates. Both systematic and random error also occur as the result of the assumptions used to derive the component values. Table 2-12 Identifies some of the assumptions.

Only a rough guess of the error can be made. If the systematic error could estimated with any certainty the component value would accordingly adjusted. The random error of water balance components has been estimated in research studies that assume the "true" value is quantifiable, Based on a review of these studies, Winter (1981), Peters (1972), and Ferguson et al. (1981) suggest the random error magnitudes that are given in Table 2-13, These error ranges are used as a guide along with the analysis of component derivation to estimate the magnitude of the random error for the components of this water balance. The range of component values estimated in previous Mono Lake water balances is also considered, Table 2-14 gives the estimated error range in percentages and translates these to ac-ft quantities by using 1975 component values. Water year 1975 is chosen because it had nearly average hydro-climatic conditions and the average lake level. was close to the current level, Average (i.e. mean) base period values are not used because the values of several of the components get progressively smaller over the base period. The components with the largest percentage error have little or no basic data (VCI, GWSC) or are

Figure 2-11a-f. Schematic Diagrams of Component Derivation

The symbols in the following figures are interpreted as follows:



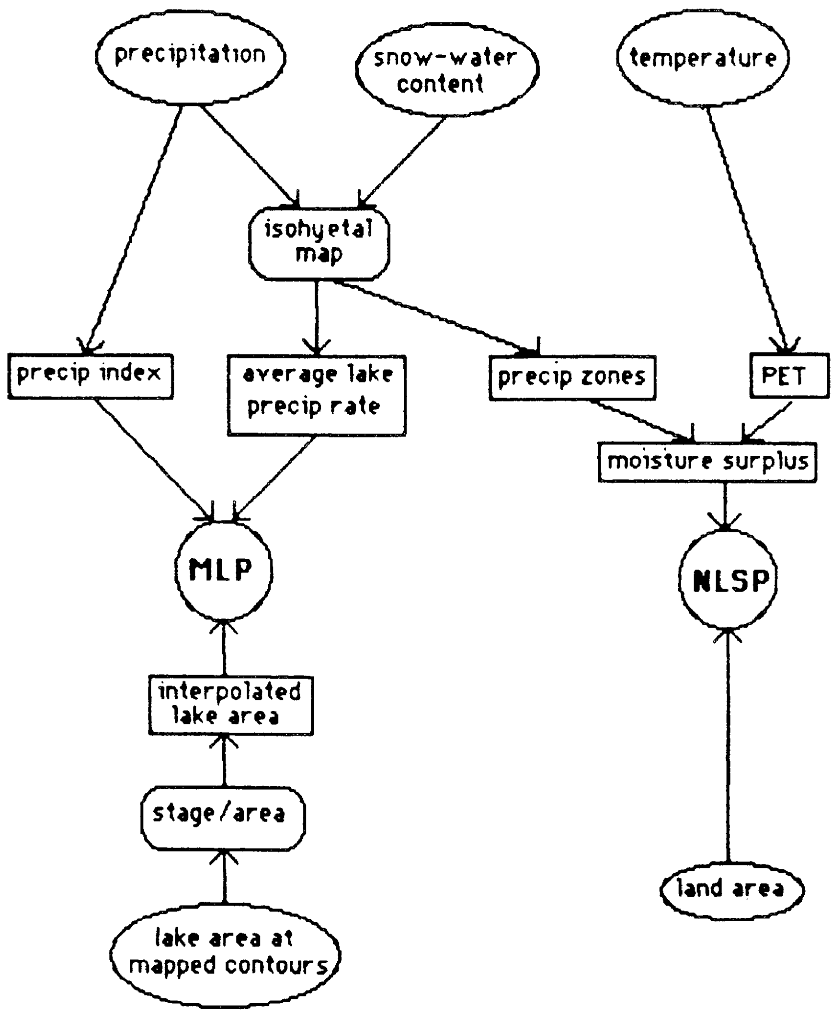


Figure 2-11a. Precipitation

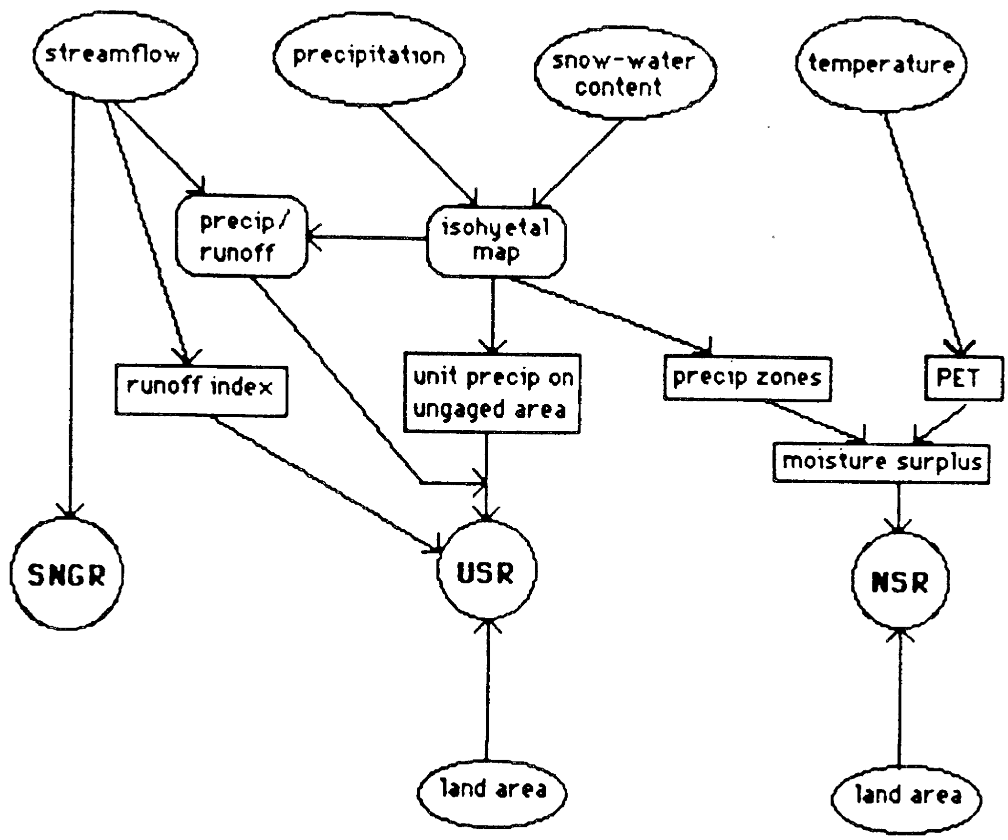


Figure 2-11b. Runoff

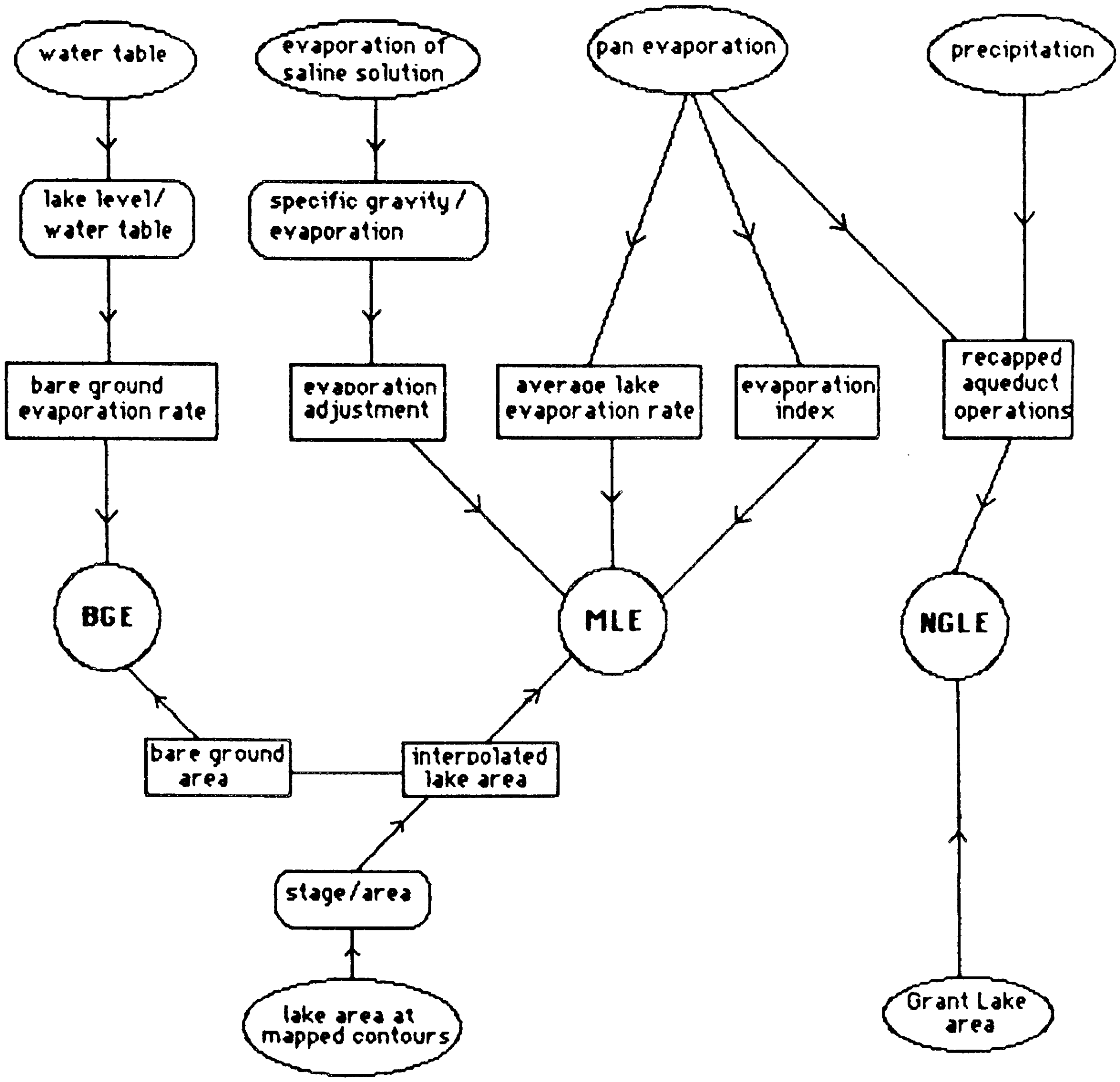


Figure 2-11c. Evaporation

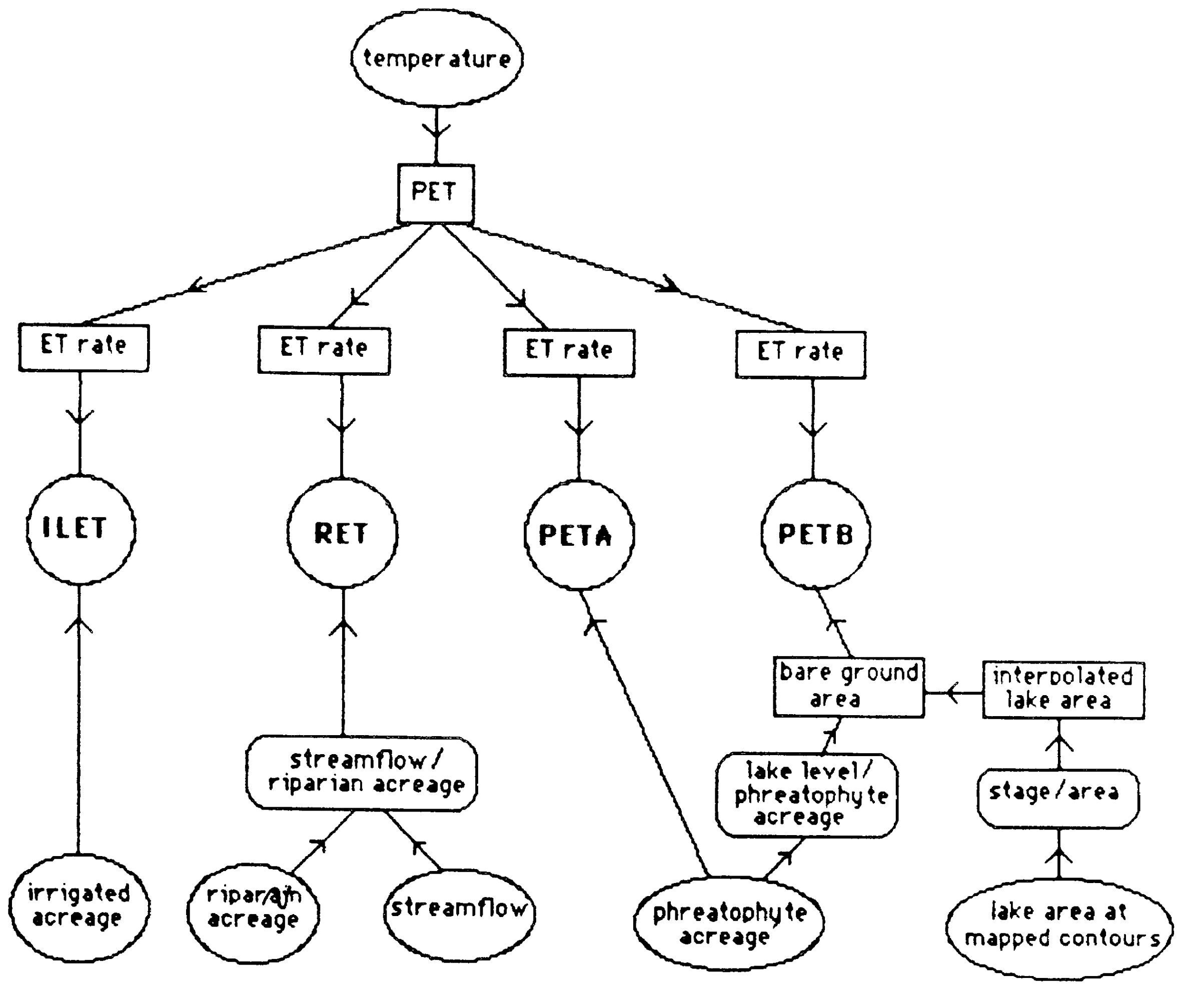


Figure 2-11d. Evapotranspiration

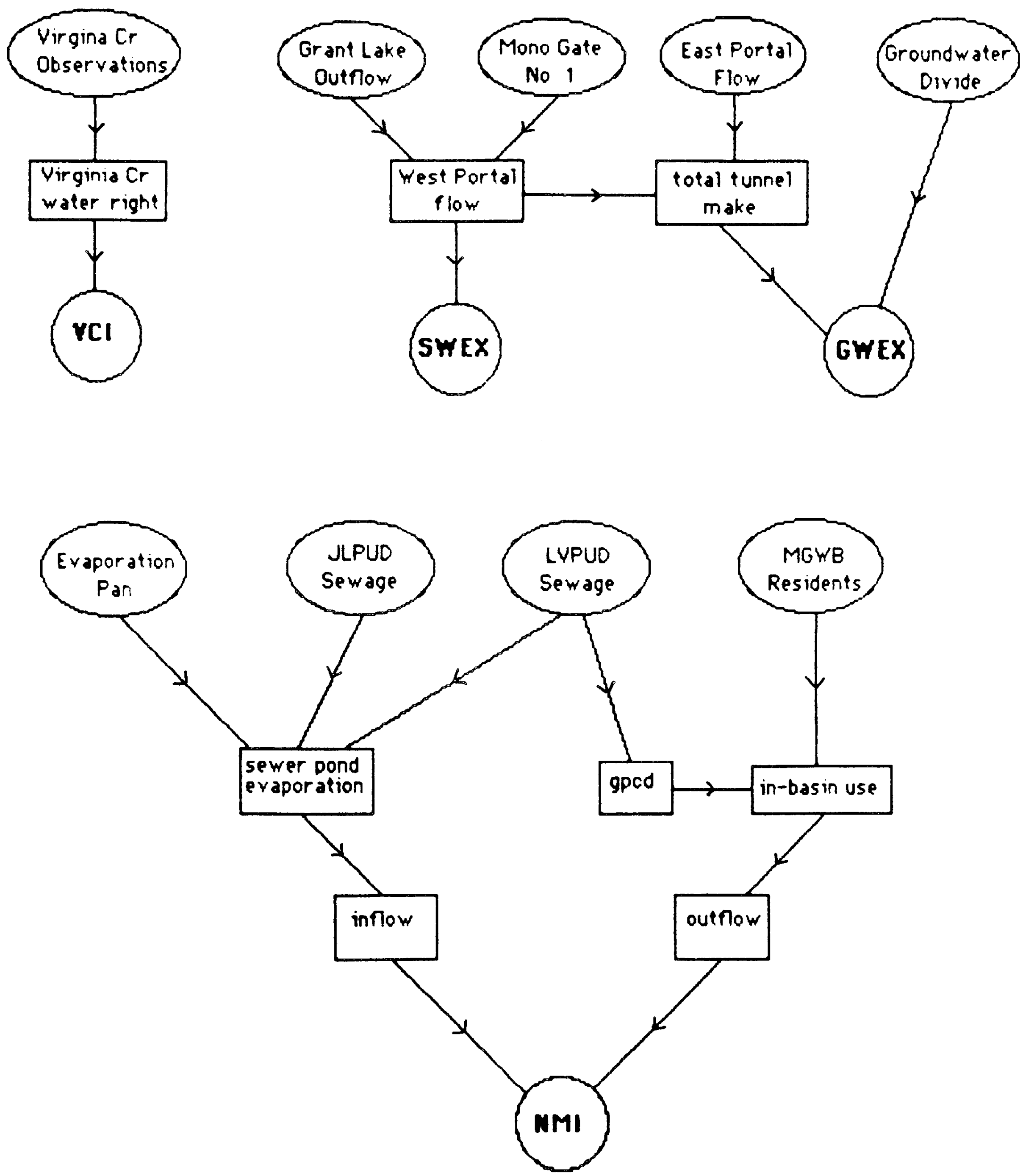


Figure 2-11e. Diversions

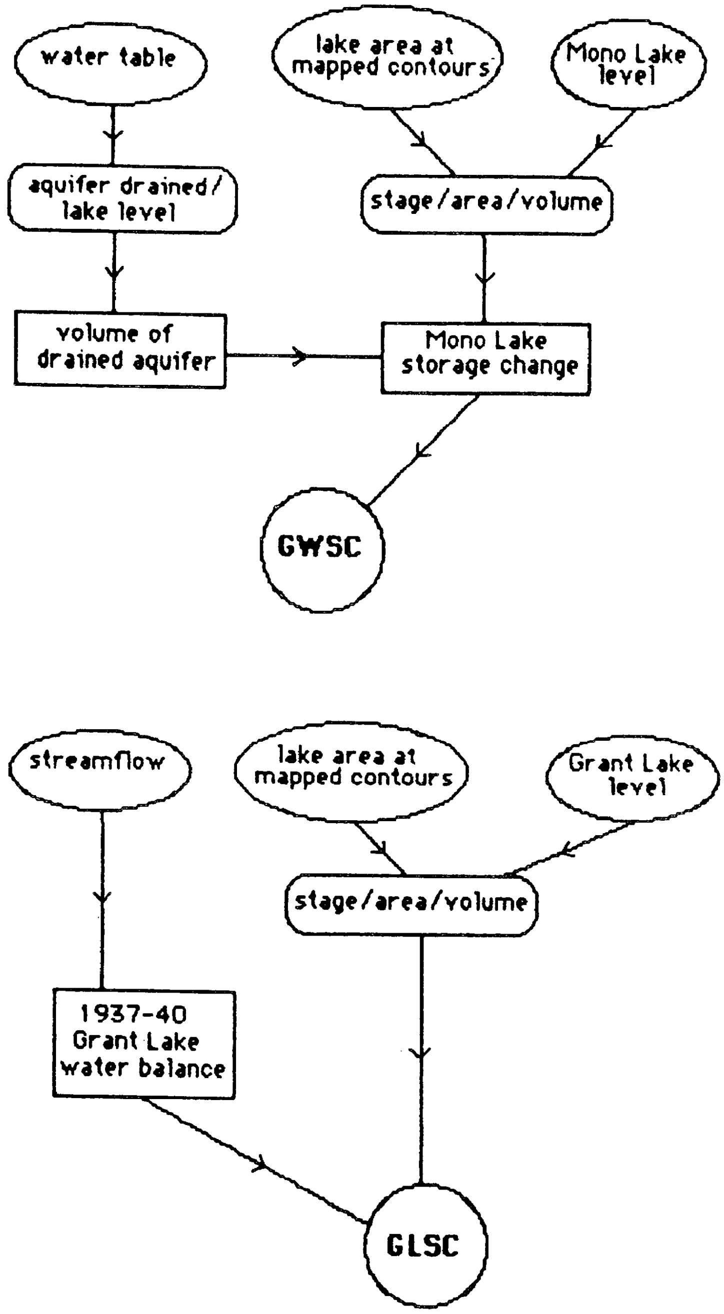


Figure 2-11f. Storage Changes

TABLE 2-12. Assumptions Used to Derive Component Values that Could Result in Component Error

Component	Assumptions
SNGR	1) gaging station measures all runoff from watershed, thus ignoring the sideflow and underflow around the station
NSR	1) unit runoff from ungaged area derived from relationship which is based on gaged watersheds with subsurface flow and indistinct drainage boundaries 2) annual variation from ungaged watersheds is same as annual variation from reservoir regulated gaged watersheds
USR and NLSP	1) constant yield in each year is equal to the average of 90% of the soil moisture surplus that is calculated by a modified Thornthwaite method that cannot account for surpluses from intense summer precipitation
MLP	1) average annual rate calculated from isohyetal map even though no long-term precipitation records are available around the north, south, or east margin of Mono Lake; isohyetal map also does not account for possible pluviometric depression over lake that results from lack of heating and roughness 2) variation of annual lake precipitation equal to annual variation of Cain Ranch precipitation although greatest lake surface area is in east half where precipitation regime is different
NM1	1) past Inflows and outflows can be extrapolated backwards from current use
VCI	1) constant inflow
MLE	1) no net heat storage change and advected energy over annual period 2) proportion of annual evaporation in May - October period equals 79% 3) annual pan coefficient equals 0.71 4) variation in annual evaporation related to annual June - September evaporation at Long Valley pan

Component	Assumptions
BGE	1) water table depth proportion to lake level 2) evaporation rate proportional to water table depth 3) constant evaporation rates for whole surface
ILET	1) constant ET rate 2) extrapolation of calculated ET rate to large area
