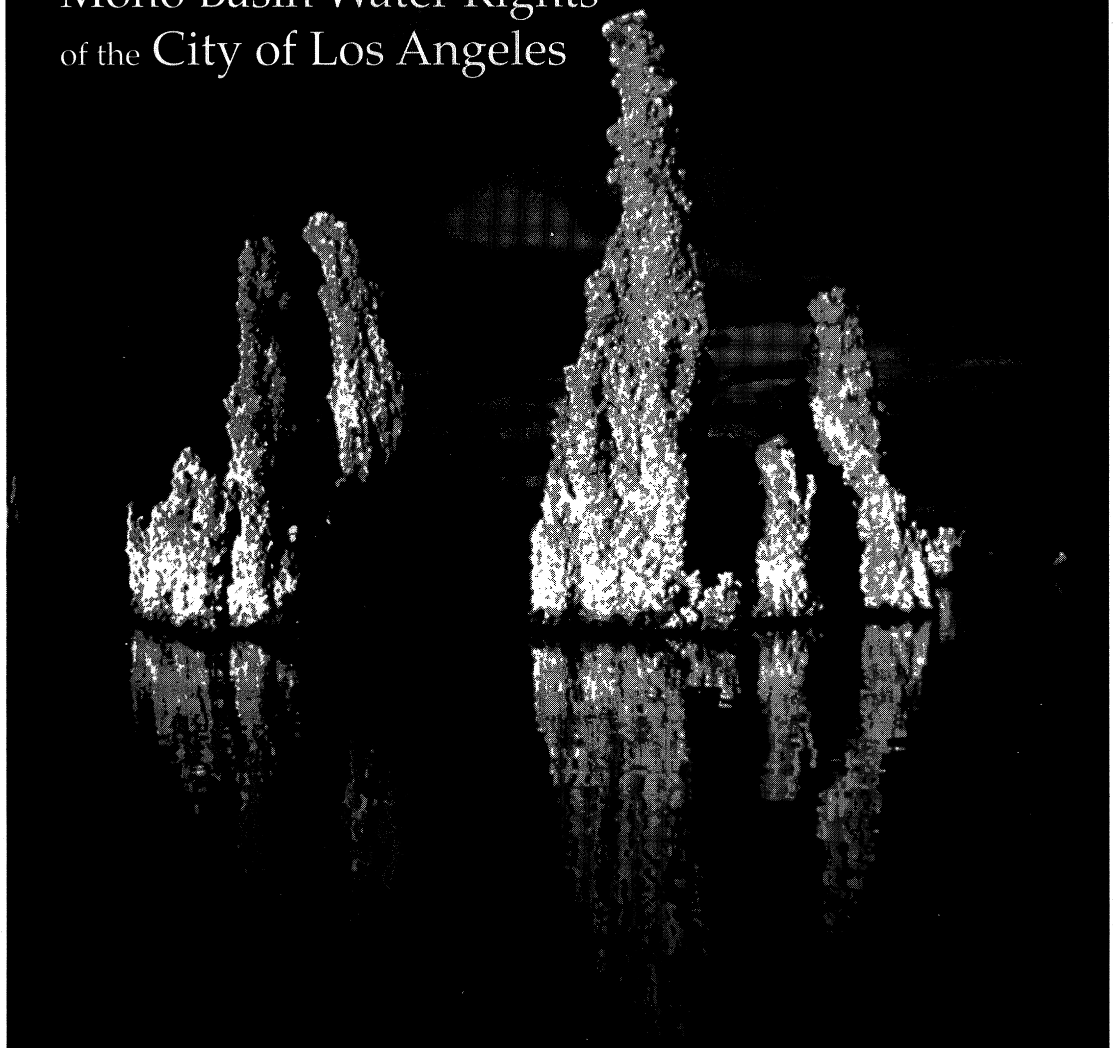
Draft Environmental Impact Report for the Review of the

Mono Basin Water Rights of the City of Los Angeles



California State Water Resources Control Board
Division of Water Rights
Sacramento, California

Appendices

MONO BASIN EIR

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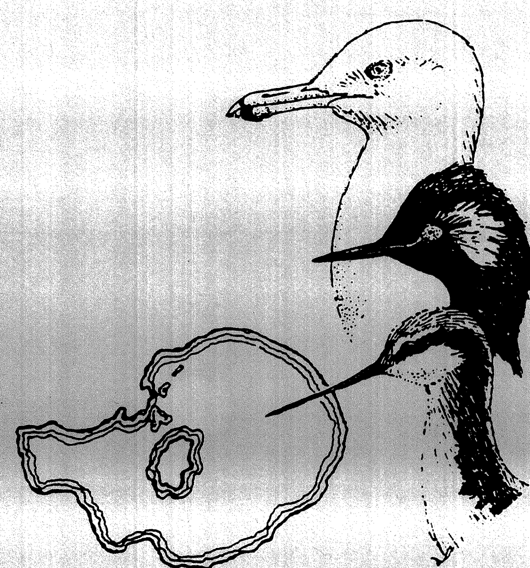
Appendix A. Mono Lake Monthly Water Balance Model



MONO BASIN EIR

Prepared by Jones & Stokes Associates

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Appendix A. Mono Lake Monthly Water Balance Model

The hydrology of Mono Lake has been analyzed by constructing a monthly water budget that includes inflow terms, a storage change term, and an outflow term. The monthly inflows are the gaged and ungaged monthly streamflows, groundwater inflows, and direct precipitation on the lake surface. Ungaged streamflow and groundwater inflows are called "unmeasured inflows". The monthly change in storage is calculated from the measured change in elevation and Mono Lake surface area. The outflow term is the unmeasured evaporation that is estimated from an assumed monthly evaporation rate and the lake surface area. The water budget method attempts to estimate each of these terms to provide a consistent description of Mono Lake hydrology.

