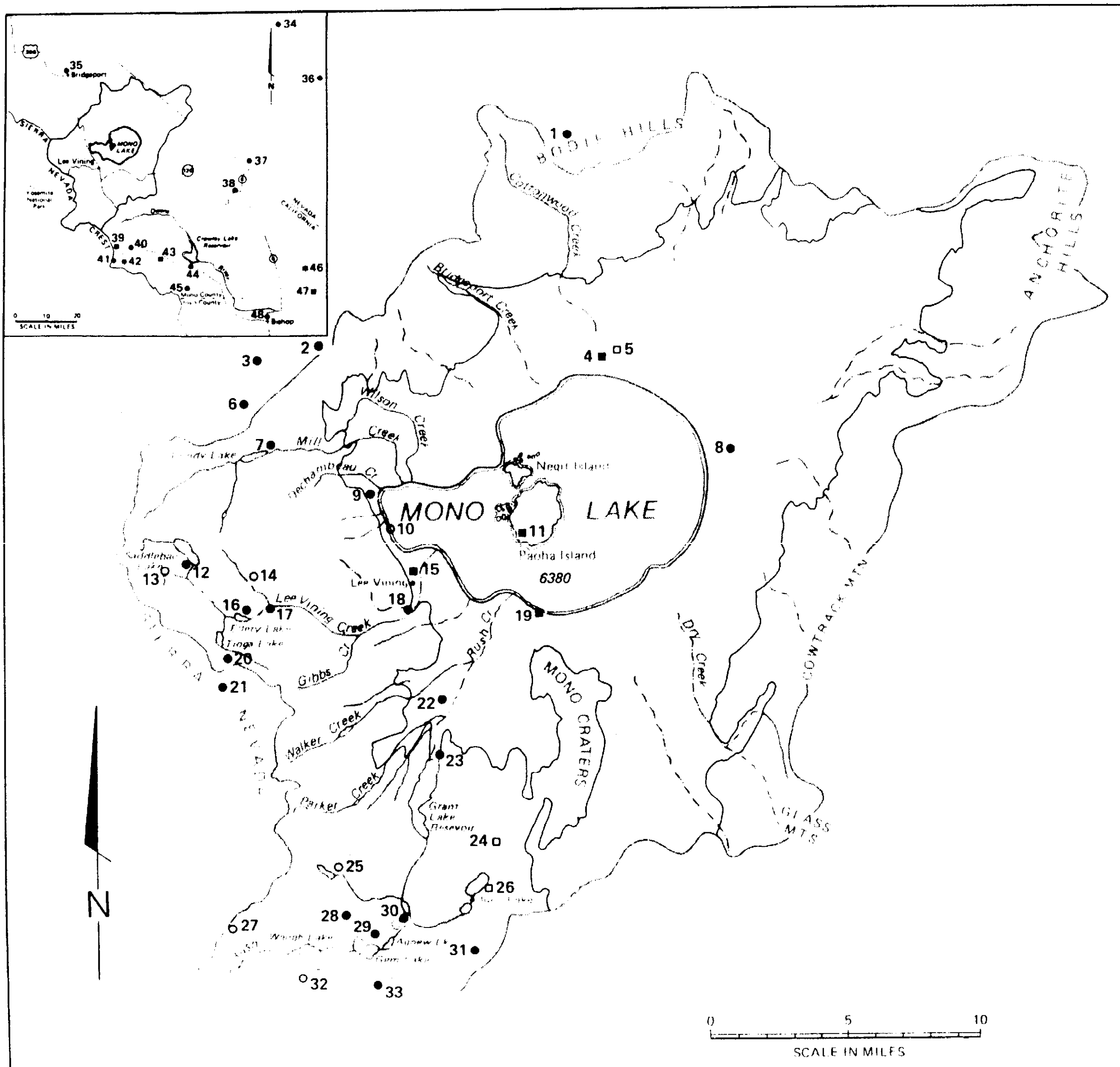
Appendix I: REFERENCE INFORMATION

A: CLIMATIC MEASUREMENT SITES

Figure Al-l locates the climatic measurement sites that are in and near the Mono Basin. The climatic parameters measured at these sites are also given in Figure Al-l. Operational sites are maintained by government agencies and public and private utilities as part of their normal monitoring activities. Research sites are maintained to gather information for a specific project.



NO	STATION NAME	CLIMATIC PARAMETER	FREQUENCY OF OBSERVATIONS	DATA AVAILABLE FROM
1	Bodie	P,T	D	NOAA
2	Conway Summit	P	D(?)	CALTRANS
3	Virginia Lakes Ridge	SC,SP	M,C	CADWR
4	Simis	E,P,RH,T,W	D[1],D,C,C,D	USBLM
5	Binderup	T,W	H[2]	LADWP
6	Virginia Lakes	SC	M	CADWR
7	Lundy Lake	P	M	SCE
8	East Side Mono Lake	P	M	LADWP
9	Mono Lake	P,T	D	NOAA
10	Mono Lake Pan	E	W	LADWP
11	Paoha Island	RH,W	C[1]	UCSB(MSI)
12	Saddlebag Lake	SC,AM	M	CADWR
13	Slate Creek	AM	M	CADWR
14	Warren Fork	AM	M	CADWR
15	Lee Vining	T,W	H[2]	LADWP
16	Ellery Lake	P,SC,T	M	SCE,CADWR
17	Poole Plant	P,T	D	SCE
18	Lee Vining Ranger Station	P,T,RH,W	D,D,D[1],D[1]	USFS
19	South Tufa	E,P	D[1]	USBLM
20	Tioga Pass	AM,SC	M	CADWR
21	Dana Meadows	AM,SC,SP	M,M,C	CADWR
22	Cain Ranch	P,RH,SR,T,W	D	LADWP
23	Grant Lake Resv	E,P	D[1]	LADWP
24	June Lake Junction	P	D	CADWR
25	Alger Lake	AM	M	CADWR
26	June Lake Marina	P,T	D	CADWR
27	Donahue Pass	AM	M	CADWR
28	Gem Pass	AM,SC	M	CADWR
29	Gem Lake	P,SC,SP,T	M,M,C,M	SCE,CADWR
30	Rush Creek Plant	P,T	D	SCE
31	June Mountain	SP	C	LADWP
32	Island Pass	AM	M	CADWR
33	Agnew Pass	AM,SC	M	CADWR
34	Hawthorne	P,T	D	NOAA
35	Bridgeport	P,T	D	NOAA
36	Mina	P,T	D	NOAA
37	Montgomery Mntc. Sta.	P,T	D	NOAA
38	Benton	P,T	D	NOAA
39	Mammoth Mt	P,SC,SP,SR,T	D	USFS,UCSB
40	Mammoth Ranger Station	P,T	D	USFS
41	Mammoth Pass	SC,SP	M,C	CADWR
42	Lake Mary Store	P	M	LADWP
43	S.N.A.R.L.	P,T,SR	D	UCSB
44	Long Valley	E,P,T,W	D[1],D,D,D	LADWP
45	Rock Creek	P,SC,SP	M	LADWP
46	White Mountain 2	P,RH,SR,T,W	D	NOAA,UCLA
47	White Mountain 1	P,RH,T,W	D	NOAA,UCLA
48	Bishop	P,RH,T,W	D	NOAA

AM - Aerial Marker
E - Evaporation
T - Temperature
P - Precipitation
RH - Relative Humidity

SC - Snow Course
SP - Snow Pillow
SR - Solar Radiation
T - Temperature
W - Wind

C - Continuous
D - Daily
H - Hourly
M - Monthly
W - Weekly

[1] Seasonal Measurements (May/June - Sept/Oct.) [2] Intermittent Measuremnts

● Operational ○ Abandoned Operational

■ Research □ Abandoned Research

Figure A1-1
Climatic Measurement Sites

B. STAGE/AREA/VOLUME RELATIONSHIP

The stage/area/volume relationship is derived by first determining the area of the lake basin (excluding any island area) at every mapped contour from the basin bottom to 6480 ft. Table A-1 lists the maps and the planimeter measurements obtained from them. Second, the volume of the lake basin at each mapped contour is determined by successively adding the volume at the preceding contour to the volume of the triangular ring segment defined between each contour. The area and volume between each contour is linearly interpolated. The stage/area/volume/ relationship for one foot intervals is given in Table A1-2. Figure Al-2A and Al-2B plot the stage/area and stage/volume relationship. Table A1-3 shows the difference in area and volume at equivalent lake elevations between the LADWP relationship and the relationship developed for this report.

TABLE A1-1. Planimetered Lake Basin Areas

CONTOUR ELEVATION (USGS DATUM)[a]	SCHOLL CONTOUR (FT BELOW 6392)	BASIN AREA AC	BASIN AREA MI^2	ISLAND AREA AC	ISLAND AREA MI^2	LAKE SURFACE AREA AC	LAKE SURFACE AREA MI^2	SOURCE MAP	PLANIMETERED BY PERSON/DATE
6480	N/A	71439	111.62	784	1.23	70655	110.40	USGS Topos	PTV/1984
6440	N/A	NR	NR	NR	NR	59650	93.20	USGS Topos	Lajoie/1979
6428	N/A	NR	NR	NR	NR	56701	88.60	LADWP Planetable Sheets	Lee/1934
6419	N/A	NR	NR	NR	NR	55533	86.77	LADWP Planetable Sheets	Lee/1934
6411[b]	N/A	55810	87.20	1694	2.64	54117	84.55	Russell Plate XIX	PTV/1983
6392[c]	0	50523	78.94	2049	3.20	48474	74.75	Scholl *et al.*	PTV/1982
6382	10	47086	73.57	2343	3.66	44762	69.94	Scholl *et al.*	PTV/1982
6372	20	38966	60.88	2238(d)	3.50	36728	57.39	Scholl *et al.* adjusted to conform with photos	PTV/1982
6362	30	34396	53.74	2441	3.81	31955	49.93	Scholl *et al.*	PTV/1982
6352	40	29117	45.50	10[e]	0.02	29167	45.57	Scholl *et al.*	PTV/1982

[a] LADWP datum .37' lower than 1929 USGS datum; rounded to nearest foot

[b] From Russell survey in summer 1883; assume lake was at least 1 ft. lower when mark at 6410 was chiseled in Nov 1883

[c] Scholl *et al.* shoreline elevation; estimated from aerial photos and boat survey in July, 1964 when lake was 6391.23 (LADWP Datum); Scholl *et al.* rounded to 6392 USGS datum (6391.23 + .37 = 6391.60)

[d] Negit Island connected to mainland

[e] Paoha Island connected to mainland

N/A - Not Applicable NR - Not Reported PTV - Peter T. Vorster

TABLE A1-1.

CONTOUR ELEVATION (USGS DATUM)[a]	SCHOLL CONTOUR (FT BELOW 6392)	BASIN AREA		ISLAND AREA		LAKE SURFACE AREA		SOURCE MAP	PLANIMETERED BY PERSON/DATE
		AC	MI^2	AC	MI^2	AC	MI^2		
6342	50	26607	41.57	8	0.01	26599	41.56	Scholl *et al.*	PTV/1982
6332	60	23971	37.45	50	0.08	23921	37.38	Scholl *et al.*	PTV/1982
6322	70	21806	34.07	167	0.26	21639	33.81	Scholl *et al.*	PTV/1982
6312	80	19329	30.20	683	1.07	18799	29.37	Scholl *et al.*	PTV/1982
6302	90	15439	24.12	0	--	15439	24.12	Scholl *et al.*	PTV/1982
6292	100	11820	18.47	5	--	11815	18.47	Scholl *et al.*	PTV/1982
6282	110	7281	11.38	2	--	7279	11.38	Scholl *et al.*	PTV/1982
6272	120	4384	6.85	19	0.03	4365	6.82	Scholl *et al.*	PTV/1982
6262	130	1987	3.10	93	0.05	1894	3.10	Scholl *et al.*	PTV/1982
6252	140	242	0.38	0	--	242	0.38	Scholl *et al.*	PTV/1982
6242	150	30	0.05	0	--	30	0.05	Scholl *et al.*	PTV/1982
6232	160	2	--	0	--	2	--	Scholl *et al.*	PTV/1982
6223	169	0	--	0	--	0	--	Scholl *et al.*	PTV/1982

[a] LADWP datum .37' lower than 1929 USGS datum

Table A1-2. Mono Lake Stage/Area/Volume Relationship

Stage (ft)	Area (ac)	Volume (ac-ft)
6224	0	0
6225	0	0
6226	1	1
6227	1	2
6228	1	3
6229	1	4
6230	2	5
6231	2	7
6232	2	9
6233	5	12
6234	8	19
6235	10	28
6236	13	39
6237	16	54
6238	19	71
6239	22	92
6240	24	115
6241	27	140
6242	30	169
6243	51	210
6244	72	271
6245	94	354
6246	115	459
6247	136	584
6248	157	731
6249	178	898
6250	200	1087
6251	221	1298
6252	242	1529
6253	407	1854
6254	572	2343
6255	738	2998
6256	903	3819
6257	1068	4804
6258	1233	5955
6259	1398	7270
6260	1564	8751
6261	1729	10398
6262	1894	12209
6263	2141	14227
6264	2388	16491
6265	2635	19003
6266	2882	21762
6267	3130	24768
6268	3377	28021
6269	3624	31521
6270	3871	35268
6271	4118	39263
6272	4365	43504
6273	4656	48015
6274	4948	52817
6275	5239	57910
6276	5531	63295
6277	5822	68971
6278	6113	74939

Table A1-2. Mono Lake Stage/Area/Volume Relationship

Stage (ft)	Area (ac)	Volume (ac-ft)
6279	6405	81198
6280	6696	87749
6281	6988	94591
6282	7279	101724
6283	7733	109230
6284	8186	117189
6285	8640	125602
6286	9093	134469
6287	9547	143789
6288	10001	153563
6289	10454	163790
6290	10908	174471
6291	11361	185606
6292	11815	197194
6293	12177	209190
6294	12540	221549
6295	12902	234270
6296	13265	247353
6297	13627	260799
6298	13989	274607
6299	14352	288778
6300	14714	303311
6301	15077	318206
6302	15439	333464
6303	15766	349067
6304	16093	364996
6305	16420	381253
6306	16747	397836
6307	17074	414747
6308	17401	431984
6309	17728	449549
6310	18055	467440
6311	18382	485659
6312	18709	504204
6313	19002	523059
6314	19295	542208
6315	19588	561649
6316	19881	581384
6317	20174	601412
6318	20467	621732
6319	20760	642346
6320	21053	663252
6321	21346	684451
6322	21639	705944
6323	21867	727697
6324	22095	749678
6325	22324	771888
6326	22552	794326
6327	22780	816991
6328	23008	839886
6329	23236	863008
6330	23465	886358
6331	23693	909937
6332	23921	933744
6333	24189	957799

Table A1-2. Mono Lake Stage/Area/Volume Relationship

Stage (ft)	Area (ac)	Volume (ac-ft)
6334	24457	982122
6335	24724	1006712
6336	24992	1031570
6337	25260	1056697
6338	25528	1082090
6339	25796	1107752
6340	26063	1133682
6341	26331	1159879
6342	26599	1186344
6343	26856	1213071
6344	27113	1240056
6345	27369	1267297
6346	27626	1294794
6347	27883	1322549
6348	28140	1350560
6349	28397	1378829
6350	28653	1407354
6351	28910	1436135
6352	29167	1465174
6353	29446	1494480
6354	29725	1524066
6355	30003	1553930
6356	30282	1584072
6357	30561	1614494
6358	30840	1645194
6359	31119	1676174
6360	31397	1707432
6361	31676	1738968
6362	31955	1770784
6363	32432	1802978
6364	32910	1835649
6365	33387	1868797
6366	33864	1902422
6367	34342	1936525
6368	34819	1971105
6369	35296	2006163
6370	35773	2041698
6371	36251	2077710
6372	36728	2114199
6373	37531	2151329
6374	38335	2189262
6375	39138	2227998
6376	39942	2267538
6377	40745	2307882
6378	41548	2349028
6379	42352	2390978
6380	43155	2433732
6381	43959	2477289
6382	44762	2521649
6383	45133	2566597
6384	45504	2611915
6385	45876	2657605
6386	46247	2703667
6387	46618	2750099
6388	46989	2796903