RET	1) constant ET rate 2) riparian area proportional to streamflow 3) area1 extrapolation of ET rate
PETB	1) constant ET rate 2) area of phreatophytes is proportional to exposed lake area 3) area1 extrapolation of calculated ET rate
PETA	1) constant ET rate 2) constant acreage over study period
GWEX	1) 60% of total tunnel-make is derived from the Mono Basin
GLSC	1) calculated storage change in 1937-40 based on estimated inflow, outflow
GWSC	1) aquifer drained proportional to lake level and lake volume 2) unquantifiable storage change
MLSC	1) lake volume calculated by triangular ring segments 2) volumes linearly interpolated

TABLE 2-13. Range of Random Error in Estimating Water Balance Components

Component	Error Range ± Percent	Source
Gaged Stream Flow	5	Ferguson *et al.* 1981
-Calibrated Weirs & Flumes	5	Winter 1981
-Current Meter	10	Winter 1981
Ungaged Runoff	10-200	Peters 1972
	70	Winter 1981
Gaged Diversions		
-Exported water	5-10	Peters 1972
-Sewage	5-10	Peters 1972
Precipitation		
-Annual. Volume	5-30	Peters 1972
	l0-20[1]	Ferguson *et al*. 1981
Evaporation		
-Annual Volume	10-20[1]	Ferguson *et al*. 1981
-Annual Rate Using Pan	10-20	Kohler pers. comm. 1983
Evapotranspiration		
-Phreatophytes	10-30	Peters 1972
-Native Vegetation	10-70	Peters 1972
Groundwater Storage Change	5-40	Peters 19172

[l] Assumes well-instrumented lake basin

TABLE 2-14. Magnitude of Component Error

Component	Error %	1975 Value (ac-ft)	Error Amount (ac-ft)	Relative To Total Inflow %	Relative To Total Outflow %
SNGR	5	147106	7355	3.2	n/a
USR	45	17341	7803	3.4	n/a
NSR	50	19673	9837	4.3	n/a
MLP	25	32942	8236	3.6	n/a
NLSP	50	9000	4500	2.0	n/a
VCI	100	1100	1100	0.5	n/a
NMI	50	300	150	0.1	n/a
MLE	20	152926	30585	n/a	10.0
BGE	60	8084	4850	n/a	1.6
NGLE	33	1500	500	n/a	0.2
ILET	33	7000	2310	n/a	0.8
RET	50	1000	500	n/a	0.2
PETA	50	1700	850	n/a	0.3
PETB	50	2676	1336	n/a	0.4
SWEX	5	122580	6129	n/a	2.0
GWEX	15	8175	1226	n/a	0.4
GLSC	10	-9900	990	0.4[1]	n/a
GWSC	100	-2548	2548	1.1[1]	n/a

n/a: not applicable

[1] These storage changes are compared to the inflow since they are both negative and therefore a release from storage.

based on extrapolations of average values to variable regimes (all the ET components, NSR, NLSP). The large percentage error of most components translates into relatively small differences in the total inflow or outflow, Not surprisingly the uncertainty in estimating the Mono Lake evaporation rate has the greatest impact on the water balance,

The net effect of the component error along with any components that may not have been taken into account causes the calculated MLSC to be different than the observed MISC. [28] The difference is the overall water balance error; its absolute and relative magnitude is shown in Table 2-15, The overall error ranges from near zero to 39435 ac-ft and its 47 year average is 2514 ac-ft with a standard deviation of 18112 ac-ft. The maximum discrepancy relative to inflow is 19.3% and relative to outflow is 16.7%; the average discrepancy relative to inflow is 6.8% and relative to outflow is 5.6%. Although the overall error is always less than the square root of the sum of the squared component error (see equation 10) a low value is no assurance that the component error is small because the individual component errors may cancel out.

The Formulated Model

The foregoing sections identify and quantify the components of a water balance model of the MGWB that will calculate MISC. The numerical model and resultant annual MLSC is assembled in Table 2-15, A schematic of the model, showing the relationship of the components to one another is presented in

Figure 2-12. Figures 2-13, 2-14 and 2-15 show the variation in annual inflow, outflow, and storage changes from 1937 to 1983.