Methods for Estimating Terms

The basic data needed to calculate an accurate monthly water budget for Mono Lake are:

- bathymetry (lake surface area and volume at each elevation),
- monthly water surface elevations,
- monthly lakewide average precipitation,
- monthly surface water and groundwater inflows, and
- monthly lakewide average evaporation.

Bathymetry data for this appendix were obtained from the combination of aerial photogrammetry by Pacific Western Aerial Surveys and a detailed bathymetric survey of Mono Lake conducted by Pelagos Corporation for LADWP in summer 1986, when Mono Lake elevation was approximately 6,380 feet. Raw data were obtained from 60,000 depth soundings throughout Mono Lake. The depth soundings were converted into 5-foot depth contours, and the area within each contour interval was estimated. Interpolation methods were used to obtain measurements of 1-foot area increments.

Monthly Mono Lake surface elevations were obtained from LADWP records of periodic (but not always end-of-month) elevation measurements, linearly interpolated to end-of-month estimates. LADWP records were adjusted by adding 0.37 foot (4.5 inches), so that the elevations are consistent with the U.S. Geological Survey (USGS) 1929 sea level datum.

Monthly lakewide average precipitation data are estimated from LADWP monthly Cain Ranch precipitation records. Because Mono Lake is in the "rain shadow" of the Sierra

Nevada crest, it is reasonable to suppose that the lakewide average precipitation is less than the Cain Ranch (elevation 6,850 feet) average of 11 inches. A precipitation station at Simis Ranch on the eastern side of Mono Lake has an estimated (short-term record) average precipitation of 7.5 inches. Each of the previous water budgets for Mono Lake use Cain Ranch as an index of lakewide precipitation. Vorster (1985) and LADWP (1990) annual water balance models each assume an average lakewide precipitation of 8 inches (73% of Cain Ranch average). The variations in lakewide precipitation are assumed to follow the Cain Ranch pattern.

Monthly surface water and groundwater inflows can only be partially measured with streamflow gages on the major tributaries (Mill, Lee Vining, Walker, Parker, and Rush Creeks). Because of irrigation diversions downstream of the gages on each tributary, the available flow records are only approximate estimates of the total surface water and groundwater inflow to Mono Lake. Additional inflow may exist that is proportional to the measured runoff, or the additional inflow may be a constant term that does not depend on variations in surface runoff. Each of the previous water budgets for Mono Lake has used the measured runoff as an index for estimating the total inflow term.

Monthly lakewide evaporation can be estimated from local evaporation pan measurements, observed changes in lake elevation, assumed relationships with meteorological data (wind and humidity), or heat budget modeling of Mono Lake surface temperatures (Romero 1992). Because the lakewide evaporation cannot be measured directly, any of these methods can provide only assumed evaporation rates. Favorable comparison between these methods of estimation increases the confidence in the assumed monthly evaporation pattern for Mono Lake.

Available Hydrologic Data

The available hydrologic data for 1941-1989 are given in the basic data file MONOWB.WK1, available from SWRCB consultants. The year and month are followed by the end-of-month elevation (USGS datum). The surface area and monthly volume changes are calculated by interpolation of the 1-foot interval bathymetry data that is given in data file BATHY.WK1. The monthly Cain Ranch precipitation is provided in the next column. The precipitation volume estimate is calculated from the average lake area and the precipitation depth.

The available streamflow measurements are given in the next several columns. Previous water budget models used various sums and adjustments to arrive at an index of surface runoff into Mono Lake. Because the total runoff from the four diverted tributary creeks are used as the index of runoff-year types (wet, normal, or dry) for Mono Basin, flow measurements for these creeks are used for the monthly Mono Lake water budget runoff index. For the historical period of 1941-1989, LADWP measured the spill at Lee Vining Creek intake and the releases and spills from Grant Lake reservoir to Rush Creek. The sum of these values was taken as the surface inflow to Mono Lake from the four diverted creeks. Releases from Walker and Parker Creeks were generally used for irrigation and were not included in the surface inflow estimates, although in wet years some nonirrigation releases were made.

For a portion of the historical period, LADWP operated streamflow gages on Lee Vining Creek (1941-1969) and Rush Creek (1952-1967) near their mouths at Mono Lake. These records provide an indication of the portion of the creek flows that infiltrated or were evapotranspirated on irrigated pasture or in the riparian corridors. They cannot provide a better estimate of the inflow to Mono Lake because the infiltrated water would enter as groundwater flow.

The next column is the difference between the observed monthly change in Mono Lake volume and the estimated terms for measured inflow and precipitation. The missing terms, evaporation and unmeasured inflow, are more difficult to identify.