Table A1-2. Mono Lake Stage/Area/Volume Relationship

Stage (ft)	Area (ac)	Volume (ac-ft)
6389	47360	2844077
6390	47732	2891623
6391	48103	2939541
6392	48474	2987829
6393	48771	3036452
6394	49068	3085371
6395	49365	3134588
6396	49662	3184101
6397	49959	3233912
6398	50256	3284019
6399	50553	3334424
6400	50850	3385125
6401	51147	3436124
6402	51444	3487419
6403	51741	3539012
6404	52038	3590901
6405	52335	3643088
6406	52632	3695571
6407	52929	3748352
6408	53226	3801429
6409	53523	3854804
6410	53820	3908475
6411	54117	3962444
6412	54294	4016649
6413	54471	4071032
6414	54648	4125591
6415	54825	4180328
6416	55002	4235241
6417	55179	4290332
6418	55356	4345599
6419	55533	4401044
6420	55663	4456641
6421	55793	4512369
6422	55922	4568227
6423	56052	4624214
6424	56182	4680331
6425	56312	4736578
6426	56441	4792954
6427	56571	4849460
6428	56701	4906097
6429	56947	4962920
6430	57193	5019990
6431	57438	5077305
6432	57684	5134867
6433	57930	5192673
6434	58176	5250726
6435	58421	5309024
6436	58667	5367569
6437	58913	5426358
6438	59158	5485394
6439	59404	5544675
6440	59650	5604203
6441	59925	5663990
6442	60200	5724053
6443	60475	5784391

Table A1-2. Mono Lake Stage/Area/Volume Relationship

Stage (ft)	Area (ac)	Volume (ac-ft)
6444	60751	5845004
6445	61026	5905892
6446	61301	5967055
6447	61576	6028493
6448	61851	6090207
6449	62126	6152195
6450	62401	6214459
6451	62676	6276998
6452	62951	6339812
6453	63227	6402901
6454	63502	6466265
6455	63777	6529904
6456	64052	6593819
6457	64327	6658008
6458	64602	6722473
6459	64877	6787213
6460	65152	6852228
6461	65428	6917518
6462	65703	6983083
6463	65978	7048923
6464	66253	7115038
6465	66528	7181429
6466	66803	7248095
6467	67078	7315036
6468	67353	7382251
6469	67629	7449743
6470	67904	7517509
6471	68179	7585550
6472	68454	7653866
6473	68729	7722458
6474	69004	7791325
6475	69279	7860467
6476	69554	7929883
6477	69830	7999576
6478	70105	8069543
6479	70380	8139785

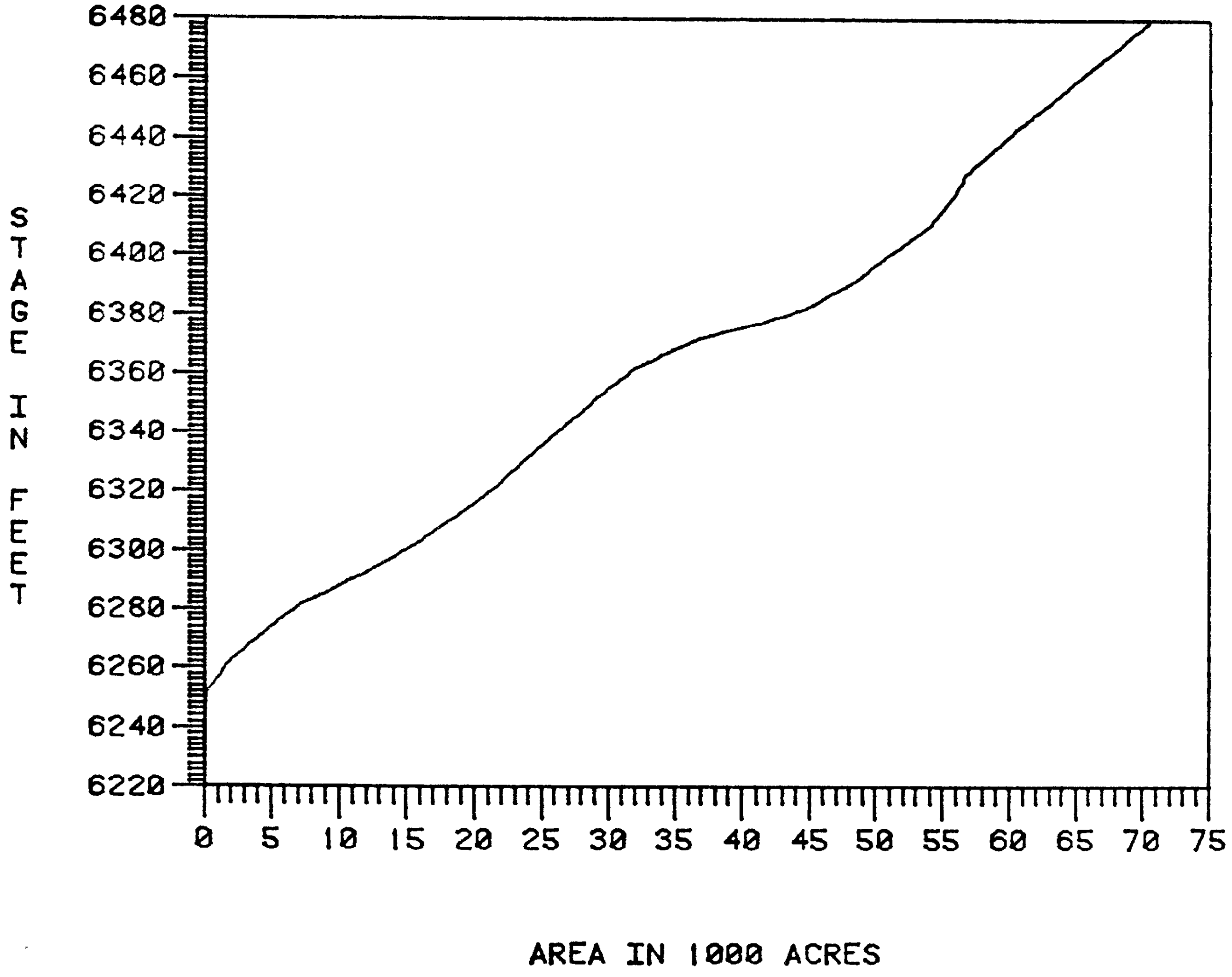


Figure A1-2A. Stage/Area Curve

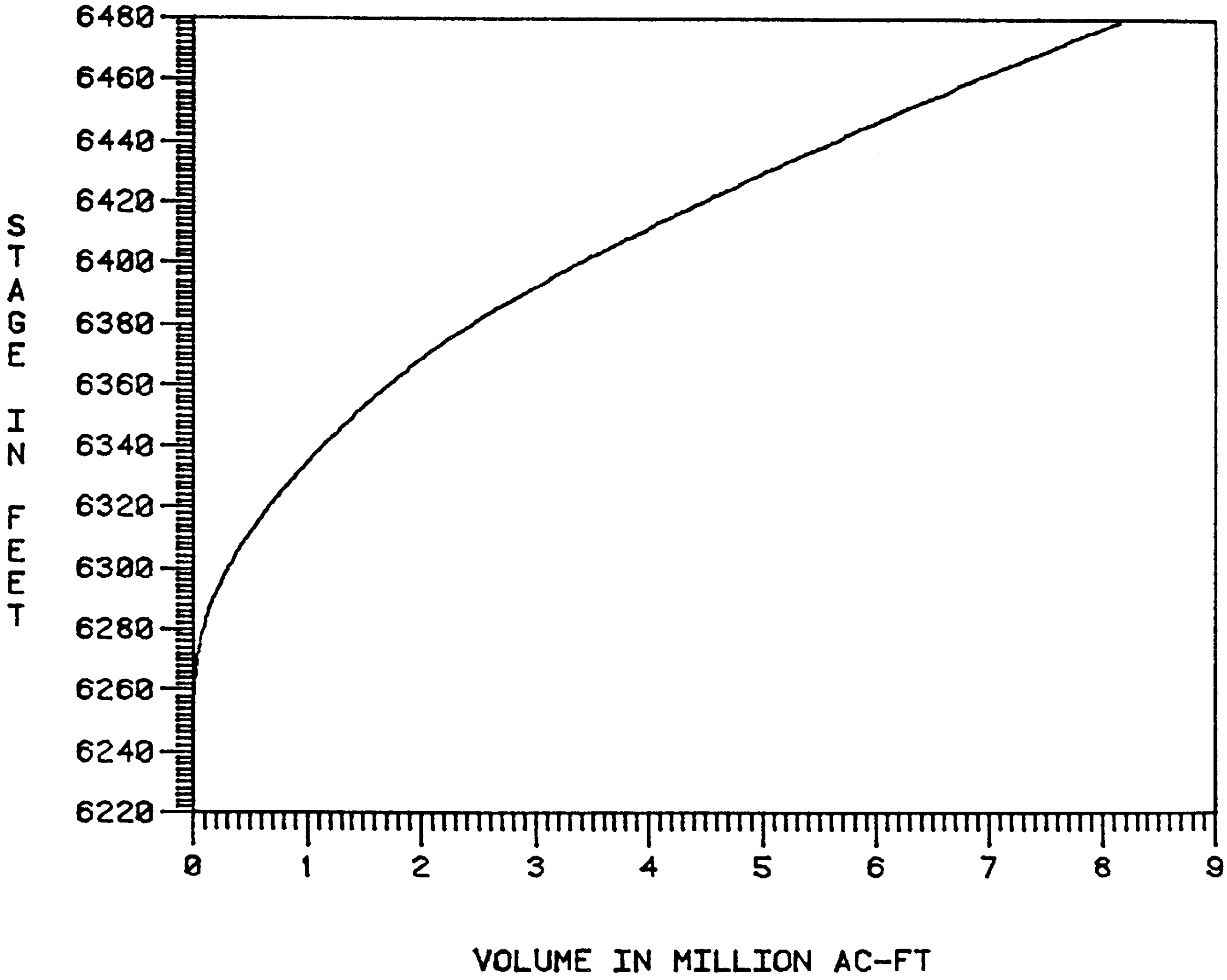


Figure A1-2B. Stage/Volume Curve

TABLE A1-3. Comparison of the Stage/Area/Volume Relationship Derived by this Study and LADWP

STAGE[1] (FT-USGS DATUM)	AREA (ac)	LADWP AREA (ac)	DIFFERENCE (ac)	VOLUME (1000 ac-ft)	LADWP VOLUME (1000 ac-ft)	DIFFERENCE (1000 ac-ft)
6428	56701	56701	0	4906.1	4833.2	72.9
6419	55533	55533	0	4401.0	4328.1	72.9
6411	54117	53194	923	3962.4	3893.2	69.2
6402	51444	50338	1106	3487.4	3427.7	60.2
6392	48474	47140	1334	2987.8	2939.8	48.0
6382	44762	43315	1447	2521.6	2485.4	36.2
6372	36728	38049	-1321	2144.2	2078.7	65.5
6362	31955	33440	-1445	1770.8	1721.1	49.6
6352	29167	30291	-620	1465.2	1404.1	61.1
6342	26599	27736	-1137	1186.3	1114.4	71.9
6332	23921	25073	-1152	933.7	849.4	84.3
6322	21639	21672	-33	705.9	615.4	80.4

1 - All lake stages except 6402 are mapped contours

C. STAGE/SALINITY RELATIONSHIP

The stage/salinity relationship given in Table Al-4 end plotted in Figure Al-3 is derived by first determining the lake's specific gravity at each lake level by assuming that the tonnage of salts remains constant throughout the range of lake volumes above lake elevation 6320 ft. The lake's specific gravity is then translated to a salinity in grams per liter with an equation developed by Herbst (pers comm 1983) that calibrates specific gravity to total dissolved solids.

The equation is:

$A = (1314.1 \times B) + (1317.2)$

A = total dissolved solids (g/l)

B = specific gravity

The relationship is not extended below 6320 ft or 332 g/l because dissolved solids chemically precipitate at lower lake levels (Lee 1934).

TABLE A1-4. Mono Lake Level/Salinity Relationship

Level (ft)	Salinity (g/l)
6320	332.2
6321	321.8
6322	311.9
6323	302.5
6324	293.6
6325	285.0
6326	276.9
6327	269.1
6328	261.7
6329	254.6
6330	247.8
6331	241.3
6332	235.1
6333	229.1
6334	223.3
6335	217.8
6336	212.5
6337	207.4
6338	202.4
6339	197.7
6340	193.1
6341	188.6
6342	184.4
6343	180.2
6344	176.2
6345	172.4
6346	168.7
6347	165.1
6348	161.6
6349	158.2
6350	154.9
6351	151.8
6352	148.7
6353	145.7
6354	142.8
6355	140.0
6356	137.3
6357	134.7
6358	132.1
6359	129.6
6360	127.2
6361	124.8
6362	122.5
6363	120.3
6364	118.1
6365	115.9
6366	113.8
6367	111.7
6368	109.7
6369	107.8
6370	105.8
6371	103.9
6372	102.1
6373	100.3
6374	98.5

TABLE A1-4. Mono Lake Level/Salinity Relationship

Level (ft)	Salinity (g/l)
6375	96.7
6376	95.0
6377	93.3
6378	91.6
6379	89.9
6380	88.3
6381	86.7
6382	85.1
6383	83.6
6384	82.0
6385	80.6
6386	79.2
6387	77.8
6388	76.4
6389	75.1
6390	73.8
6391	72.6
6392	71.3
6393	70.1
6394	69.0
6395	67.9
6396	66.7
6397	65.7
6398	64.6
6399	63.6
6400	62.6
6401	61.6
6402	60.7
6403	59.7
6404	58.8
6405	57.9
6406	57.1
6407	56.2
6408	55.4
6409	54.6
6410	53.8
6411	53.0
6412	52.3
6413	51.5
6414	50.8
6415	50.1
6416	49.4
6417	48.7
6418	48.1
6419	47.4
6420	46.8
6421	46.2
6422	45.6
6423	45.0
6424	44.4
6425	43.9
6426	43.3
6427	42.8
6428	42.2
6429	41.7

TABLE A1-4. Mono Lake Level/Salinity Relationship

Level (ft)	Salinity (g/l)
6430	41.2
6431	40.7
6432	40.2
6433	39.7
6434	39.3
6435	38.8
6436	38.3
6437	37.9
6438	37.4
6439	37.0
6440	36.6
6441	36.2
6442	35.8
6443	35.3
6444	34.9
6445	34.6
6446	34.2
6447	33.8
6448	33.4
6449	33.0
6450	32.7
6451	32.3
6452	32.0
6453	31.6
6454	31.3
6455	31.0
6456	30.6
6457	30.3
6458	30.0
6459	29.7
6460	29.4
6461	29.1
6462	28.7
6463	28.5
6464	28.2
6465	27.9
6466	27.6
6467	27.3
6468	27.0
6469	26.8
6470	26.5
6471	26.2
6472	26.0
6473	25.7
6474	25.4
6475	25.2
6476	24.9
6477	24.7
6478	24.5
6479	24.2