TABLE 2-15. Water Balance Model of the Mono Groundwater Basin
(1000 ac-ft unless noted otherwise)

Water Year	1937	1938	1939	1940	1941	1942	1943	1944	1945	1946
Mono Lake										
October 1 Elevation (ft)	6415.04	6414.97	6418.09	6417.66	6416.92	6416.99	6417.50	6418.05	6416.61	6417.16
October 1 Area (1000 ac)	54.832	54.820	55.372	55.296	55.165	55.177	55.268	55.365	55.110	55.207
October 1 Volume	4182.521	4178.683	4350.582	4326.788	4285.918	4289.780	4317.943	4348.367	4268.825	4299.162
Runoff										
Gaged Sierra	148.882	242.457	121.819	154.695	195.517	192.722	189.352	128.267	171.305	156.038
Ungaged Sierra	17.550	28.581	14.360	18.235	23.047	22.718	22.321	15.120	20.193	18.394
Non-Sierra	19.673	19.673	19.673	19.673	19.673	19.673	19.673	19.673	19.673	19.673
Precipitation										
Mono Lake Surface	42.179	72.072	26.275	24.889	45.337	33.605	32.833	26.006	39.987	36.129
Net Land Surface	9.000	9.000	9.000	9.000	9.000	9.000	9.000	9.000	9.000	9.000
Diversion Inflows										
Virginia Creek	1.100	1.100	1.100	1.100	1.100	1.100	1.100	1.100	1.100	1.100
Net Municipal	.100	.100	.100	.100	.100	.100	.100	.100	.100	.100
Total Inflow	238.484	372.983	192.327	227.692	293.775	278.918	274.379	199.266	261.358	240.433
Evaporation										
Mono Lake Surface	205.190	178.141	197.265	209.733	183.945	205.227	203.803	220.747	196.028	220.773
Exposed Mono Lake Bottom	2.141	1.968	1.951	1.998	2.004	1.974	1.937	2.010	1.998	2.003
Net Grant Lake Reservoir	1.000	1.000	1.000	1.000	1.500	1.500	1.500	1.500	2.200	1.800
Evapotranspiration										
Irrigated Land	10.000	10.000	10.000	10.000	9.000	9.000	9.000	9.000	9.000	9.000
Riparian Vegetation	2.200	2.200	2.200	2.200	2.200	2.200	2.200	2.200	2.200	2.000
Phreatophytes below 6428 ft	.379	.325	.277	.298	.310	.300	.281	.297	.312	.306
Phreatophytes above 6428 ft	1.700	1.700	1.700	1.700	1.700	1.700	1.700	1.700	1.700	1.700
Diversion Outflows										
LADWP Surface Water Export	0.000	0.000	0.000	.322	31.174	1.568	7.323	56.019	12.248	0.000
LADWP Ground Water Export	1.403	3.581	4.426	9.160	11.761	10.096	9.874	8.338	8.483	8.285
Total Outflow	224.014	198.915	218.819	236.411	243.593	233.564	237.618	301.810	234.170	245.867
Storage Changes										
Grant Lake Reservoir	2.600	-1.900	-4.400	4.800	24.838	16.795	-8.463	-6.850	1.878	10.335
Groundwater	-.134	6.016	-.833	-1.430	.135	.986	1.065	-2.784	1.062	-.406
Mono Lake Storage Change										
Calculated	12.004	169.951	-21.259	-12.088	25.208	27.573	44.159	-92.910	24.249	-15.363
Observed	-3.838	171.899	-23.794	-40.870	3.862	28.163	30.424	-79.542	30.337	-11.590
Difference (= Overall Error)	15.842	-1.948	2.534	28.782	21.346	-.591	13.735	-13.368	-6.089	-3.774
Error Relative to Inflow (%)	6.643	.522	1.318	12.641	7.266	.212	5.006	6.709	2.330	1.570
Error Relative to Outflow (%)	7.072	.979	1.158	12.175	8.763	.253	5.780	4.429	2.600	1.535
Mono Lake Elevation Change (ft)										
Calculated	.22	3.08	-.38	-.22	.46	.50	.80	-1.68	.44	-.28
Observed	-.07	3.12	-.43	-.74	.07	.51	.55	-1.44	.55	-.21
Difference	.29	-.04	.05	.52	.39	-.01	.25	-.24	-.11	-.07
Mono Lake Elevation (ft)										
Calculated	6415.26	6418.05	6417.71	6417.44	6417.38	6417.49	6418.30	6416.37	6417.05	6416.88
Observed	6414.97	6418.09	6417.66	6416.92	6416.99	6417.50	6418.05	6416.61	6417.16	6416.95
Difference	.29	-.04	.05	.52	.39	-.01	.25	-.24	-.11	-.07
Indices of Variation										
Actual Sierra Runoff	.995	1.620	.814	1.033	1.306	1.287	1.265	.857	1.144	1.042
Natural Sierra Runoff	.998	1.673	.748	1.046	1.336	1.291	1.256	.832	1.154	1.047
Mono Lake Precipitation Rate	1.153	1.961	.712	.676	1.232	.912	.890	.706	1.087	.981
Mono Lake Evaporation Rate	1.029	.889	.979	1.043	.916	1.021	1.012	1.097	.977	1.099
Runoff with 2 Year Lag	1.019	1.354	1.088	1.055	1.150	1.255	1.278	1.044	1.076	1.045
Precip. with 2 Year Lag	1.070	1.544	1.153	.879	.987	.973	.948	.792	.943	.972

TABLE 2-15. Water Balance Model of the Mono Groundwater Basin
(1000 ac-ft unless noted otherwise)

Water Year	1947	1948	1949	1950	1951	1952	1953	1954	1955	1956
Mono Lake										
October 1 Elevation (ft)	6416.95	6416.33	6414.06	6411.92	6410.08	6408.22	6408.73	6407.60	6405.28	6403.18
October 1 Area (1000 ac)	55.170	55.060	54.659	54.280	53.844	53.291	53.443	53.107	52.418	51.794
October 1 Volume	4287.573	4253.401	4128.870	4012.306	3912.782	3813.146	3840.363	3780.162	3657.753	3548.330
Runoff										
Gaged Sierra	112.873	113.120	112.921	113.332	146.223	203.111	129.331	90.944	100.981	195.497
Ungaged Sierra	13.305	13.334	13.311	13.359	17.237	23.943	15.245	10.720	11.904	23.045
Non-Sierra	19.673	19.673	19.673	19.673	19.673	19.673	19.673	19.673	19.673	19.673
Precipitation										
Mono Lake Surface	35.350	18.051	29.788	20.655	37.969	58.248	18.820	24.811	25.223	50.621
Net Land Surface	9.000	9.000	9.000	9.000	9.000	9.000	9.000	9.000	9.000	9.000
Diversion Inflows										
Virginia Creek	1.100	1.100	1.100	1.100	1.100	1.100	1.100	1.100	1.100	1.100
Net Municipal	.100	.100	.100	.100	.100	.100	.100	.100	.100	.100
Total Inflow	191.402	174.379	185.893	177.220	231.302	315.174	193.269	156.348	167.980	299.036
Evaporation										
Mono Lake Surface	221.941	223.508	222.006	187.991	186.119	182.121	192.682	199.190	186.467	179.641
Exposed Mono Lake Bottom	2.040	2.175	2.325	2.491	2.724	2.772	2.851	3.126	3.441	3.645
Net Grant Lake Reservoir	2.100	2.000	2.100	2.300	2.300	1.500	2.200	2.100	2.000	1.200
Evapotranspiration										
Irrigated Land	9.000	7.000	7.000	7.000	7.000	9.000	9.000	9.000	7.000	9.000
Riparian Vegetation	2.000	1.900	1.900	1.900	1.900	1.800	1.800	1.800	1.800	1.700
Phreatophytes below 6428 ft	.321	.372	.450	.532	.631	.671	.689	.792	.923	1.016
Phreatophytes above 6428 ft	1.700	1.700	1.700	1.700	1.700	1.700	1.700	1.700	1.700	1.700
Diversion Outflows										
LADWP Surface Water Export	12.429	77.375	93.165	94.124	95.042	28.856	64.377	51.681	74.499	96.894
LADWP Ground Water Export	7.998	8.935	6.767	6.284	7.459	6.999	6.896	7.829	6.456	6.913
Total Outflow	259.529	324.965	337.412	304.322	304.875	235.419	282.196	277.218	284.286	301.709
Storage Changes										
Grant Lake Reservoir	-10.521	8.397	-9.474	-8.451	16.339	12.151	-21.709	.523	6.785	14.497
Groundwater	-1.196	-4.359	-4.080	-3.483	-3.487	.953	-2.107	-4.284	-3.830	-1.862
Mono Lake Storage Change										
Calculated	-56.411	-154.624	-137.966	-115.168	-86.425	66.652	-65.111	-117.109	-119.261	-15.309
Observed	-34.171	-124.531	-116.564	-99.524	-99.636	27.217	-60.201	-122.409	-109.423	-53.191
Difference (= Overall Error)	-22.239	-30.093	-21.402	-15.643	13.211	39.435	-4.910	5.301	-9.837	37.882
Error Relative to Inflow (%)	11.619	17.257	11.513	8.827	5.712	12.512	2.540	3.390	5.856	12.668
Error Relative to Outflow (%)	8.569	9.260	6.343	5.140	4.333	16.751	1.740	1.912	3.460	12.556
Mono Lake Elevation Change (ft)										
Calculated	-1.02	-2.82	-2.53	-2.13	-1.61	1.25	-1.22	-2.22	-2.29	-.30
Observed	-.62	-2.27	-2.14	-1.84	-1.86	.51	-1.13	-2.32	-2.10	-1.03
Difference	-.40	-.55	-.39	-.29	.25	.74	-.09	.10	-.19	.73
Mono Lake Elevation (ft)										
Calculated	6415.93	6413.51	6411.53	6409.79	6408.47	6409.47	6407.51	6405.38	6402.99	6402.88
Observed	6416.33	6414.06	6411.92	6410.08	6408.22	6408.73	6407.60	6405.28	6403.18	6402.15
Difference	-.40	-.55	-.39	-.29	.25	.74	-.09	.10	-.19	.73
Indices of Variation										
Actual Sierra Runoff	.754	.756	.754	.757	.977	1.357	.864	.608	.675	1.306
Natural Sierra Runoff	.750	.747	.721	.728	1.045	1.368	.788	.646	.672	1.350
Mono Lake Precipitation Rate	.962	.493	.820	.573	1.063	1.636	.530	.705	.726	1.470
Mono Lake Evaporation Rate	1.106	1.120	1.121	.957	.957	.941	.997	1.041	.988	.962
Runoff with 2 Year Lag	.899	.798	.755	.756	.878	1.153	1.029	.797	.683	1.012
Precip. with 2 Year Lag	.986	.707	.743	.635	.879	1.305	.942	.792	.690	1.132

TABLE 2-15. Water Balance Model of the Mono Groundwater Basin
(1000 ac-ft unless noted otherwise)

Water Year	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966
Mono Lake										
October 1 Elevation (ft)	6402.15	6401.14	6401.57	6399.80	6397.60	6395.57	6394.00	6392.76	6390.54	6389.06
October 1 Area (1000 ac)	51.489	51.189	51.316	50.791	50.137	49.534	49.068	48.700	47.932	47.383
October 1 Volume	3495.139	3443.287	3465.326	3374.961	3263.940	3162.774	3085.371	3024.755	2917.453	2846.920
Runoff										
Gaged Sierra	137.558	170.704	102.589	82.752	81.992	145.591	158.327	101.589	168.191	125.157
Ungaged Sierra	16.215	20.122	12.093	9.755	9.665	17.162	18.663	11.975	19.826	14.753
Non-Sierra	19.673	19.673	19.673	19.673	19.673	19.673	19.673	19.673	19.673	19.673
Precipitation										
Mono Lake Surface	29.526	45.218	26.626	12.301	27.771	39.207	42.988	24.028	33.835	29.137
Net Land Surface	9.000	9.000	9.000	9.000	9.000	9.000	9.000	9.000	9.000	9.000
Diversion Inflows										
Virginia Creek	1.100	1.100	1.100	1.100	1.100	1.100	1.100	1.100	1.100	1.100
Net Municipal	.100	.100	.100	.100	.100	.100	.100	.100	.100	.100
Total Inflow	213.172	265.918	171.181	134.681	149.301	231.833	249.851	167.466	251.725	198.921
Evaporation										
Mono Lake Surface	193.817	177.268	197.305	189.186	167.503	163.922	199.974	189.030	148.319	190.159
Exposed Mono Lake Bottom	3.793	3.886	3.803	4.145	4.572	4.965	5.269	5.505	5.976	6.324
Net Grant Lake Reservoir	1.900	1.400	1.800	2.000	1.000	1.300	1.600	1.400	1.700	2.600
Evapotranspiration										
Irrigated Land	9.000	9.000	9.000	7.000	7.000	8.000	8.000	7.000	7.000	7.000
Riparian Vegetation	1.700	1.700	1.600	1.600	1.600	1.500	1.500	1.500	1.400	1.400
Phreatophytes below 6428 ft	1.076	1.094	1.133	1.251	1.377	1.484	1.567	1.681	1.813	1.928
Phreatophytes above 6428 ft	1.700	1.700	1.700	1.700	1.700	1.700	1.700	1.700	1.700	1.700
Diversion Outflows										
LADWP Surface Water Export	49.333	20.409	80.362	69.807	66.074	91.534	86.935	86.235	96.292	80.782
LADWP Ground Water Export	7.545	7.367	5.788	5.533	4.057	4.119	7.174	8.719	6.685	5.700
Total Outflow	269.864	223.823	302.491	282.223	254.882	278.524	313.719	302.769	270.884	297.593
Storage Changes										
Grant Lake Reservoir	-1.411	-1.718	-26.717	-6.614	-.065	11.501	24.480	-15.004	17.084	-20.244
Groundwater	-1.815	.771	-3.163	-3.886	-3.541	-2.709	-2.122	-3.756	-2.469	-2.702
Mono Lake Storage Change										
Calculated	-53.466	43.041	-101.431	-137.043	-101.975	-55.483	-86.227	-116.544	-33.775	-75.726
Observed	-51.852	22.039	-90.365	-111.021	-101.167	-77.403	-60.616	-107.302	-70.533	-77.208
Difference (= Overall Error)	-1.614	21.003	-11.066	-26.022	-.809	21.920	-25.611	-9.242	36.758	1.482
Error Relative to Inflow (%)	.757	7.898	6.465	19.321	.542	9.455	10.250	5.519	14.603	.745
Error Relative to Outflow (%)	.598	9.384	3.658	9.220	.317	7.870	8.164	3.052	13.570	.498
Mono Lake Elevation Change (ft)										
Calculated	-1.04	.84	-1.99	-2.72	-2.05	-1.12	-1.77	-2.41	-.71	-1.61
Observed	-1.01	.43	-1.77	-2.20	-2.03	-1.57	-1.24	-2.22	-1.48	-1.64
Difference	-.03	.41	-.22	-.52	-.02	.45	-.53	-.19	.77	.03
Mono Lake Elevation (ft)										
Calculated	6401.11	6401.98	6399.58	6397.08	6395.55	6394.45	6392.23	6390.35	6389.83	6387.45
Observed	6401.14	6401.57	6399.80	6397.60	6395.57	6394.00	6392.76	6390.54	6389.06	6387.42
Difference	-.03	.41	-.22	-.52	-.02	.45	-.53	-.19	.77	.03
Indices of Variation										
Actual Sierra Runoff	.919	1.140	.685	.553	.548	.973	1.058	.679	1.124	.836
Natural Sierra Runoff	.840	1.224	.598	.568	.544	.989	1.085	.622	1.166	.734
Mono Lake Precipitation Rate	.862	1.323	.782	.365	.835	1.192	1.318	.746	1.064	.928
Mono Lake Evaporation Rate	1.044	.957	1.069	1.038	.932	.923	1.137	1.089	.867	1.127
Runoff with 2 Year Lag	.998	1.099	.857	.681	.570	.782	.956	.836	.980	.899
Precip. with 2 Year Lag	1.024	1.207	.956	.634	.686	.961	1.208	.984	1.007	.942