The average monthly evaporation pattern was estimated from the observed loss of water from Mono Lake. The observed monthly changes in Mono Lake volume are usually less than the estimated inflows (measured surface flows plus precipitation) and these differences are greatest in the warm summer months. These average differences were used to approximate the monthly evaporation rates.

Surface inflow from portions of Mono Basin without streamflow gages and groundwater inflow cannot be measured. Some reasonable estimate for these unmeasured inflows must be used; a constant long-term average and/or some fraction of measured precipitation or gaged runoff can be used.

Because both evaporation and unmeasured inflows must be estimated from the change in Mono Lake volume that is not explained by measured inflows and direct precipitation, the magnitude of one term must be assumed to calculate the magnitude of the other. An independent estimate of annual evaporation based on temperature modeling by the University of California, Santa Barbara (UCSB) (1992) was used to set the magnitude of annual Mono Lake evaporation at 48 inches. This allowed the magnitude of the unmeasured inflow to be estimated to complete the monthly Mono Lake water budget model.

Previous Mono Lake Water Balance Models

SWRCB staff evaluated two annual (runoff year) water budget models and determined that the historical accuracy of both models, when compared with recorded Mono Lake volume changes from 1937 to 1989, was essentially equivalent (Rich pers. comm.). Vorster (1985) had developed a model that included many separate hydrologic terms, although several could not be measured directly. LADWP (1990) had developed a model with fewer terms that lumped many measured and unmeasured inflows into a single "runoff factor" regression equation. The following review of each model will explain the basic techniques of constructing a water balance model.

Vorster Model

Vorster (1985) summarized all previous water budgets for Mono Lake and analyzed all available hydrologic data to estimate terms for an annual water balance for Mono Lake. LADWP runoff and lake elevation data for 1937-1983 formed the basis for estimates of the annual water budget terms. Vorster attempted to separate each identifiable hydrologic term to provide an accurate and reliable water budget and sensitivity analysis. However, because data were not available for direct estimation of each term, several terms were based on assumptions and indirect evidence. The accuracy of each individual term is unknown, although the overall match with the historical Mono Lake elevation record is good.

Vorster's model is based on the following water budget terms:

- Precipitation at Mono Lake is assumed to average 8 inches and to fluctuate with Cain Ranch measurements.

- Evaporation is assumed to average 45 inches, to fluctuate with Long Valley evaporation pan data, and to be reduced slightly (3-5%) by Mono Lake salinity.

- Sierra Nevada runoff as measured at streamflow gages (150 thousand acre-feet per year [TAF/yr]) is increased by 11% to account for unmeasured Sierra runoff, with an additional 20 TAF assumed from non-Sierran areas, 9 TAF from precipitation on land around the lake, and 1.5 TAF from Virginia Creek diversions. The total average inflows are 197.5 TAF and can be estimated as 111% of measured runoff plus a constant of about 30.5 TAF.

- Several water losses are assumed; bare ground ET around the lake perimeter averaged 5.5 TAF, Grant Lake reservoir evaporation averaged 1.5 TAF, phreatophytes around the lake account for 3 TAF, riparian ET averaged 1.5 TAF, irrigated pasture ET averaged 8 TAF, and the export of groundwater in the Mono Craters Tunnel accounts for about 7 TAF. These relatively constant losses total 26.5 TAF.

- The recorded LADWP exports from West Portal are subtracted from the available water.

- A final regression of unexplained lake volume changes with evaporation and runoff is used to correct the average 2.5 TAF/yr error in the modeled estimates of Mono Lake volume change during 1937-1983. The resulting estimates of Mono Lake elevation had an average error of 0.25 foot (3 inches).

The Vorster water balance includes many separate hydrologic terms that can be evaluated throughout the basin but does not provide validation of the individual estimates because hydrologic data are not collected for each identified term. The ability of the model to account accurately for the net water balance for Mono Lake suggests that the relative magnitude of the assumed inflows and losses is correct.

LADWP Model

LADWP developed a water balance with precipitation, evaporation, and a single net inflow term that used the available streamflow and diversion data to estimate the total releases toward Mono Lake. For an assumed evaporation rate, LADWP used a regression analysis to adjust the estimated inflows to match the historical fluctuations in Mono Lake volume for 1937-1989.

The LADWP-90RY model is based on the following water balance terms:

- Precipitation at Mono Lake is assumed to average 8 inches and to fluctuate with Cain Ranch measurements.
- Evaporation is assumed to average 41 inches, to fluctuate with Long Valley evaporation pan data, and to be reduced slightly (3-5%) by Mono Lake salinity.
- Sierra Nevada runoff as measured at streamflow gages (148 TAF/yr average) is decreased by irrigation diversions (7.5-12 TAF/yr), storage in Grant Lake reservoir, and West Portal exports. This is the measured portion of the estimated net inflow toward Mono Lake.
- A linear regression of unexplained historical lake volume changes with estimated releases to the lake is used to estimate the total inflow. The regression equation was estimated to be:

Unmeasured inflow = 18.5 - .0585 x measured releases to Mono Lake

The LADWP formulation recognizes that the only available data are the measured streamflows, diversions, and lake level fluctuations. However, the regression equation for the unmeasured inflow could also be formulated in terms of the measured runoff, rather than the releases toward Mono Lake. Nevertheless, the historical match is comparable to the Vorster model, with an average error of 0.25 foot (3 inches).