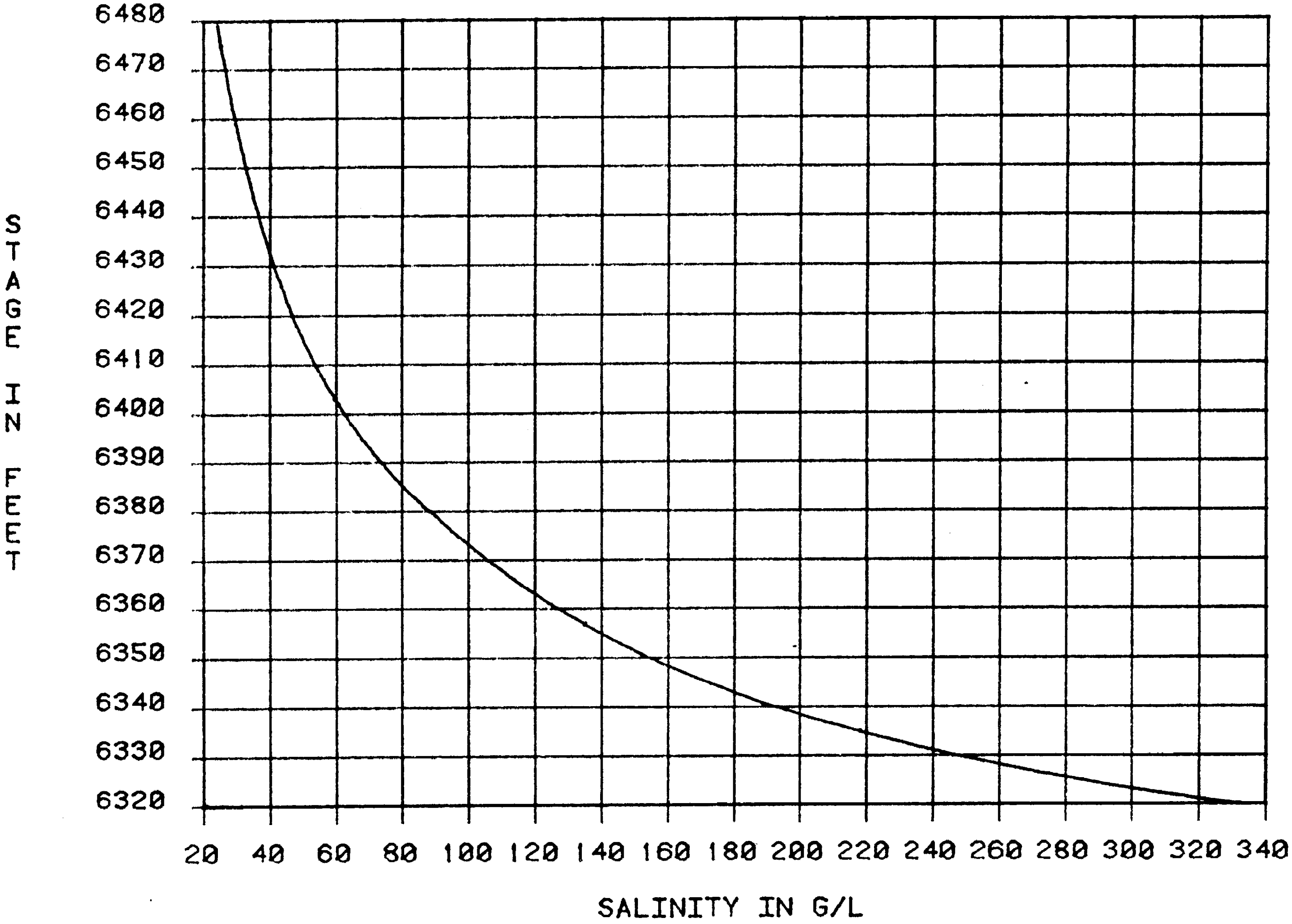
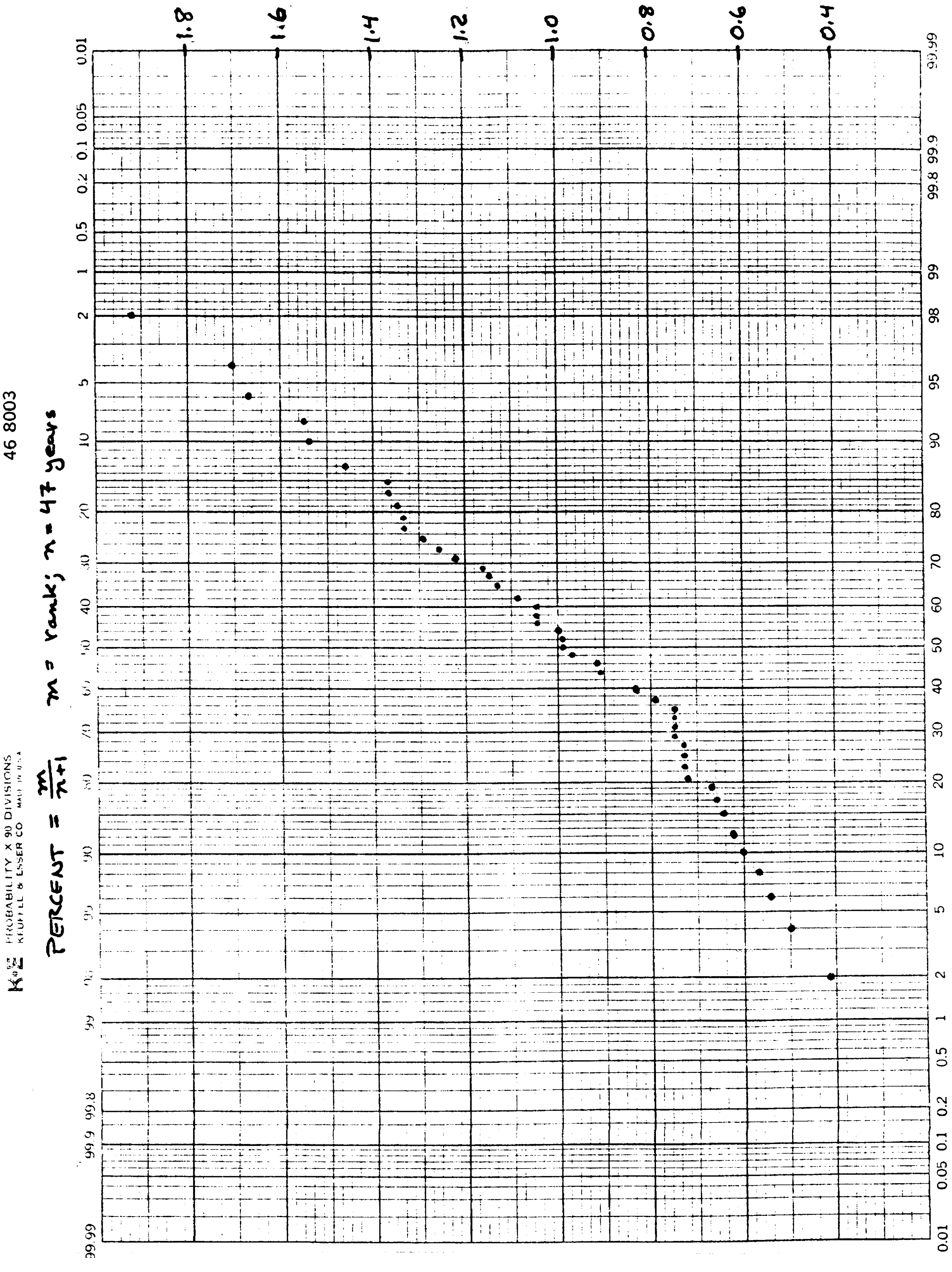


Figure A1-3. Stage/Salinity Curve

D. STATISTICAL DISTRIBUTION OF THE RUNOFF INDEX

Figures Al-4a and Al-4b plot the annual natural runoff index on arithmetic normal probability paper and log/normal probability paper. The natural runoff index is equal to the annual natural (unimpaired) runoff from the gaged Sierra Nevada watersheds divided by the 1937-83 average natural runoff. The figures show that the index plots close to a straight line using a logarithmic transformation. There may be other distributions that the runoff index fits more closely. Determining the best-fitting statistical distribution is necessary for developing a stochastic model that can generate synthetic sequences.

The distribution of the actual runoff index is similar to the natural runoff index. The actual runoff index reflects the reservoir regulation of runoff and may therefore not be as easily modeled.


K+E PROBABILITY X 90 DIVISIONS
KEUFFEL & ESSER CO. MADE IN U.S.A.
46 8003
PERCENT = $\frac{m}{n+1}$
m = rank; n = 47 years
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.01
0.05
0.1
0.2
0.5
1
2
5
10
20
30
40
50
60
70
80
90
95
98
99
99.8
99.9
99.99

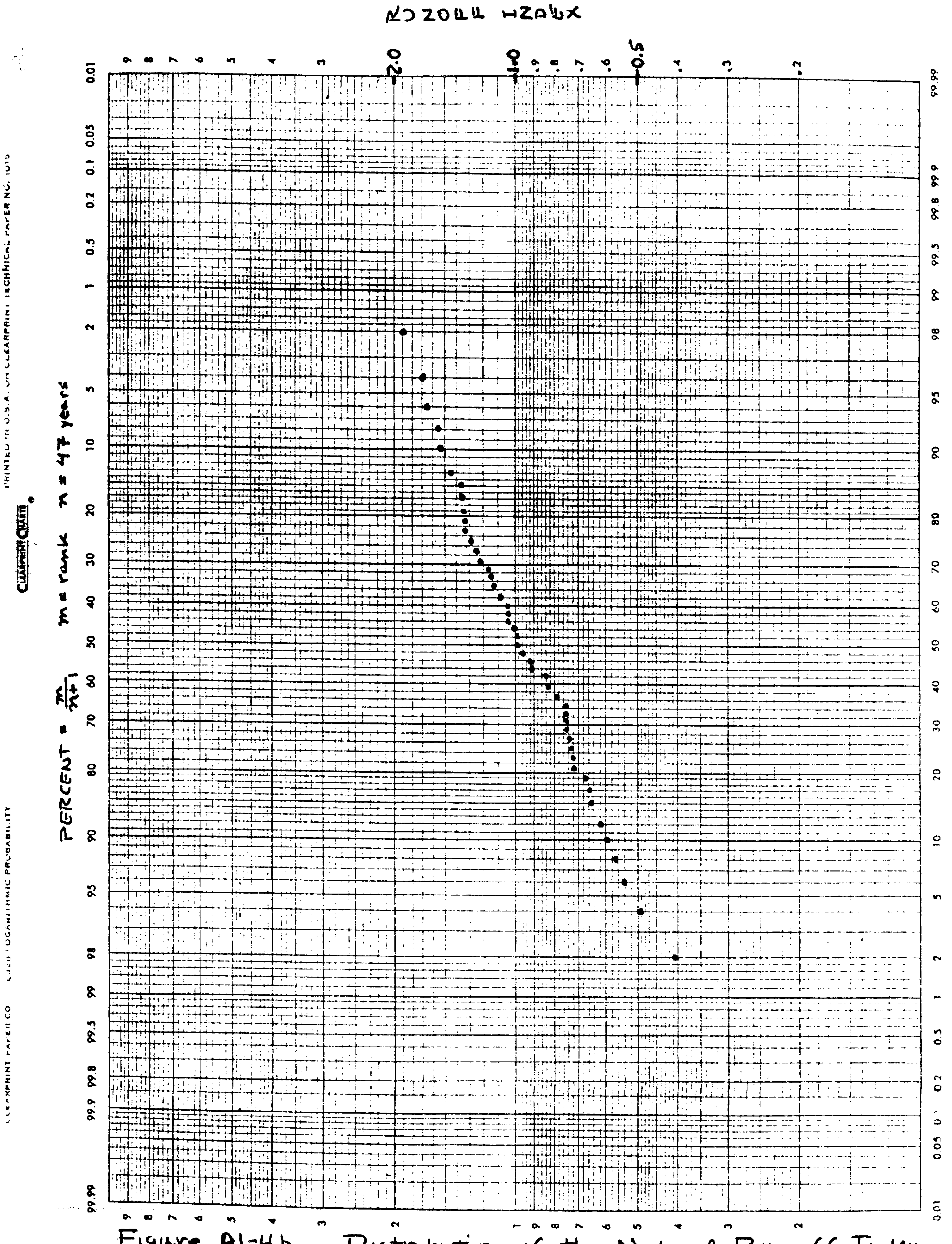


Figure A1-4b. Distribution of the Natural Runoff Index (Log-Normal Plot)

E. COMPUTER USAGE

A computer is used in order to facilitate the computational processes involved in developing and applying the water balance forecast model. The computer used at Cal State Hayward is a Control Data Corporation (CDC) Cyber 720 using the network operating system (NOS) version 2.0. Programs to calculate the water balance and forecast lake levels and salinities are written in Fortran Extended IV (Fortran 66). Statistical analysis of the overall error is done with the Statistical Package for the Social Sciences (SPSS) version 9.0. Results are plotted with a Textronic 4051 terminal and a single pen plotter using interactive graphics programs ("IGP" and "EZGRAPH") that are based on "Plot 10" graphics routines. Additional computer graphics are done with an Apple Macintosh 128k personal computer using the Microsoft Chart and Macintosh Macpaint software packages.

Appendix II: SUPPORTING MATERIALS USED TO DERIVE COMPONENTS

A. DERIVATION OF ISOHYETAL MAP

The following procedure was used to construct the current map.

(1) All precipitation records for sites in and near the Mono Basin are compiled and where possible adjusted to a common base period (1937-83). Table A2-1 presents relevant information for these sites.

(2) The average April 1 water content at snowcourses and aerial markers are translated into average annual precipitation amounts using the formula:

$$\text{annual precipitation} = \frac{\text{April 1 water content}}{.77}$$

(see Table A2-2)

The ".77" is the ratio of the October through March precipitation to the annual precipitation at the Gem Lake and Ellery Lake precipitation stations and thus the assumed percentage of annual precipitation that is represented in the April 1 water content. Anderson (pers comm 1981) and Goodridge (pers comm 1980) support the assumption that nearly all of the October through March precipitation above approximately 8500 ft in the Mono Basin is accumulated in the snowpack and would be reflected in the April 1 water content measurements.

(3) All precipitation measurement sites in the Mono Basin are

TABLE A2-1. Precipitation Stations Used in Isohyetal Map

Station	Mean Precip (in)	Mean Period	Adjusted Mean Precip* (in)	Percent of M.A.P. Oct-Mar**	Elevation (ft)	Distance From Crest*** (mi)	Notes
Within Mono Basin							
Cain Ranch	11.53	1932-83	11.57	77	6850	7.5	
East Side Mono L.	5.58	1975-83	4.80	53	6480	24	gage on exposed knoll
Mono Lake	14.17	1951-83	13.89	75	6450	8.5	gage close to houses and trees
Lundy Lake	17.26	1935-82	17.22	78	7760	7	gage below dam
Conway Summit	17.46	1965-77	17.46	78	8150	10	windy site
Ellery Lake	25.59	1925-83	23.95	77	9645	2	windy site - undermeasures compared to nearby snow course
Gem Lake	21.81	1926-83	21.32	77	8970	1.5	gage below dam - undermeasures compared to nearby snow course
Rush Creek Power House	25.26	1957-81	25.74	78	7300	3	gage right next to building
Poole Power House	27.55	1957-81	28.08	N.D.	7850	3.5	site at head of deep canyon
Simis	9.90	1981-83	7.30	65	6460	18	
Lee Vining Ranger Station	12.80	1963-79	12.74	N.D.	7175	7.5	gage next to building in winter; during winter, weekday measurements only

Outside Mono Basin

Station	Mean Precip (in)	Mean Period	Adjusted Mean Precip* (in)	Percent of M.A.P. Oct-Mar**	Elevation (ft)	Distance From Crest*** (mi)	Notes
Lake Mary Store	29.54	1947-83	29.81	77	8930	1.5	
Long Valley	9.97	1942-83	10.15	77	6890	11	
Bodie	14.93	1965-80	14.42	65	8370	22	gage near house; windy site
Benton	8.26	1966-79	8.05	74	5461	30	
Bridgeport	9.31	1958-80	9.20	68	6470	16	
Bishop	5.67	1948-79	5.79	78	4108	23	
White Mt. 1	13.48	1950-77	13.90	58	10150	37	windy site - undermeasures according to National Weather Service per Rush and Katzner (1973)
White Mt. 2	18.64	1954-77	19.22	57	12470	34	windy site - undermeasures according to National Weather Service per Rush and Katzner (1973)
Hawthorne	4.58	1941-79	4.98	49	4186	54	
Montgomery	8.00	1965-77	8.39	46	7100	44	
Mini	4.05	1936-65	4.18	48	3977	72	

$$* \text{ adjusted mean} = \frac{\text{mean precip.}}{\text{correction factor}} \qquad \text{correction factor} = \frac{\text{Cain Ranch average in station mean period}}{\text{1937-83 Cain Ranch mean (11.57")}}$$

** percentage of mean annual precipitation (M.A.P.) from October through March

*** distance from Sierra Nevada crest along a SW trending line (corresponds to direction of prevailing winter storm winds.)