TABLE 2-15. Water Balance Model of the Mono Groundwater Basin
(1000 ac-ft unless noted otherwise)

Water Year	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976
Mono Lake										
October 1 Elevation (ft)	6387.42	6388.72	6387.16	6389.49	6388.02	6386.13	6384.29	6382.78	6381.07	6379.39
October 1 Area (1000 ac)	46.774	47.256	46.677	47.542	46.997	46.295	45.612	45.052	44.015	42.665
October 1 Volume	2769.711	2830.831	2757.563	2867.329	2797.842	2709.682	2625.127	2556.676	2480.368	2407.557
Runoff										
Gaged Sierra	209.305	117.452	241.726	142.083	132.179	110.951	155.376	171.591	147.106	82.431
Ungaged Sierra	24.673	13.845	28.494	16.749	15.581	13.079	18.316	20.227	17.341	9.717
Non-Sierra	19.673	19.673	19.673	19.673	19.673	19.673	19.673	19.673	19.673	19.673
Precipitation										
Mono Lake Surface	45.788	14.236	45.799	23.208	23.171	26.111	31.034	33.208	32.943	19.971
Net Land Surface	9.000	9.000	9.000	9.000	9.000	9.000	9.000	9.000	9.000	9.000
Diversion Inflows										
Virginia Creek	1.100	1.100	1.100	1.100	1.100	1.100	1.100	1.100	1.100	1.100
Net Municipal	.100	.100	.100	.100	.100	.100	.100	.100	.300	.500
Total Inflow	309.638	175.407	345.892	211.913	200.804	180.014	234.599	254.899	227.462	142.392
Evaporation										
Mono Lake Surface	150.933	159.870	153.692	171.495	150.558	161.670	153.264	158.324	152.926	141.154
Exposed Mono Lake Bottom	6.709	6.403	6.770	6.223	6.568	7.012	7.404	7.661	8.313	9.253
Net Grant Lake Reservoir	-.600	1.300	.700	1.300	1.300	.500	1.000	1.700	1.500	1.200
Evapotranspiration										
Irrigated Land	9.000	7.000	9.000	7.000	7.000	7.000	7.000	7.000	7.000	6.000
Riparian Vegetation	1.400	1.300	1.300	1.200	1.200	1.200	1.100	1.100	1.000	.900
Phreatophytes below 6428 ft	1.941	1.951	1.922	1.890	2.015	2.153	2.278	2.437	2.676	2.943
Phreatophytes above 6428 ft	1.700	1.700	1.700	1.700	1.700	1.700	1.700	1.700	1.700	1.700
Diversion Outflows										
LADWP Surface Water Export	21.354	72.989	5.934	87.199	94.314	104.526	101.679	123.561	122.580	76.000
LADWP Ground Water Export	6.468	8.243	8.383	6.789	7.129	6.867	8.252	8.033	8.175	10.081
Total Outflow	198.905	260.756	189.401	284.796	271.784	292.628	283.676	311.516	305.870	249.230
Storage Changes										
Grant Lake Reservoir	17.621	-26.000	24.922	-12.043	1.850	-19.404	12.691	7.601	-9.913	-13.173
Groundwater	2.139	-2.564	3.842	-2.432	-3.086	-2.959	-2.396	-2.671	-2.548	-2.411
Mono Lake Storage Change										
Calculated	90.973	-56.785	127.727	-58.408	-69.745	-90.251	-59.373	-61.547	-65.947	-91.255
Observed	61.120	-73.268	109.766	-69.486	-88.161	-84.555	-68.451	-76.309	-72.811	-68.890
Difference (= Overall Error)	29.853	16.483	17.961	11.078	18.416	-5.697	9.078	14.761	6.864	-22.364
Error Relative to Inflow (%)	9.641	9.397	5.193	5.228	9.171	3.165	3.870	5.791	3.018	15.706
Error Relative to Outflow (%)	15.009	6.321	9.483	3.890	6.776	1.947	3.200	4.739	2.244	8.973
Mono Lake Elevation Change (ft)										
Calculated	1.93	-1.21	2.71	-1.23	-1.49	-1.96	-1.31	-1.38	-1.52	-2.18
Observed	1.30	-1.56	2.33	-1.47	-1.89	-1.84	-1.51	-1.71	-1.68	-1.64
Difference	.63	.35	.38	.24	.40	-.12	.20	.33	.16	-.54
Mono Lake Elevation (ft)										
Calculated	6389.35	6387.51	6389.87	6388.26	6386.53	6384.17	6382.98	6381.40	6379.55	6377.21
Observed	6388.72	6387.16	6389.49	6388.02	6386.13	6384.29	6382.78	6381.07	6379.39	6377.75
Difference	.63	.35	.38	.24	.40	-.12	.20	.33	.16	-.54
Indices of Variation										
Actual Sierra Runoff	1.398	.785	1.615	.949	.883	.741	1.038	1.146	.983	.551
Natural Sierra Runoff	1.539	.661	1.696	.906	.916	.732	1.048	1.131	.992	.497
Mono Lake Precipitation Rate	1.460	.454	1.458	.736	.745	.852	1.026	1.118	1.140	.713
Mono Lake Evaporation Rate	.897	.950	.912	1.012	.901	.984	.947	.997	.991	.946
Runoff with 2 Year Lag	1.188	.976	1.333	1.124	1.013	.815	.926	1.053	1.040	.770
Precip. with 2 Year Lag	1.241	.827	1.157	.910	.849	.802	.932	1.051	1.116	.902

TABLE 2-15. Water Balance Model of the Mono Groundwater Basin
(1000 ac-ft unless noted otherwise)

Water Year	1977	1978	1979	1980	1981	1982	1983	Mean
Mono Lake								
October 1 Elevation (ft)	6377.75	6375.60	6374.99	6373.44	6373.87	6372.37	6372.77	6398.10
October 1 Area (1000 ac)	41.348	39.620	39.130	37.885	38.230	37.025	37.347	49.270
October 1 Volume	2338.666	2251.626	2227.607	2167.920	2184.285	2127.843	2142.718	3327.799
Runoff								
Gaged Sierra	64.685	184.020	153.118	203.494	119.787	217.926	288.644	149.696
Ungaged Sierra	7.625	20.463	17.027	22.628	13.320	24.233	32.097	17.480
Non-Sierra	19.673	19.673	19.673	19.673	19.673	19.673	19.673	19.673
Precipitation								
Mono Lake Surface	15.514	44.292	27.184	34.893	17.737	43.587	38.027	32.472
Net Land Surface	9.000	9.000	9.000	9.000	9.000	9.000	9.000	9.000
Diversion Inflows								
Virginia Creek	1.100	1.100	1.100	1.100	1.100	1.100	1.100	1.100
Net Municipal	.500	.500	.500	.500	.500	.500	.500	0.172
Total Inflow	118.097	279.048	227.601	291.288	181.117	316.019	389.041	229.594
Evaporation								
Mono Lake Surface	141.962	141.471	139.069	132.657	145.146	117.470	128.297	176.999
Exposed Mono Lake Bottom	10.170	11.423	11.862	12.977	12.668	13.747	13.459	5.414
Net Grant Lake Reservoir	.500	.600	1.300	1.300	2.100	.800	1.000	1.447
Evapotranspiration								
Irrigated Land	6.000	7.000	7.000	7.000	7.000	7.000	7.000	7.936
Riparian Vegetation	.800	.800	.700	.700	.700	.700	.700	1.545
Phreatophytes below 6428 ft	3.247	3.469	3.643	3.733	3.819	3.907	3.408	1.518
Phreatophytes above 6428 ft	1.700	1.700	1.700	1.700	1.700	1.700	1.700	1.700
Diversion Outflows								
LADWP Surface Water Export	44.998	98.101	140.756	89.194	109.174	102.585	0.000	62.124
LADWP Ground Water Export	8.644	6.386	5.860	7.238	8.661	7.554	7.723	7.258
Total Outflow	218.021	270.951	311.890	256.499	290.967	255.463	163.287	265.939
Storage Changes								
Grant Lake Reservoir	-3.249	34.570	-14.003	16.368	-20.268	23.200	-4.040	0.983
Groundwater	-3.046	-.841	-2.089	.573	-1.975	.521	8.069	-1.347
Mono Lake Storage Change								
Calculated	-93.628	-25.632	-68.197	17.848	-87.606	36.835	221.725	-35.981
Observed	-87.040	-24.019	-59.687	16.365	-56.442	14.874	230.544	-38.495
Difference (= Overall Error)	-6.588	-1.613	-8.510	1.483	-31.165	21.961	-8.819	2.514
Error Relative to Inflow (%)	5.578	.578	3.739	.509	17.207	6.949	2.267	6.780
Error Relative to Outflow (%)	3.022	.595	2.729	.578	10.711	8.597	5.401	5.646
Mono Lake Elevation Change (ft)								
Calculated	-2.32	-.65	-1.78	.47	-2.35	.98	5.60	1.55*
Observed	-2.15	-.61	-1.55	.43	-1.50	.40	5.81	1.46*
Difference	-.17	-.04	-.23	.04	-.85	.58	-.21	0.31*
Mono Lake Elevation (ft)								
Calculated	6375.43	6374.95	6373.21	6373.91	6371.52	6373.35	6378.37	6397.37
Observed	6375.60	6374.99	6373.44	6373.87	6372.37	6372.77	6378.58	6397.33
Difference	-.17	-.04	-.23	.04	-.85	.58	-.21	0.31*
Indices of Variation								
Actual Sierra Runoff	.432	1.229	1.023	1.359	.800	1.456	1.928	1.000
Natural Sierra Runoff	.413	1.336	.971	1.373	.754	1.551	1.918	1.000
Mono Lake Precipitation Rate	.575	1.686	1.058	1.375	.707	1.757	1.437	1.000
Mono Lake Evaporation Rate	.988	1.015	1.021	.987	1.092	.895	.916	0.998
Runoff with 2 Year Lag	.550	.888	.996	1.239	1.001	1.245	1.617	0.990
Precip. with 2 Year Lag	.701	1.207	1.174	1.326	.960	1.385	1.423	0.992

