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CITY OF RENO
FEB 24 1993
ENGINEERING DIV.

February 16, 1993

Mr. Thomas J. Gribbin, P.L.S.
Pyramid Engineers & Land Surveyors
330 Crampton Street
Reno, NV 89502

Dear Mr. Gribbin:

Enclosed is a report which addresses the 100-year water surface elevation in Silver Lake which is located in the City of Reno. Unlike the two previous 100-year water surface elevation determinations, this current re-analysis was done with a completely different methodology that utilized stream gage records for similar water courses in the region.

The results of this stochastic methodology combined with a risk analysis show that both the median and the mean estimate of the 100-year water surface elevation in Silver Lake would be approximately 4963 feet NGVD.

Because Silver Lake is a closed basin an estimate of the 100-year water surface elevation was developed which is more conservative than the "best estimate" mentioned above, even though it is believed that the elevation of 4963 feet would satisfy FEMA criteria. A water surface elevation of 4965 feet was selected for the LOMR to be requested of FEMA. This elevation provides for two feet of freeboard above the "best estimate" of 4963 feet. In terms of risk analysis, the elevation of 4965 feet provides a 75 percent confidence that the 4965 is less than or equal to the "true" 100-year lake elevation.

Both the City of Reno and the property owners are willing to accept the 4965 elevation for purposes of flood plain management. Therefore, this is the value which will be recommended to FEMA for purposes of obtaining a Letter of Map Revision.

If you have any questions or need additional information do not hesitate to give me a call.

Very truly yours,
SCHAAF & WHEELER

James R. Schaaf

James R. Schaaf, PhD, CA PE

Enclosure: Report
Appendices Bound Separately

Thomas J. Gribbin, P.L.S.
President

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Civil Engineering • Planning • Surveying

100-YEAR WATER LEVEL

FOR SILVER LAKE

Prepared for:

Pyramid Engineers and Land Surveyors
Reno, Nevada

February , 1993

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100-YR WATER LEVEL
FOR
SILVER LAKE

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100-YR WATER LEVEL
FOR
SILVER LAKE

1. Introduction, Background

This report of the reanalysis of the 100-year water surface elevation of Silver Lake in Reno, Nevada was done by Schaaf & Wheeler, Consulting Civil Engineers under contract to Pyramid Engineers of Reno who were under contract to the Lear Estate Trustees. The present analysis follows two previous analyses which were done utilizing unit hydrograph rainfall-runoff procedures. The present analysis utilizes a stochastic hydrology approach to determining the 100-year water surface elevation in Silver Lake.

Silver Lake is the terminus of an enclosed watershed. Dry lakes such as this are often called playas. The watershed is approximately 53 square miles in area and ranges in elevation from 4950 to 8000 feet. The Silver Lake watershed is situated partially in the city of Reno, Nevada with the remainder of the watershed situated in Washoe County. Silver Lake itself is in the city of Reno.

1.1 1985 Analysis by Schaaf & Wheeler

In March, 1985 Schaaf & Wheeler, under contract to Reimer Associates analyzed the surface water flood hydrology of Silver Lake. The methodology utilized was the Soil Conservation Service (SCS) procedure for determining runoff based on daily rainfall information. The daily rainfall information was developed based on the December, 1955 rainfall pattern and the rainfall statistics from the Reno rain gage which has been in operation since 1870. The impact of runoff on the impervious area of the Silver Lake watershed was taken into consideration in the analysis. The resulting 100-year water surface elevation in the Lake was 4965 feet NGVD. This was the value applied for in the request to FEMA for a Letter of Map Amendment.

The rainfall statistics from the Reno gage were utilized for the Silver Lake watershed. This was done because the NOAA Atlas for Nevada indicated that when incorporating the area reduction factor for a 53 square mile watershed into the computations, the average 100-year, 24-hour isohyet for the Silver Lake watershed was identical to that at the Reno gage. This 100-year, 24-hour value was 2.6 inches.

The storms of December 17, 1955 to January 5, 1956 were used as the 20-day storm pattern because these two months experienced 7.83 inches of rainfall at the Reno gage. This was the most recent, most critical combination of precipitation events at the Reno gage. Other months with more than five inches of rainfall at Reno occurred in 1890, 1911, 1914 and 1916.

A 13-day storm pattern was used for the frequency analysis. This pattern mimicked the maximum 13-day period of the December, 1955 storm. Using 5-day Antecedent Moisture Conditions to alter the Curve Number depending upon wet or dry antecedent conditions, the runoff to the lake was estimated for the 2-, 5-, 10-, 20-, 50-, 100-, 200-, and 500-year storms. The water surface elevation for the 100-year storm was 4964.4 feet.

During the technical review of the application for the Letter of Map Amendment, FEMA's Technical Evaluation Contractor requested that the analysis include the rainfall which fell directly on the Lake and that a "carry-over" storage be determined so that the impact of preceding runoff could be included in the 100-year water surface elevation.

The inclusion of the rainfall which would fall directly on the lake surface did not alter the results. However, the inclusion of the "carry-over" storage was difficult to estimate. A value of 500 acre-feet was used as this was the annual average inflow estimated by the US Geological Survey during an investigation into the groundwater resources of the area. The inclusion of this storage increased to water surface elevation to 4965.0 feet for the 100-year event. This is the value requested and it was the elevation granted by FEMA.

1.2 1987 Analysis by Nimbus Engineers under contract to FEMA

In December, 1987 a revised report was issued by Nimbus Engineers of Reno concerning the hydrologic analysis of Silver Lake and Lemon Valley playas. This report was done under contract to FEMA for the flood insurance restudy of portions of the city of Reno and portions of Washoe County. The red insurance restudy of portions of the city of Reno and portions of Washoe County. The report detailed the methodology used to establish the 100-year water surface elevations in both the Silver Lake and the Lemmon Valley playas. The 100-year water surface elevation for Silver Lake was stated to be 4967.0 feet.

The analysis utilized the US Army Corps of Engineers HEC-1 hydrology model. The rainfall input pattern was that of the 10-day storm of February-March, 1986. The frequency-duration curve for rainfall in the Silver Lake watershed was developed based on an analysis of gages in the region and the NOAA Atlas for Nevada was ignored. This step was coordinated with the local office of the National Weather Service. However, the rainfall pattern and depths used in the model did not include the area-reduction rations recommended for use in drainage areas greater than ten square miles.

The rainfall-runoff model was calibrated by determining the constant loss rate which when combined with the 1986 rain storm produced the measured 1986 water level in Silver Lake. This loss rate was found to be 0.14 inches per hour. When applied with the 10-day, 100-year rain storm, the water surface elevation in Silver Lake was found to be only 4963.6 feet. To this value was added "carry-over" storage.

The "carry-over" storage analysis done as part of this 1987 work was based on the runoff from hypothetical 24-hour storms. If there was no "carry-over" storage the 100-year lake water surface elevation would be 4963.6 feet. If there was 1,278 acre-feet of such storage (corresponding to the runoff from a 5-year, 24-hour storm) the 100-year lake water surface elevation would be 4965.2 feet. The 10-year, 24-hours storm would produce 1,862 acre-feet of "carry-over" storage and the resulting 100-year water surface elevation in Silver Lake would be 4965.7 feet. The 25-year, 24-hour storm would produce 2,728 acre-feet resulting in a 100-year lake elevation of 4966.5 feet. The 50-year, 24-hour storm would produce 3,424 acre-feet of "carry-over" storage resulting in a 100-year lake elevation of 4967.1 feet.

The "carry-over" storage selected was that corresponding to the runoff from a 25-year, 24-hour storm. There was no justification for selection of this particular "carry-over" storage value except that the report noted that this value was considered reasonable.

The flood insurance restudy utilized the 4967.0 feet value for the 100-year water surface elevation in Silver Lake. This is the elevation shown on the Flood Insurance Rate Maps currently in effect for the city of Reno.

1.3 Historic Information

Pyramid Engineers & Land Surveyors of Reno measured the water surface elevation of Silver Lake at various times since June of 1983. The information is shown in Table 1. There are separate readings for the three playas in the Silver Lake area: Silver Lake itself, the NE playa and the NW playa. At high water levels in Silver Lake there would one continuous water surface elevation covering all three of these dry lakes.

Silver Lake has been essentially dry since the summer of 1989.

The elevations in Table 1 have been rounded to the nearest tenth of a foot. The elevation datum for the elevations is NGVD.

TABLE 1

SILVER LAKE WATER ELEVATION MONITORING DATA

DATE	SILVER LAKE	NE PLAYA	NW PLAYA	DATE	SILVER LAKE	NE PLAYA	NW PLAYA
06-29-83	4958.3		4962.4	08-19-86	4960.0		
				08-25-86	4959.9	DRY	4960.0
03-23-84	4959.7		4963.0	09-12-86	4959.5		
11-12-84	4957.3			09-19-86	4959.4		
				09-22-86	4959.5		
04-25-85	4958.			09-25-86	4959.4		
07-31-85	4956.4			10-02-86	4959.4		
				10-13-86	4959.4		
02-25-86	4960.8	4964.5	4961.7	12-03-86	4959.1		
03-12-86	4961.4	4964.7		12-10-86	4955.1		
03-19-86	4961.6	4964.6					
03-24-86	4961.7			04-01-87	4959.7		
04-04-86	4961.7	4964.5		04-08-87	4959.6		
04-11-86	4961.8	4964.5		04-24-87	4959.5		
04-17-86	4961.7	4964.4		07-07-87	4958.6		
04-25-86	4961.8	4964.3		10-08-87	4956.8		
05-03-86	4961.8	4963.9		10-13-87	4956.8		
05-09-86	4961.9	4963.3		12-02-87	4956.7		
05-19-86	4961.9	4962.7					
05-27-86	4961.8	4962.3		03-25-88	4956.8		
06-03-86	4961.6	4962.1		06-10-88	4955.8		
06-10-86	4961.5	4962.0		07-08-88	4955.4		
06-17-86	4961.4	4961.8					
06-23-86	4961.2	4961.7					
07-02-86	4961.0	4961.7					
07-09-86	4960.8	4961.4	4960.9				
07-14-86	4960.6	4961.2	4960.8				
07-25-86	4960.6	4961.1	4960.6				
07-30-86	4960.5	4961.1	4960.6				
08-08-86	4960.4	4960.9	4960.4				

1.4 Need for Additional Analysis

The runoff volumes for the two 100-year analyses previously performed were: 4,550 acre-feet by Schaaf & Wheeler in 1985, and 5,080 acre-feet by Nimbus Engineers in 1987. These values are relatively close together. Thus, the runoff methodology utilized in both analyses produces similar results even though the rainfall input was significantly different in each analysis. The major difference in producing the two different 100-year water surface elevations was the "carry-over" storage added to the 100-year runoff volume.

Schaaf & Wheeler utilized 500 acre-feet of "carry-over" storage as this was the average annual runoff estimated by the US Geological Survey. Nimbus Engineers utilized 2,728 acre-feet of "carry-over" storage as this was the direct runoff from a 25-year, 24-hour storm over the Silver Lake watershed. If the 5-year, 24-hour storm would have been selected, the "carry-over" storage would have been reduced to 1,278 acre-feet and the 100-year water surface elevation would have been reduced to 4965.2 feet.