N.D. either not enough data or data not available to calculate percentage

TABLE A2-2. Average April 1 Water Content and Annual Precipitation at Snow Courses and Aerial Markers Used in Isohyetal Map

Name	Elev.	W.C.	M.A.P.
SNOW COURSES			
Gem Lake[4]	9,150	30.7	39.9
Gem Pass[4]	10,400	31.7	41.2
Ellery Lake[[4]	9,600	28.7	37.3
Tioga Pass[5]	9,800	26.1	33.9
Saddlebag Lake[4]	9,750	32.2	41.8
Agnew Pass[4]	9,450	31.4	40.8
Dana Meadows[4]	9,850	30.0	39.0
Virginia Lake[6]	9,500	18.4	23.9
Virginia Lake Ridge[7]	9,200	17.6	22.9
AERIAL MARKERS[8]			
Donahue Pass	10,800	29.2	37.9
Alger Lake	10,600	24.2	31.4
Slate Creek	10,300	30.9	40.1
Saddlebag Lake	10,200	45.1	58.6
Warren Creek	10,200	24.7	32.1
Tioga Pass	9,800	26.1	33.9
Island Pass	10,300	38.5	50.0
Agnew Pass	9,450	31.4	40.8
Dana Meadows	9,850	30.0	39.0

1. Elev. - Elevation above mean sea level from CADWR (1981)
2. W.C. - Water content average April 1, 1931-75 period; aerial markers W.C. = (average depth at marker) x (average density at nearest snow course); period of record for aerial marker = 1952-75
3. M.A.P.- Mean Annual Precipitation = W.C./.77
4. no record at snow course 1937-49
5. no record at snow course 1937-1938
6. record began 1947
7. record began 1969
8. aerial markers no longer regularly used

analyzed for exposure and areal representativeness. Because of their location, Rush Creek Power Plant and Poole Power Plant may overmeasure the actual precipitation; many of the other gages may undermeasure precipitation because of the site exposure.

(4) The average annual precipitation at the measurement sites is plotted on 15 minute topographic quadrangles. The distribution of sites is very non-uniform and is insufficient to accurately draw isohyets over the entire basin without additional guidance. Long term precipitation measurements, for example, are totally lacking in the eastern two-thirds of the Mono Basin. A plot of precipitation vs. altitude and precipitation v. distance from the Sierra crest (Figure A2-1 and Figure 2-2 in main text) for sites in and near the Mono Basin indicate that altitude and distance from the Sierra crest are the main factors influencing the variation of precipitation in the Mono Basin. Lee (1912) showed the same factors prevailed in the Owens River Basin with a family of curves. The height and breadth of the mountain mass that creates the rain shadow also influences precipitation distribution east of the Sierra Nevada (the Mammoth "gap" provides such evidence). Spreen (1947) showed that slope, orientation, exposure, and local topographic barriers also influence precipitation in mountainous areas. These other factors are secondary to the influence in the Mono Basin of altitude and distance from the Sierra crest. Since altitude accounts for a large part of the variation in areas of similar distance from the crest, three curves corresponding to distance 'zones" are drawn through the precipitation vs. altitude plot and

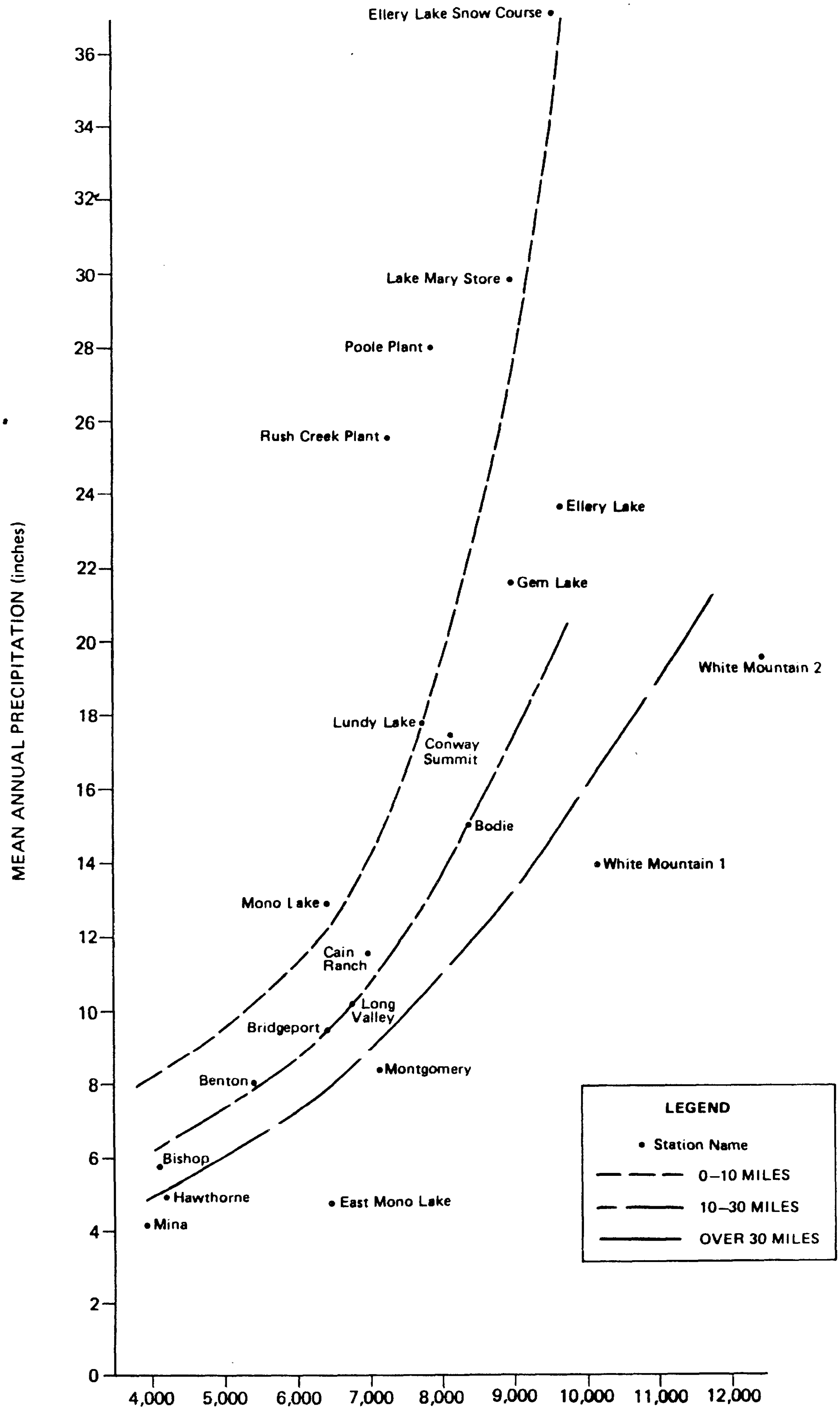


Figure A2-1 **Approximate Relationships of Precipitation to Elevation East of the Sierra Nevada Crest** used as the principal guidance for drawing the isohyets in the ungaged areas. The distribution and suggested (Vaughn pers comm 1981) lower precipitation limits of bitterbrush (8 inches), jeffreypine (12 inches), pinyon pine and juniper (10 inches), also are used for determining the precipitation amounts in the eastern part of the Mono Basin; anomalous vegetation distributions due to groundwater conditions were considered.

B. METHODOLOGY FOR THORNTHWAITE SOIL MOISTURE BALANCE

A Thornthwaite soil moisture water balance is computed to estimate the soil moisture excess available for net land surface precipitation (NLSP) in the Mono Groundwater Basin and for runoff from the non-Sierra bedrock (NSR) of the Mono Basin. The land area that these two components encompass is divided into six precipitation zones, three of which use Bodie climate station data and the other three use Mono Lake station climatic data.[l] It is assumed that the monthly Bodie temperature and precipitation variation is representative of high altitude regions or the area where precipitation exceeds 12.5 inches per year; the Mono Lake station data are assumed to be representative of all the lower elevation regions in the Mono Basin or those areas with less than 12.5 inches per year.

A typical annual computation for a given precipitation zone is shown in Table A2-3 and summarized in the following steps.

(1) The average monthly temperatures for a given year are tabulated.

(2) From these temperatures, a heat index is estimated using Thornthwaite's method and an unadjusted potential evapotranspiration (PET) for each month is calculated.

(3) The unadjusted PET is adjusted for the latitude of the Mono Basin and the length of months according to the standard Thornthwaite procedure.

(4) The PET is then further adjusted using Shelton's regression equations to represent the PET for a semi-arid Mediterranean

Table A2-3. Sample Soil Water Balance Calculation
Non-Sierra Bedrock Area, 12.5 to 15" Precipitation Zone

Month	O	N	D	J	F	M	A	M	J	J	A	S
Ave Temp F	40.1	23.5	21.3	21.3	22.2	23.7	32.3	35.7	43.7	49.8	49.8	39.8
Heat Index I	.85	0	0	0	0	0	.01	.26	1.49	2.81	2.81	.80
Unadj PE mm	45	0	0	0	0	0	5	27	57	75	75	44
PE mm	43	0	0	0	0	0	6	33	71	94	88	46
Shelton PE mm		0	0	0	0	0	41	76				
Precip mm	33	80	76	99	35	18	39	26	23	56	43	10
Snowpack mm		80	156	255	290	308	77					
Snowmelt mm							231	77				
Water Avble	33	0	0	0	0	0	270	103	23	56	43	10
Soil Moisture Storage	1	1	1	1	1	1	75	75				
Soil Moisture Deficit	74	74	74	74	74	74	0	0				
Soil Moisture Surplus	0	0	0	0	0	0	155	27	0			

Total 182 mm recharge

Note: The Table shows only the numbers that are germane to the soil moisture surplus calculation.

climate (Shelton 1978).

(5) The average precipitation for each month is then tabulated. The monthly precipitation for each zone is adjusted so that it corresponds to the ratio of the zone's annual average precipitation to Bodie's average annual precipitation (15") or the Mono Lake station's average annual precipitation (12.8"). It is assumed that this precipitation occurs as snowfall whenever the average monthly temperature is less than 32 degrees F.

(6) This snowfall is accumulated over the winter until the first month in which the average temperature exceeds 32 degrees F.

(7) In this first snowmelt month it is assumed that 75% of the snowpack melted and the remaining 25% melted in the succeeding month. These percentages are gross estimates partly based upon reconnaisance field examinations.

(8) The water available, equal to the given month's precipitation plus snowmelt, is then tabulated.

(9) The estimated soil moisture storage within the root zone and the soil moisture deficit is tabulated. It is assumed that for the MGWB the maximum soil moisture storage is 100 millimeters (mm), for the non-Sierra bedrock areas it is assumed to be 75 mm. These estimates are based on a USBLM Soil Survey (Vaughn pers comm 1981).

(10) Subtracting the soil moisture deficit from the difference between the water available and the PET gives the monthly soil moisture surplus. In most years, only one month resulted in a soil moisture surplus, usually a spring snowmelt month. In some years there was no contribution to soil moisture surplus.

The foregoing steps and Table A2-3 do not show all of the intermediate calculations that are involved in a Thornthwaite water balance including calculating the precipitation (P) minus the PET, the accumulated potential water loss (accumulated sum of the negative P - PET values), the change in soil moisture, and the actual evapotranspiration (AET). The Thornthwaite water balance methodology is outlined in Thornthwaite and Mather (1955).

The annual surplus in each precipitation zone is calculated for each year from 1965 to 1979. This is the longest period for which coincident temperature and precipitation records are available for the Mono Lake and Bodie stations (the 1965-79 average precipitation is nearly equal to the 1937-83 base period average at Cain Ranch, the only climate station that has data for the entire 1937-83 study period).[2] The surplus for the entire 1965-79 period was totalled and averaged over each year to give an average annual surplus. The average annual surplus in inches is multiplied by the area of each precipitation zone to give the acre-foot surplus for the zone. The total for the six zones results in a total surplus available for surface and subsurface runoff into the groundwater basin. Table A2-4 shows the results of these calculations. Some of the surplus would experience losses from the point of production to the point of entrance into the aquifers of the groundwater basin, therefore the total surplus is multiplied by 0.90 to account for these losses.

TABLE A2-4. Estimate of Yield of Mono Groundwater Basin and Non-Sierra Watersheds by Modified Thornthwaite Methodology

Precip Zone (in)	Average Precip (in)	Groundwater Basin			Non-Sierra Bedrock		
		Area (ac)	Surplus (in/yr)	Surplus (af/yr)	Area (ac)	Surplus (in/yr)	Surplus (af/yr)
5.0 - 7.5	6.25	32196	0	0	0	0	0
7.5-10.0	8.75	54172	.05	226	15669	.35	457
10.0-12.5	11.25	38697	0.61	1967	38368	1.15	3677
12.5-15.0	13.75	17780	2.05	3037	42129	2.76	9690
15.0-17.5	16.25	14261	3.21	3815	20719	3.8	6561
17.5-20.0	18.75	0	0	0	3369	5.25	1474
Totals		157106		9045	120254		21859

C. BARE GROUND EVAPORATION RATES FROM THE EXPOSED MONO LAKE BOTTOM

From the available data the following observations and assumptions are made about the relationship of Mono Lake levels to water table depth and consequently to bare ground evaporation rates.

a) As the lake recedes from 6428 ft to 6402 ft the exposed lake bottom is composed primarily of sand-size material although coarser material derived from Black Point is prevalent around the north shore of the lake. The water table depths are assumed to have decreased noticeably up from the shoreline, as the land surface slope increases upward (the land surface profile is approximately parabolic from 6402 ft to 6428 ft). The average bare ground evaporation rate for the acreage exposed between 6428 ft and 6402 ft is assumed to be 0.70 ft/yr, a rate that Rush and Katzer (1973) use in nearby Fish Lake Valley for hard playa surfaces with water table depths less than 12 ft. That rate is close to the 0.62 ft/yr rate Sorey (1978) uses in neighboring Long Valley for land with water table depths less than 8 ft.

b) Along with the evaporation from the exposed bare ground between 6428 ft and 6402 ft there was evaporation from a series of lagoons northeast of the lake that were hydraulically connected to the lake (the bottom of the lagoons were from 6407 ft to 6414 ft but they were physically separated from the lake by a berm). The surface area of the lagoons when the lake was at 6420.7 ft is estimated from December 1929 aerial photographs to have been approximately 280 ac. These same photos are used to estimate the lagoon surface area when the lake stood at 6428 ft by adding the area of the exposed alkali "ring" to their existing surface area. The lagoon area at 6248 ft is estimated to be about 400 ac. Lee (1934) estimated the surface area of the lagoons to be 251 ac presumably when he did his field surveys at a Mono Lake height of around 6416.7 ft. The lagoons were generally dry by 1957 when the lake reached 6402 ft. A linear relationship of the lagoon area to the lake height is estimated from the foregoing data. assumed that the lagoons evaporated at the free water surface rate of 3.75 ft/yr. When the lake drops below 6402 ft the bare ground rate for the exposed lagoon bottoms corresponds to the rates for land exposed below 6402 ft.