* Mean of Absolute Value

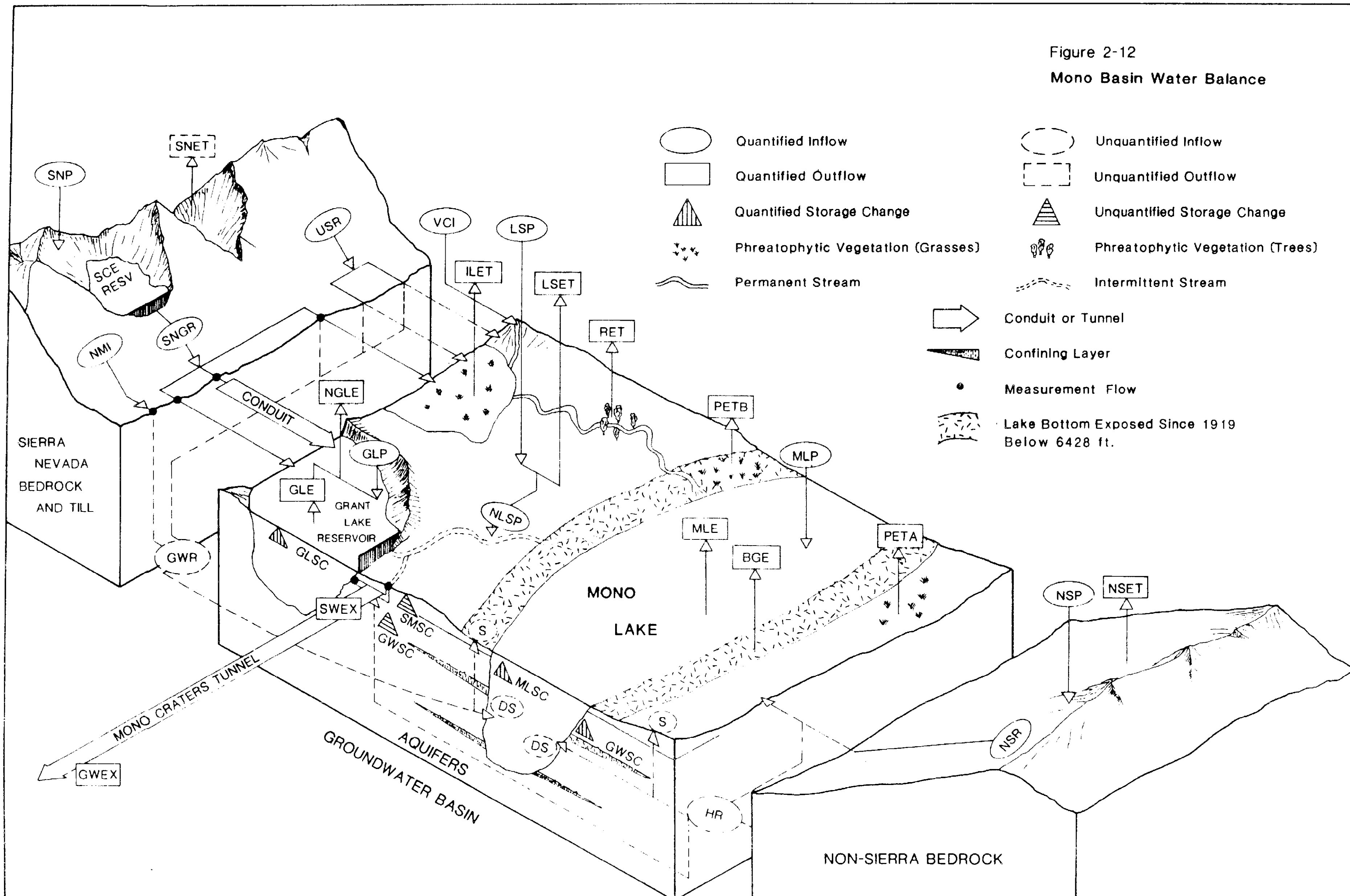


Figure 2-12
Mono Basin Water Balance

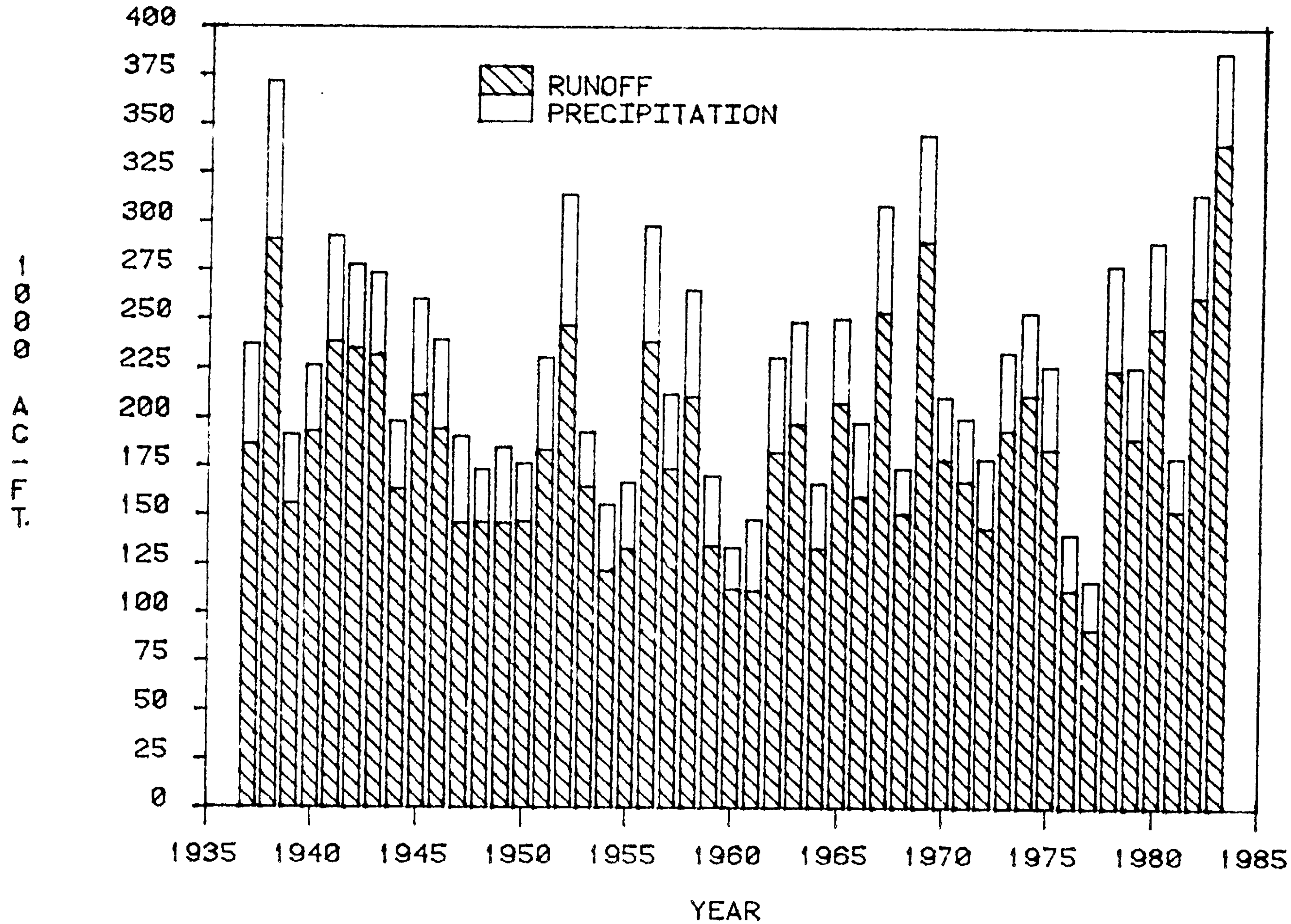


Figure 2-13. Annual Inflow, 1937-83

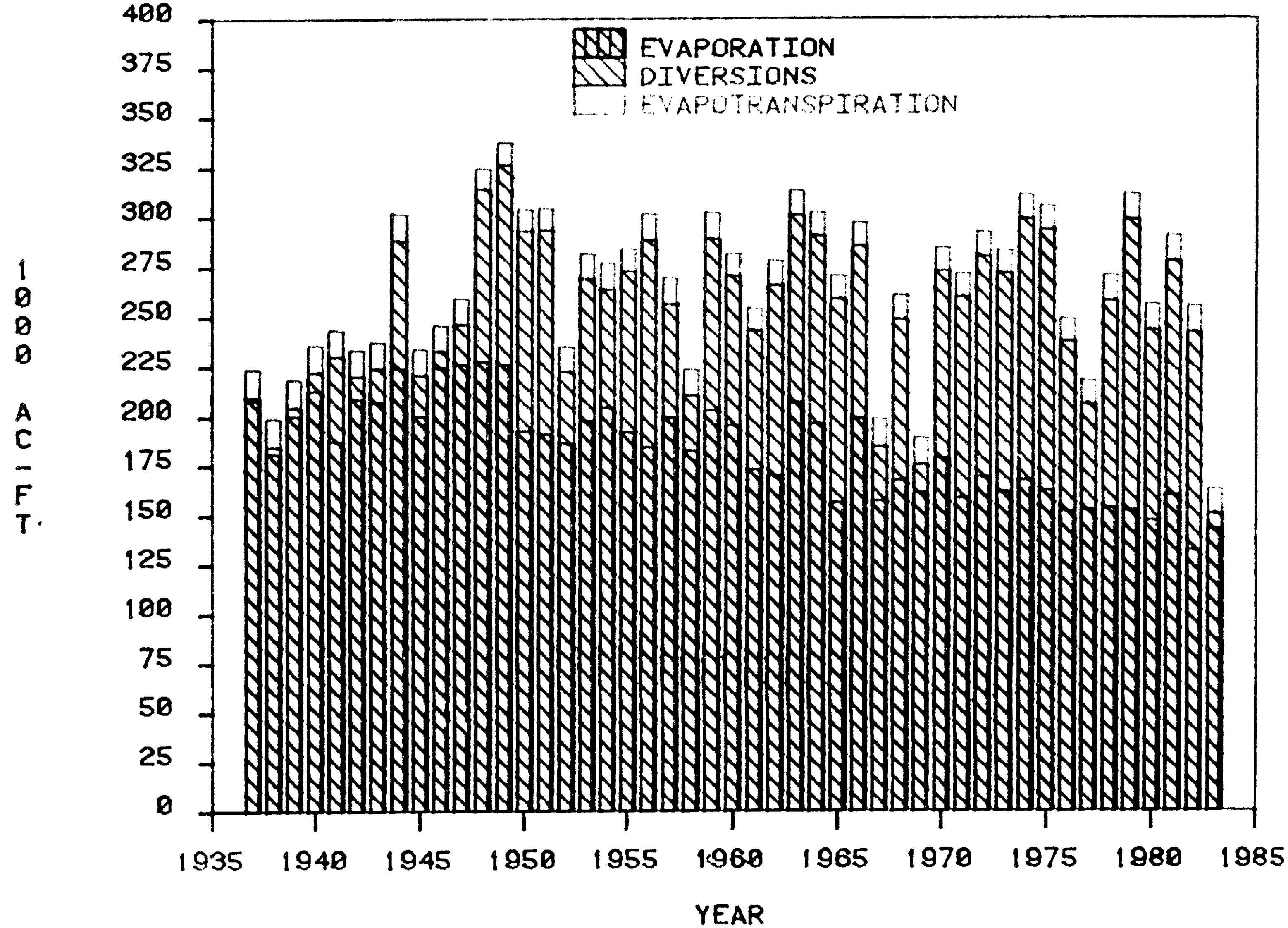


Figure 2-14 Annual Outflow, 1937-83

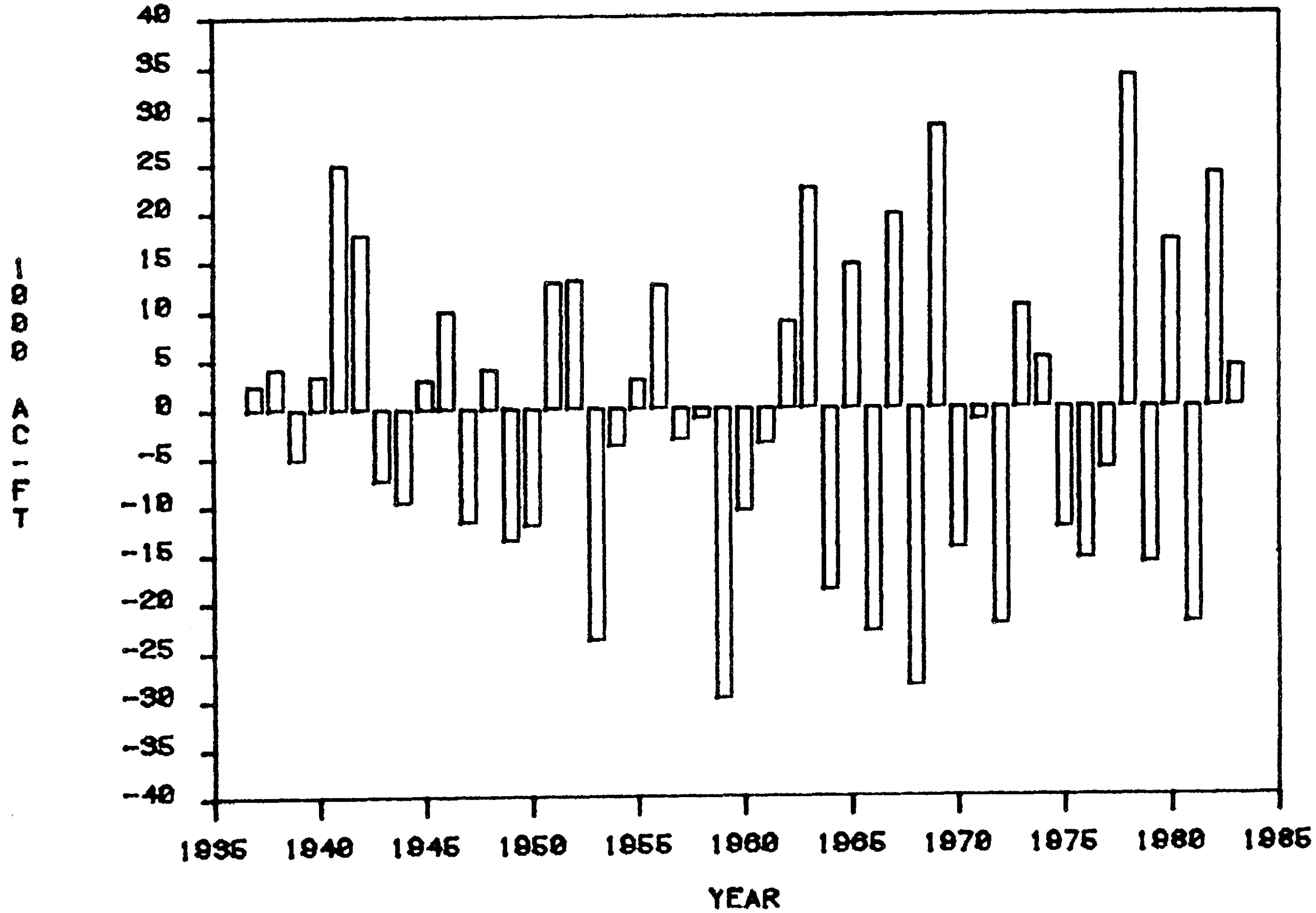


Figure 2-15. Annual Storage Change Excluding Mono Lake, 1937-83

CALIBRATION

Before the water balance model can be applied to forecasting Mono Cake levels it must be calibrated and verified. Calibration adjusts the model in order to minimize the difference between the calculated MLSC and the actual MLSC. Since this difference is equivalent to the overall error, calibration can also be viewed as "explaining" the overall error so that it can be logically predicted.