A storage of 2,728 acre-feet corresponds to an water surface elevation of approximately 4960.6 using the elevation-storage curve used by Nimbus Engineers. This value is higher than the maximum water surface elevation measured during the 1983-1984 wet period. These two years produced the most two-year precipitation at the Reno gage since 1890-1891. The elevation of 4960.6 is just slightly below the elevation of 4960.8 measured on the 25th of February of 1986. As the storm which struck California and Nevada that month began on the 12th and lasted until the 20th with the maximum intensities occurring during the 17th, 18th and 19th, and since the response time shown by the unit hydrograph which Nimbus Engineers utilized had a time to peak of approximately 9 hours and a total time of runoff of 42 hours, the initial lake level would be expected to be much lower than 4960.6 feet prior to the beginning of the storm on the 12th of February. Thus, the "carry-over" storage used in the Nimbus Engineers' analysis appears to include a rather large amount of runoff - 2,728 acre-feet is greater than the volume contained by Silver Lake during 1983-1984 and approximately 85 percent of the total volume stored in Silver Lake at it peak elevation in May of 1986.

The issue of the "carry-over" storage needs to be addressed to develop a more scientifically defendable estimate of the 100-year water surface elevation in Silver Lake.

2. Plan of Analysis

Because the problem involves flooding and flood elevations, the previous two analyses used rainfall-runoff models. However, unlike a riverine situation, the water surface elevation in the lake not only depends upon the short duration, high intensity rainfall, but also upon the sequencing of runoff events. When a period of high runoff occurs, will it occur after a relatively wet period or will it occur after a dry period. Obviously, the sequencing of runoff is at the heart of the "carry-over" storage estimates used in the two previous analyses. Because sequencing is so important in determining the 100-year water surface elevation of Silver Lake the problem becomes similar to determining the yield of a water supply project. For those types of projects it is not the average runoff which matters but rather the length and severity of dry periods which governs the yield calculations for these types of projects. During extended periods of high flows the reservoir project can fill and this "carry-over" storage can be used to provide supply during periods of low or no flow.

Determining the 100-year water surface elevation for Silver Lake is similar to determining the water yield for water supply projects. It follows that a similar methodology should provide a dependable answer to the 100-year water surface elevation question. The strategy in the present analysis is to abandon the rainfall-runoff model approach that uses a 13-day or 10-day storm pattern and replace it with a generated sequence of monthly stream flow values. This substitute procedure to the rainfall-runoff model concentrates heavily upon the sequencing of monthly average discharges thereby creating the proper "carry-over" storage for large flood months as part of the procedure. While the 10-day or 13-day storm pattern in the rainfall-runoff model will tell the analyst which day contained the most runoff, the monthly discharge analysis does not determine the daily distribution of flow but only utilizes the monthly average discharge. The monthly average discharges were determined to be adequate for purposes of analyzing Silver Lake because the determination of the instantaneous peak discharge was not considered important, nor was the maximum daily discharge considered important in determining the maximum lake level. Whether the runoff entered the lake in one day or over 30-days was not considered important. As evaporation during the wet winter months is generally low (on the order of two inches), applying the discharge on a monthly basis and the evaporation on a monthly basis should not affect the maximum water surface elevation by more than about a maximum of two inches.

Developing the 100-year water surface elevation using the stochastic process for monthly average discharge is seen as a five-step process. These five steps are:

1. Develop Monthly Statistics At Nearby Stream Gages using HEC-4
2. Perform Regression Analysis to Relate Monthly Statistics to Basin Parameters
3. Determine Best Fit Parameters and Root Mean Square Error for All Monthly Statistics
4. Apply Best Fit Parameters to Silver Lake Watershed to Develop Monthly Statistics
5. Utilize Root Mean Square Error of the Regression Analysis to Develop A Risk Analysis

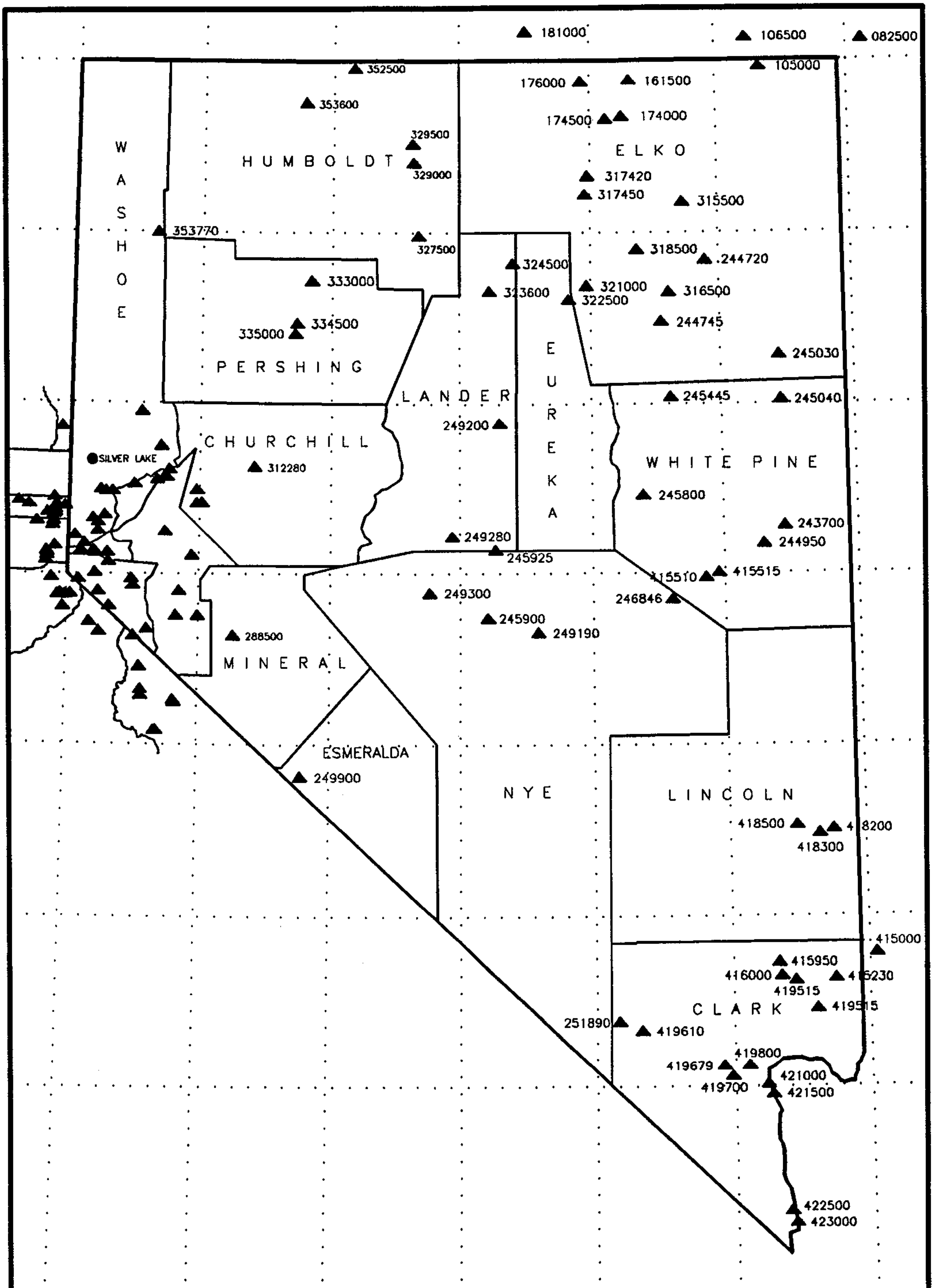
The computer program HEC-4 (developed by the US Army Corps of Engineers was purchased for this investigation from Spectrum Engineering of Bozeman, Montana - one of the authorized HEC program vendors). HEC-4 analyzes and generates monthly stream flows and stream flow statistics. Monthly average discharges were readily available from the US Geological Survey's WATSTORE stream gage data storage and retrieval system.

The report will now discuss the above five steps in depth. All basic data used in the analysis, the results of the analyses, and all computer codes written to support this analysis effort are included in separately bound appendices to this report so as to provide complete documentation of the methodology to determine the 100-year water surface elevation in Silver Lake.

3. Monthly Statistics

As shown in Figure 1, there are quite a number of US Geological Survey stream gages in the hydrologic area known as the Great Basin. Because the methodology will be used to estimate a 100-year water surface elevation for Silver Lake, not all of the gages shown in Figure 1 can be used in the regression analysis. The stream gages selected should drain watersheds which are somewhat similar to the Silver Lake watershed. The first subject of this section will describe how the final 15 stream gage stations were selected. The second subject of this section of the report will be a discussion of the HEC-4 statistical results.

Figure 1



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3.1 Selection of Representative Stream Gage Stations

The first cut in determining the group of most representative stream gage stations was to review the records of all stream gages in the Great Basin and discard any that were significantly affected by upstream storage, diversion or any type of regulation. The second cut was to eliminate all stations south of latitude 37 degrees and all stations north of latitude 42 degrees. The rational for this cut was that any further south than about latitude 37.5 degrees was actually the southern desert and not the high northern desert. North of latitude 42 degrees was outside of the state of Nevada and these stations were considered too far north to be similar to the Silver Lake watershed. The third cut was to eliminate all stations east of longitude 115 degrees because these were so far to the east that the "rain shadow" effect of the Sierra Nevada was probably not present in these watersheds. The fourth cut was to eliminate all stations which drained an area in excess of 500 square miles. As the Silver Lake watershed was approximately 53 square miles in area, it was felt that utilizing data from watersheds larger than 500 square miles would not provide comparable results. These five criteria were used to do the initial screening of all the stream gage stations in the US Geological Survey's WATSTORE data system for the Great Basin hydrologic area.

The results of this first cut (using the five criteria) are shown in Table 2 and in Figure 2. Note that stations 109, 110, 111 and 112 are not shown on Figure 2 as they are off to the east of the right side of that figure. Table 2 shows various information for the 34 stations which made the cut. The USGS station number and the map number are shown on the left side of the table. The state in which the station is located is also shown. The bars and X's show the years during which the station was in operation collecting stream flow data. The bar indicates a complete data for a water year and an X indicates a partial record for that particular year.

Table 2 indicates that six stations (102, 110, 113, 121, 122 and 124) have 50 or more years of recorded data. There are 13 stations with 30 or more years of record and 17 stations with 20 or more years of record. Only six stations had less than 10 years of record.

A further series of criteria was developed to eliminate some of the 34 stations to make the group have more similarity to the Silver Lake watershed. The first cut was to eliminate all stations to the east of longitude 119 degrees. This would limit the stations to those very close to the Sierra Nevada range and would keep the stations in a more homogeneous meteorologic area. This cut eliminated eight stations: 100, 101, 109, 110, 111, 112, 113, 117, and 118. Now there were only 25 station left.