Mono Lake Bathymetry

The bathymetric data for Mono Lake are summarized by the surface area and volume at 1-foot intervals from the lake bottom at elevations of 6,230-6,440 feet. The bathymetric data originated from a bottom depth-sounding survey conducted by Pelagos for LADWP in 1986 (Pelagos 1986) when the lake surface elevation was approximately 6,380 feet. The transects for the sounding equipment required at least 5 feet of depth. Aerial photogrammetry was used to estimate 5-foot elevation contours from 6,372 to 6,430 feet.

These basic data have been modified slightly in the elevation range of 6,365-6,430 feet and were extended to 6,440 by SWRCB consultants who mapped several contours based on visible benchmarks on aerial photographs (see Appendix G). The bathymetry data for elevations 6,300-6,440 feet are given in Table A-1. Estimates of salinity and specific gravity (density) are given for reference. The surface area of Mono Lake for elevations between 6,340 feet and 6,440 feet are shown in Figure A-1. The areas mapped by the SWRCB consultants are shown for comparison with the Pelagos bathymetry. The volume of Mono Lake for elevations between 6,340 and 6,440 feet is shown in Figure A-2.

The 1-foot incremental areas are the basic building block for the bathymetric data; the lake surface area is the sum of the incremental areas to that elevation, and the incremental volumes are calculated from the average area at the top and bottom of the increment. Review of the original Pelagos incremental area data showed that large incremental areas occurred near the 5-foot contour elevations, with much smaller increments midway between the 5-foot contours. This result is attributable to the SURFACE II graphics interpolation program used by Pelagos. SWRCB staff and consultants determined that this effect could be eliminated by 11-foot interval linear smoothing of the incremental area values (Rich pers. comm.).

Figure A-3 shows the original Pelagos and "smoothed" 1-foot incremental area values for Mono Lake between elevations of 6,350-6,420 feet. The largest incremental areas (more than 600 acres per foot of elevation) occur in the range of 6,365-6,375 feet because the shoreline slope is generally smallest at these elevations. The smallest incremental areas (about 200 acres per foot of elevation) occur between elevations 6,400 and 6,415 feet where the shoreline is steepest. The smoothing has relatively small effects on the lake surface and volume increments used in the water budget.

The bottom of Mono Lake is at about 6,230 feet elevation. At an elevation of 6,370 feet, the lake surface area is approximately 35,820 acres (56 square miles), and the lake volume is approximately 2.1 million af (MAF). At an elevation of 6,420 feet, the lake surface area is approximately 55,500 acres (87 square miles), and the lake volume is about 4.5 MAF. For the August 1989 point of reference for this EIR, Mono Lake surface elevation was 6,376.3 feet above sea level, with a surface area of about 41,000 acres and a volume of approximately 2.33 MAF.

In the water balance model, monthly volume changes of the lake were estimated from the surface areas interpolated from the 1-foot bathymetric data.

Evaporation and Precipitation

The monthly evaporation rates (inches/month) were assumed to be constants for each year. The monthly volume change from evaporation was estimated for the 1940-1989 historical period as the assumed evaporation rate multiplied by the surface area of the lake at the beginning of the month. The monthly precipitation contribution to the lake volume was estimated using the observed monthly Cain Ranch precipitation multiplied by the lake area. As previously noted, the average 1940-1989 Cain Ranch annual precipitation was approximately 11 inches. This is slightly higher than the estimated lakewide average precipitation of 8 inches based on maps of precipitation contours (Vorster 1985, LADWP 1990). This uncertainty in net evaporation (evaporation minus precipitation) is accounted for in the residual inflow estimate discussed in the next section.

The available hydrologic data were used to provide the initial estimate of monthly evaporation for Mono Lake. The monthly measured change in Mono Lake volume was compared with the estimated inflows from precipitation and measured surface inflows. This residual volume change was then divided by the surface area to give a residual elevation change in inches. These monthly estimates were averaged for each calendar month. The results provide an estimate of the minimum possible monthly average evaporation because any unmeasured inflows must be balanced by additional evaporation to match the historical surface elevation changes. Figure A-4 shows all the monthly estimates of "missing water", sorted by calendar months. These monthly residual estimates are scattered because of data errors and unmeasured inflows.

The monthly averages of these residual estimates of minimum evaporation rates are listed in Table A-2. The seasonal pattern is quite reasonable. The annual average sum of "missing water" is about 38 inches. This can be interpreted as the minimum possible evaporation because unmeasured inflows must be balanced by increased evaporation. This initial evaporation pattern can be confirmed with other estimates of evaporation for Mono Lake.

Two evaporation pan records for Mono Basin are available. A floating pan was maintained by LADWP in Grant Lake reservoir from 1942 to 1969, and a land pan replaced the floating pan in 1968 (elevation 7,200 feet). Measurements are only obtained in non-freezing months, and Cain Ranch precipitation estimates are used to correct the actual pan data. Nevertheless, the average May-October Grant Lake reservoir evaporation measurements given in Table A-2 suggest a similar, but greater, seasonal pattern when compared to the residual monthly estimates.

The second evaporation pan record was collected at the Simis Ranch meteorological station from 1980 to 1983 (Vorster 1985). The monthly average values were higher than Grant Lake reservoir data but followed a similar seasonal pattern.