Much of the overall error is unpredictable because it is the result of random component error, which may or may not cancel out in the balance equation, A portion of the overall error, however, is the result of systematic component error. If that portion can be correlated with the factors that cause or explain the systematic component error, then some of the overall error can be predicted. The simplest technique for discerning correlation among several variables is multiple linear regression, Multiple regression is one of the few numerical methods that can be used to evaluate the effects of several factors acting simultaneously on a dependent variable. This is a well established technique for predictive purposes in hydrologic investigations, In multiple relationships, linear equations are much easier to analyze than non-linear ones. Some investigators use multi.-variate analysis such as principal component analysis, factor analysis, and canonical analysis. These techniques are normally advocated when the structure of the solution is more important than predicting the dependent variable with minimum error. It is generally agreed that multiple regression is preferable if prediction of the dependent variable (in this case the overall error) with minimum error is the desired result (Julian et al. 1967).

PROCEDURE

The calibration procedure used in this model involves determining the linear relationship between the overall error (the dependent variable) and the "explaining" factors (the independent variables). A stepwise multiple linear regression, from the Statistical Package for the Social Sciences (SPSS) (Nie et al. 1975) is utilized for the data analysis. In the stepwise procedure the independent variables are added in "steps" which will, in combination with those variables previously included, effect the greatest reduction in the unexplained variance of the dependent variable in a single step (Julian et al. 1967). The stepwise multiple regression method does not necessarily give the optimum equation, however. There may be other combinations of the initial set of variables which will explain more of the variance In the dependent variables than the particular combinations selected in the stepwise procedure.

The 27-year period, 1957-83, is used for calibration purposes. Only a portion of the 47-year base period can be used because some data are needed for verification, The minimum number of years considered for a calibration time period is 24 years, equivalent to half of the base period. After examining a number of possible calibration time periods, the 1957-83 period is chosen for the following reasons:

1) it is a period whose average error and standard deviation (2.592 ± 17.669) are closest to the average error and standard deviation of the base period (2.514 ± 18.287),

2) the 1957-83 average runoff, precipitation rate, and evaporation rate and corresponding standard deviations are close to the equivalent base period statistics (see Table 2-16),

3) it displays the widest range of hydroclimatic conditions (i.e. runoff, precipitation, evaporation), LADWP export amounts, and annual lake level changes of any time period exceeding 24 years.

4) it includes the years when the second barrel of the Los Angeles Aqueduct is in operation,

Since multiple regression explains the variance and not the magnitude of the dependent variable all the factors that might cause or correlate to systematic component error and thus explain the variance of the overall error are initially included, An error analysis of the components suggests the factors to include= The factors and the component error they explain are shown in Table 2-17.

The result of the initial stepwise multiple regression is shown in Table 2-18. This table shows that with all the nine variables tested, only the evaporation index, (EVAPIND), riparian bare ground evaporation (RIMEVAP), precipitation index (PPTIND) and runoff index (RUNIND) make a significant contribution (at the

Table 2-16 Comparison of 1957-83 and 1937-83 Hydroclimatic Statistics

Period	Runoff Index(l)		Precipitation Index(2)		Evaporation Index(3)	
	Mean	SD	Mean	SD	Mean	SD
1957-83	0.994	0.350	1.026	0,363	0.986	0.074
1937-83	1.0	0.317	1.0	0.368	0.998(4)	0.072

SD = Standard Deviation

(1) Index 1.0 = 149,696 ac-ft.

(2) Index 1.0 = 8 inches

(3) Index 1.0 = 45 inches

(4) Base Period average is not 1.0 because Tinemaha Reservoir index used in first 7 years of base period was not normalized.

Table 2-17. Factors That May Reflect Systematic Component Error

Factor	SPSS Abbreviation	Component Error Explained
Runoff Index	RUNIND	SNGR, VSR, GWSC
Precipitation Index	PPTIND	MLP, GWSC, NSR, LSP
Evaporation Index	EVAPIND	MLE
Precipitation Lag Index*	PRECLAG	GWSC, NSR, LSP
Bare Ground Evaporation	RIMEVAP	BGE
Exposed Lake Area	EXAREA	BGE, PETB
Grant Lake Storage Change	GRNTSTCH	GWSC, GLSC
LADWP Groundwater Export	TUNMAKE	GWSC, GWEX

* Precipitation Lag Index= 0.55 * Current year Precipitation Index (PI) +

0.30 * Previous Year PI +

0.15 * 2 Years Previous PI

The coefficients of this equation (geometric decreasing coefficients that add up to 1.0) are analogous to the coefficients of equation for groundwater inflow to Great Salt Lake. (James et al. 1979)

Table 2-18. Multiple Regression Statistics for 1957-83 Nine-Factor Equation

STEP	VARIABLE ENTERED	VARIABLE REMOVED	F TO ENTER OR REMOVE	SIGNIFICANCE	MULTIPLE R	R SQUARE	R SQUARE CHANGE	SIMPLE R	OVERALL F	SIGNIFICANCE
1	EVAPIND		23.38562	.000	.69521	.48332	.48332	-.69521	23.38562	.000
2	RIMEVAP		3.49112	.074	.74090	.54893	.06561	-.16041	14.60350	.000
3	PPTIND		6.01966	.022	.80156	.64250	.09357	.38395	13.77846	.000
4	EXAREA		1.78488	.195	.81812	.66933	.02683	-.17877	11.13271	.000
5	RUNIND		4.69217	.042	.85423	.72972	.06039	.41397	11.33929	.000
6	GRNTSTCH		1.17444	.291	.86296	.74471	.01499	.39228	9.72364	.000
7	TUNMAKE		1.09164	.309	.87096	.75858	.01387	-.15114	8.52869	.000
8	PRECLAG		.23498	.634	.87275	.76169	.00311	.22474	7.19150	.000
9	RUNAQF1		.11573	.738	.87367	.76330	.00161	.31498	6.09127	.001

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TABLE 2-19. Multiple Regression Statistics for 1957-83 Two-factor Equation

STEP	VARIABLE ENTERED	VARIABLE REMOVED	F TO ENTER OR REMOVE	SIGNIFICANCE	MULTIPLE R	R SQUARE	R SQUARE CHANGE	SIMPLE R	OVERALL F	SIGNIFICANCE
1	EVAPIND		23.38562	.000	.69521	.48332	.48332	-.69521	23.38562	.000
2	RUNIND		1.16541	.291	.71221	.50725	.02393	.41397	12.35288	.000

TABLE 2-24. Multiple Regression Statistics for 1937-83 Two-Factor Equation

STEP	VARIABLE ENTERED	VARIABLE REMOVED	F TO ENTER OR REMOVE	SIGNIFICANCE	MULTIPLE R	R SQUARE	R SQUARE CHANGE	SIMPLE R	OVERALL F	SIGNIFICANCE
1	EVAPIND		27.49237	.000	.61583	.37925	.37925	-.61583	27.49237	.000
2	RUNIND		3.59422	.065	.65278	.42612	.04688	.46903	16.33576	.000

90 percent level) to explaining the error variance. Although the nine variables explain about 74% of the overall error variance, several of them might be spuriously correlated, Use of all nine factors is a case of overfitting a small data set with too many factors. Only three of the factors -- the indices of runoff, precipitation, and evaporation - are statistically significant above the 95% level of confidence. These factors are related to the components with the greatest magnitude error and thus by extension to the magnitude of the overall error. Explaining the magnitude of the error is a desired result if the physical plausibility of the model is of Interest (i.e. if the desire is for more than just a black-box, statistical model). The high intercorrelation between the indices of precipitation and runoff requires that one of them be eliminated, The precipitation index is eliminated because physical reasoning suggests that the runoff index would explain more error; not surprisingly, the runoff index correlates somewhat better with the overall error than the other two indices.

When the runoff and evaporation index are regressed against the overall error the resulting multiple regression coefficient (R^2) is 0.51, meaning that 51% of the overall error variance is "explained" by the variation of the two indices. The importance of these two factors in explaining the larger magnitude error Is emphasized by the significantly improved multiple R^2 of 0.77 that results when the two indices are regressed only against the overall error that exceeds +/- 10,000 ac-ft (which occurs in 15 out of the 27 years). Similarly if these two factors are regressed against the overall error that exceeds ±20,000 ac-ft in the 1937-83 base period -- which occurs in 15 out of 47 years -- the multiple R^2 is 0.81.

These results are consistent with physical reasoning, It is expected that the use of an annual evaporation index derived from June-September pan measurements would give rise to a large error, This is because -- besides the obvious error resulting from applying four months measurements to a twelve month period -- pans do not have significant heat storage, and thus measurements of evaporation would vary more than the actual evaporation from a nearby deep lake, An index derived from these measurements would likely be systematically too high during years of high evaporation, and too low during years of low evaporation. In nine out of ten years in which the evaporation index is greater than 1.06, the overall error is negative, that is, the model either over-estimates the outflow, the majority of which is due to Mono Lake evaporation, or underestimates the inflow.

The runoff index, derived from the variation of the actual (reservoir-regulated) runoff, would also correlate with the overall error for the following reasons:

1) The runoff index is used to calculate the ungaged Sierra runoff (USR) because the USR is dampened and lagged by considerable subsurface flow. It is possible, however, that the USR is dampened even more than is reflected in the actual runoff index and therefore the use of the runoff index would result in systematically high USR in wet years and systematically low USR

in dry years.

2) A significant portion of the groundwater storage change (GWSC) could not be quantified because of the lack of data, This unquantified GWSC would occur in the higher elevations of the Mono Groundwater Basin (MGWB), just downstream from where the runoff is measured. The few years of available runoff measurements (1935-37 and 1953-66) from the Rush Creek County Road gaging station, which is located about 8 miles downstream from the MGWB boundary, suggest a mechanism that accounts for GWSC: runoff recharges the MGWB in wet years -- especially following dry years -- and is released from the MGWB in dry years, If the absorbed runoff did not reach the lake in the same water year, the inflow estimated in the model (which mainly reflects the runoff calculated with the index) would be too high. Indeed the years in which the overall error exceeds +20,000 acre-feet (1940,41,52,56,58,62,65,47,82) all have above normal runoff (index > 1.10, except for 1940 and 1962 which are close to normal) and immediately follow a dry year (except for 1941 which follows the normal 1940).[29] A regression of the overall error against the previous year's runoff index did not indicate a significant relationship.

The equation that results from regressing the 1957-83 overall error with indices of runoff and evaporation is:

$$E = 8.487 \times RI - 151.332 \times EI + 143,440 \quad (28)$$

Where E = Error, RI = Runoff Index, EI = Evaporation Index

The relevant statistics for the equation are shown in Table 2-19 on P. 173. Although the calculated "F" statistic for the runoff index indicates that it does not explain a significant portion of the error, the RI is kept in the equation because of the aforementioned physical reasoning,

When "E" in equation (4) is replaced by the above equation, and the appropriate inflows, outflows, and storage changes quantified in the formulated model are inserted, the resulting equation that will calculate MLSC for any given data set is:

$$\begin{aligned} MLSC = {} & SNGR + USR + NSR + NLSP + VCI + NM1 \\ & - MLE - BGE - NGLE - PETA - PETB - ILET - RET - SWEX - GWEX \\ & - GLSC - GWSC \\ & - (8.487 \times RI - 151.332 \times EI + 143.440) \end{aligned} \tag{29}$$

Equation (28) calibrates the model. Equation (29) is thus a calibrated water balance model for the Mono Groundwater Basin.