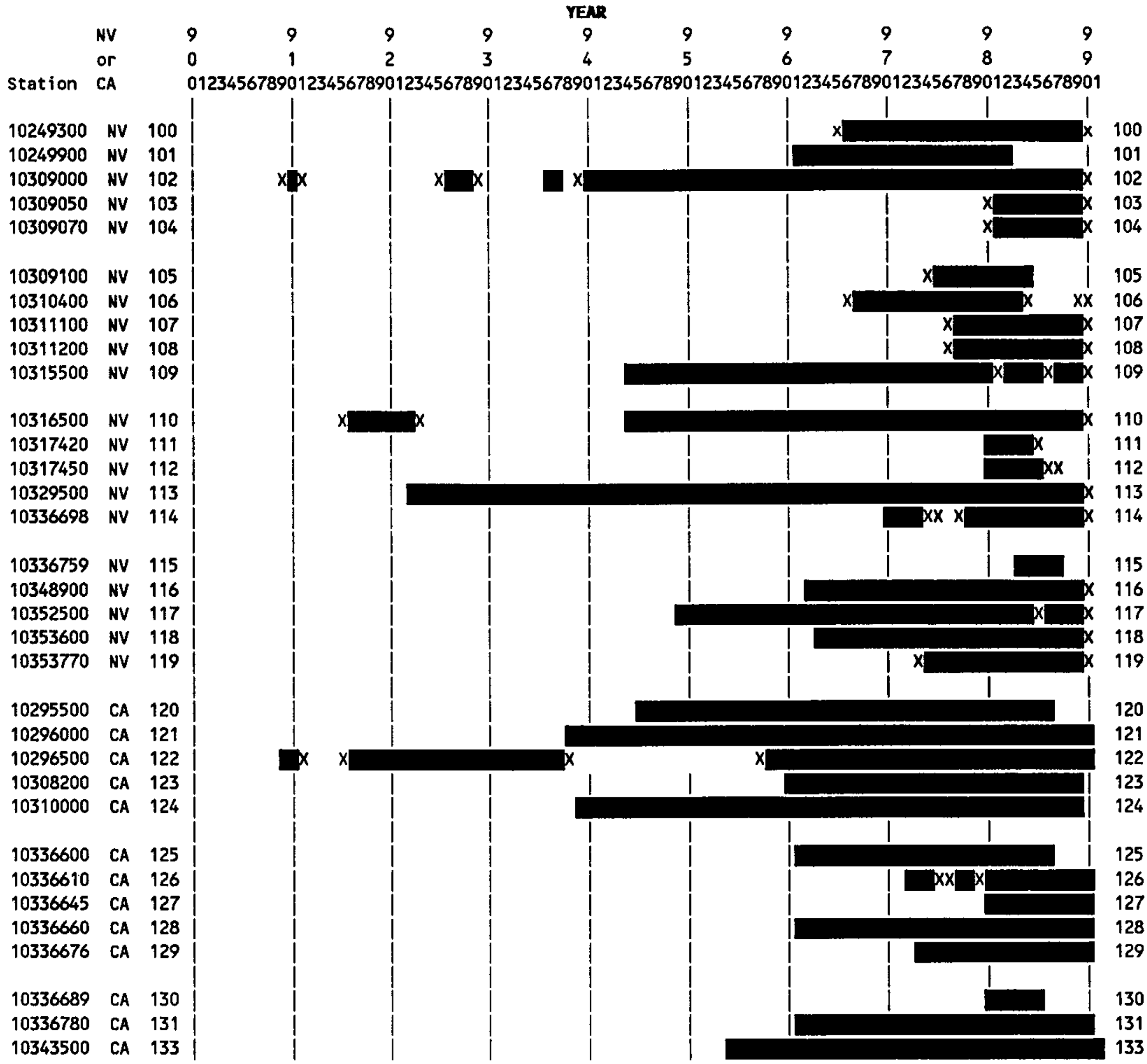
The next cut was to eliminate all those stations which drained into Lake Tahoe as it was felt that the meteorology and hydrology of these stations would not be as similar to Silver Lake as would stations located on the eastern slopes of the Sierra Nevada range. This cut eliminated ten stations: 114, 115, 125, 126, 127, 128, 129, 130, 131 and 133. Thus only fifteen stations met all criteria. These stations are shown in Table 3 and in Figure 3. These were considered the most hydrologically and meteorologically similar to the Silver Lake watershed. These fifteen stations had their records retrieved from the WATSTORE system and had a statistical analysis performed on all records of all the fifteen stations.

3.2 HEC-4 Statistical Results

US Army Corps of Engineers computer program HEC-4 - "Monthly Streamflow Simulation" was used to calculate statistical parameters from the monthly streamflow data of each of the fifteen stations. The statistical parameters computed were: mean, standard deviation, skew coefficient, and lag one serial correlation coefficient. In addition, the HEC-4 added an increment of flow (usually 0.10 cfs) to all monthly flows to get around the problem of zero monthly discharges. These zero flows were troublesome because the HEC-4 program performed a logarithmic (to the base 10) transform of all the data. The incremental flow addition would prevent the computer from trying to compute the logarithm of zero.

TABLE 2

HISTORIES OF STATIONS SURVIVING THE FIRST CUT



CODE

█ = COMPLETE RECORD FOR THE WATER YEAR

X = INCOMPLETE RECORD FOR THE WATER YEAR

Figure 2

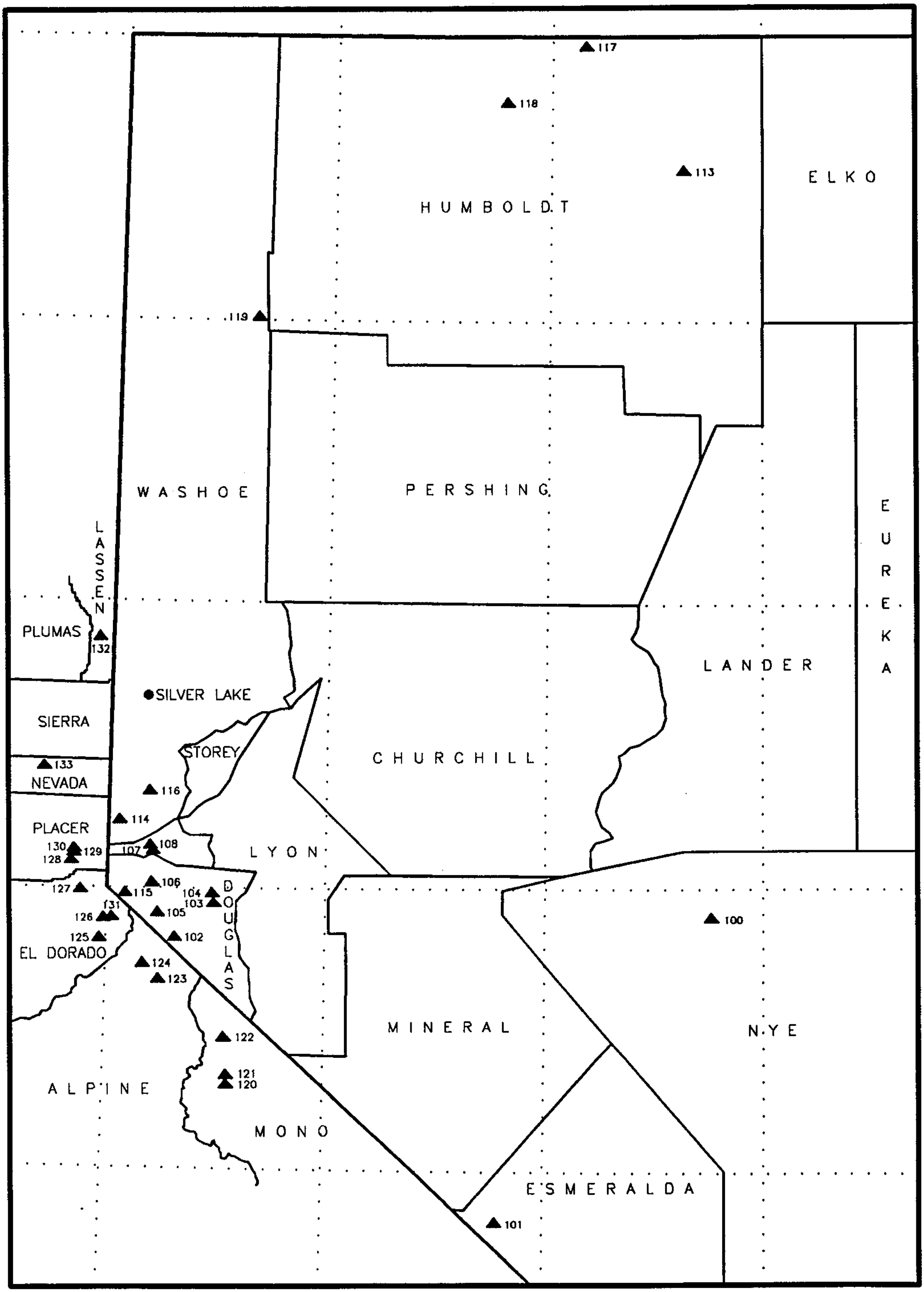


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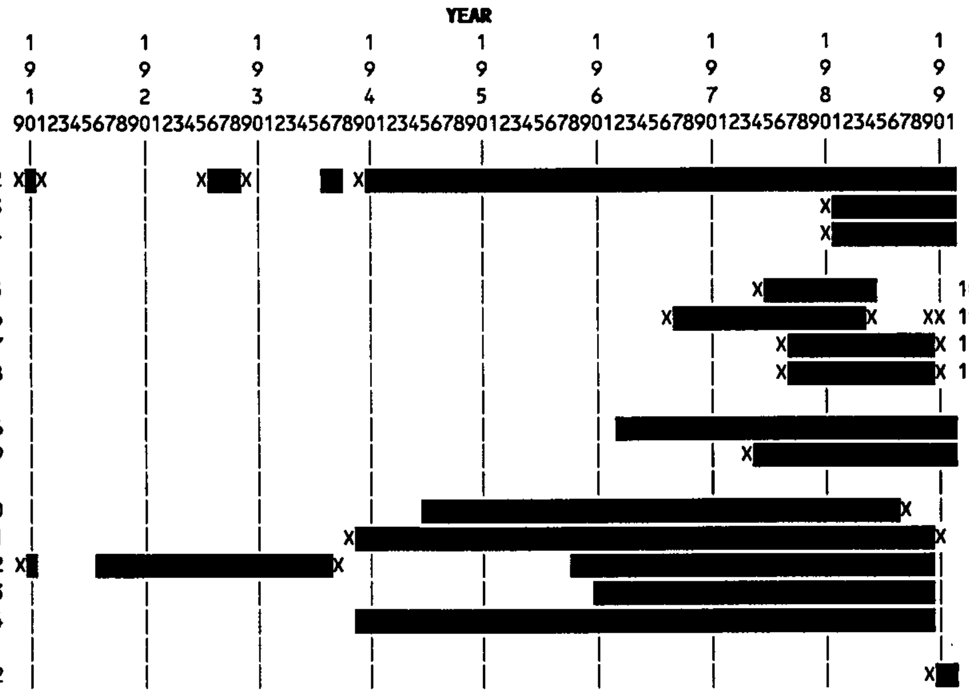
TABLE 3

HISTORIES OF THE FINAL FIFTEEN STATIONS USED IN THE STATISTICAL ANALYSIS



Station	NV or CA		AREA SQ. MI.
10309000	NV	102	356
10309050	NV	103	10.14
10309070	NV	104	46.3
10309100	NV	105	392
10310400	NV	106	3.82
10311100	NV	107	4.06
10311200	NV	108	5.2
10348900	NV	116	8.5
10353770	NV	119	31
10295500	CA	120	63.1
10296000	CA	121	180
10296500	CA	122	250
10308200	CA	123	276
10310000	CA	124	65.4
10354000	CA	132	125