Temperature and salinity modeling of Mono Lake by UCSB staff independently estimated the evaporation for 1990 that provided the best match with biweekly surface temperature measurements. The annual value was approximately 48 inches (Romero 1992). This value was therefore selected for use in the Mono Lake monthly water budget model. Figure A-5 shows the sensitivity of modeled Mono Lake surface temperatures to the evaporation coefficient. The resulting annual evaporation rates are shown. The best estimate was determined to be 0.8 times the base estimate. UCSB staff plan to collect daily surface temperatures and complete local meteorological data in hopes of determining an even more accurate estimate of Mono Lake evaporation. However, some uncertainty will always remain in evaporation and all other terms of the water budget.

Unmeasured Inflows

The monthly water balance model uses the monthly residual water estimates to determine the monthly fractions of an assumed total annual evaporation (Table A-2). A linear regression equation was then estimated between unmeasured inflows and monthly runoff to complete the monthly water budget. Both the constant and the fraction of runoff increase with the assumed evaporation. For the assumed evaporation of 48 inches, the constant term is 2,915 af/month (34,992 af/year), and the fraction of runoff is 22.8%. This 22.8% fraction of runoff regression term includes Mill and DeChambeau Creeks because the runoff term was selected to correspond to the diverted tributary creeks. Because the Mill and DeChambeau Creeks average 18% of the diverted creeks' runoff, unmeasured inflow is about 5% of diverted creeks' runoff, plus the constant term of about 35 TAF/yr.

This regression of unmeasured inflows is consistent with the assumed evaporation rate because the runoff from Mill and DeChambeau Creeks is about 18% of the diverted creeks' total runoff. If the runoff variable term is assumed to equal runoff from Mill and DeChambeau Creeks, then at least 44 inches of evaporation are required for an 18% runoff term in the unmeasured inflow regression. Alternatively, if the total unmeasured inflow term is assumed to equal runoff from Mill and DeChambeau Creeks, then at least 37 inches of evaporation are needed. The assumed 48 inches of evaporation are consistent with this unmeasured inflow regression estimate.

Model Calibration with Observed Lake-Level Fluctuations

The monthly water balance can be summarized as:

- assumed constant annual evaporation of 48 inches, distributed in constant monthly fractions;
- measured Cain Ranch monthly precipitation;
- monthly releases from Lee Vining, Walker, Parker, and Rush Creeks to Mono Lake; and

- additional monthly inflow of 2,916 af plus 22.8% of monthly runoff from the four diverted creeks; the total additional inflow averages 63,116 af per year.

These monthly estimated evaporation and additional inflow terms, together with the measured historical releases to Mono Lake from the diverted tributaries, provide an accurate simulation of the observed variations in lake volume and surface elevation. Figure A-6 shows the simulated and observed Mono Lake elevations for the 1941-1989 period. The average error for the 49-year period is 0.5 foot. However, the average absolute error since 1965 when the lake level declined below 6,390 feet is only 0.27 foot.

The calibration using the assumed 48 inches of evaporation and results for a 36 inch evaporation estimate are shown. Lower evaporation rates are balanced by smaller unmeasured inflows regressions, so that the resulting match with the historical Mono Lake elevation pattern is nearly identical. The simulated elevations remain consistently below the measured elevations from about 1950 to 1983, suggesting an error in the measured inflow terms.

The monthly water budget terms can be summarized with annual values for the historical period 1941-1989, as shown in Figure A-7. The terms are shown as cumulative annual values. The first term is the unmeasured inflows that fluctuate with runoff. The next term is precipitation on Mono Lake. The third inflow is the measured releases to Mono Lake from the four diverted creeks. These inflow terms have varied from about 50 TAF to more than 350 TAF. When the assumed 48 inches of evaporation are subtracted from these inflows, the final estimated change in Mono Lake volume is given. For calibration purposes, the actual observed changes in Mono Lake volume also are shown.

This monthly water budget for Mono Lake is considered adequate for purposes of this EIR and was used in the aqueduct simulation model (Auxiliary Reports 5 and 18) and, in modified form, in the extended drought analysis (Appendix H).

CITATIONS

Printed References

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Pacific Western Aerial Surveys. 1986. Topographic map of Mono Lake. n.p.

Pelagos Corporation. 1986. Executive summary, a bathymetric and geologic survey of Mono Lake, California. San Diego, CA.

Romero, J. 1992. 50-year DYRESM simulations of Mono Lake with different water management scenarios. (Mono Basin EIR Auxiliary Report No. 14.) California State Water Resources Control Board. Sacramento, CA.

Vorster, P. 1985. A water balance forecast model for Mono Lake, California. (MA thesis.) California State University. Hayward, CA.

Personal Communications

Rich, Charles A. Senior water resources control engineer. Hearing Unit, California State Water Resources Control Board, Sacramento, CA. February 8, 1991 - memorandum to files regarding evaluation of models.