VERIFICATION

In the verification phase the calibrated water balance model is used to calculate lake levels in the 1937-56 period. The lake levels can be calculated sequentially, i.e. the calculated lake level at the end of one water year becomes the initial lake level at the beginning of the next water year, or the lake levels can be calculated separately year-to-year, i.e. the observed lake level is always used as the initial lake level. The sequentially and year-to-year calculated lake levels are compared with the observed lake levels for the 1937-56 period in Tables 2-20 and 2-21. These tables also compare the annual calculated lake bevel change with annual observed lake level change, Figure 2-16 plots

TABLE 2-20. Comparison of Observed and Sequentially Calculated Lake Levels: 1937-56

Year	Calculated Elevation	Clctd Change in Elev	Observed Elevation	Obsvd Change in Elev	Dif Btw Obsvd & Clctd Elev	Dif Btw Obsvd & Clctd Annual Change
1937	6415.31	.27	6414.97	-.07	-.34	-.34
1938	6418.00	2.68	6418.09	3.12	.09	.44
1939	6417.57	-.42	6417.66	-.43	.09	-.01
1940	6417.43	-.14	6416.92	-.74	-.51	-.60
1941	6417.60	.16	6416.99	.07	-.61	-.09
1942	6418.09	.49	6417.50	.51	-.59	.02
1943	6418.85	.76	6418.05	.55	-.80	-.21
1944	6417.45	-1.41	6416.61	-1.44	-.84	-.03
1945	6417.79	.34	6417.16	.55	-.63	.21
1946	6417.75	-.04	6416.95	-.21	-.80	-.17
1947	6417.04	-.71	6416.33	-.62	-.71	.09
1948	6414.59	-2.45	6414.06	-2.27	-.53	.18
1949	6412.43	-2.16	6411.92	-2.14	-.51	.02
1950	6410.22	-2.20	6410.08	-1.84	-.14	.36
1951	6408.48	-1.74	6408.22	-1.86	-.26	-.12
1952	6409.47	.99	6408.73	.51	-.74	-.48
1953	6408.25	-1.22	6407.60	-1.13	-.65	.09
1954	6406.19	-2.06	6405.28	-2.32	-.91	-.26
1955	6403.92	-2.27	6403.18	-2.10	-.74	.17
1956	6403.43	-.50	6402.15	-1.03	-1.28	-.53

TABLE 2-21. Comparison of Observed and Year-to-Year Calculated Lake Levels: 1937-56

Water Year	1937	1938	1939	1940	1941	1942	1943	1944	1945	1946
Mono Lake Elevation (ft)										
Calculated	6415.33	6417.65	6417.67	6417.54	6417.09	6417.49	6418.28	6416.65	6416.95	6417.14
Observed	6414.97	6418.09	6417.66	6416.92	6416.99	6417.50	6418.05	6416.61	6417.16	6416.95
Difference	.36	-.44	.01	.62	.10	-.01	.23	.04	-.21	.19

Water Year	1947	1948	1949	1950	1951	1952	1953	1954	1955	1956
Mono Lake Elevation (ft)										
Calculated	6416.25	6413.87	6411.89	6409.70	6408.34	6409.23	6407.51	6405.55	6403.00	6402.71
Observed	6416.33	6414.06	6411.92	6410.08	6408.22	6408.73	6407.60	6405.28	6403.18	6402.15
Difference	-.08	-.19	-.03	-.38	.12	.50	-.09	.27	-.18	.56

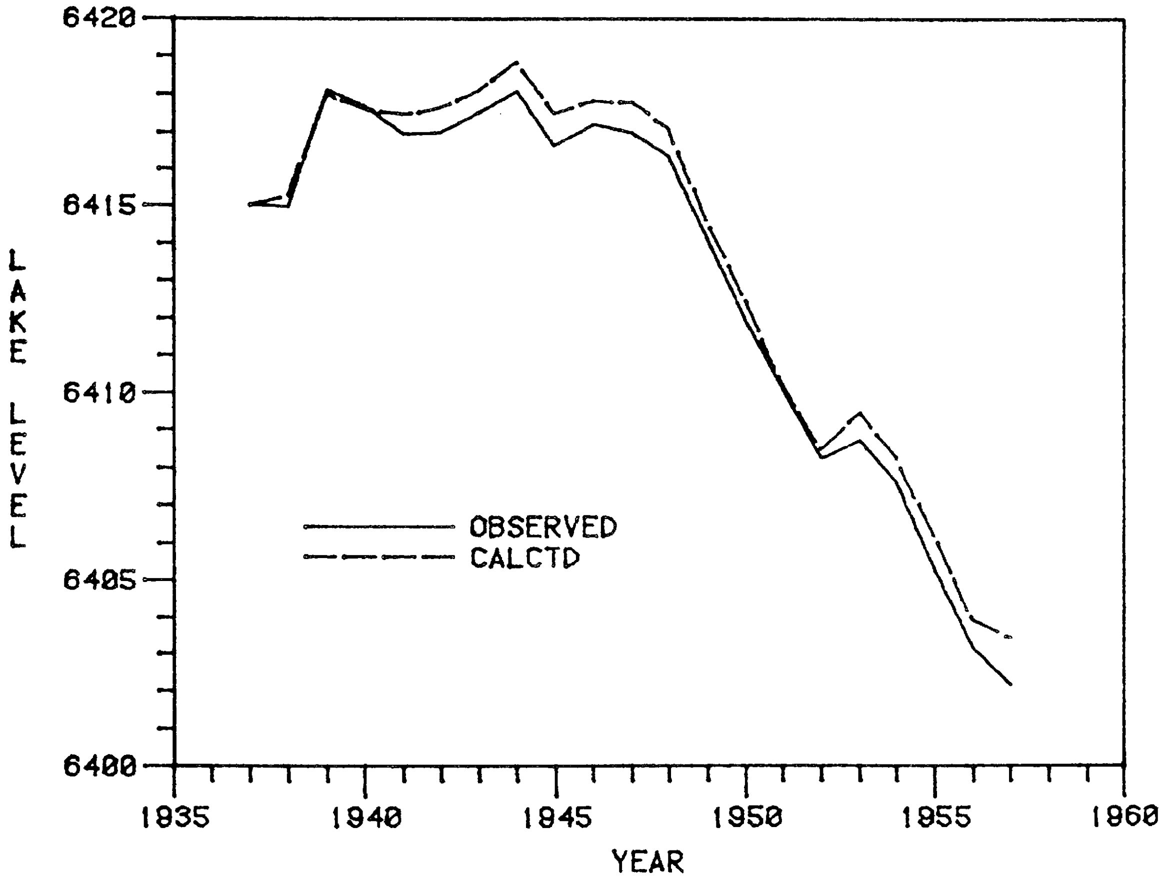

FIGURE 2-16. COMPARISXON OF OBSERVED AND SEQUENTIALLY CALCULATED LAKE LEVELS (MODEL VERIFICATION)

the observed and sequentially calculated lake levels for the verification period.

Table 2-22 makes the same comparisons as Table 2-20 and 2-21 using the lake levels calculated sequentially with the uncalibrated model. Table 2-22 shows that the calculated lake level deviates more than the observed lake level using the uncalibrated model (i.e. no error equation) than with the calibrated model. The average difference between the annual calculated lake level change and the annual observed lake level change is 0.224 ft when the lake levels are calculated sequentially with the calibrated model and 0.274 ft when calculated with the uncalibrated model; the average difference is 0.231 ft when the lake levels are calculated year-to-year with the calibrated model and 0.285 ft when calculated with the uncalibrated model. The verification thus confirms that a calibrated model is a somewhat more accurate predictor of lake levels than an uncalibrated model.

The problem with explaining variance and not the magnitude of the overall error is borne out by verifying the model calibrated with the equation derived in the initial SPSS run using all nine factors. A comparison of Table 2-23 with Table 2-20 shows that the two-factor calibration equation results in a more accurate prediction than the nine-factor equation even though the latter equation explains more of the error variance.

The verification indicates that the model calibrated with 1957-83 data is properly formulated and is a reasonable

TABLE 2-22. Comparison of Observed and Sequentially Calculated Lake Levels Using the Uncalibrated Model: 1937-56

Year	Calculated Elevation	Clctd Change in Elev	Observed Elevation	Obsvd Change in Elev	Dif Btw Obsvd & Clctd Elev	Dif Btw Obsvd & Clctd Annual Change
1937	6415.25	.21	6414.97	-.07	-.28	-.28
1938	6418.32	3.08	6418.09	3.12	-.23	.04
1939	6417.94	-.39	6417.66	-.43	-.28	-.04
1940	6417.70	-.24	6416.92	-.74	-.78	-.50
1941	6418.13	.44	6416.99	.07	-1.14	-.37
1942	6418.62	.49	6417.50	.51	-1.12	.02
1943	6419.39	.77	6418.05	.55	-1.34	-.22
1944	6417.72	-1.67	6416.61	-1.44	-1.11	.23
1945	6418.15	.43	6417.16	.55	-.99	.12
1946	6417.86	-.28	6416.95	-.21	-.91	.07
1947	6416.85	-1.01	6416.33	-.62	-.52	.39
1948	6414.06	-2.80	6414.06	-2.27	.00	.53
1949	6411.54	-2.51	6411.92	-2.14	.38	.37
1950	6409.43	-2.11	6410.08	-1.84	.65	.27
1951	6407.82	-1.61	6408.22	-1.86	.40	-.25
1952	6409.04	1.22	6408.73	.51	-.31	-.71
1953	6407.82	-1.22	6407.60	-1.13	-.22	.09
1954	6405.60	-2.22	6405.28	-2.32	-.32	-.10
1955	6403.33	-2.28	6403.18	-2.10	-.15	.18
1956	6403.00	-.33	6402.15	-1.03	-.85	-.70

TABLE 2-23. Comparison of Observed and Sequentially Calculated Lake Levels Using 9-Factor Equation: 1937-56

Year	Calculated Elevation	Clctd Change in Elev	Observed Elevation	Obsvd Change in Elev	Dif Btw Obsvd & Clctd Elev	Dif Btw Obsvd & Clctd Annual Change
1937	6415.23	.19	6414.97	-.07	-.26	-.26
1938	6417.49	2.26	6418.09	3.12	.60	.86
1939	6417.14	-.35	6417.66	-.43	.52	-.08
1940	6417.22	.08	6416.92	-.74	-.30	-.82
1941	6417.56	.33	6416.99	.07	-.57	-.26
1942	6418.20	.65	6417.50	.51	-.70	-.14
1943	6419.06	.86	6418.05	.55	-1.01	-.31
1944	6417.90	-1.16	6416.61	-1.44	-1.29	-.28
1945	6418.35	.46	6417.16	.55	-1.19	.09
1946	6418.52	.16	6416.95	-.21	-1.57	-.37
1947	6418.06	-.46	6416.33	-.62	-1.73	-.16
1948	6415.94	-2.11	6414.06	-2.27	-1.88	-.16
1949	6413.96	-1.99	6411.92	-2.14	-2.04	-.15
1950	6411.89	-2.06	6410.08	-1.84	-1.81	.22
1951	6410.22	-1.67	6408.22	-1.86	-2.00	-.19
1952	6410.99	.77	6408.73	.51	-2.26	-.26
1953	6409.76	-1.23	6407.60	-1.13	-2.16	.10
1954	6407.94	-1.82	6405.28	-2.32	-2.66	-.50
1955	6405.84	-2.10	6403.18	-2.10	-2.66	.00
1956	6405.10	-.74	6402.15	-1.03	-2.95	-.29

predictor of lake levels, Because the average and variance of the overall error in the 1937-83 period is similar to the 1957-83 period one could conclude that a model calibrated with the entire 47 year base period data set would also be properly formulated. Although a model calibrated with the entire data set cannot be validly tested, by using the larger data set and thus incorporating a greater range of hydroclimatic and lake level conditions, confidence in forecasting with a wide range of LADWP export scenarios should ideally be increased (Fryberg, pers comm 1984).[30] The equation for the overall error using the 1937-83 data set and the same two independent variables (runoff and evaporation indices) is:

$$E = 13.950 \times RI - 128.845 \times EI + 117.096 \qquad (30)$$

The summary statistics are shown in Table 2-24 on P. 173. These results show that about 41% of the overall error variance can be explained by the variation in the two indices; the rest of the error variance is the result of random component error. The calibrated model that will be applied to forecasting is thus:

$$\begin{aligned} MLSC = {} & SNGR+USR+NSR+NLSP+VCI+NMI \\ & - MLE-BGE-NGLE-PETA-PETB-ILET-RET-SWEX-GWEX \\ & - GLSC-GWSC \\ & - 13.950 \times RI - 128.845 \times EI + 117.096 \end{aligned} \qquad (31)$$

The overall error with the calibrated model is less than the overall error in the uncalibrated model in 33 out of 45 years (about 73%) when the lake levels are calculated on a year-to-year basis. In two of the years the overall error with the calibrated model is about the same as the error of the uncalibrated model.

Figure 2-17 compares the observed lake levels with those calculated sequentially by the model calibrated with the 1937-83 data. Not surprisingly, there is a good fit, Figure 2-17 is not, however, the true verification that Figure 2-16 is.

Although no absolute standards exist for determining the adequacy of the calibration or verification results, one test would be to compare the average annual difference between the observed and calculated lake level change with the average annual observed lake level change (i.e. the average of the absolute value of the lake level change). The result, expressed as a percentage, is a measure of the relative accuracy in predicting changes in lake level. Another measure of the adequacy of the prediction is to calculate the percentage of years the difference between the observed and calculated lake level change is greater than or equal to an arbitrarily chosen 0.33 ft, The results of these two "tests" for the different time periods are shown in Table 2-25. These tests are also applied to the prediction results given in LADWP (1984a). In three of the five years in which the LADWP model was applied to data not used in model calibration, the error in annual prediction exceeded one foot. In the model presented here, the error never exceeded one foot in the 20 year verification period; the maximum prediction error in the model was 0.64 ft. Table 2-25 also shows that when this report's model Is calibrated with 1941-76 data, the average prediction error is significantly less than LADWP's error.