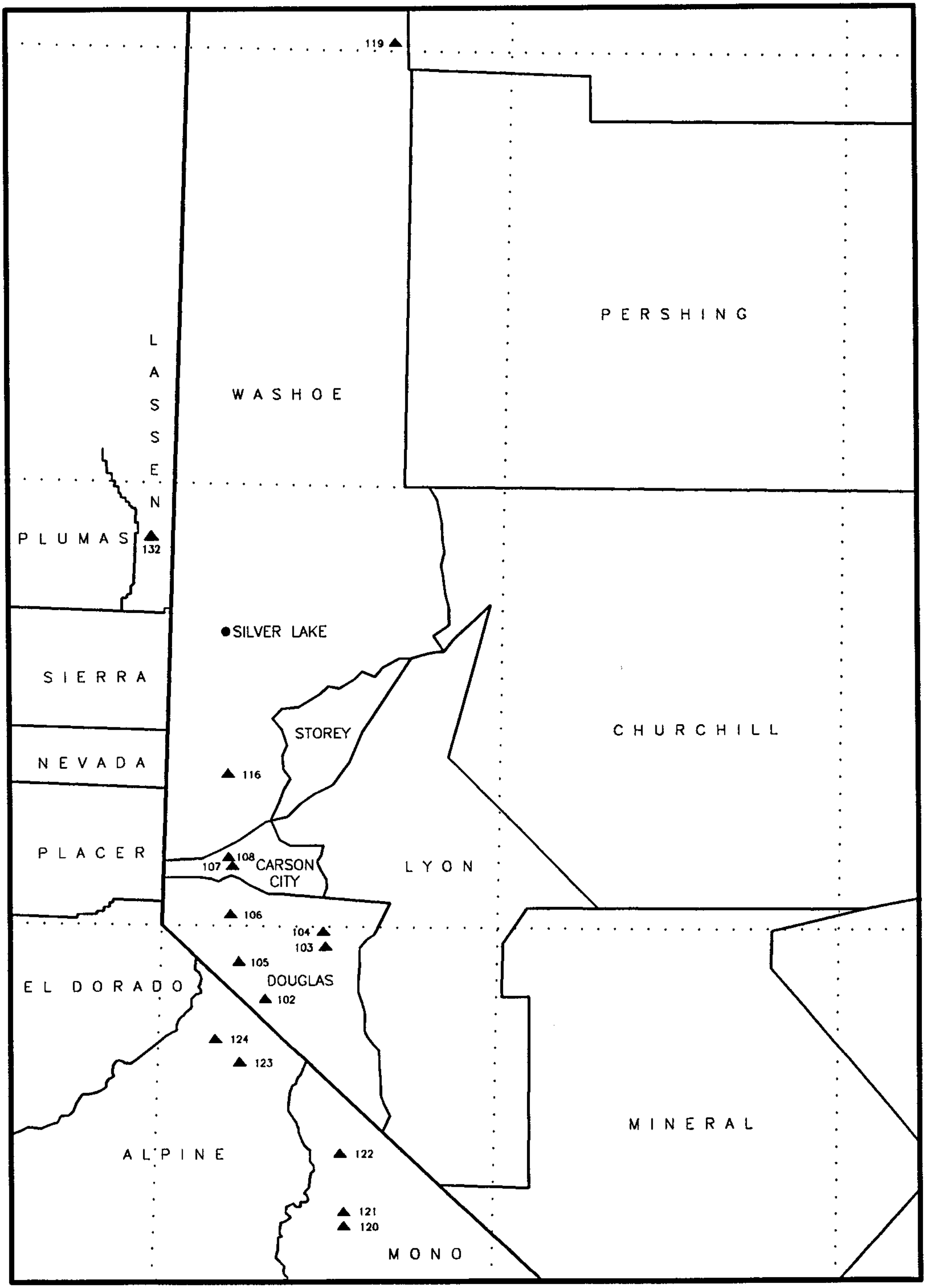
CODE

█ = COMPLETE RECORD FOR THE WATER YEAR

X = INCOMPLETE RECORD FOR THE WATER YEAR

.po1.00"

Figure 3



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The mean is the average value of the logarithms of the average discharge for any particular month and is a measure of the central tendency of the data. The standard deviation is a measure of the dispersion of the data. The skew is a measure of how symmetrically or unsymmetrically the actual data is distributed with respect to the mean. A zero value for skew indicates that the data is distributed symmetrically. The skew can be positive or negative. The lag one serial correlation coefficient is a measure of how persistent the runoff is from month to month. It has been discovered that a persistence does exist in the hydrology of a region, i.e., wet months tend to follow wet months and dry months tend to follow dry months. The lag one serial correlation coefficient can vary from zero (no persistence) to one (absolute persistence).

The lag one correlation coefficient is usually not normally distributed but the following transformed correlation coefficient (Draper and Smith, *Applied Regression Analysis*, Second Edition, Wiley-Interscience, 1981, page 46) is:

$$R = 1/2 \ln((1+r)/(1-r)) \tag{1}$$

where: R is the transformed correlation coefficient for any month, and r is the computed lag one correlation coefficient.

Therefore, each lag one correlation coefficient for each month for each of the stations was transformed using Equation 1. After all the regression analyses were completed, the transformed correlation coefficient was subject to the following inverse transform to return to the physical space of the lag one serial correlation coefficient:

$$r = (\exp(2R) - 1)/(\exp(2R) + 1) \tag{2}$$

where: R and r have the same definitions as in Equation 1.

Because Silver Lake has no discharge records, the statistical analysis was performed on the 15 nearby stations which were thought to be somewhat similar meteorologically and hydrologically to the Silver Lake watershed. Table 4 shows the statistics for each month for each of the fifteen stations. Note that station 132 only shows the mean and standard deviation. The skew coefficient and the lag one serial correlation coefficient are not shown. This is due to the fact that station 132 only had three complete years of record and three months had four years of record. There are not enough values to compute the skew and the lag one serial correlation coefficient. While the mean and standard deviation are weak with only three or four years of record, it was felt that this station's statistics should be used as it is the closest station to the Silver Lake watershed and even though it drains to the west rather than to the Great Basin, its watershed is oriented in a similar manner to that of Silver Lake so that even though the data was limited, this station could make a positive contribution to predicting the statistics at Silver Lake. (Where no value for "Increment" is shown in Table 4, the value of the increment for all months is 0.1 cfs.)

The statistical information shown in Table 4 is based on a logarithmic transformation of the average daily flow for each of the twelve months of the water year. The first month in the water year as shown in Table 4 is October - the tenth month of the calendar year. The actual data from the WATSTORE system is shown in Appendix A.

Note that in Table 4 the skew values vary widely but are generally positive. Also note that the lag one serial correlation coefficient varies somewhat but that almost 60 percent of the 168 shown values are in excess of 0.8 - a rather high value; thus indicating that persistence is rather strong in the region particularly the persistence of little or no runoff during the summer months and those of early autumn.

TABLE 4

MONTHLY STATISTICS FOR THE FIFTEEN FINAL STATIONS

STA	STATISTIC	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
102	MEAN	1.898	2.014	2.079	2.136	2.235	2.387	2.743	3.023	2.907	2.438	2.061	1.895
	STD DEV	.183	.267	.312	.297	.255	.211	.184	.200	.287	.326	.234	.229
	SKEW	.455	1.539	1.325	.489	.708	.017	-.346	-.933	-.459	.193	.295	-.136
	LAG1	.892	.658	.713	.757	.640	.668	.547	.565	.819	.957	.949	.943
	INCRMT	.86	1.33	1.67	1.73	2.07	2.71	5.96	11.45	9.68	3.59	1.32	.89
	YEARS	59	59	59	60	60	60	60	60	61	62	62	62
103	MEAN	-.167	.050	.034	.002	.178	.248	.284	.187	-.029	-.290	-.366	-.372
	STD DEV	.276	.316	.258	.231	.276	.333	.259	.365	.376	.443	.494	.238
	SKEW	.225	.980	.736	-.148	1.032	1.297	.322	1.018	1.194	1.846	2.526	.677
	LAG1	.916	.835	.905	.954	.576	.559	.696	.887	.962	.851	.843	.878
	YEARS	11	11	11	11	11	11	12	12	12	12	12	12
104	MEAN	-.566	-.611	-.569	-.572	-.167	-.210	-.213	-.325	-.497	-.645	-.661	-.628
	STD DEV	.263	.278	.350	.333	.651	.687	.613	.533	.465	.377	.463	.315
	SKEW	-.527	1.142	1.303	1.249	.721	.780	.372	.916	1.328	1.340	2.002	.530
	LAG1	.591	.831	.927	.763	.514	.618	.638	.723	.890	.242	.249	.662
	YEARS	11	11	11	11	11	11	12	12	12	12	12	12
105	MEAN	.876	1.487	1.734	1.927	2.032	2.126	2.277	2.735	2.563	1.766	.707	.544
	STD DEV	.824	.827	.707	.687	.629	.628	.699	.599	.747	.933	.739	.679
	SKEW	.649	-.131	-.264	-.868	-1.033	-1.982	-1.659	-1.886	-1.209	-.253	1.386	.662
	LAG1	.831	.800	.940	.730	.760	.622	.599	.859	.830	.918	.896	.944
	INCRMT	.36	1.01	1.40	1.81	2.05	2.18	3.47	8.49	7.53	2.36	.29	.12
	YEARS	10	10	10	10	10	10	11	11	11	11	11	11
106	MEAN	.165	.268	.232	.292	.288	.318	.339	.420	.343	.229	.147	.131
	STD DEV	.173	.155	.136	.145	.140	.115	.111	.185	.263	.278	.279	.207
	SKEW	.800	.282	.547	-.293	.691	.033	.141	-.264	.201	.456	1.327	.859
	LAG1	.710	.804	.832	.583	.526	.659	.621	.730	.893	.925	.901	.869
	YEARS	19	20	20	20	20	20	20	19	19	19	19	19
107	MEAN	.165	.156	.121	.172	.297	.267	.223	.132	.194	.181	.146	.133
	STD DEV	.310	.299	.285	.213	.268	.241	.278	.290	.400	.398	.383	.328
	SKEW	.329	.434	.510	.682	.565	.236	.336	.348	.340	.270	.331	.162
	LAG1	.954	.961	.921	.905	.751	.924	.879	.913	.947	.989	.991	.988
	YEARS	14	14	14	13	13	13	13	13	14	14	14	14
108	MEAN	.377	.424	.428	.444	.482	.526	.585	.651	.572	.386	.305	.303
	STD DEV	.211	.197	.174	.151	.196	.167	.159	.269	.355	.342	.299	.253
	SKEW	.745	.940	.961	.622	.953	.845	.359	.535	.805	.797	.746	.672
	LAG1	.983	.935	.983	.855	.799	.885	.893	.919	.985	.990	.989	.982
	YEARS	15	15	15	15	15	15	15	15	15	16	16	16