When the lake drops below 6402 ft the slope of the land surface becomes significantly flatter until elevation 6368 ft (gradients of 0.05% are measured by Stine, pers comm 1984). As the lake drops to 6374 ft the water table depths around the north and east shores stay within 2 to 3 ft of the exposed land surface. (6374 ft is the lake elevation when a transect of water table measurements from the shoreline to 6402 ft were made by the author and Philip Williams in March 1981). As a result, a significant amount of the bare ground below 6402 ft is moist within a few inches of the surface and in many places up to 400 yards above the north and east shoreline the ground can be characterized as "mucky". Consequently the assumed average annual bare ground evaporation rate for the acreage exposed between 6402 ft and 6368 ft is 1.0 ft/yr or over 40% higher than the rate for the acreage exposed above 6402 ft. 1.0 ft/yr is the rate Rush and Katzer (1973) use for wet playa surfaces with water table depths less than 2 ft. It is also assumed that the water table depths between 6428 ft and 6402 ft continue to lower as the lake drops below 6402 ft so that the bare ground acreage above 6402 ft that evaporates at 0.7 ft/yr gradually decreases until nearly all of it has an average annual evaporation rate of 0.1 ft/yr. a rate that Van Denburgh and Glancey (1970) use for playas in neighboring Mineral County and that Van Denburgh et al. (1973) use for the dry bed of Winnemucca Lake.

d. 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)

D. METHODOLOGY TO DETERMINE ACREAGE OF PHREATOPHYTES BELOW 6428 FEET

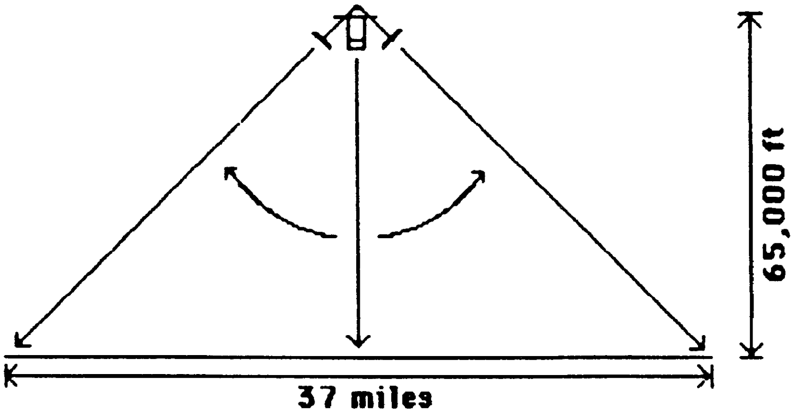
In order to ascertain the nature and extent of the phreatophytes on the relicted lake bottom, both ground surveys and aerial photos are employed.

RECONNAISSANCE GROUND SURVEY

An initial ground reconnaissance around the entire perimeter of Mono Lake identified sites with phreatophyte vegetation. The reconnaissance surveys, conducted in the summer of 1980 and 1981, noted the general types (e.g., grasses, sedges, rushes, shrubs) of vegetation and their relation to water availability.

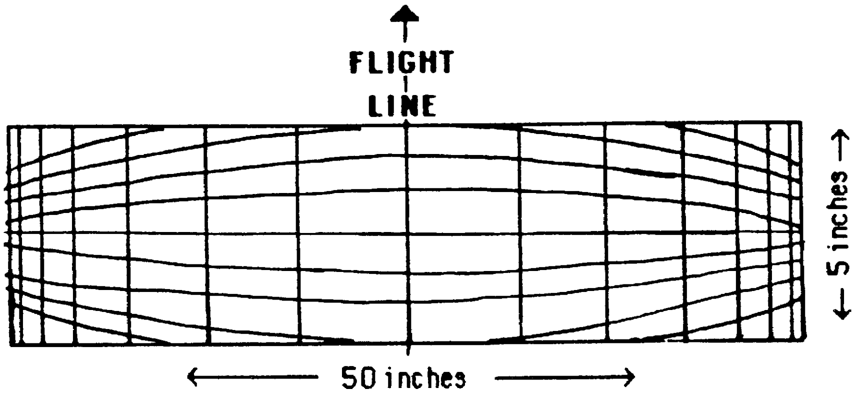
MEASUREMENTS FROM AERIAL PHOTOS

Infra-red aerial photos taken by the United States Forest Service in July 1978, September 1978, September 1979, and September 1980, permit determination of the areal extent of the phreatophyte vegetation identified on the ground surveys. The aerial photos are taken on small-grain, high-resolution, (ground resolution of 2 ft) infra-red film with an optical bar scan camera. The photo missions are flown in a U-2 aircraft at an altitude of 65,000 ft. Because the camera pivots (scans) around the line of the flight, the scale of the image changes from approximately 1:30,000 directly beneath the plane to about 1:50,000 near the edge of the field of vision.



The ground area covered by the camera increases towards the extremes of the rotation, causing a "bow-tie" appearance:

Since the film is consistently 5 inches wide and 50 inches long, the bow tie is translated into a pattern of vertical and horizontal lines converging away from the center of the picture:



A transparent grid overlay was developed by the USFS that adjusts for the converging lines so that acreages can be determined by counting the number of grid cells over a particular image area. The grid is also adjusted for an average elevation of 5000 ft above sea level. The grid results in approximately a 6.5% overestimation of area because the average elevation of the vegetation around Mono Lake is about 6400 ft above sea level.

The infra-red film highlights the differences between phreatophytes and xerophytes through the different radiation signatures of the vegetation, translated to our eyes as shades of color. Each species of plant has a characteristic signature based upon its internal structure, leaf orientation, background surface, canopy makeup, pigment, etc. A species signature, however, displays great temporal and spatial variability. Phreatophyte vegetation displays a signature that is characteristically redder than the surrounding xerophyte vegetation due to its greater reflectance in the near infra-red spectrum, The greater reflectance of a phreatophyte can be attributed to the higher portion of spongy mesophyll and higher plant densities, as compared to a xerophyte. A xerophyte displays a gray color on infra-red film.

Visual interpretation of phreatophyte vegetation from infra-red imagery requires numerous assumptions, some of which can be checked by ground surveys. A careful ground check must confirm if and how the various shades of color correspond to different species of phreatophytes.

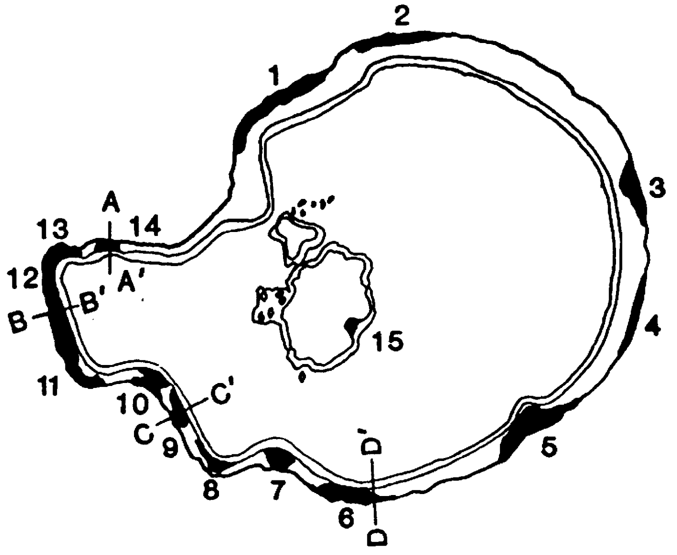
DETAILED GROUND SURVEY

A detailed ground survey of the phreatophyte vegetation was conducted on May 31 and June 1, 1982. It consisted of four linear transects shown on Figure A2-2. The transects went from the shore of Mono Lake up to an elevation where the phreatophyte vegetation was no longer dominant. Each transect sampled the dominant species, noted the number of different species, estimated the percent of ground cover, and measured the elevation and distance above the lake at which significant vegetation shifts occurred.

Because the initial surveys showed considerable variation in the dominant species and density of the phreatophyte vegetation, the transects were done at four different sites. The information from the transects is summarized graphically on Figures A2-3a, b, c, d. Both Jepson (1951) and Correll (1972) were consulted for species identification. Samples were also submitted to the Univ. Calif. Berkeley Herbarium but the lack of influorescence on most samples prevented identification to species level.

SURVEY RESULTS

The ground surveys and infra-red imagery allowed distinction of 15 major sites of phreatophyte vegetation around Mono Lake. The sites are located on Figure A2-2 and identified in Table A2-5. Each site is either a discrete expanse of phreatophytes or a collection of disconnected patches of phreatophytes. Small



12	Site Numbers Referenced in TABLE A2-5
B–B'	Veg~~a~~etation Transects shown in FIGURE A2-3

Figure A2-2
Phreatophyte Sites and Veg~~a~~etation Transects on Exposed Lake Bottom

Figure A2-3 a,b,c,d.
Vegetation Transects on the Exposed Lake Bottom

INTERPRETATION OF FIGURES

Each figure represents a profile of the land surface in each of the four transects. Below each profile the location and density of major vegetation types is displayed in relation to its distance from the lake and elevation above the lake. The location of species or genera, where known, is also displayed. Miscellaneous observations are shown in their relative location by reference to the profile.

KEY:

GROUND COVER - represents all low lying herbaceous vegetation.

1: 0-33% cover - solitary plants to scattered patches
2: 34-66% cover - regular clumps with some bare ground
3: 67-100% - nearly continuous with little bare ground

SHRUBS

0: isolated occurrence
---: scattered occurrence < 10% coverage
____: more continuous coverage > 10% coverage
|: line of shrubs parallel to land contour

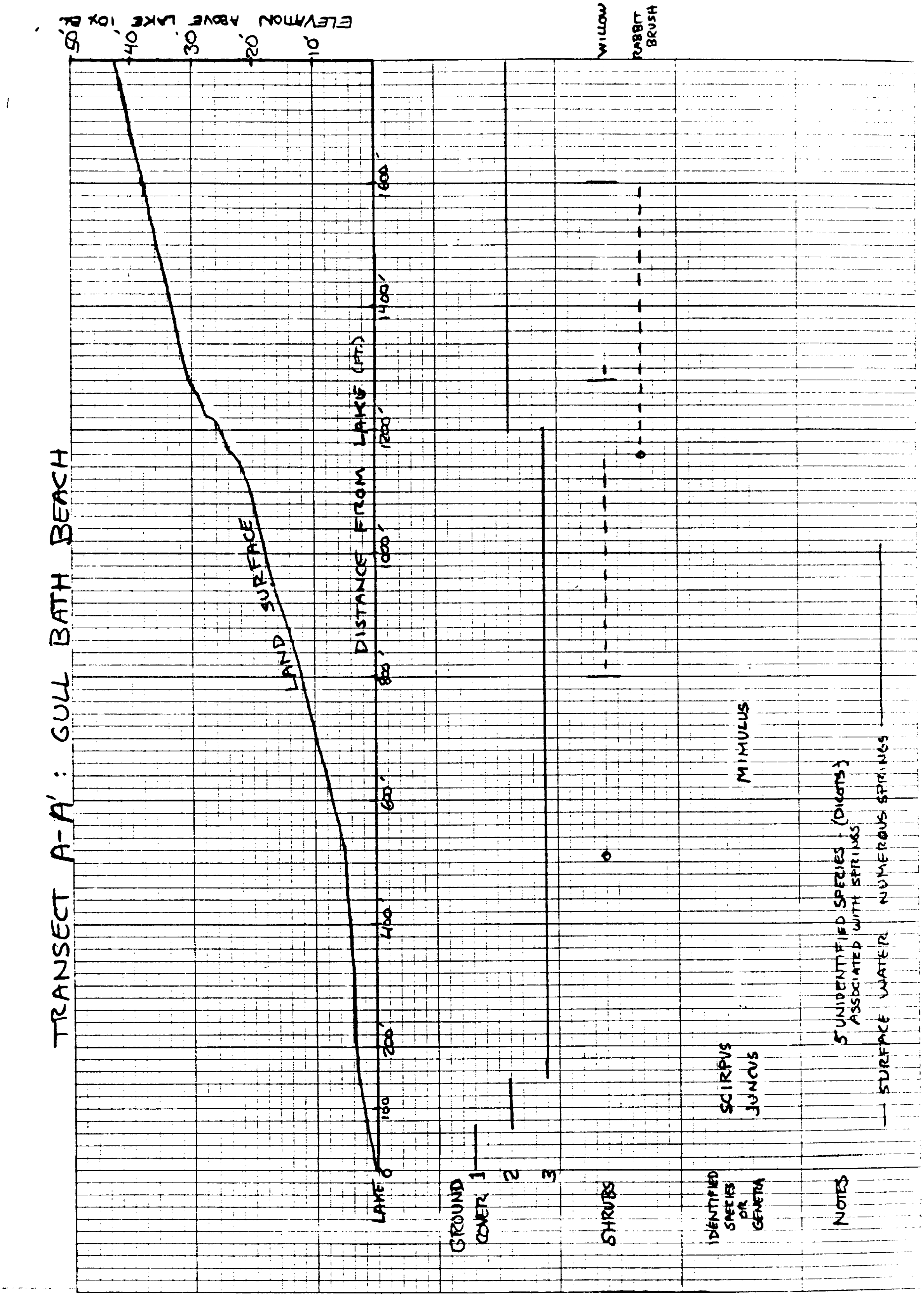

TRANSECT A-A' : GULL BATH BEACH
ELEVATION ABOVE LAKE 10X EX
50'
40'
30'
20'
10'
LAND SURFACE
DISTANCE FROM LAKE (FT)
0
100
200'
400'
600'
800'
1000'
1200'
1400'
1600'
LAKE
GROUND COVER
1
2
3
SHRUBS
WILLOW
RABBIT BRUSH
IDENTIFIED SPECIES OR GENERA
SCIRPUS
JUNCUS
MIMULUS
NOTES
5 UNIDENTIFIED SPECIES (DICOTS) ASSOCIATED WITH SPRINGS
SURFACE WATER NUMEROUS SPRINGS