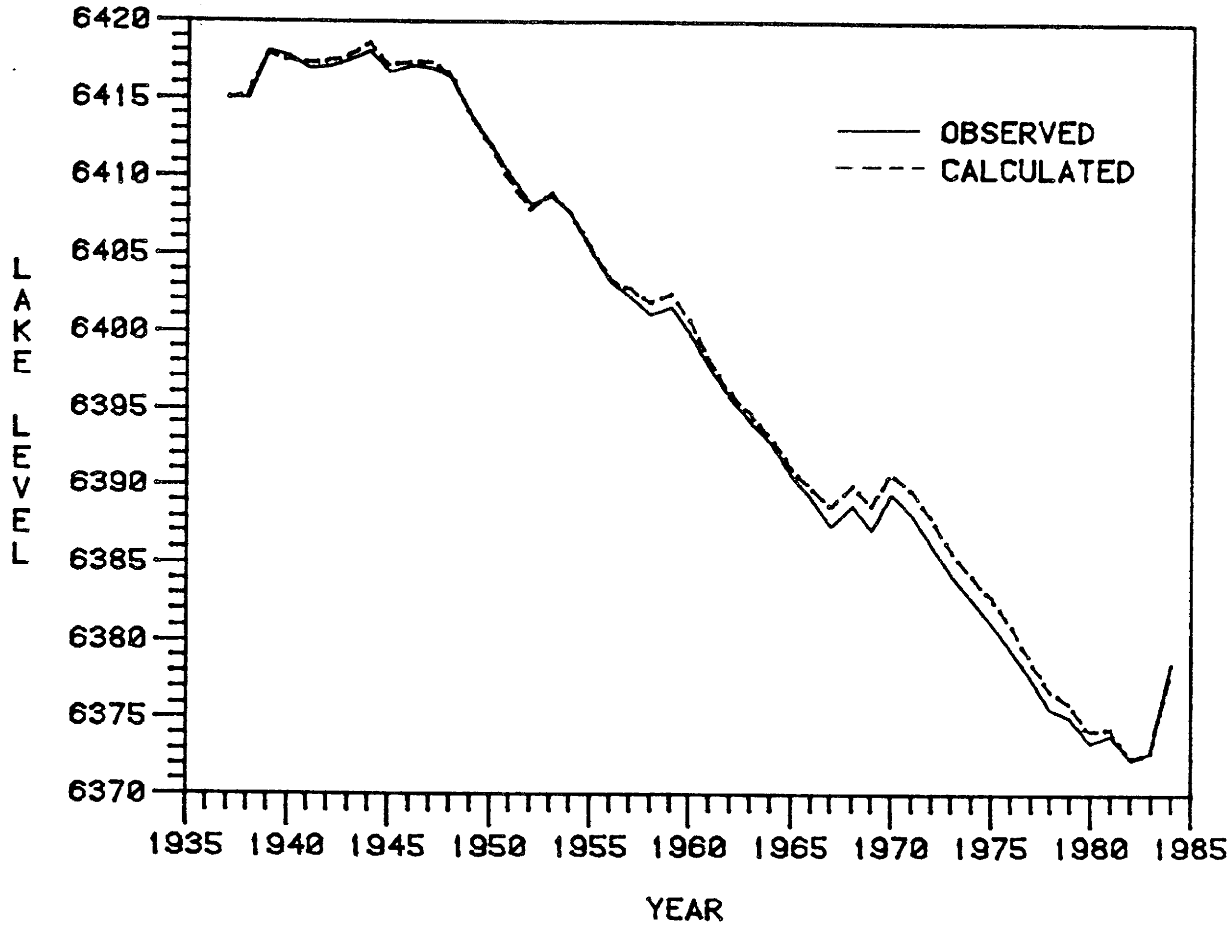

Figure 2-17. Comparisxon of Observed Lake levels and Those Calculated by Model Calibrated with 1937-83 Data

TABLE 2-25. Tests of Calibration and Verification Results

1	2	3	4	5	6	7	8
Model	Period Tested	Years	Average Annual Elevation Change	Average Difference Between Annual Calculated & Observed Elevation Change*	% 5÷4	No. Years Difference Between Observed & Calculated Elevation Change > 0.33 ft	% 7÷3
VORSTER							
Calibrated with 1937-83 Data	1937-83 (Base Period)	47	1.45	0.22	15	10	21
Calibrated with 1957-83 Data	1937-56 (Verification)	20	1.15	0.23	20	6	30
Calibrated with 1941-76 Data	1941-76 (Same as LADWP base period)	36	1.42	0.16	11	5	14
Calibrated with 1941-76 Data	1977-81 (Verification)	5	1.26	0.31	25	1	20
LADWP							
Calibrated with 1941-76 Data	1941-76 (Base Period)	36	1.42	0.32	23	17	47
Calibrated with 1941-76 Data	1977-81 (Verification)	5	1.26	0.83	66	3	60

* Mean of Absolute Value

Footnotes

(1) SSP and its allied companies, California Nevada Power Co. and Nevada-California Electric Co. no longer exist and thus background information on their runoff records is practically non-existent; SCE bought out the companies but does not have much information other than the runoff records.

(2) Because of the strong winds over the Sierra Crest, the highest precipitation in the Mono Basin occurs somewhat below and to the east (perhaps one to two miles) of the crest.

(3) Other indices of precipitation variability, including an indicator based on the variation of gaged runoff and another calculated from a network of intraregional precipitation stations were analyzed. These other indices would probably not increase the accuracy of the estimated annual variation of precipitation on Mono Lake.

(4) Bohler Creek is not included because measurements were not begun until 1970.

(5) Post Office, Log Cabin, and Andy Thompson Creeks are ungaged and shown as intermittent streams on USGS topographic maps. Since 1978, however, they have flowed continuously.

(6) The precip/runoff relationship is plotted as three separate curves because the runoff characteristics of the large streams are so different from the smaller streams (see Table 2-4).

(7) As a check to the computed USR, the analogue method developed by Riggs and Moore (1965) is also used to determine the average annual yield. The Riggs and Moore (1965) method applies a unit runoff/elevation zone relationship to the ungaged area. The resulting yield is less than 4% higher than the amount computed by the other method.

(8) The use of an index of runoff variation from Dechambeau or South Parker Creeks - two of the gaged watersheds most analogous to the ungaged areas in terms of unit runoff, underlying substrate, and crest exposure - was considered as an indicator of the annual variation in the yield. The measured runoff in both these creeks, however, may have considerable error because (a) their gaging stations are in alluvium, (b) high runoff is observed to flow around the

gaging stations, (c) irrigation diversions occur upstream from the gaging stations. Also the use of one indicator over the other cannot not be justified given the different characteristics of each ungaged area. It was therefore decided not to use either creek as indicators of the variation in yield.

(9) Examination of the unpublished floating pan data reveals that some measurements are seemingly free from wind and wave splash (i.e. there are no notations to that effect in the hydrographers record), but if these "good" measurements are extrapolated to a monthly estimate, the results must still be questioned on several points. First the pan was located along the west shore of Mono Lake and received less insolation than most of the lake because of the shadow cast by the Sierran escarpment. Second the pan coefficient for the floating pan is not firmly established. A coefficient of 0.8 (i.e. the estimated lake evaporation is eight-tenths of the measured pan evaporation) is suggested in CADPW (1947) but a wide range in the coefficient is noted. The coefficient question is muddled by the fact that the suggested pan coefficient for the floating pan measurements would be lower than the land pan because of the cooling effect of being in the water. The measurements from floating and land pans maintained by LADWP at Haiwee and Tinemahka Reservoir in the Owens Valley confirm this. The relationship between the measurements from floating and land pan measurements at Long Valley and Grant Lake reservoirs, also maintained by LADWP, is exactly the opposite, i.e. the floating pan measurements are higher than the land pan. This evidence suggests significant geographic variablity in floating pan coefficients,

(10) Pierre St. Amand (pers comm 1981), one of the co-authors of the Scholl et al.(1967) study, agreed that the use of unadjusted Haiwee Reservoir pan data is unwarranted.

(11) The pan is located in a medium density grass area (Distichlis and Carex) which extends for a minimum of 100 ft on all sides. The water table depth is usually less than 3 ft and the soil surface stays relatively moist except where a thin salt layer has accumulated. This site was selected in part because it was felt that the corrected (with a pan coefficient) pan evaporation in this area would be equivalent to the fresh water evaporation rate. (Inouye, pers comm 1983)

(12) The rise to 6428 ft in 1919 killed off all vegetation; thus any land exposed since 1919 is bare until colonized by vegetation,

(13) In late 1984, after this author's bare ground evaporation analysis, detailed topographic maps (5 foot contours) of the exposed lake bottom were prepared for the California State Lands Commission vs. U.S. Government lawsuit (U.S.D.C.-E.d.-Civ. S-80-696 L.K.K.). These maps can be used to determine land surface gradients.

(14) Sorey (pers comm 1984) applied the rate to land that is a mixture of salt-encrusted bare soil and scattered salt grass. He felt that the rate is applicable to bare ground in the Mono Basin. Sorey emphasized the high degree of uncertainty in bare ground evaporation estimates because very few evaporation measurements have been made from playa surfaces. Sorey also calculated vertical water movement rates using sub-surface temperature profiles in wells drilled into the Smith Creek playa and Lemon Valley playa in Nevada. He calculated rates of 0.33 ft./yr. and 0.85 ft./yr. respectively which he interpreted as the upward movement of groundwater as a result of evaporation,

(15) The BGE will increase until the lake drops below 6368 ft at which point the rills on the north and east shore will incise, lower the water table, and reduce the evaporation rate (Stine pers comm 1984)

(16) The term "phreatophyte" was coined by hydrologist O.E. Meinzer (1923) to describe plants that habitually obtain their water supply from the zone of saturation, either directly or through the capillary fringe. Meinzer did not intend phreatophytes to be a part of the principal ecologic grouping of plants -- hydrophytes, halophytes, mesophytes and xerophytes. Phreatophytic species can either be . hydrophytes (e.g. tules), halophytes (e.g. saltgrass), or xerophytes (e.g. rabbitbrush). Because phreatophytes exhibit wide diversity and do not display any characteristic adaptation in obtaining their water supply, they have received comparatively little recognition from plant ecologists and botanists,

(17) The PET rate as defined by Miller (1979), is the rate of moisture conversion of a vegetation covered surface with these idealized characteristics: (1) plants short and densely spaced, growing actively with unlimited soil moisture; (2) surface uniform and infinite. PET is a a theoretical concept which is a measure of the energy available for ET if water is not limiting.

(18) Reference ET as defined by Doorenbos and Pruit (1974) is "the

rate of ET from an extended surface of 8 to 15 cm tall green grass cover of uniform height, actively growing, completely shading the ground and not short of water." The consumptive water requirement as defined by Doorenbos and Pruit (1974) is "the amount of water potentially required to meet the evapotranspiration needs of vegetative areas so that plant production is not limited from the lack of water."

(19) The growing season in the Mono Basin is usually from about April 15 to October 15. The growing season, as defined by Kruse and Haise (1974) is the time between the spring and fall occurrence of either (a) 24 degrees F minima sustained for more than three days or (b) the time between 40 degrees F average temperature sustained for more than three days. Using these criteria, the growing season at the Simis climate station in 1981 was from April 17 to October 11 (criteria a) or April 14 to October 10 (criteria b). The 1982 growing season was May 14 to October 1 (criteria a) or April 23 to November 1 (criteria b).

(20) There are several methods that are more accurate (Jenson 1973), but they require more data.

(21) The USGS vegetation maps that Lee (1934) refers to have yet to be found.

(22) Part of the difference (22 acres) is explained by the presence of the marshes and meadows in the Rush Creek riparian zone that are included in Lee's measurement*

(23) The biggest areas of increase from 1940 to 1978 occurred along the northwest shore where spring discharges are very high and the north, east, and southeast shores where spring discharge and high water tables occur over a wide area.

(24) CADWR (1964) estimated that the population of the Mono Basin in 1940 was approximately 600 (cf. current year-round population of 1500). LVPUD (1979) stated that Lee Vining's population has changed slowly in the past 20 years.

(25) Some of this "tunnel-make" is an outflow that occurs upstream from the boundary of the groundwater basin and should be accounted for as a depletion of the non-Sierra runoff. All of it is quantified as a diversion outflow component because of its direct relationship to the surface water export by LADWP and the difficulty of quantifying it in two separate components.

(26) This approximation is based on the estimated water surface elevation of the old reservoir and LADWP's area/capacity curve for the existing reservoir.

(27) The wells include Marjorie Green, Warm Springs Test Hole No. 1 and 2, Clover Test Hole No. 3; these wells are not maintained and may have filled in with sand, These wells are located north and east of Mono Lake. More than one aquifer may be drained. In addition to the uppermost aquifer of the permeable surface layers, there is a second permeable layer separated from the uppermost aquifer by the lake sediments of the 220 year old high stand (Stine, pers comm 1984). The second layer may pinch out between 6390 ft and 6400 ft and would drain when the lake dropped below that level. The wells that have not dried up, such as the Thomas Ault and Nettie Ault well, are artesian wells that tap a confined aquifer that stands below the lake sediments of the 2400 year-old high stand.

(28) It is assumed that the actual MLSC is a "true" value, i.e. it is error-free. This assumption is technically not valid mainly because of the inaccuracies involved in the derivation of the stage/volume relationship which is used to calculate the MLSC. In addition, the measurement of the actual lake level change subject to very small errors.

(29) One interpretation of this high positive error is that the inflow is too high although it could reflect outflow that is underestimated, The two years with the highest positive overall error -- 1952 and 1956 -- have substantially above normal runoff (index > 1.30) and follow a series of below normal years (1947-51 and 1953-55). A further illustration of the possibility that the overall error could be reflecting some of the unquantified groundwater storage change, is that if the runoff that is absorbed by the MGWB in the above normal years flows into the lake the next year, the inflow estimated in the model would be too low in that year and a negative error would result (assuming for the moment that all other factors are error-free). Indeed the overall error in all of the years that follow the years of above normal runoff and high positive error (except 1968) are negative.

(30) Water year 1984 data are not included in the calibration data set since final runoff and evaporation measurements were not available at the time of model development.