TABLE 4 CONTINUED

STA	STATISTIC	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
116	MEAN	.811	.469	.196	.200	.179	.282	.764	1.247	1.347	1.088	.894	.808
	STD DEV	.198	.374	.465	.410	.421	.387	.259	.194	.319	.348	.269	.208
	SKEW	.268	-.277	.501	.251	.550	.945	-.354	.124	.125	.403	.537	.301
	LAG1	.905	.732	.696	.654	.704	.676	.409	.317	.757	.900	.943	.942
	YEARS	30	30	30	30	30	30	30	30	30	30	30	30
119	MEAN	-.918	-.852	-.755	-.475	-.048	.006	-.213	-.310	-.537	-.836	-.962	-.975
	STD DEV	.191	.340	.482	.609	.772	.667	.558	.535	.401	.179	.079	.055
	SKEW	2.742	2.715	2.840	1.079	.366	.318	.211	.457	.994	.656	2.467	2.382
	LAG1	.755	.580	.946	.474	.846	.877	.919	.920	.757	.900	.943	.942
	YEARS	18	18	18	18	18	18	18	18	18	18	19	19
120	MEAN	1.276	1.305	1.300	1.289	1.310	1.386	1.666	2.032	2.185	1.882	1.492	.551
	STD DEV	.168	.174	.209	.178	.172	.155	.183	.239	.238	.367	.315	.361
	SKEW	-.021	.619	1.193	.341	.767	.302	-.078	-.693	-.596	-.280	.005	-.851
	LAG1	.022	.782	.757	.755	.762	.702	.362	.734	.803	.931	.943	.942
	INCRMT	.20	.22	.23	.21	.22	.26	.50	1.22	1.73	1.03	.39	.10
	YEARS	43	43	42	42	42	42	42	42	42	42	42	42
121	MEAN	1.701	1.755	1.765	1.771	1.825	1.971	2.434	2.846	2.919	2.530	2.048	1.793
	STD DEV	.214	.252	.274	.242	.215	.200	.185	.182	.239	.387	.322	.257
	SKEW	.223	1.436	1.252	.331	.549	.026	-.376	-.879	-.709	-.276	.253	.085
	LAG1	.865	.707	.704	.828	.842	.696	.395	.406	.706	.935	.960	.939
	INCRMT	.56	.70	.74	.69	.75	1.03	2.92	7.51	9.35	4.72	1.46	.73
	YEARS	53	53	53	53	53	53	54	54	54	54	54	54
122	MEAN	1.770	1.795	1.770	1.776	1.847	2.020	2.437	2.849	2.906	2.507	2.048	1.819
	STD DEV	.222	.211	.209	.212	.198	.196	.174	.184	.274	.396	.331	.260
	SKEW	.354	.581	.844	.536	.908	.264	-.192	-.758	-.981	-.440	-.065	-.038
	LAG1	.912	.804	.816	.825	.834	.695	.509	.363	.686	.939	.957	.937
	INCRMT	.67	.70	.66	.67	.78	1.15	2.92	7.58	9.36	4.50	1.46	.78
	YEARS	57	57	57	57	57	58	58	58	58	58	58	58
123	MEAN	1.858	1.974	2.041	2.125	2.206	2.364	2.646	2.990	2.886	2.421	2.078	1.877
	STD DEV	.246	.284	.295	.320	.311	.244	.250	.242	.330	.372	.268	.285
	SKEW	.332	.796	1.181	.342	.782	.113	-1.489	-.771	-.392	.209	.127	-.402
	LAG1	.915	.740	.751	.707	.777	.713	.388	.225	.872	.963	.968	.921
	INCRMT	.84	1.18	1.44	1.73	2.12	2.68	4.99	11.04	9.75	3.72	1.43	.90
	YEARS	31	31	31	31	31	31	31	31	31	31	31	32
124	MEAN	1.375	1.491	1.526	1.562	1.609	1.769	2.257	2.493	2.279	1.857	1.576	1.396
	STD DEV	.185	.269	.317	.271	.266	.234	.209	.241	.305	.303	.239	.241
	SKEW	.160	1.717	1.511	.594	.963	.228	-.834	-.715	-.072	.365	.298	.034
	LAG1	.815	.680	.725	.802	.814	.660	.540	.297	.876	.963	.927	.921
	INCRMT	.26	.40	.48	.45	.50	.68	1.98	3.52	2.37	.92	.44	.29
	YEARS	53	53	53	53	53	53	53	53	53	53	53	53
132	MEAN	-.106	.244	.726	.512	.669	1.218	.794	.456	-.128	-.207	-.343	-.282
	STD DEV	.500	.350	.150	.160	.360	.420	.400	.180	.290	.080	.070	.270
	YEARS	3	3	3	4	4	3	3	3	3	3	3	3

The statistics shown in Table 4 are those for the actual recorded data for each of the twelve months in the water year for each of the fifteen stations. A correlation study could have been done to try to extend the period of record of some of the stations with short periods. However, this was not done because it was felt that the use of correlation while it serves to extend the periods of record also seems to tend to somewhat homogenize the data and to eliminate or mask the individuality of the separate records. So, even though some of the records are short (one at 3 years, one at 10 years, 2 at 11 years, one at 14 years, one at 17 years and one at 18 years) the statistics were used as computed and no attempt was made to extend the shorter records by means of correlation studies.

4. Regression Analyses

The second step in the five step stochastic hydrology process was to perform regression analyses to relate statistical parameters to measurable watershed parameters. This analysis was done utilizing a standard statistical package for the DOS-based personal computer. The name of the package was "Microstat-II", an interactive statistical software system produced by Ecosoft, Inc. of Indianapolis, Indiana. This package was selected because it was described as very user friendly, and had both stepwise regression and multiple regression functions. This system was purchased specifically to do the regression analysis on the Silver Lake stochastic hydrology assignment. While the Microstat-II program did not list non-linear regression as a potential, this was not considered a drawback because it was felt that simple transforms of the data could in effect accomplish the non-linear regression and because it was believed that the linear portion of any regression would probably account for most of the relationship between statistics and watershed parameters.

This section of the report will describe the watershed parameters initially considered for the regression analysis and will discuss the final parameters selected. Determining the best fit equations for use in the Silver Lake area and determining the root mean square error of each regression equation is step three in the five step process. This step will be described in this section. The best fit equations and the error bounds are both important in the stochastic hydrology process for they will form the basis for the risk analysis completed as an integral part of determining the 100-year water surface elevation of Silver Lake.

4.1 Parameters Considered and Parameters Selected

The watershed parameters considered initially were: drainage area, elevation at the gage, latitude of the gage, longitude of the gage, elevation of the centroid of the watershed, latitude of the centroid, and longitude of the centroid. Note that a commonly used parameter - rainfall - is not among the item listed. This omission was done purposefully because of the uncertainty in the rainfall amounts shown in the NOAA atlas for Nevada. The investigative work done by Nimbus Engineers for the 1987 report on the hydrology of Silver Lake indicated that the local weather service personnel did not possess sufficient confidence in the NOAA atlas for Nevada for it to be used as a basis for selecting watershed parameters which represented the meteorology of any particular watershed. While experience indicates that rainfall is a very important parameter in regression analyses dealing with flood hydrology or water supply hydrology, it was felt that the elevation parameter could serve as a reasonable surrogate for the rainfall. This "substitution" was felt to be reasonable because the rainfall in this area is strongly influence by orographic effects during the wet winter and spring months and the stations selected for use in the regression analysis were all located along the eastern slopes of the Sierra Nevada range. Thus the rainfall parameter should be adequately represented by an elevation parameter. Note that while the substitution is believed to provide an acceptable basis for the regression analysis it would be preferable to have rainfall maps which meteorologists agree do represent the rainfall regimes in the various portions of Nevada. While such maps are long overdue, the paucity of rainfall data in the state, however, indicates that such maps may not be developed in the near future.

Forty eight Microstat-II data files were set up for the multiple regression function. There was a data file for each of the twelve months for each of the four statistics being investigated.

The regression analysis showed that the longitude parameters did not significantly assist in developing predictive equations for the statistics. This was probably because the fifteen stations were restricted to a relatively narrow strip along the eastern slopes of the Sierra Nevada range. Thus both longitude parameters were eliminated leaving just five parameters to consider.

The two latitude parameters were the next two eliminated as they did not contribute a significant amount to the goodness of fit of the regression. Apparently it did not matter too much just were the station was located in a north to south direction as long as it was on the eastern slopes of the Sierra Nevada range. It is belived that this conclusion to disregard longitude comes about partly because of the paucity of data in the areas north of Silver Lake. Most of the remaining stream gage stations are located to the south of Silver Lake in a relatively narrow band of longitude. Many people believe that there is more precipitation in the watersheds of the southern stations than in the watersheds of the northern stations including Silver Lake. The regression analysis did not turn up any such correlation and thus the differences in precipitatation and thus in runoff from north to south will have to remain a point of argument.

Of the three parameters left, the station elevation was next eliminated as it did not contribute a significant amount to the goodness of fit. This left just two parameters - drainage area and elevation of the centroid of the watershed. This was not too surprising as most stochastic hydrology regression equations in the far west utilize just three parameters - drainage area, a rainfall indicator, and an elevation indicator. As rainfall was eliminated due to the lack of maps which meteorologists consider adequate for the local area, this left only two parameters - drainage area and elevation.

When the regression depend upon only one parameter - drainage area, the goodness of fit decreased thus confirming that two parameters provided the best fit of the data.

4.2 Results - Best Fit Coefficients and Intercept and Root Mean Square Error

The results of the regression analysis are shown in Tables 5 through 8. Table 5 shows the results for the best fit for the mean of the logarithm (base 10) of the average monthly flows. The "Standard Error" in Table 5 represents the root mean square error of the regression equation's fit to the data points. Hand computations indicated that the Microstat-II computer program was producing a standard error which was consistently 11 percent greater than the root mean square error developed by hand computations. Thus use of the Microstat-II root mean square errors was considered a conservative estimate of the root mean square error and was used in all subsequent computations which required an estimate of the error.

The "coefficients" shown in Table 5 are those from the regression fit for the area (in square miles) and the elevation of the centroid of the watershed (CELEV) in feet. The intercept is the value of the intercept of the linear equation. The coefficients and the intercept allow one to predict the mean at an ungaged site by use of the multiple regression formula. For example the equation for the mean value for the month of October is:

$$\text{October Mean} = -4.04544 + 0.003130644 \times \text{AREA} + 0.000607221 \times \text{CELEV} \qquad (3)$$

TABLE 5

RESULTS OF REGRESSION ANALYSES FOR THE MEAN

MONTH	STANDARD ERROR	COEFFICIENT	INTERCEPT	PARAMETERS	MONTH	STANDARD ERROR	COEFFICIENT	INTERCEPT	PARAMETERS
OCT	0.46828	0.003130644	-4.04544	AREA	APR	0.45623	0.005536921	-3.45814	AREA
		0.000607221		CELEV			0.000566337		CELEV
NOV	0.45564	0.004139637	-3.46768	AREA	MAY	0.54035	0.006257652	-4.43511	AREA
		0.000524709		CELEV			0.000712281		CELEV
DEC	0.47849	0.004784234	-2.88241	AREA	JUNE	0.59959	0.005997294	-5.20493	AREA
		0.000439594		CELEV			0.000808944		CELEV
JAN	0.44368	0.004945129	-2.82914	AREA	JULY	0.58613	0.004882964	-5.06227	AREA
		0.000434591		CELEV			0.000764385		CELEV
FEB	0.36315	0.004926573	-2.32104	AREA	AUG	0.55159	0.003204130	-5.01554	AREA
		0.000381006		CELEV			0.000746339		CELEV
MARCH	0.43127	0.005280878	-2.09445	AREA	SEPT	0.50907	0.003075057	-4.38548	AREA
		0.000360056		CELEV			0.000641114		CELEV

TABLE 6

RESULTS OF REGRESSION ANALYSES FOR THE STANDARD DEVIATION

MONTH	STANDARD ERROR	COEFFICIENT	INTERCEPT	PARAMETERS	MONTH	STANDARD ERROR	COEFFICIENT	INTERCEPT	PARAMETERS
OCT	0.12988	0.000830992	0.81031	AREA	APR	0.16020	0.000474236	0.94456	AREA
		-.000086873		CELEV			-.000093342		CELEV
NOV	0.13430	0.000715563	0.61137	AREA	MAY	0.13982	0.000207955	0.71987	AREA
		-.000053557		CELEV			-.000061964		CELEV
DEC	0.14730	0.000479762	0.38977	AREA	JUNE	0.11379	0.000422307	0.71882	AREA
		-.000018884		CELEV			-.000057364		CELEV
JAN	0.15740	0.000521213	0.48422	AREA	JULY	0.16765	0.000718824	0.27473	AREA
		-.000034124		CELEV			0.000001606		CELEV
FEB	0.18728	0.000274813	0.91025	AREA	AUG	0.16727	0.000397494	0.29375	AREA
		-.000082984		CELEV			-.000002810		CELEV
MARCH	0.18070	0.000292140	0.96678	AREA	SEPT	0.11719	0.000570106	0.36329	AREA
		-.000096508		CELEV			-.000020683		CELEV