Figure A2-3a

TRANSECT B-B': WEST SHORE

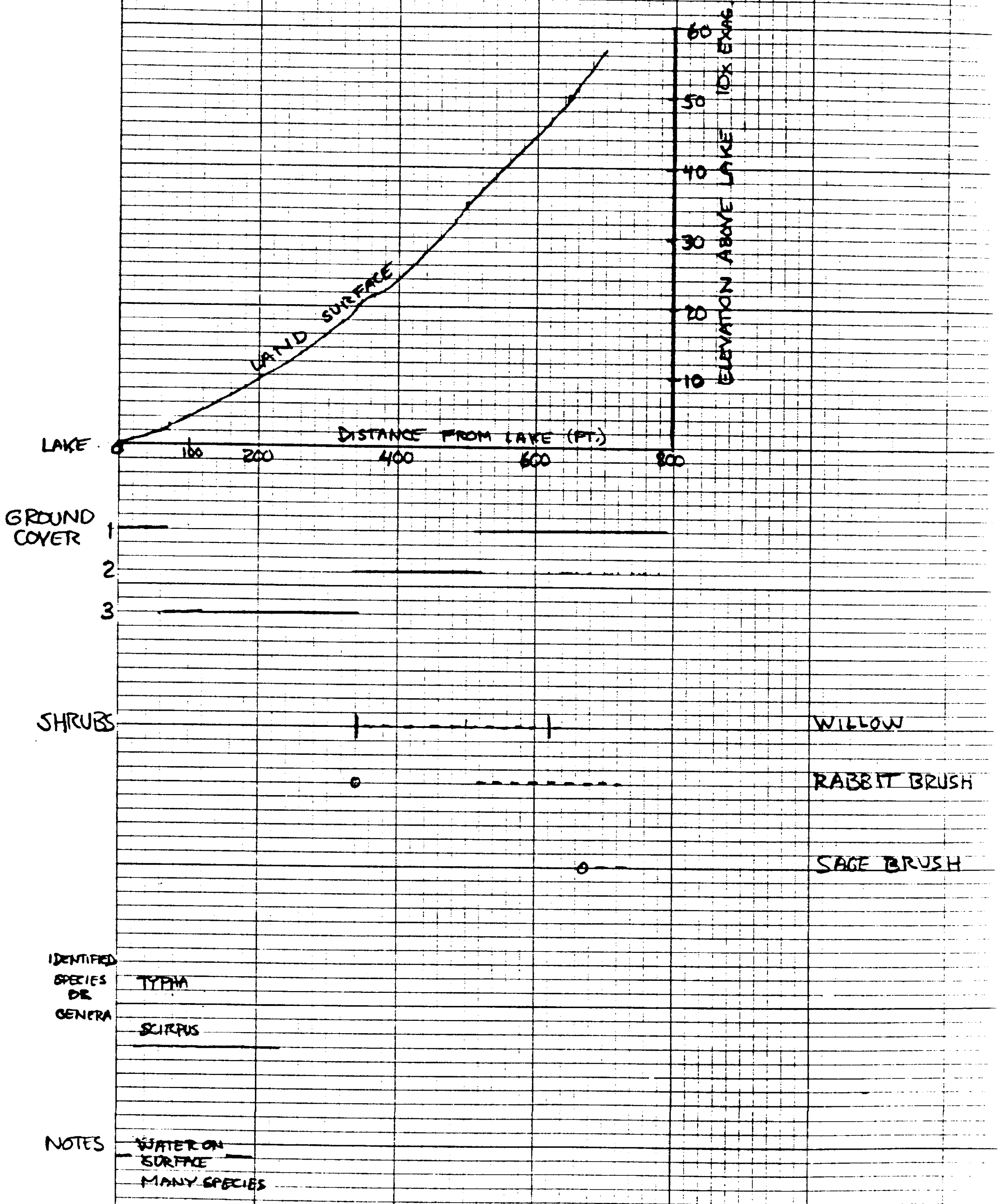


Figure A2-3b

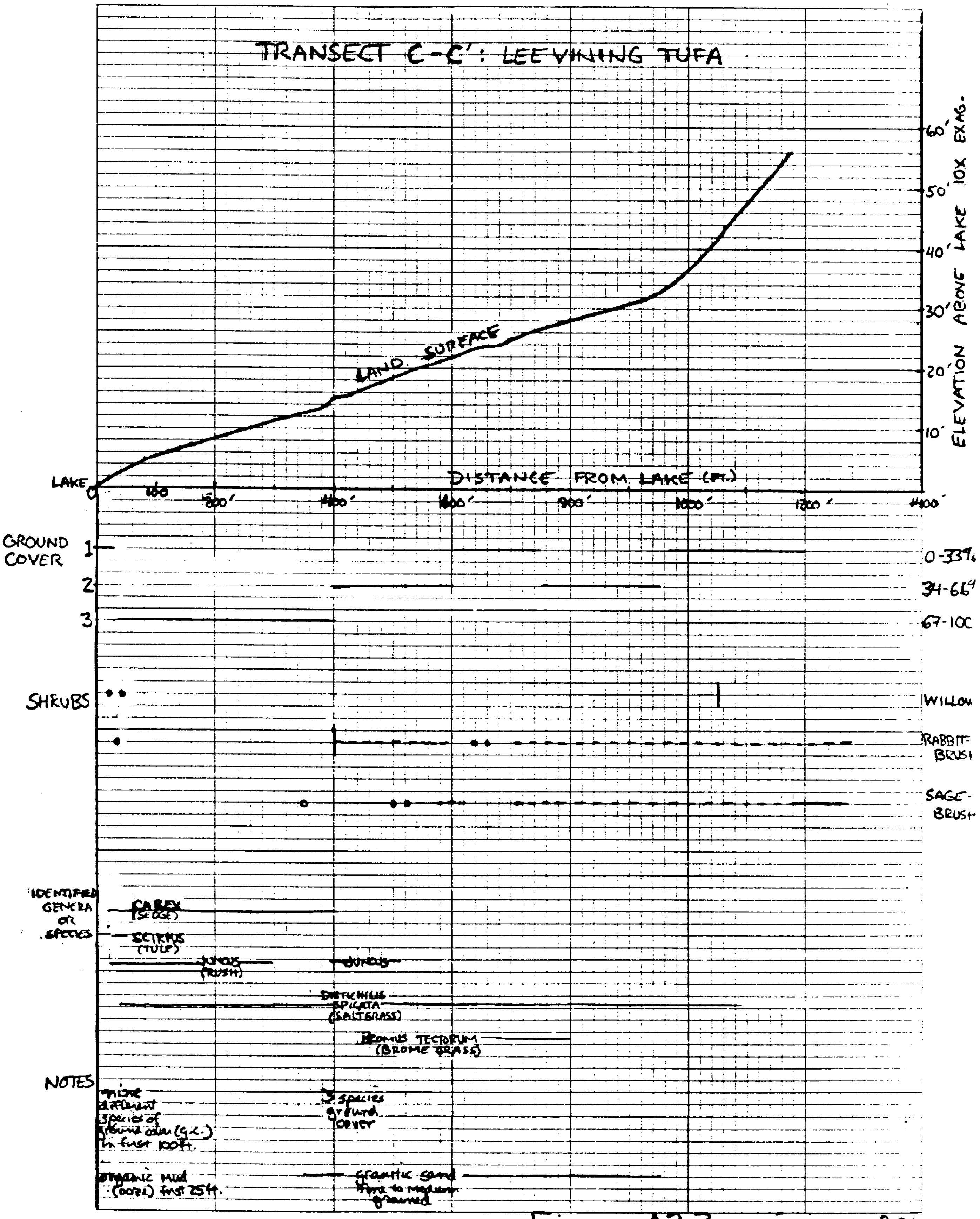

TRANSECT C-C': LEE VINING TUFA
LAND SURFACE
LAKE
0
DISTANCE FROM LAKE (FT.)
100
200'
400'
600'
800'
1000'
1200'
1400'
10'
20'
30'
40'
50'
60'
ELEVATION ABOVE LAKE 10X EXAG.
GROUND COVER
1
2
3
0-33%
34-66%
67-100
SHRUBS
WILLOW
RABBIT-BRUSH
SAGE-BRUSH
IDENTIFIED GENERA OR SPECIES
CAREX (SEDGE)
SCIRPUS (TULE)
JUNCUS (RUSH)
JUNCUS
DISTICHLIS SPICATA (SALTGRASS)
BROMUS TECTORUM (BROME GRASS)
NOTES
nine different species of ground cover (G.C.) in first 100ft.
3 species ground cover
organic mud (ooze) first 25ft.
granitic sand fine to medium grained

Figure A2-3c

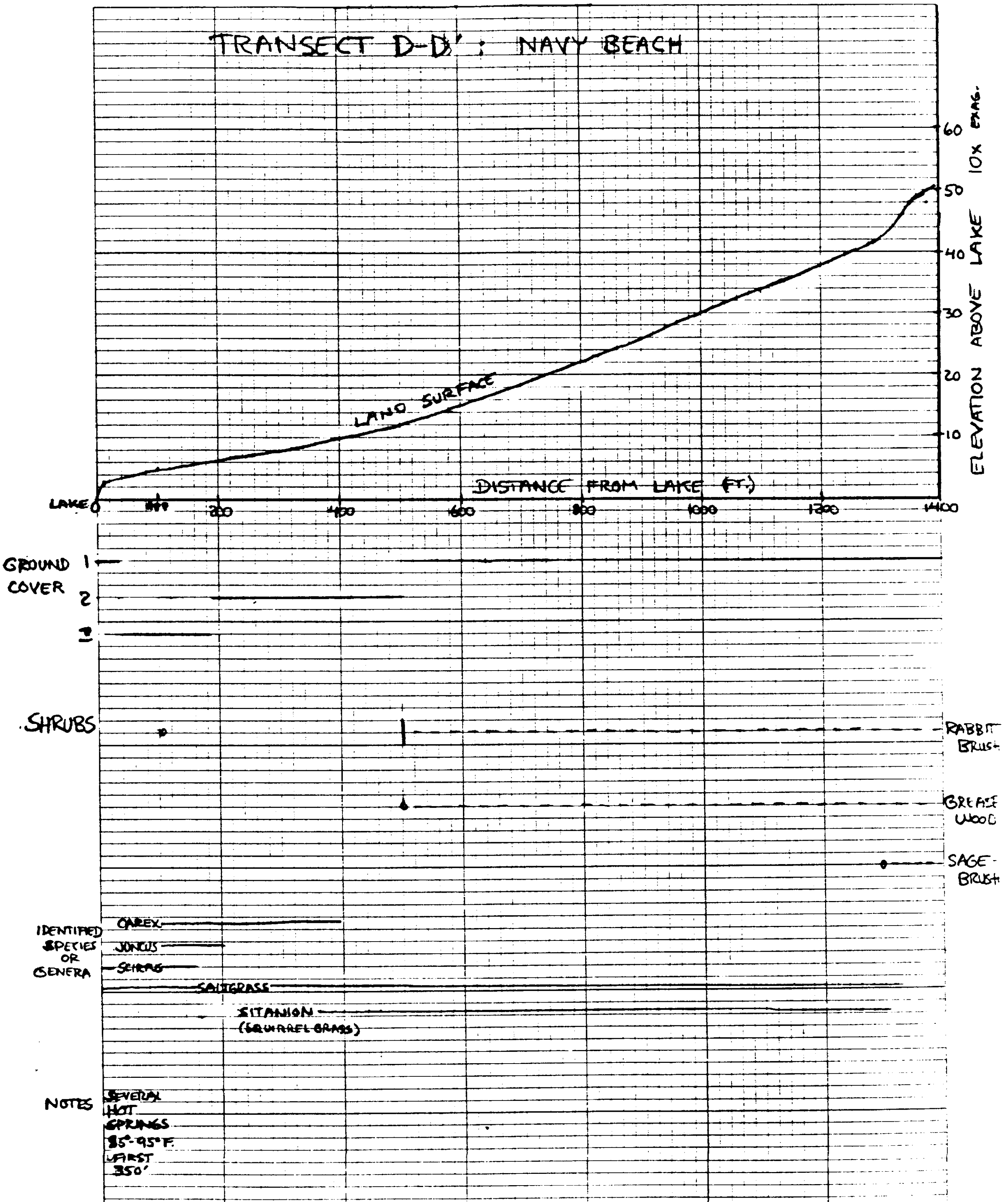

TRANSECT D-D' ; NAVY BEACH
LAND SURFACE
DISTANCE FROM LAKE (FT.)
ELEVATION ABOVE LAKE 10X EXAG.
10
20
30
40
50
60
LAKE 0
100
200
400
600
800
1000
1200
1400
GROUND COVER
1
2
3
SHRUBS
RABBIT BRUSH
GREASE WOOD
SAGE-BRUSH
IDENTIFIED SPECIES OR GENERA
CAREX
JUNCUS
SCIRPUS
SALTGRASS
SITANION (SQUIRREL GRASS)
NOTES
SEVERAL HOT SPRINGS 85°-95°F. FIRST 350'

Figure A2-3d

TABLE A2-5. Phreatophyte Sites and Acreages on the Exposed Mono Lake Bottom

Site No.*	Site Name**	1978 Phreatophyte Area (ac)
1	Dechambeau Ranch/ Bridgeport Creek Delta	106
2	Cottonwood Creek Delta	70
3a	Warm Springs Central	145
3b	Warm Springs South	121
4	Southeast Shore	51
5	Simon Springs	238
6	South Tufa	42
7	Rush Creek Delta	117
8	Dondero Ranch	36
9	Lee Vining Tufa	52
10	Lee Vining Creek Delta	89
11	Marina	33
12	West Shore	65
13	County Park	129
14	Gull Bath Beach/ Mill Ck. Delta	31
15	Hot Springs Cove	12
16	Miscellaneous Unnamed Sites	23
	Total	1360

*Site number is identified in figure A2-2.

**The Site Name is for identification purposes; refers to the closest geographical feature.

isolated areas of of phreatophytes were also observed. The total phreatophyte area of 1360 acres represents the area measured on the 1978 imagery. The difference between the 1978 area and current phreatophyte area is relatively small. If one assumes the ratio of phreatophyte vegetation to exposed lake bottom remained about the same, then the difference between the 1978 area and the current (January 1985) area is about 100 acres.

A zonation of phreatophyte species was observed at most of the sites. The zone immediately above the shoreline was a sparsely vegetated swath of saturated unconsolidated mud that may be from 15 ft (Site 12) to 5000 ft (Site 3) wide. Plants in this zone such as pickleweed, saltgrass, or alkali grass have to withstand high alkalinity in the soil. The alkalinity of the soil could only be evaluated qualitatively by observing the presence or absence of alkali deposits.[3] The next zone up from the lake contained more dense stands of alkaline tolerant species or, if springs or seeps were located nearby, dense stands of tule or rushes. A number of other unidentified but presumably less alkaline tolerant species occurred in the very wet areas. The next zone above the shore contained a few isolated shrubs, either willow or rabbitbrush, among a dense cover of grass, rushes, or sedges. New species of grass were noted but not identified. A line of shrubs demarcates the fourth zone up from the lake. Depending on the available water supply, the shrubs were either willow, rabbitbrush, or greasewood, among an herbaceous cover of varying density, As one moved further from the lake, the shrubs, especially rabbitbrush or greasewood, became more common and the grass cover less continuous. In the highest zone up from the lake, the phreatophytic shrubs and grass cover became patchy in distribution and xerophytic shrubs, commonly sagebrush (Artemesia tridentata) or bitterbush (Purshia tridentata), occurred with increasing frequency. A line of xerophytes was found near the historic high stand of 6428 ft. This line shows clearly on the infra-red imagery.

The zonation from near shore alkali flat to wet marsh to drier marsh to wet shrubs to shrub/grass mix to xerophytes corresponds to the increasing depth of the water table and to the amount of fresh water available to flush the alkaline soils. In the sites with high spring discharge (3, 5, 11-14), the wet marsh zone, with tule and rushes, is the dominant zone. Sites with little or no spring discharge (1, 2, 4, 6, 7, 8, 10, 15) have correspondingly less of the wet marsh zone and more of the alkaline tolerant saltgrass zone.

The signature, i.e. color, on the infra-red imagery showed some correspondence to the type and density of phreatophyte vegetation. The brighter and deeper red color corresponds to the areas of dense cover of tule or rushes and the pinker colors were associated with areas dominated by saltgrass and stands of greasewood or rabbitbush. More subtle color differences could also be distinguished. The differences may correspond to different species or species density. Other factors such as soil characteristics or standing water may explain the color differences. Visual interpretation of the imagery and reconnaissance ground surveys permit a qualitative color-vegetation correspondence to be established. Optical density analysis and more detailed ground checking are required to establish quantitative relationships between the respective vegetation types and their optical signatures (Jones 1977).

INTERPRETATION OF SURVEY RESULTS

The phreatophytes around Mono Lake can be used as indicators of spring discharge, water table depth, and groundwater quality. The nearly continuous band of phreatophytes from Site 11 through Site 14 reflects the abundant spring and seep discharge that occurs where the steeply sloping fractured rocks and talus of the Sierra Nevada meet the less permeable lake sediments. Sites 13 and 14 are associated with high discharge springs that are recharged by the runoff from Mill, Wilson, and Dechambeau Creeks, Keenan Lee (1969) noted that the shoreline springs around Sites 13 and 14 had the highest discharge of any of the springs around Mono Lake. Sites 13 and 14 are the lushest, brightest red-imaging of the 15 phreatophyte sites. Sites 9 through 14 contain numerous clumps of willows that manifest the considerable flushing action of the springs. Sites 6, 7, and 8 have minor spring activity. They are proximate to the delta of Rush and Lee Vining Creeks whose recharge areas have been depleted by LADWP diversions. Hot springs at Sites 6 and 15 suggest that faults bring water up from deeper layers. Sites 2, 3, 4, and 5 are associated with concentrations of numerous small springs and seeps located considerable distances (from 1000 to 5000 ft) up from the current shoreline. The spring and seep discharge upslope may be related to where the surface sand layer pinches out.[4] Site 1 is associated with an area of high water table that is recharged by Bridgeport Creek and irrigation tailwater from Dechambeau Ranch.

CHANGES IN THE DISTRIBUTION OF PHREATOPHYTES

The long-term changes in the distribution of phreatophyte vegetation is determined by comparing the area of phreatophytes on 1940 imagery with the area of phreatophytes on 1978 imagery. Qualitative assessments of the changes in the phreatophyte vegetation in the intervening years are made using imagery from 1951, 1956, 1964, 1968, and 1976.

The imagery available for 1940 consists of 9" x 9" black and white photos at a scale of 1:20,000. The photos, taken for the U.S. Forest Service in June, 1940, are the first photos known to have covered the entire shoreline of Mono Lake. The earliest air photos of the Mono Basin, taken in the 1929-1932 period, only cover a small part of the south and west shoreline. Due to the relative evenness of the topography immediately surrounding the lake, area estimates are made using a dotted grid with 0.1 inch diversions. Only non-irrigated (or not intentionally irrigated) areas of phreatophytes below the historic high stand are measured, although the distinction between irrigated and non-irrigated areas around the western shoreline was sometimes indiscernible. This is because some of the irrigated areas bordered the lakeshore and, as a result, non-irrigated areas were benefitting from irrigation water applied upslope. A major consideration when making distinctions is to achieve consistency between photo periods; relative change remains valid if the same area is defined as being irrigated or non-irrigated for both sets of imagery unless an obvious change has occurred.

The imagery available from 1978 is the infra-red optical bar photography described in the previous section. The determination of the 1978 phreatophyte area is also previously described.