Table A-1. Bathymetry of Mono Lake

Elevation (ft)[a]	Original Pelagos Corporation Bathymetry: Surface Area (acres)	Area Increment (acres)	Lake Volume (af)	Volume Increment (af)	Smoothed Pelagos Corporation Bathymetry: Surface Area (acres)	Area Increment[b] (acres)	Lake Volume (af)	Volume Increment (af)	Jones & Stokes Associates Mapped Area (acres)[c]	Average Salinity (g/l)[d]	Specific Gravity[e]
6,300	14,786	360	301,744	14,606	14,776	395	302,324	14,579		693	1.530
6,301	15,150	364	316,712	14,968	15,162	386	317,293	14,969		661	1.506
6,302	15,502	352	332,036	15,324	15,536	374	332,642	15,349		630	1.482
6,303	15,892	390	347,728	15,692	15,903	367	348,362	15,719		602	1.461
6,304	16,335	443	363,840	16,112	16,259	356	364,443	16,081		575	1.441
6,305	16,698	363	380,361	16,521	16,609	350	380,877	16,434		550	1.422
6,306	17,027	329	397,223	16,862	16,952	343	397,657	16,780		527	1.404
6,307	17,354	327	414,418	17,195	17,289	337	414,777	17,121		505	1.388
6,308	17,674	320	431,923	17,505	17,623	333	432,233	17,456		485	1.372
6,309	17,977	303	449,753	17,830	17,949	326	450,019	17,786		466	1.357
6,310	18,271	294	467,877	18,124	18,264	315	468,126	18,106		448	1.344
6,311	18,561	290	486,289	18,412	18,574	310	486,544	18,419		431	1.331
6,312	18,862	301	504,999	18,710	18,882	308	505,272	18,728		415	1.319
6,313	19,169	307	524,013	19,014	19,189	307	524,308	19,036		400	1.307
6,314	19,482	313	543,339	19,326	19,498	309	543,651	19,344		386	1.296
6,315	19,799	317	562,978	19,639	19,808	310	563,304	19,653		372	1.286
6,316	20,106	307	582,929	19,951	20,117	309	583,267	19,962		359	1.277
6,317	20,417	311	603,187	20,258	20,424	307	603,537	20,270		347	1.267
6,318	20,735	318	623,762	20,575	20,727	303	624,113	20,576		336	1.259
6,319	21,070	335	644,659	20,897	21,025	298	644,989	20,876		325	1.250
6,320	21,384	314	665,886	21,227	21,319	294	666,161	21,172	21,639	315	1.243
6,321	21,672	288	687,420	21,534	21,609	290	687,625	21,464		305	1.235
6,322	21,939	267	709,222	21,802	21,895	286	709,378	21,752		295	1.228
6,323	22,196	257	731,293	22,071	22,179	283	731,415	22,037		287	1.221
6,324	22,449	253	753,614	22,321	22,455	276	753,732	22,317		278	1.215
6,325	22,716	267	776,197	22,583	22,723	268	776,321	22,589		270	1.209
6,326	22,990	274	799,052	22,855	22,986	263	799,175	22,854		262	1.203
6,327	23,253	263	822,173	23,121	23,246	261	822,291	23,116		255	1.197
6,328	23,534	281	845,564	23,391	23,505	259	845,667	23,376		248	1.192
6,329	23,774	240	869,221	23,657	23,766	261	869,302	23,635		241	1.187
6,330	24,017	243	893,118	23,897	24,029	263	893,199	23,897	24,251	235	1.182
6,331	24,272	255	917,263	24,145	24,292	263	917,360	24,161		228	1.177
6,332	24,538	266	941,668	24,405	24,557	265	941,785	24,425		223	1.173
6,333	24,786	248	966,332	24,664	24,826	268	966,476	24,692		217	1.168
6,334	25,067	281	991,260	24,928	25,094	268	991,436	24,960		211	1.164
6,335	25,343	276	1,016,469	25,209	25,366	272	1,016,666	25,230		206	1.160
6,336	25,609	266	1,041,941	25,472	25,643	277	1,042,171	25,505		201	1.156
6,337	25,909	300	1,067,699	25,758	25,926	283	1,067,955	25,785		196	1.153