TABLE 7

RESULTS OF REGRESSION ANALYSES FOR THE SKEW

MONTH	STANDARD ERROR	COEFFICIENT	INTERCEPT	PARAMETERS	MONTH	STANDARD ERROR	COEFFICIENT	INTERCEPT	PARAMETERS
OCT	0.70638	0.000334777	3.05137	AREA	APR	0.49527	-.002876067	1.60919	AREA
		-.000355234		CELEV			-.000209518		CELEV
NOV	0.84617	-.000547182	0.65762	AREA	MAY	0.51670	-.004661879	1.45592	AREA
		0.000043066		CELEV			-.000160159		CELEV
DEC	0.73501	-.001349050	0.62819	AREA	JUNE	0.53485	-.004116876	2.15735	AREA
		0.000075801		CELEV			-.000224279		CELEV
JAN	0.54542	-.001504760	0.38896	AREA	JULY	0.56447	-.002484752	1.44527	AREA
		0.000020977		CELEV			-.000106938		CELEV
FEB	0.39762	-.002472644	-0.89723	AREA	AUG	0.79328	-.000992258	4.70413	AREA
		0.000243371		CELEV			-.000506260		CELEV
MARCH	0.51226	-.004491854	-0.91365	AREA	SEPT	0.58744	-.000501807	4.22718	AREA
		0.000227257		CELEV			-.000519892		CELEV

TABLE 8

REGRESSION ANALYSIS RESULTS FOR TRANSFORMED LAG ONE COEFFICIENT

MONTH	STANDARD ERROR	COEFFICIENT	INTERCEPT	PARAMETERS	MONTH	STANDARD ERROR	COEFFICIENT	INTERCEPT	PARAMETERS
OCT	0.60199	0.000318485	1.41181	AREA	APR	0.29081	-.000553128	2.85943	AREA
		-.000022374		CELEV			-.000274324		CELEV
NOV	0.34157	-.000556142	1.96290	AREA	MAY	0.36971	-.000163893	3.81073	AREA
		-.000106650		CELEV			-.000394442		CELEV
DEC	0.31473	0.000103293	4.13214	AREA	JUNE	0.44559	-.000977276	2.21714	AREA
		-.000385306		CELEV			-.000100914		CELEV
JAN	0.35967	-.000166438	0.48502	AREA	JULY	0.67133	-.000072860	0.62889	AREA
		0.000083151		CELEV			0.000140016		CELEV
FEB	0.25386	0.000078750	0.60165	AREA	AUG	0.68614	-.000428932	0.01369	AREA
		0.000047473		CELEV			0.000235003		CELEV
MARCH	0.27945	-.000659774	1.66293	AREA	SEPT	0.68334	0.000800373	1.22377	AREA
		-.000087062		CELEV			0.000029475		CELEV

The standard error of estimate of this equation is 0.46828. This means that if the predicted mean value for October is -0.8 (recall that there has been a logarithmic transformation of the average monthly flows so that negative numbers are acceptable) that value is good to plus or minus 0.46828 approximately 67 percent of the time. This indicates that the underlying assumption on the error bound is that it is normally distributed. This assumption allows the use of random number generators to produce normally distributed random values. The concept of these random numbers and the use they will play in the risk analysis will become clearer in the next section where the application of these regression results to Silver Lake will be discussed.

Tables 6, 7 and 8 show the regression results for the standard deviation, the skew and the transformed lag one serial correlation coefficient. Note that the standard error for the standard deviation is quite low whereas for the lag and the transformed lag one coefficient the standard errors are much higher and indicate that the regression equations produced less precise predictive tools.

A graphical view of the data and its trends is shown in Appendix B. In that appendix the raw data is plotted for each statistic for each month against first of all drainage area in square miles and then against elevation of the centroid of the watershed. The data relationship is plotted in the lower left hand portion of the graphs. This was done so that is would be slightly easier to see the straight line trend of the data.

With the regression equations in place it is now possible to predict the four statistics for each month of the year for any watershed in the region with only two physical parameters: the drainage area, and the elevation of the centroid of the watershed.

5. Application To Silver Lake

The regression equations described in the preceding section were next applied to the Silver Lake watershed. However, the HEC-4 model results only produced a theoretically possible monthly average inflow to Silver Lake over a given period of time. This series of inflows needed to be converted into a monthly lake level elevation. The complete model used to determine the monthly lake levels is described in this section. Included in the discussion are how the model handled evaporation from the lake surface and how the model accounted for runoff from the urban area surrounding the lake.

5.1 Input-Output Model

A model which accounted for the inflow to Silver Lake during each month and the outflow from Silver Lake during each month was conceptualized. This simple model assumed that the only inflow to the lake was the average monthly runoff obtained from the HEC-4 model and the runoff from the impervious area surrounding the lake as well as rainfall which fell directly on the surface of the lake. The outflow from the lake was only attributed to evaporation. Gains or losses between the lake and groundwater basin were ignored. This was done because previous work done by the US Geological Survey indicated that there might be an impermeable barrier not far below the bottom of the lake. This barrier would prevent the efficient transfer of water between the lake and the groundwater basin.

The mean monthly evaporation was estimated by utilizing data from *The Water Encyclopedia* (Lewis Publishers, Second Edition, 1990). The average annual evaporation at Silver Lake was estimated at 55.5 inches. The monthly distribution of that 55.5 inches is shown below and is based on the monthly distribution at Salt Lake City, Utah which as a mean annual evaporation of 55.5 inches and was the nearest evaporation station listed in *The Water Encyclopedia* believed to be representative of Silver Lake.

The monthly evaporation amounts for Silver Lake are:

October = 3.9"; November = 2.0"; December = 1.0"; January = 0.8"; February = 1.0"; March = 2.0";

April = 3.5"; May = 5.1"; June = 7.9"; July = 10.6"; August = 10.4"; September = 7.3".

The average evaporation was applied to the lake surface each month. The average evaporation in inches was multiplied by the surface area of the lake at the beginning of the month to estimate the loss of water from Silver Lake to the atmosphere due to evaporation. No variation was allowed in the model, *i.e.*, only the average evaporation was applied each month. This assumption was believed to be warranted because evaporation is believed to be rather stable with a fairly low standard deviation.

The HEC-4 model provided mean monthly inflows to Silver Lake from the pervious portions of the watershed. There was no accounting for the additional runoff which would come from impervious portions of the watershed. The regression model was based on drainage area and as the drainage basins utilized in the regression were located in sparsely populated areas, there was little or no runoff from impervious area included in the mean monthly runoff values. Because the Silver Lake watershed has approximately 728 acres of impervious area both existing and planned, it was felt that an additional inflow due to the increased runoff from this 728 acres should be accounted for. This was done by using the logic which is explained below.

The mean monthly runoff from HEC-4 was estimated from the entire Silver Lake watershed area - including both pervious and impervious areas. Added to this monthly inflow was an additional inflow due to rain which fell directly on the lake surface and runoff from the 728 acres of impervious surface. The average monthly rainfall was multiplied by the 728 acres and also by the surface area of the lake at the beginning of the month to estimate the additional inflow.

The monthly precipitation was obtained from data recorded in North East Lemmon Valley at 11845 Mistletoe, Section 15, T21N, R19E, Lot 6, block 12, Hepner Subdivision #3, Elevation 4,938 feet. The data covered the period from January 1975 to May of 1992. The seventeen plus years of data consisted of daily precipitation values including both rainfall and snowfall depths each day.

The mean annual precipitation for the rain gage was approximately 8.5 inches when averaged over the 17 complete years of record. The monthly average precipitations were:

October = 0.37"; November = 1.12"; December = 0.91"; January = 1.00"; February = 1.35";

March = 0.76"; April = 0.43"; May = 0.38"; June = 0.55"; July = 0.43"; August = 0.47"; September = 0.72"

Even though the procedure of using average monthly precipitation to determine additional runoff from the lake surface and the impervious area would understate the runoff during wetter than normal months it would overstate it during drier than normal months. It was felt that this procedure would provide that little additional runoff which would make the results a little bit more conservative without attempting to correlate monthly rainfall amounts with monthly runoff amounts.

The elevation-area-volume relationship was developed from topographic maps of the lake area. Two maps were spliced together to form the base map shown in Plate 1 located in the pocket at the end of this report. The first set of maps used was done by Millard Spink Associates, Inc. from aerial photography dated July 15, 1968. These maps were at a scale of 1"=200' with contour intervals of 5 feet. The second map was the 7.5 minute USGS quadrangle for Reno NW. The topography for that map was done in 1966 and 1967. The planimetric features on the map were updated in 1982.

As can be seen in Plate 1, the maps fit together fairly well. The extrapolations of the 4955, 4960, 4965 and 4970 contours are shown as dotted lines on Plate 1. The USGS quadrangle sheet indicated that the ridge line between Silver Lake and Lemmon Lake was approximately 4970 to 4975. The elevation-area-volume relationship shown below assumed that the dividing line between the two lakes had a wall at least as high as elevation 5000 so that flood waters from the watershed of one of the lakes could not mingle with those generated in the other watershed. The resulting elevation-area-volume relationship was:

Elevation (Feet)	Area (Acres)	Volume (Acre-feet)
4952	0	0
4955	248	372
4960	652	2,622
4965	1,141	7,106
4970	1,403	13,465
4980	2,199	31,473
5000	3,450	59,716

The computer code used to generate the monthly lake levels was written in Fortran and was named SLAKE. The code itself is shown in Appendix C. The program took HEC-4 output as its basic input, added the inflow volume due to monthly rainfall, subtracted the outflow due to monthly evaporation, and, given the lake elevation at the start of the month, computed the lake elevation at the start of the next month. The SLAKE program's output consisted of the monthly inflow, monthly runoff from impervious area and lake surface, monthly evaporation and new lake level. The program also output the maximum lake level for each water year into a separate file for subsequent statistical analysis.

The statistical analysis was done with a computer program named TWOSTA. The code for this Fortran program is located in Appendix D. The TWOSTA program took the annual lake level maxima and did a plotting position analysis on the information. While the median plotting position was used to determine the 100-year flood elevation, any statistical plotting position formula would have produced essentially identical results because each HEC-4 run simulated 2,000 years of record. Determining the 100-year water level given 2,000 years of record is not a difficult assignment and any plotting position formula would give very similar results. There was no need to utilize the log-Pearson III equations or the Pearson III equations or any other popular frequency curve equation. The plotting position formula gave acceptable results.

Thus the procedure that was followed included: 1) running HEC-4 with a series of statistical parameters for each of the four statistics for each of the twelve months and simulating 2,000 years of record; 2) using the monthly inflows from HEC-4 and running them through the SLAKE program to produce monthly lake levels and annual maxima for the 2,000 years of simulated record; and 3) performing a statistical plotting position computation on the 2,000 annual maxima to determine the 100-year lake level.

5.2 Best Fit Results Using HEC-4

The two physical parameters of watershed drainage area in square miles and the elevation in feet at the centroid of the watershed were sufficient to determine all four of the statistics for each of the twelve months. The drainage area for the Silver Lake watershed is 34,112 acres or 53.3 square miles. The elevation of the centroid is 5,060 feet. Both parameters were determined by using 7.5 minute USGS quadrangle sheets.

There has been some concern voiced by local land owners that major portions of the upper watershed are themselves closed basins and would not contribute runoff to Silver Lake. A watershed reconnaissance was conducted via automobile and no conclusive evidence of the non-contributory nature of portions of the upper watershed could be found. While some of the slopes in the upper watershed are surprisingly flat, there does appear to be a positive slope down toward Silver Lake in the vast majority of major drainages viewed.

The four statistics for each of the twelve months were determined from using the above two physical parameters together with the regression coefficients and intercepts shown in Tables 5 through 8 in equations like Equation 3 shown on page 16. The forty eight statistics are presented in Table 9.

These statistics were input to HEC-4 and 2,000 years of record were simulated. The HEC-4 output is shown in Appendix E. The SLAKE program was run with the HEC-4 output and the results are shown in Appendix F. The SLAKE results were used as input to the TWOSTA program and the results of that statistical analysis program are shown in Appendix G.