Short-term changes in the distribution of phreatophytes is evaluated by comparing the 1978 imagery with similar imagery from 1980 and by comparing those two sets of imagery with ground transects conducted in June 1982. The detailed ground transects measured the vertical distance of the vegetation above the current shoreline in order to compare the elevation of the existing vegetation with the known elevation of the 1978 and 1980 shoreline.

RESULTS. The area of phreatophyte vegetation in 1940 was 170 acres and in 1978 it was 1360 acres for a total increase of about 1190 acres. The 1940 acreage represented about 12% of the exposed lake bottom; the 1978 acreage represented about 8% of the exposed lake bottom. The higher percentage in 1940 is partly explained by the greater recharge of the aquifers by streamflow and upslope irrigation. Irrigation immediately upslope of Sites 7, 8, 10, 11 that occurred in 1940 has been virtually eliminated. Also some phreatophytes above the historic high stand may have been included in the 1940 estimates due to their indistinct separation from intentionally irrigated areas on the photos. The biggest areas of increase from 1940 to 1978 occurred around the northwest shore (Sites 13 and 14) where spring discharge is very high and at Sites 1 through 5 on the north, east, and southwest shores where spring discharge and high water tables occur over a wide area.

The short-term changes from 1978 to 1980 were nearly impossible to discern on the photos for two reasons. First, the drop in lake level (1.3 ft) and increase in relicted lake area (about 1000 acres) were relatively small so that proportional increases in vegetation may be only about 80 acres. This amount is within the error range in estimating the 1978 phreatophyte acreage. Second the flight lines for 1978 and 1980 imagery are different so the angle of the camera and scale of the photos are different, making side by side comparison difficult.

The changes from 1978 to 1982 are also hard to document. The June 1982 level was about 3.5 ft lower than the July 1978 level and about 2800 additional acres of lake bottom were exposed. Assuming the increase in vegetation is proportional to the increase in exposed lake bottom area, an additional 280 acres of phreatophytes would have colonized. The most noticeable increase was at Site 14, where the delta of Wilson Creek has shifted westward several hundred yards, allowing areas that were formerly subject to scour and fill to be vegetated. The ground transects showed that in general the dense phreatophyte coverage begins at elevations equivalent to the summer 1978 or summer 1979 lake level. Thus, it appears that it takes no more than 3 or 4 years for a dense phreatophyte cover to establish itself.

Footnotes:

The six zones are:

a) 5" - 7.5"
b) 7.5"-.10"
c) 10"-12.5"
d) 12.5"-15"
e) 15"-17.5"
f) 17.5"-20.0"

Although Bodie is just outside the Mono Basin, it is the only high-altitude climate station in the non-Sierra topographic province.

(2) This calculation was done in 1981. The 1982 and 1983 precipitation record at Bodie is missing several key winter months.

(3) In late 1984 and early 1985, Paul Zinke of the Dept. of Forestry, Univ. Calif. Berkeley, chemically analyzed soil and vegetation samples from the exposed lake bottom.

(4) Deposition of the surface sand layer by longshore drift has been reduced dramatically because the major sand source (Rush Creek) has been virtually eliminated by the LADWP stream diversions (Stine pers comm 1984). Rush Creek drains through Pumice Valley and once provided significant quantities of volcanic sand. Stine also theorizes that the sand supply was reduced when the lake lowered below the elevation of the delta plain; longshore currents are no longer picking up sand that was formerly deposited on the delta plains.

APPENDIX IV: CLIMATIC DATA FROM SIMIS STATION

A. EVAPORATION MEASUREMENTS

Table A3-1a. 1980 Evaporation Data

Month	Period	Number of Days	Number of Measurements	Measured Pan Evaporation* (inches)	Monthly Pan Evaporation** (inches)
June (a)	6/13 - 6/27	14	4	4.29	9.09
July	6/29 - 7/31	32	8	10.39	10.07
August	7/31 - 9/1	32	8	9.89	9.58
September	9/1- 9/30	30	8	6.55	6.55
October	9/30 -11/2	32.5	7	4.69	4.47
Total	June-Sept	108	28	31.12	35.29
Total	June-Oct	140.5	35	35.81	39.76

(a) measurements started on June 13

* includes precipitation

** adjusted for number of days in month

Table A3-1b. 1981 Evaporation Data

Month	Period	Number of Days	Number of Measurements	Measured Pan Evaporation* (inches)	Monthly Pan Evaporation** (inches)
May	4/28 - 5/23	25	7	7.67 (a)	9.51
June	6/5 - 6/30	25	10	9.1	10.92
July	6/30 -8/1	32	12	11.79	11.42
August	8/1 - 9/1	32	14	10.92	10.58
September	9/1- 10/1	30	14	7.27	7.27
October	10/1 - 10/28	28	11	4.18	4.33
Total	May-Sept	144	57	46.75	49.7
Total	May-Oct	172	68	50.93	54.03

* includes precipitation

** adjusted for number of days in month

(a) no freshwater pan msmt. in May; used saline water pan msmt.

Table A3-1c. 1982 Evaporation Data

Month	Period	Number of Days	Number of Measurements	Measured Pan Evaporation* (inches)	Monthly Pan Evaporation** (inches)
May	5/6 -5/29	23.5	11	5.86	7.73
June	6/8 - 7/1	23	19	6.19	8.71
July	7/2 - 8/1	31	17	9.99	9.99
August	8/2 - 9/1	31	15	8.74	8.91
September	9/2 - 10/1	30	11	7.13	7.13
October	10/1 - 10/31	30	6	3.98	4.11
Total	May-Sept	138.5	73	37.91	42.47
Total	May-Oct	168.5	79	41.89	46.58

* includes precipitation

** adjusted for number days in month

Table A3-1d. 1983 Evaporation Data

Month	Period	Number of Days	Number of Measurements	Measured Pan Evaporation* (inches)	Monthly Pan Evaporation** (inches)
May	4/30 - 5/31	31	13	8.84	8.84
June	5/31 - 6/30	30	9	9.36	9.36
July	6/30 - 8/1	32	14	11.07	10.72
August	8/1 - 9/1	31	11	8.31	8.31
September	9/1- 9/30	30	11	7.47	7.47
October	10/1 - 10/31	30.5	13	4.05	4.12
Total	May-Sept	154	58	45.05	44.7
Total	May-Oct	184.5	71	49.1	48.82

* includes precipitation

** adjusted for number of days in month

B. OTHER CLIMATIC MEASUREMENTS AT SIMIS STATION

TABLE A3-2a. 1980 Climatic Measurements at Simis Station*

Month	Precipitation (inches)	Average Daily Temperature Maximum (degrees F)	Average Daily Temperature Minimum (degrees F)	Average Daily Temperature Mean (degrees F)	Average Wind Speed (m.p.h.)
July	0.14	81.4	39	60.2	4.79
August	0.16	80.1	35.8	57.9	4.4
September	0.76	74	31	52.5	4.4
Total	1.06	N/A	N/A	N/A	N/A
Average	N/A	78.5	35.3	56.9	4.53

* Station Record Began June 18, 1980

TABLE A3-2b. 1981 Climatic Measurements at Simis Station

Month	Precipitation	Average Daily Temperature			Average Wind Speed
	(inches)	Maximum (° F)	Minimum (° F)	Mean (° F)	(m.p.h.)
October	0.01	64.9	21.8	43.4	3.76
November	0	53.5	17.1	35.3	3.63
December	0.86	40	13.7	26.9	2.98
January	1.76	42.8	14.6	28.7	3.63
February	0.46	42.3	15.1	28.7	3.37
March	0.95	46.6	19.9	33.3	4.92
April	0.6	60.4	23.7	42.1	4.92
May	0.63	65.9	31	48.5	5.44
June	0.19	80.5	38.2	59.4	5.18
July	T	84.6	37.8	61.2	4.66
August	T	85.7	36.2	61	4.92
September	0.05	76.4	33.4	54.9	4.14
Total	5.51	N/A	N/A	N/A	N/A
Average	N/A	62	25.2	43.6	4.3

TABLE A3-2c. 1982 Climatic Measurements at Simis Station

Month	Precipitation (inches)	Average Daily Temperature			Average Wind Speed (m.p.h.)
		Maximum (°F)	Minimum (°F)	Mean (°F)	
October	0.62	57.2	19.5	38.4	4.66
November	1.59	51.3	22.4	36.9	4.66
December	0.41	46.9	19.8	33.4	4.66
January	2.16	31.9	6.3	19.1	3.63
February	0.82	44.7	15	29.9	3.63
March	0.52	44.7	19	31.9	5.7
April	2.17	52.8	21.6	37.2	5.7
May	0.27	64.4	28.6	46.5	5.18
June	1.08	69.2	35	52.1	4.92
July	0.44	79.4	39	59.2	4.53
August	1.4	79.9	38.9	59.4	4.14
September	1.01	69	33	51	4.53
Total	12.49	N/A	N/A	N/A	N/A
Average	N/A	57.6	24.8	41.2	4.66

TABLE A3-2d. 1983 Climatic Measurements at Simis Station

Month	Precipitation	Average Daily Temperature			Average
	(inches)	Maximum (° F)	Minimum (° F)	Mean (° F)	Wind Speed (m.p.h.)
October	1.09	58.6	24.6	41.6	3.94
November	1.69	45	17.8	31.4	3.42
December	1.39	33.1	14.3	23.7	4.14
January	1.78	30.3	7.8	19.1	3
February	1.43	40.2	16.3	28.3	4.58
March	1.58	44.6	22.9	33.8	4.82
April	0.06	47.1	22.3	34.7	6.06
May	T	63.8	25.7	44.8	5.15
June	0.34	72.2	34	53.1	4.87
July	0	78.1	35.4	56.8	5.28
August	1.55	76.7	43	59.9	4.35
September	0.58	73.9	34.9	54.4	4.84
Total	11.49	N/A	N/A	N/A	N/A
Average	N/A	55.3	24.9	40.1	4.54

APPENDIX IV: HISTORICAL GEOGRAPHY OF THE MONO BASIN

A. THE HUMAN DEVELOPMENT OF THE MONO BASIN

Settlement and development of the Mono Basin was shaped in part by its geographic location, the nature of its resource base, and the ownership of land in the basin.

The original human inhabitants of the Mono Basin were nomadic Indians who left little trace of their existence. Approximately 500 years ago the Paiute Indians, locally called the Monache (from which the name "Mono" is derived) or Kuzedika Paiutes, displaced the earliest inhabitants. The Kuzedika Paiutes harvested brine fly larvae from around the shores of Mono Lake.

The discovery of gold in 1852 attracted the first European settlers into the Mono Basin. The first settlers were primarily involved in mining or activities associated with supplying the mining camps with resources such as lumber or food. Early areas of population concentration in the Mono Basin were centered around the boom or bust mining camps. The infamous mining camp of Bodie was just north of the Mono Basin. Much of the food and building supplies for Bodie came from the Mono Basin.

Some of the early settlers were attracted to the abundant water and grazing lands found in the western part of the Mono Basin, and were content at ranching and farming and establishing permanent settlements in the basin (Browne 1865). The waning of mining activities in the late 1800's allowed ranching and farming to become the most common livelihood in the basin. Fletcher (1982) presents a detailed history of 19th century Mono Basin.

Settlement of the Mono Basin in the 20th century was limited by its distance from urban areas. The majority of the land in the basin came under federal control through the administration of what today is the United States Forest Service and through the United States Bureau of Land Management. The unincorporated towns of Lee Vining and June Lake became the population centers in the basin as the recreation potential of the public lands in the Mono Basin was developed. Improved automobile access stimulated year-round recreation and today the economy of the Mono Basin is primarily based on tourism. Although perhaps no more than 1,400 people make the Mono Basin their permanent home, tourist use is about 1.4 million visitor-days per year (Harris pers comm 1985).[l]

The 20th century has been a period of development of the Mono Basin's Sierra Nevada streams for agriculture, hydroelectric power, and urban water and power supply. Shortly after the turn of the century public stock companies attempted to exploit the potential for irrigating large parcels of grazing land with Sierra Nevada runoff by securing water rights, damming natural lakes, and maintaining miles of irrigation ditches. The short growing season and porous soils, however, restricted the development of irrigated and cultivated land in the Mono Basin.

Hydropower development, on the other hand, was facilitated by the steep-gradient streams and high elevation lakes that could be regulated with small dams. By 1926 hydroelectric facilities were installed on Rush, Lee Vining and Mill Creeks.

The most intensive use of the Sierra Nevada runoff was for the municipal water and power supply of Los Angeles. As early as 1913 Los Angeles expressed interest, in the water of the Mono Basin by protesting the regulation and use of water for irrigation. In 1930 Los Angeles voters approved a measure to finance the extension of the Los Angeles Aqueduct into the Mono Basin and by 1935 LADWP had purchased most of the privately held land including much of the irrigated or potentially irrigated acreage in the Mono Basin.[2] In 1941 LADWP began exporting water from Rush, Lee Vining, Walker and Parker Creeks. [3] Since the completion of the second Los Angeles Aqueduct in 1970, nearly the entire flow of these creeks is exported by LADWP except in very high runoff years when capacity restrictions in the Los Angeles Aqueduct system require water to be released into Mono Lake.

B. THE IRRIGATION HISTORY OF THE MONO BASIN

Irrigation in the Mono Basin can be traced back to the early 1860's when the first European immigrants who opted for ranching and farming instead of mining settled in the area (Fletcher 1982 and Browne 1865). Extensive areas of sagebrush were cleared and cultivated with hay grass, alfalfa, grains, and various vegetable crops, all of which required supplemental irrigation during the short but dry growing season. Surplus meat and vegetables raised by the farmers supplied the mining camps in and around the Mono Basin. It appears, however, that a major portion of the irrigation was devoted to crudely cultivated pasture lands that were expansions of former meadows of native phreatophyte vegetation, Irrigation practices were simple: springs and streams were diverted into dirt lined ditches which were systematically breached to flood the land and enhance the growth of native sedges and grasses or the cultivated crops. With the waning of mining activities in the late 1800's, ranching and farming persisted and became the most common livelihood in the Basin. Lane *et al*. (1974) state that in the late 1800's "some 100 families farmed nearly 50,000 acres." Since there is neither land nor water to economically irrigate 50,000 acres much of that acreage had to have been devoted to dry grazing. The total irrigated acreage in the 1880's and 1890's was probably close to 4,000 acres, although it fluctuated depending on demand for products and the hydrological conditions. Estimates of irrigated acreage in the Mono Basin are always complicated by the fact that some native pasture land is only intermittently irrigated when water is available while the cultivated land is usually regularly irrigated.

Shortly after the turn of the century public stock companies were formed to develop projects that could irrigate larger parcels of the dry grazing land. The companies, including the Cain Irrigation District and the Rush Creek Mutual Ditch Company, bought land, secured water rights, constructed small dams and maintained miles of irrigation ditches. Competition for land and water rights was fierce and resulted in court adjudications (e.g., 1915 decrees on Rush, Lee Vining and Mill Creeks). The largest company, the Cain Irrigation District, was also associated with a hydroelectric development company (Southern Sierra Power). It has been suggested that some of the activities of the irrigation company were a front for the hydroelectric development (Harding 1922).

There was no shortage of land that could be potentially irrigated. The State of California estimated that potentially irrigable land in the Mono Basin was about to 13,000 acres (CASWRCB 1951). Entrepreneurs, of course, made even bolder claims. Much of the land proposed for irrigation, however, was marginally suitable because it was underlain by porous pumice soil that required large amounts of water (up to 45 ft/yr according to Harding 1962) and produced low forage yields. An attempt to irrigate land in the northeastern portion of the basin by constructing ditches around the south shore of Mono Lake had to be abandoned because of the tremendous conveyance losses through the porous alluvium. The short growing season and distance from markets also restricted the growing of more profitable crops.