6,338	26,206	297	1,093,760	26,061	26,215	288	1,094,026	26,070		192	1.149
6,339	26,483	277	1,120,102	26,342	26,509	295	1,120,388	26,362		187	1.146
6,340	26,767	284	1,146,732	26,630	26,805	296	1,147,045	26,657	26,928	183	1.142
6,341	27,068	301	1,173,645	26,913	27,101	295	1,173,998	26,953		179	1.139
6,342	27,382	314	1,200,872	27,227	27,398	298	1,201,247	27,250		174	1.136
6,343	27,711	329	1,228,422	27,550	27,695	296	1,228,794	27,547		171	1.133
6,344	28,030	319	1,256,294	27,872	27,987	292	1,256,635	27,841		167	1.130
6,345	28,320	290	1,284,467	28,173	28,277	291	1,284,767	28,132	28,595	163	1.127
6,346	28,592	272	1,312,923	28,456	28,565	288	1,313,188	28,421		160	1.125
6,347	28,886	294	1,341,664	28,741	28,848	283	1,341,895	28,707		156	1.122
6,348	29,166	280	1,370,691	29,027	29,124	276	1,370,881	28,986		153	1.120
6,349	29,420	254	1,399,982	29,291	29,391	267	1,400,138	29,258		150	1.117
6,350	29,681	261	1,429,532	29,550	29,650	259	1,429,659	29,521	29,880	147	1.115
6,351	29,931	250	1,459,339	29,807	29,904	254	1,459,436	29,777		144	1.113
6,352	30,184	253	1,489,396	30,057	30,158	253	1,489,467	30,031		141	1.110
6,353	30,413	229	1,519,696	30,300	30,409	251	1,519,750	30,283		138	1.108
6,354	30,651	238	1,550,227	30,531	30,662	253	1,550,286	30,536		135	1.106
6,355	30,875	224	1,580,989	30,762	30,920	258	1,581,077	30,791	31,080	133	1.104
6,356	31,119	244	1,611,984	30,995	31,182	262	1,612,128	31,051		130	1.102
6,357	31,379	260	1,643,234	31,250	31,449	267	1,643,443	31,315		128	1.100
6,358	31,652	273	1,674,745	31,511	31,720	271	1,675,028	31,584		125	1.099
6,359	31,951	299	1,706,543	31,798	31,998	279	1,706,886	31,859		123	1.097
6,360	32,258	307	1,738,649	32,106	32,283	285	1,739,027	32,141	32,340	121	1.095
6,361	32,559	301	1,771,058	32,409	32,575	292	1,771,456	32,429		118	1.093
6,362	32,864	305	1,803,775	32,717	32,873	298	1,804,180	32,724		116	1.092
6,363	33,165	301	1,836,790	33,015	33,182	309	1,837,207	33,027		114	1.090
6,364	33,478	313	1,870,113	33,323	33,517	336	1,870,557	33,350		112	1.089
6,365	33,787	309	1,903,745	33,632	33,869	352	1,904,250	33,693	33,831	110	1.087
6,366	34,086	299	1,937,684	33,939	34,224	355	1,938,297	34,047		108	1.086
6,367	34,392	306	1,971,918	34,234	34,593	369	1,972,705	34,409		106	1.084
6,368	34,777	385	2,006,491	34,573	35,070	477	2,007,537	34,832		104	1.083
6,369	35,345	568	2,041,538	35,047	35,619	549	2,042,882	35,345		103	1.081
6,370	35,819	474	2,077,137	35,599	36,266	647	2,078,825	35,943		101	1.080
6,371	36,165	346	2,113,131	35,994	36,970	704	2,115,443	36,618		99	1.079
6,372	36,619	454	2,149,503	36,372	37,688	717	2,152,772	37,329	36,859	97	1.077
6,373	38,113	1,494	2,186,471	36,968	38,409	721	2,190,820	38,048	37,592	96	1.076
6,374	39,203	1,090	2,225,300	38,829	39,127	718	2,229,588	38,768		94	1.075
6,375	40,590	1,387	2,264,835	39,535	39,915	789	2,269,109	39,521	39,418	92	1.074
6,376	41,535	945	2,306,053	41,218	40,724	809	2,309,428	40,320	40,323	91	1.072
6,377	41,976	441	2,347,827	41,774	41,531	807	2,350,556	41,128	40,876	89	1.071