The statistical results in Appendix G show that the 100-year water surface elevation in Silver Lake is 4960.1 feet. This is the best estimate provided by the regression analysis and the HEC-4 simulation of 2,000 years of record. Note that the statistical plotting position analysis in Appendix G shows that the largest annual maximum was 4962.8 feet; the 50-year water surface elevation was 4956.3 feet; and the 2-year water surface elevation was 4955.5 feet. The maximum elevation of 4961.9 feet recorded in May of 1986 would translate into a approximately a 500-year event using these statistics in Appendix G.

While 4960.1 may be the best estimate from the regression-simulation analysis, there are estimation errors associated with the regression analysis. These estimation errors may have a significant effect on the best estimate of the 100-year water surface elevation. The next section will discuss the errors and will present a procedure whereby these estimation errors may be considered in the final estimate of the 100-year water surface elevation of Silver Lake.

TABLE 9

SILVER LAKE WATERSHED STATISTICS

BASED ON REGRESSION EQUATIONS

Month	Mean	Standard Deviation	Skew	Lag One Coeff.
October	-0.8060	0.4150	1.2717	0.8657
November	-0.5920	0.3785	0.8464	0.8840
December	-0.4031	0.3198	0.9398	0.9752
January	-0.3665	0.3393	0.4149	0.7148
February	-0.1306	0.5050	0.2024	0.6890
March	+.0089	0.5100	-.0031	0.8297
April	-0.2974	0.4815	0.3957	0.8941
May	-0.4974	0.4174	0.3970	0.9474
June	-0.7920	0.4511	0.8031	0.9295
July	-0.9342	0.3212	0.7717	0.8701
August	-1.0683	0.3007	2.0896	0.8290
September	-0.9775	0.2890	1.5698	0.8887

5.3 Error Analysis

The regression analysis done using the Microstat-II computer program not only determined the linear regression coefficients and intercepts, but it also presented the standard error of the regression equation. The standard error is the indicator of how well the regression equation fit the data. The standard error was taken to be equivalent to a standard deviation for purposes of the error analysis. It was assumed that there was no bias in the creation of the regression equations so that the error function of the regression equation results could be expressed by making the error equivalent to that generated by a normal distribution with mean equal to zero and standard deviation equal to the standard error. Thus it could be possible to "sample" from a population of statistics given by the mean being equal to the best estimate and the standard deviation given by the standard error. The sampling would be done from a population that was normally distributed.

With the above assumptions regarding normal distribution of the error and the interpretation of standard error, it was possible to generate sequences of statistics with each new statistic being sampled from its own population based on the best fit parameter and the standard error. In this manner four of the statistics for each month could be resampled to generate a whole new set of statistics for the Silver Lake watershed. In fact, this procedure was used repeatedly to generate 250 new sets of statistics to be used as inputs to HEC-4. The procedure used to generated these new sets of statistics is described in the next few paragraphs.

The HEC-4 computer program has a built-in random number generator. This feature is required because the program generates the monthly average stream flow using the following equation:

$$Q_i = X_i + r_i\,[S_i / S_{i-1}]\,[Q_{i-1} - X_{i-1}] + S_i \sqrt{1 - [r_i^2]}\,[E_i] \qquad (4)$$

where: Q_i = flow during month i

Q_{i-1} = flow during month i-1

X_i = mean for month i

X_{i-1} = mean for month i-1

S_i = standard deviation for month i

S_{i-1} = standard deviation for month i-1

r_i = lag one correlation coefficient for month i

E_i = independent normal variate with mean 0 and variance 1.

The variable "E" in the above equation is determined by the random number generator. This variable attempts to account for the uncertainty that is left over even when all the statistics are used to predict the next month's flow given the previous month's flow. HEC-4 treats this variable as a normally distributed random number with mean equal to zero and standard deviation equal to one. Having the mean equal to zero will assure that no bias will be introduced into the sequence of generated discharges. Having the standard deviation equal to one will preserve important statistical parameters such as standard deviation of the monthly generated flows and the lag one serial correlation coefficient of the generated flows. This means that no matter how many sequences one generates or how long those sequences are, the initial statistics which were used as the basis for the generation will not be improved upon. This just means that one cannot improve upon the statistics from the recorded data without collecting more data. The only thing the HEC-4 generation does is look at the potential of having different sequences of monthly average flows than the one found in the recorded data.

The random number generator in the HEC-4 program was in a sub-routine called RNGEN. This subroutine was pulled out and put into a Fortran program called RANPAR. This program generated monthly statistics each based on the best fit parameter, the standard error and a standard deviate sampled from the normally distributed population with mean equal to zero and standard deviation equal to one obtained from the random number generator. The RANPAR program code is shown in Appendix H as are the results of running the program to generate 250 sets of monthly statistics for the Silver Lake watershed.

The RANPAR program allowed the best estimate of a statistic as the mean value and the random number times the standard deviation as the variation of that particular statistic for the trial in question. For two of the statistics, the procedure had to be varied somewhat. For the standard deviation the program would not allow the resultant standard deviation to fall below 0.01. This limit was required because it was theoretically possible for the resultant standard deviation to be less than zero - a negative number would be meaningless and thus the lower bound was considered necessary. For the lag one correlation coefficient both an upper and a lower limit were required because it was very possible that the RANPAR result could be greater than 1.0 - a meaningless value. Similarly, it was possible that RANPAR would compute a value less than zero - again a meaningless result. Therefore, the upper bound on the lag one serial correlation coefficient was set to 0.99 and the lower bound was set to 0.01.

Before discussing the RANPAR results, it should be noted that the RANPAR program was tested by generating 12,000 random numbers (48 per year times 250 years) and computing the mean and standard deviation of those 12,000 values. The mean of the 12,000 numbers was computed to be -0.0023 and the standard deviation was computed to be 1.0074. These results indicated that the random number generator was performing its function acceptably. The standard deviation was off by less than three quarters of one percent from its expected value and the mean being within 0.0023 of its expected value indicated that very little, if any, bias would be introduced by using the RNGEN generator.

The actual results of the RANPAR program are shown in Appendix H. The results show the set of 48 statistics which are to be read into the HEC-4 program. For each of these 250 sets of input the following procedure was followed: 1) the HEC-4 program was run to simulate 2,000 years of record; 2) the SLAKE program was run to generate a sequence of 2,000 annual maximum lake levels; and 3) the TWOSTA program was run to use the plotting position formula to determine the 100-year lake level.

After running the 250 sets of statistics plus the original, best fit set of statistics, there were 251 estimates of the 100-year water surface elevation in Silver Lake.

6. Results

The 251 sets of statistics (the best fit set obtained from the regression equations as applied to the physical parameters of the Silver Lake watershed and the 250 RANPAR-generated sets) were each separately used as input data for the HEC-4 monthly flow model and 2,000 years of simulated record were generated. These 250 years of monthly average flows into Silver Lake were then input to the SLAKE computer program and the monthly and maximum annual lake elevations were determined. The annual maxima were then input to the TWOSTA program where the 100-year lake elevation was determined based on the median plotting position formula applied to the 2,000 annual maximal values.

The 251, 100-year water surface elevation estimates were then plotted in the form of a histogram as shown in Figure 4. That figure presents the relative frequency of the 100-year water surface elevation being in one foot elevation ranges from 4954 to 5002. The frequency response as shown in Figure 4 is a somewhat skewed bell-like curve which is typical of the response from some type of log-normal distributed population.

The values shown in Figure 4 indicate the number of 100-year water surface elevations which fell in each one-foot elevation range and the percent of those values which were less than (or equal to) the indicated elevation range. For example, twenty of the 251 100-year water surface elevations fell between 4959 and 4960, and there were 16.7 percent of all the values which were less than or equal to elevation 4960.

The median value from Figure 4 was from 4962 to 4963, i.e., half the values were greater than this range and half were less. The arithmetic mean of the 251 values was 4963.96 feet which would be rounded up to 4964. Eighty percent of the 100-year water surface elevation estimates were less than 4966 to 4967 range. An analysis of the eleven values between 4966 and 4967 indicated that the 80 percent limit would be at 4966.2 feet.

The seven values on Figure 4 which were greater than 4979 were investigated to determine why they produced values which were so high. It was found that they were high because the RANPAR program provided both means and standard deviations of some months that were both more than 1.5 standard errors past the best estimate value for the month and usually the standard deviation was in excess of 2.0 standard errors past the best estimate value. These very high estimates combined with the HEC-4 random number generator to produce incredibly large flows during some months.

To illustrate the impact of these combinations of high estimates, two examples will be discussed. The first is from RANPAR set 89. In this set the mean for May was set at 3.28 standard errors beyond the best estimate value. The standard deviation for that month was 2.28 standard errors beyond the best estimate value. HEC-4 generated a number of May's with large inflows but the largest was 3,573 cfs. The second example is from RANPAR set 123. In this set the mean for August was set 2.89 standard errors beyond the best estimate value and the standard deviation was set 1.85 standard deviations beyond the best estimate value. HEC-4 produced one August with an average monthly discharge of 2,344 cfs.

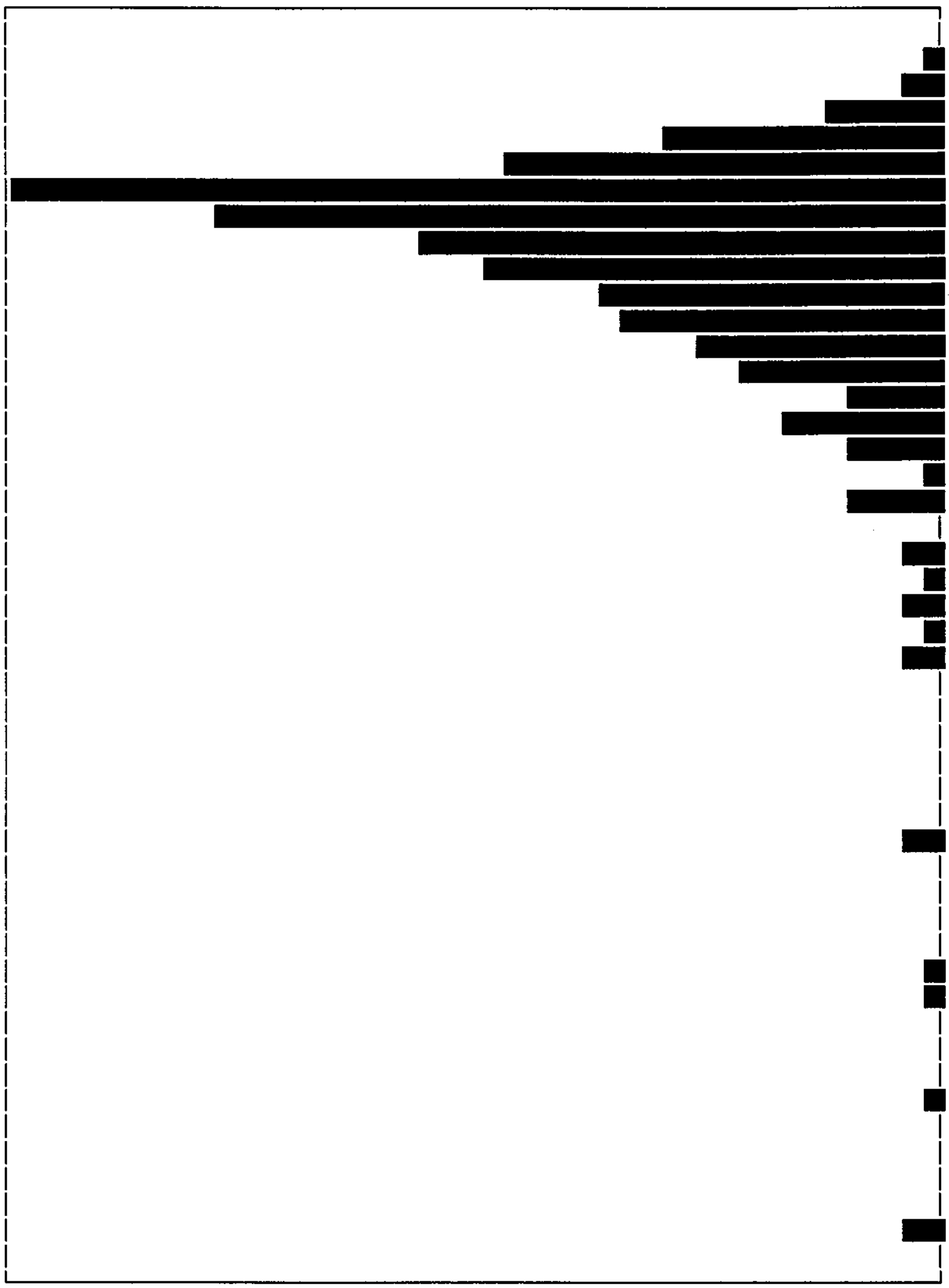
To put these large flows in perspective it must be pointed out that for the 2,000 year simulation using the best fit statistics, the largest monthly average inflow was only about 100 cfs. The 1986 inflow during February would have averaged only 294 cfs for 30 days if the lake was dry on February 1, 1986 and filled to its maximum of approximately 4962 30 days later. Now apparently the lake was not dry on February 1, 1986 and it only reached 4961 in 30 days (see Table 1). The occurrence of 2,000 to 3,500 cfs for 30 days would seem to be extremely unlikely.