Despite its below normal runoff, the decade from 1925 to 1934 was a period of significant irrigation activity in the Mono Basin. Grant Lake Reservoir, which was originally built in 1915 for storing irrigation water, was enlarged in 1925 in order to augment the late summer flows of Rush Creek.[4] A survey in 1929 reported irrigation on 11,000 acres of land (Harding 1962).[5]

In the mid-1930's LADWP purchased a major portion of the irrigated and potentially irrigable land in the Mono Basin, The land was then leased back to agricultural operators (mainly sheep grazers). LADWP maintained irrigation on most of the land that previously had been regularly irrigated, 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 the planning for the second barrel of the Los Angeles Aqueduct. The new policy was designed to eliminate irrigation of land from the pumaceous soil of low forage yield and extremely high water requirements, which 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 irrigate including about 2,000 acres around Cain Ranch, about 150 acres in Lee Vining Canyon and around Horse Meadow, and about 200 acres on the north shore of Mono Lake (Yoha pers comm 1980).

In addition to the irrigated land owned by LADWP about another 1,000 acres of irrigated land remains in private hands. These lands are located primarily around the northwest shore of Mono Lake. Since LADWP does not export from streams that supply the private land, the acreage has remained fairly constant since the 1930's.

Wild flooding is still the most common irrigation method on both the LADWP and privately irrigated land. The land is used primarily for sheep grazing. Because the sheep are susceptible to hoof rot, the land is flooded episodically and then allowed to dry out before the sheep return to graze.

Footnotes

[1] A visitor-day or more properly a recreation visitor-day is equivalent to the visit of one person for a twelve hour period. The estimate is provided by Mark Harris of the Inyo National Forest and is for the area covered by the Mono District of the Inyo National Forest. It does not include the estimated 150,000 (1983 figures) visitors to the Mono Lake Tufa State Reserve.

[2] In 1931 the United States Congress withdrew public lands in the Mono Basin for the protection of the watershed supplying the City of Los Angeles.

[3] Construction of the aqueduct facilities began in 1934. The Los Angeles Aqueduct extension included building the Mono Basin diversion facilities, Grant Lake Reservoir, Mono Craters tunnel, and Long Valley Reservoir.

[4] Despite the larger dam and reservoir, the entire summer

flow of Rush Creek was often diverted in order to flood the sagebrush land.

11,000 acres may have had water spread over them in some years, but it is doubtful the land and water resources in the Mono Basin would economically support 11,000 acres for a prolonged period.

Appendix V: TERMINAL LAKES

A. GENERAL DESCRIPTION

DEFINITION

Terminal lakes are the terminus of all surface and groundwater in their watersheds. They have no surface outlets and thus are distinguished from drainage or exhoreic lakes that have surface outlets. Terminal lakes are ephemeral features in the geologic time scale because of climatic and tectonic change, but in the historical record terminal lakes are permanent features as compared to the modern day playa or "dry" lake. Playas are normally dessicated and only have surface water for short time periods during brief wet periods. Terminal lakes have water for longer than a year, usually for periods lasting hundreds of years and longer. The distinction is not clear cut because in a wet cycle playas may have water for several years in a row and conversely in a dry cycle a terminal lake may dessicate completely.[l]

Almost one half of the earth's water outside the oceans is found in terminal lakes. Thirteen of the forty largest lakes in the world are terminal lakes including the Caspian Sea, the largest lake in the world with an area of 150,000 mi^2 (Greer 1977). At its current surface area of 68 mi^2 Mono Lake is comparatively small.

OCCURRENCE

Terminal lakes are confined to regions where climate and topography restrict the outflow of water to evaporation, i.e. a hydrologically closed basin, but have sufficient runoff to maintain relatively permanent bodies of water. Although hydrologically closed basins (endoreic regions) cover 27% of the earths surface (33% excluding Antarctica) only 37% of these lands manifest surface runoff.

The climatic conditions that cause the evaporation to exceed the precipitation and runoff exist in the high-pressure (subsidence) belts of the sub-tropical and polar regions, as well as in the rain shadows created by local topography independent of latitude. A theoretical climatic limit for terminal lakes exists where net lake evaporation (evaporation minus precipitation) is equal to zero; a lake near this limit would overflow because of fluctuations in precipitation and contributions from tributary areas. Therefore terminal lakes are restricted to regions where evaporation is appreciably in excess of inflow.[2] The requirement of sufficient inflow limits the occurrence of large terminal lakes to basins that display a wide range of relief with high mountains that trap precipitation, or have large tributary areas in which to capture runoff.

Many of the larger and more well known terminal lakes such as the Dead Sea, Caspian Sea, and the Salton Sea are found near or below sea level. Terminal lakes occur at higher elevations albeit with decreasing frequency, ranging up to near 14,000 ft at Lake Cuing-ha in China.

Terminal lakes are found on every continent including Antarctica. A survey of the terminal lakes on each continent is presented in Greer (1977) and Williams (1981).

DISTINGUISHING CHARACTERISTICS

The environmental conditions that govern the occurrence of terminal lakes also contribute to distinctive morphologic, hydrologic, chemical and biologic characteristics.

Morphologic. Because terminal lakes act as base level for sediment deposition many occupy depressions that are filled to great depth with sediment. As a consequence many terminal lakes are shallow and have relatively flat bottom contours. Deep terminal lakes such as Lake Issy-Ku1 and the Dead Sea, which occupy grabens, are rare. Mono Lake is considered a relatively deep terminal lake (average depth about 60 ft, maximum depth about 157 ft) although it occupies a tectonic depression filled with over 3,000 ft of sediment.

Hydrologic. Since terminal lakes have no outlets, the volume of water fluctuates in response to the climatic and hydrologic factors that determine the inflows and outflows. Variations in volume can only be reflected by changes in surface area and lake level.[3] For a given climatic state, variation in the amount of inflow is the primary cause of fluctuations since the evaporative outflow per unit area is relatively constant. Seasonal and annual fluctuations characterize many terminal lakes because seasonal and annual inflow variability are typical of most terminal lake basin hydrologic regimes. Groundwater inflow to a terminal lake, however, can be an important stabilizing factor in seasonal and annual lake fluctuations. Dramatic lake recessions and transgressions occur when changes in climate cause long-term variations in inflow and outflow. Most mid-latitude terminal lakes are remnants of much larger pluvial lakes from the Pleistocene when the climate was significantly cooler and perhaps wetter (Mifflin and Wheat 1979).[4]

A terminal lake will reach a relative "equilibrium" level and area such that the evaporative outflow is balanced by the long-term inflow if the climate remains "stable" for a long enough period, The climate usually doesn't stabilize long enough for most terminal lakes and thus the "equilibrium" level is more of a theoretical concept.

The large scale fluctuations of terminal lakes -- recorded on the landscape as terraces, former shorelines, vegetation lines and sediment layers -- are considered good indicators of climatic change or geological evolution (Mifflin and Wheat 1979; Antevs 1952). [5] Mono Lake is considered an excellent climatic indicator by Stine (1984) because it never dried up, unlike many other large terminal lakes.[6]

<u>Chemical.</u> The lack of surface outflow from terminal lakes results in the concentration of mineral salts through evaporation. These mineral salts are brought in mainly as

dissolved solutes by inflowing tributary waters. In addition, minerals are brought in as aerosols through precipitation, wind and volcanic eruptions. The redissolving of precipitated minerals by fluctuating lake levels can also add to the lake salt content. Langbein (1961) relates the total salt content and composition to the hydrologic properties of terminal lakes. Langbein suggests that terminal lakes add and lose salts in a cyclic manner related to volume fluctuations. The chemical makeup of a terminal lake is highly sensitive to its environmental setting including, for example, chemical composition of the rocks in its watershed, and the local geological history including lake fluctuations.

Terminal lakes display a wide salinity range and compositional variability that is surveyed in Eugster and Hardie (1979). Although some terminal lakes such as the Dead Sea or Great Salt Lake contain highly concentrated brines, most contain salt concentrations far less than the oceans (Greer 1977).

Biologic. W.D. Williams (1981) stated "Salt (terminal) lakes almost by definition are discrete ecosystems since they are the hydrological terminal within a closed basin.“ As a result of their high salinity many terminal lake ecosystems are relatively simple with low species diversity and discrete trophic relationships, especially when compared to other aquatic environments (Williams 1981). Terminal lakes hold a great deal of scientific interest because the individual species and the ecosystems provide a laboratory for studying adaptations to harsh and changeable conditions.

B. WATER BALANCE MODELS AT OTHER TERMINAL LAKES

The economic and environmental consequences of the climatic and human-induced fluctuations of terminal lakes has stimulated the development of terminal lake water balance models. The Great Salt Lake and the Caspian Sea, the two biggest terminal lakes on their respective continents, have been the subject of many water balance studies. Rising lake levels at Great Salt Lake threaten industries and transportation facilities. Several water balance models were developed to evaluate the effect of control measures on minimizing further lake rises (Waddell and Fields 1977; James et al. 1979). The lowering lake levels at the Caspian Sea threaten the fishery resource, the biological productivity of the lake, and the industrial and recreational access to the lake shore. Efforts to stabilize the Caspian Sea levels include diverting Siberian rivers into the Caspian watershed (Ratcovich pers comm 1983).

Pyramid Lake, a terminal lake in western Nevada, has also been the subject of several water balance studies. Pyramid Lake is experiencing generally declining lake levels due mostly to up-stream agricultural and municipal diversions in its watersheds.[7] The lower lake levels and thus increasing salinity of Pyramid Lake threaten endemic fisheries and waterfowl habitats. A number of water balances for Pyramid Lake were developed to evaluate alternative inflow scenarios (e.g. Wilsey and Ham 1970).

A compilation of some of the water balance models developed at terminal lakes in the United States and Soviet Union is shown in Table A5-1. Analysis of these water balances reveals the following:

1. Nearly all the models fail to explicitly state their boundaries even though all acknowledge the problem of a fluctuating shoreline. In most models the lake is the assumed boundary for the calculation of most component values. Several Great Salt Lake studies (James et al. 1979; Steed 1970; Waddell and Fields 1977) noted that the surface inflow and precipitation have to be adjusted for the non-fixed boundary. In Steed (1970) and Waddell and Fields (1975), for example, measured surface inflow is reduced by the consumptive use of native vegetation downstream from the gages.

2. The study periods for each lake reflect the different observation periods at each lake. Models for the same lake, however, use different study periods reflecting the different assessments of the reliability of long-term hydrologic records at the lake in question. In most cases short-term hydrologic records are extended by correlation with longer-term records.

3. Most water balances are compiled on an annual basis; those compiled on a monthly basis acknowledged the imprecision of monthly estimates of evaporation and groundwater inflow.

4. All the models acknowledge the existence of groundwater

TABLE A6-1. Analysis of Terminal Lake Water Balance Models

LAKE	STUDY	APPLICATION	FORMULATION			CALIBRATION	TIME SERIES USED IN FORECASTING	NOTES
			Boundary Specification	Study Period	Time Interval			
Great Salt Lake	James *et al.* (1979)	Estimate water surface elevation probabilities and associated damages for GSL	No	1890-1977	Annual	Trial and error estimate of groundwater (gw) inflow	Multivariate stochastic model for precipitation, evaporation, streamflow	Attempted but failed to model residual.
Great Salt Lake	Waddell and Fields (1977)	Evaluate the effectiveness of various diking alternatives	Yes	1931-1973	Monthly	Used constant evap rate except adjustment in 3 separate years; unmeasured inflow plus all other error = Ium; Ium = (observed lake altitude - 4190) x C; "C" calculated by trial and error fitting of actual and calculated lake levels	Historic period (1931-73) for runoff and precipitation indices	Constant gw inflow
Great Salt Lake	Steed (1972)	Historic water balance; no predictions	No	1944-70	Monthly and annual	Adjusted Theissen weighting factors in estimating evap; gw inflow = 6% of surface inflow	N/A	Included transpiration losses from around margins of lake

LAKE	STUDY	APPLICATION	FORMULATION			CALIBRATION	TIME SERIES USED IN FORECASTING	NOTES
			Boundary Specification	Study Period	Time Interval			
Great Salt Lake	Utah DWR (1974)	Evaluate effect of present conditions on historic lake elevations	No	1944-73	Annual	Trial and error for estimating gw inflow and ungaged inflow	1901-73 present modified inflows	Included transpiration losses from wetlands around GSL
Walker	Rush (1970)	Evaluate effect of lake recession on water balance conponents	No	1919-68	50 year mean water balance	1/2 of error assigned to inflows; other 1/2 assigned to outflows	N/A	Approximate annual water balance error = 18000 ac-ft/yr
Pyramid	Wilsey and Ham (1970)	Predict impacts of various amounts of Truckee River inflow on lake level	No	1940-66	Annual	Error equal to unmeasured inflow	Average of Study Period	
Pyramid	Kraeger and Linsley (1975)	Formulate management strategy that provided sufficient inflow to stabilize the lake	No	1931-70	Monthly	Created bank storage term = 10% total water storage	1918-70 runoff	Evaluated other management strategies

LAKE	STUDY	APPLICATION	FORMULATION			CALIBRATION	TIME SERIES USED IN FORECASTING	NOTES
			Boundary Specification	Study Period	Time Interval			
Abert	Phillips and Van Denburgh (1971)	Recreate 1915 63 levels; determined inflow necessary to bring lake up to historic high stand	No	1915-63	Annual	Regression equation between calculated inflow and measured streamflow	Historic runoff (1915-63)	Determined evaporation by mass-transfer
Salton Sea	Hely <u>et al</u> (1966)	Evaluation of different methods of evaporation measurement	No	1908-62	Annual; Daily & Monthly for Evap.	Pre-1944 residual equal to surface inflow	N/A	Determined evaporation by 3 methods: water budget, evaporation pan, and mass transfer
Caspian Sea	Ratcovich (pers comm 1983)	Predict impact of increasing in-basin consumptive use on lake levels; also determine amount of increased inflow needed to stablize lake at various elevations	No	?	Annual	Error distributed among other components, mostly assigned to groundwater	First order Markov model of inflow and net evaporation	

and unmeasured surface inflow but few are able to calculate these terms directly. These terms are usually derived from residuals while calibrating the model.

5. Calibration procedures include introducing a bank storage term, and the trial and error adjustment of evaporation, groundwater, or unmeasured runoff terms.

6. None of the models explicitly analyze error of the individual components although all acknowledge the imprecision of their estimates. Evaporation estimates are singled out most often as being subject to error and needing refinement.

7. None of the models are verified because the entire period of record is used in calibrating the models. This lack of verification means that there is no statistical confidence in the respective calibration procedures. Most of the models use the historical record for inputs into their predictive models. Only James et al. (1979) and Ratcovitch (pers comm 1983) develop synthetic sequences as input to the water balance forecast model. The inconsistent and incomplete data bases, common to terminal lakes, makes the generation of valid statistical models a complex problem (James et al. 1979).

Footnotes

(1) Although a continuum exists, playas can be distinguished from terminal lake by the concept of a flooding ratio, i.e., the amount of time during a specified time period that water exists on the surface. The concept is usually applied to distinguished playa types (Neal 1965). Most terminal lakes would have a ratio of "1" in a ten year flooding ratio.

(2) Since the climatic state of a region depends on the time period considered, evaporation can exceed inflow in normally more humid areas during dry periods and temporarily create terminal lakes as in the case of Lake Tahoe. And, conversely, lakes in

semi-arid regions can have outflow in wet periods as in the case of Goose Lake.

(3) Lake basin morphometry determines how the volume fluctuations will translate into level and area fluctuations. Flat lake bottom contours will manifest inflow variations with large surface area fluctuations while steeper sided lake bottoms will manifest the same inflow variation with greater lake level fluctuations.

(4) These lakes reached maximum extent roughly coincident with the maximum advance of glaciers (Chappell 1977). The pluvial lakes began a steady although irregular recession about 10,000 years ago following the melting of the glaciers and in response to the increasingly arid conditions of the Holocene. Within this time, however, variations in climate have caused periodic contractions and enlargements of terminal lakes. Equatorial terminal lakes did not follow the same cycle of fluctuations because they are governed by much different climatic controls (Chappell 1977).

[5] Further analysis of the hydrologic characteristics of terminal lakes is found in Langbein (1961). Langbein's theoretical discussion includes the concept of response time as an important characteristic of terminal lakes that can help explain the nature of lake fluctuations.

(6) Some terminal lakes may have dried up completely during the more prolonged warm, dry spells. The Aral Sea, Great Salt Lake, Walker Lake, and Pyramid Lake may have all dried up at one time or another in the past 10,000 years (Benson 1979; Willet 1977).

(7) Recent wet years have caused a temporary rise in lake level.

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