These high values in and of themselves were only part of the problem. The problem occurred because the SLAKE computer program which computed lake level at the end of the month could not go beyond the lake area for the 5000-foot elevation. This constrained the maximum elevation at 5000 but constrained the area to be 3,450 acres and thus the volume could not evaporate at more than the monthly average evaporation rate times the 3,450 acres. Now, as 2,000 cfs flowing into Silver Lake for 30 days would generate 120,000 acre feet, this would create an additional 60,000 acre-feet which needed to be evaporated at approximately 5 feet per year over 3,450 acres. Thus without any additional runoff, it would take almost four years to reduce the water level below elevation 5000. Thus, the combinations of high estimates for the mean combined with a high estimate for the standard deviation could lead to extremely high monthly flows generated by HEC-4. These high flows would then create such high inflows that the lake level would need to stay at an elevation of 5,000 feet for many years before evaporation could reduce it further. As the statistical program used the median plotting position formula on the annual maxima, a high value could keep the annual maximum water level up at 5000 for many years

FIGURE 4

DISTRIBUTION OF 100-YEAR WATER SURFACE ELEVATIONS

FREQUENCY OF SILVER LAKE 100-YEAR WATER SURFACE ELEVATIONS



ELEVATION	NO.	% LESS THAN
4954-4955	0	0.0
4955-4956	1	0.4
4956-4957	2	1.2
4957-4958	6	3.6
4958-4959	13	8.8
4959-4960	20	16.7
4960-4961	44	34.3
4961-4962	34	47.8
4962-4963	24	57.4
4963-4964	21	65.7
4964-4965	16	72.1
4965-4966	15	78.1
4966-4967	11	82.5
4967-4968	9	86.1
4968-4969	4	87.6
4969-4970	7	90.4
4970-4971	4	92.0
4971-4972	1	92.4
4972-4973	4	94.0
4973-4974	0	
4974-4975	2	94.8
4975-4976	1	95.2
4976-4977	2	96.0
4977-4978	1	96.4
4978-4979	2	97.2
4979-4980	0	
4980-4981	0	
4981-4982	0	
4982-4983	0	
4983-4984	0	
4984-4985	0	
4985-4986	2	98.0
4986-4987	0	
4987-4988	0	
4988-4989	0	
4989-4990	0	
4990-4991	1	98.4
4991-4992	1	98.8
4992-4993	0	
4993-4994	0	
4994-4995	0	
4995-4996	1	99.2
4996-4997	0	
4997-4998	0	
4998-4999	0	
4999-5000	0	
5000-5001	2	100.0
5001-5002	0	

(BASED ON 251 HEC-4 SIMULATIONS OF 2,000 YEARS EACH) thus adding many 5000 values to the annual maxima data set. The 100-year water surface elevation was between the 19th and 20th largest values in the 2,000 piece data set. Therefore, a long period at 5,000 could easily influence the value of the 100-year water surface elevation.

Because it was felt that these "high outliers" might be biasing the result, it was decided to eliminate the highest seven values, i.e, those beyond 4979 in Figure 4. This elimination did not alter the results significantly. The median value was still between 4962 and 4963 and the arithmetic mean only changed from 4963.9 to 4963.1 feet. The 80 percent less than or equal to value dropped to 4966.0 feet down from the estimate of 4966.2 feet found with all 251 values. Thus while some of the values were extremely large in the 251 data set their presence or absence did not alter the final statistical results to any significant degree.

One final statistical test was performed on the 244 estimates of the 100-year water surface elevation of Silver Lake. A log-Pearson type III analysis was done. This analysis resulted in a mean value of 1.79944, a standard deviation of 0.02747 and a skew of approximately 1.2. The skew value was that of the data with no adjustment for a "regional" skew value. These statistics resulted in the value for the 50 percent less than or equal to being 4962.2 feet, and the 80 percent less than or equal to value being 4966.0 feet.

The results of the statistical analyses indicate that the median or mean estimate of the 100-year water surface elevation in Silver Lake was approximately 4963 feet. Although there was some variation ranging down to 4962.2 and up to 4963.9, the value of 4963 is the best estimate of the 100-year water surface elevation in Silver Lake. This value is four feet below the current estimate of 4967 feet and is two feet below the Schaaf & Wheeler estimate of 1985. The physical situation of Silver Lake, however, leads one to select a 100-year water surface elevation that is somewhat more conservative than the value of 4963 feet.

Because Silver Lake is a closed system, the runoff generated must leave only via the evaporation process. Thus once the lake level rises it will fall rather slowly. Even if it rises rapidly it will still fall slowly. Thus, once an elevation estimate is exceed either due to a weak estimate or due to a more sever runoff event, the additional water level over and above the 100-year level will not dissipate very rapidly. It may take weeks or months for the water to recede causing the potential for additional flood damage and at the very least restricting access to the structures built in the flooded area.

Even though the best estimate for the 100-year water surface elevation of Silver Lake would be in the approximately 4963 feet, it was considered better to select the 100-year water surface elevation of Silver Lake which would be used to regulate building in the area somewhat greater than this best estimate value. The owners of the property, while obviously believing that the 4963 value is the best estimate, would be more than willing to accept the 4965 value which was first proposed by Schaaf & Wheeler in 1985 because a lot of preliminary planning has already been done using the 4965 elevation. In addition, the engineers at the Department of Public Works in the City of Reno have stated that the City would not be comfortable with an elevation lower than 4965. Therefore, a value of 4965 as the regulatory 100-year water surface elevation is recommended.

The 100-year regulatory elevation in Silver Lake would provide two feet of freeboard above the best estimate elevation of 4963. Using the risk analysis approach, adopting the elevation of 4965 would provide an approximately 75 percent chance that the "true" 100-year lake elevation was less than or equal to 4965.

The 4965 value is recommended to FEMA to be used for purposes of revising the current Flood Insurance Rate Maps. It is a value which is conservative but not overly so and which is based on a sophisticated statistical procedure coupled with a standard streamflow generation procedure supplied by the US Army Corps of Engineers. It is a value which is believed to be more defendable than the present value of 4967 feet.

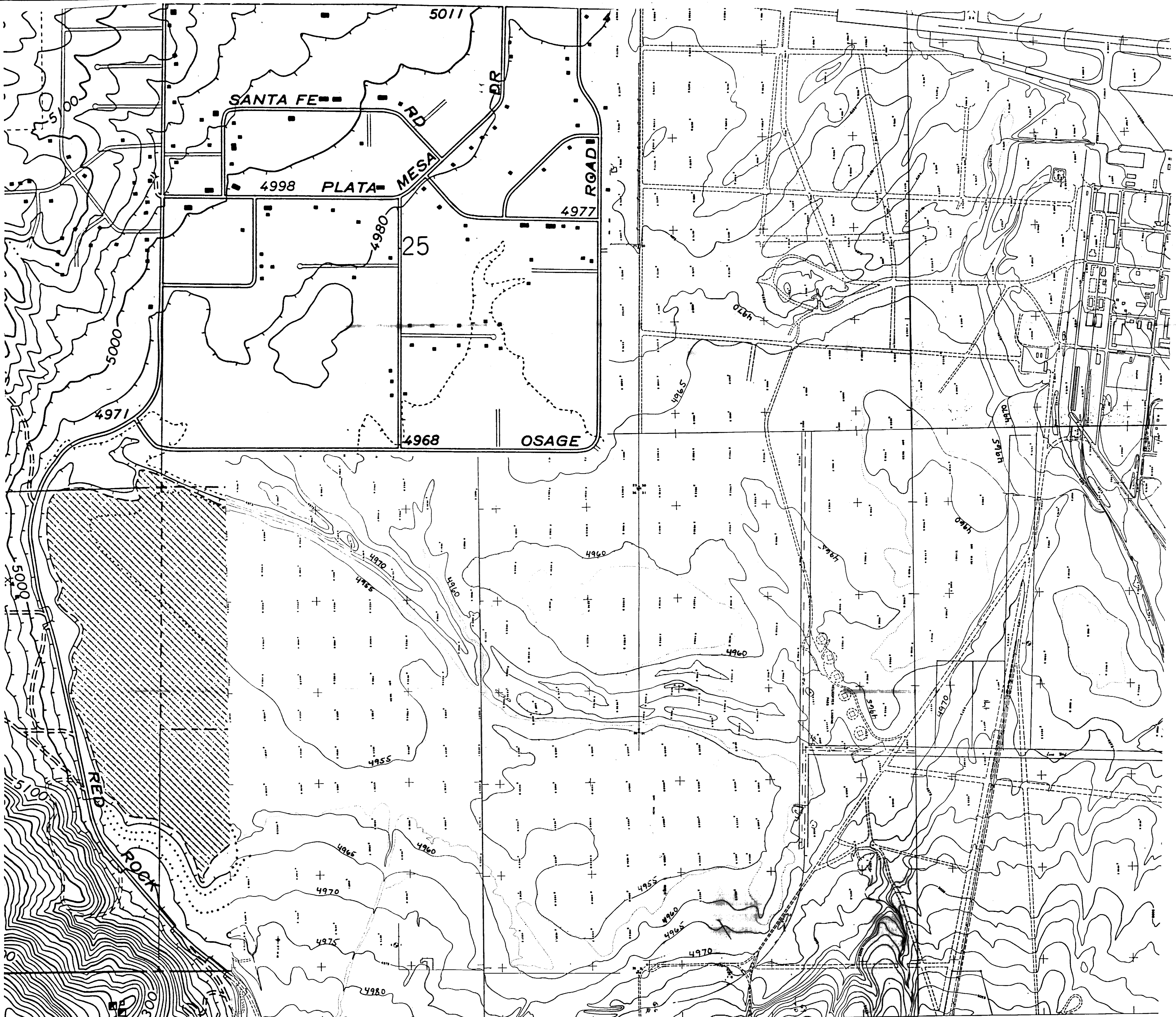


PLATE 1

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SILVER LAKE TOPOGRAPHY

SCALE 1" = 500'
500 0 500 1000