Table A-1. Continued

	Original Pelagos Corporation Bathymetry				Smoothed Pelagos Corporation Bathymetry				Jones & Stokes Associates		
Elevation (ft)[a]	Surface Area (acres)	Area Increment (acres)	Lake Volume (af)	Volume Increment (af)	Surface Area (acres)	Area Increment[b] (acres)	Lake Volume (af)	Volume Increment (af)	Mapped Area (acres)[c]	Average Salinity (g/l)[d]	Specific Gravity[e]
6,378	42,323	347	2,389,985	42,158	42,325	794	2,392,484	41,928		88	1.070
6,379	42,677	354	2,432,473	42,488	43,012	687	2,435,153	42,669		86	1.069
6,380	44,021	1,344	2,475,351	42,878	43,670	658	2,478,494	43,341		85	1.068
6,381	44,715	694	2,519,878	44,527	44,256	585	2,522,457	43,963	43,895	83	1.067
6,382	45,039	324	2,564,761	44,883	44,783	527	2,566,976	44,519		82	1.066
6,383	45,356	317	2,609,959	45,198	45,295	512	2,612,015	45,039	44,886	80	1.064
6,384	45,668	312	2,655,465	45,506	45,799	505	2,657,562	45,547	45,323	79	1.063
6,385	46,445	777	2,701,320	45,855	46,310	511	2,703,617	46,055		78	1.062
6,386	47,028	583	2,748,135	46,815	46,734	424	2,750,139	46,522		76	1.061
6,387	47,335	307	2,795,323	47,188	47,112	378	2,797,062	46,923	46,597	75	1.060
6,388	47,607	272	2,842,794	47,471	47,492	380	2,844,364	47,302		74	1.060
6,389	47,873	266	2,890,535	47,741	47,865	373	2,892,042	47,679		72	1.059
6,390	48,294	421	2,938,554	48,019	48,245	379	2,940,097	48,055	48,295	71	1.058
6,391	48,685	391	2,987,074	48,520	48,584	339	2,988,512	48,414		70	1.057
6,392	48,870	185	3,035,910	48,836	48,893	309	3,037,250	48,739		69	1.056
6,393	49,224	354	3,085,012	49,102	49,194	301	3,086,294	49,044	49,402	68	1.055
6,394	49,461	237	3,134,354	49,342	49,491	297	3,135,637	49,343		67	1.054
6,395	49,841	380	3,183,957	49,603	49,796	304	3,185,280	49,644		66	1.054
6,396	50,178	337	3,233,993	50,036	50,093	297	3,235,225	49,944		65	1.053
6,397	50,426	248	3,284,298	50,305	50,375	282	3,285,459	50,234		64	1.052
6,398	50,649	223	3,334,837	50,539	50,660	284	3,335,976	50,518		63	1.051
6,399	50,875	226	3,385,597	50,760	50,930	270	3,386,771	50,795		62	1.051
6,400	51,220	345	3,436,601	51,004	51,204	274	3,437,838	51,067	51,635	61	1.050
6,401	51,566	346	3,488,019	51,418	51,469	265	3,489,175	51,336		60	1.049
6,402	51,789	223	3,539,698	51,679	51,720	252	3,540,769	51,595		59	1.048
6,403	51,999	210	3,591,595	51,897	51,967	246	3,592,613	51,844		58	1.048
6,404	52,199	200	3,643,691	52,096	52,208	241	3,644,700	52,087		58	1.047
6,405	52,472	273	3,696,012	52,321	52,451	243	3,697,030	52,329		57	1.047
6,406	52,753	281	3,748,642	52,630	52,685	235	3,749,598	52,568		56	1.046
6,407	52,948	195	3,801,493	52,851	52,904	218	3,802,392	52,794		55	1.045
6,408	53,135	187	3,854,536	53,043	53,117	214	3,855,403	53,011		54	1.045
6,409	53,304	169	3,907,754	53,218	53,326	208	3,908,624	53,221		54	1.044
6,410	53,544	240	3,961,154	53,400	53,534	209	3,962,054	53,430	53,626	53	1.044
6,411	53,800	256	4,014,845	53,691	53,741	207	4,015,692	53,638		52	1.043
6,412	53,968	168	4,068,730	53,885	53,939	197	4,069,532	53,840		52	1.043
6,413	54,140	172	4,122,788	54,058	54,134	196	4,123,568	54,036	54,115	51	1.042
6,414	54,289	149	4,177,003	54,215	54,327	193	4,177,799	54,231		50	1.042
6,415	54,495	206	4,231,376	54,373	54,527	200	4,232,226	54,427		50	1.041
6,416	54,751	256	4,286,015	54,639	54,730	203	4,286,854	54,628		49	1.041
6,417	54,922	171	4,340,854	54,839	54,924	194	4,341,681	54,827	54,698	48	1.040
6,418	55,099	177	4,395,865	55,011	55,120	196	4,396,703	55,022		48	1.040
6,419	55,256	157	4,451,041	55,176	55,318	199	4,451,922	55,219		47	1.039
6,420	55,504	248	4,506,394	55,353	55,534	215	4,507,348	55,426		46	1.039
6,421	55,772	268	4,562,055	55,661	55,756	223	4,562,993	55,645		46	1.038
6,422	55,939	167	4,617,912	55,857	55,976	220	4,618,859	55,866		45	1.038
6,423	56,123	184	4,673,940	56,028	56,205	229	4,674,950	56,091		45	1.038
6,424	56,324	201	4,730,163	56,223	56,450	245	4,731,278	56,328		44	1.037
6,425	56,656	332	4,786,612	56,449	56,760	310	4,787,883	56,605		44	1.037
6,426	56,945	289	4,843,440	56,828	57,066	305	4,843,440	55,557		43	1.036
6,427	57,170	225	4,900,496	57,056	57,365	299	4,900,496	57,056		43	1.036
6,428	57,443	273	4,957,793	57,297	57,668	303	4,957,793	57,297	56,433	42	1.036
6,429	57,794	351	5,015,397	57,604	57,972	304	5,015,397	57,604		42	1.035
6,430	58,662	868	5,073,424	58,027	58,276	304	5,073,424	58,027	57,004	41	1.035
6,431	58,864	202	5,132,187	58,763	58,569	293	5,132,187	58,763		41	1.035
6,432	59,066	202	5,191,152	58,965	58,853	285	5,191,152	58,965		40	1.034
6,433	59,268	202	5,250,319	59,167	59,136	283	5,250,319	59,167		40	1.034
6,434	59,470	202	5,309,688	59,369	59,412	276	5,309,688	59,369		39	1.033
6,435	59,672	202	5,369,259	59,571	59,675	263	5,369,259	59,571		39	1.033
6,436	59,874	202	5,429,032	59,773	59,920	245	5,429,032	59,773		39	1.033
6,437	60,076	202	5,489,007	59,975	60,150	230	5,489,007	59,975		38	1.033
6,438	60,278	202	5,549,184	60,177	60,365	215	5,549,184	60,177		38	1.032
6,439	60,480	202	5,609,563	60,379	60,565	200	5,609,563	60,379		37	1.032
6,440	60,682	202	5,670,144	60,581	60,750	185	5,670,144	60,581	60,674	37	1.032

[a] USGS datum.

[b] Jones & Stokes Associates smoothed with 11-foot moving average, as described in text.

[c] GIS results using aerial photographs of previous shorelines.

[d] Estimated from lake volume assuming 285 million tons of dissolved salt; TDS (g/l) = 2.096×10^8/Volume (af).

[e] Estimated from LADWP experiments with Mono Lake water (see Chapter 3B); SG = $1.004 + 0.00072 \times$ Salinity (g/l).

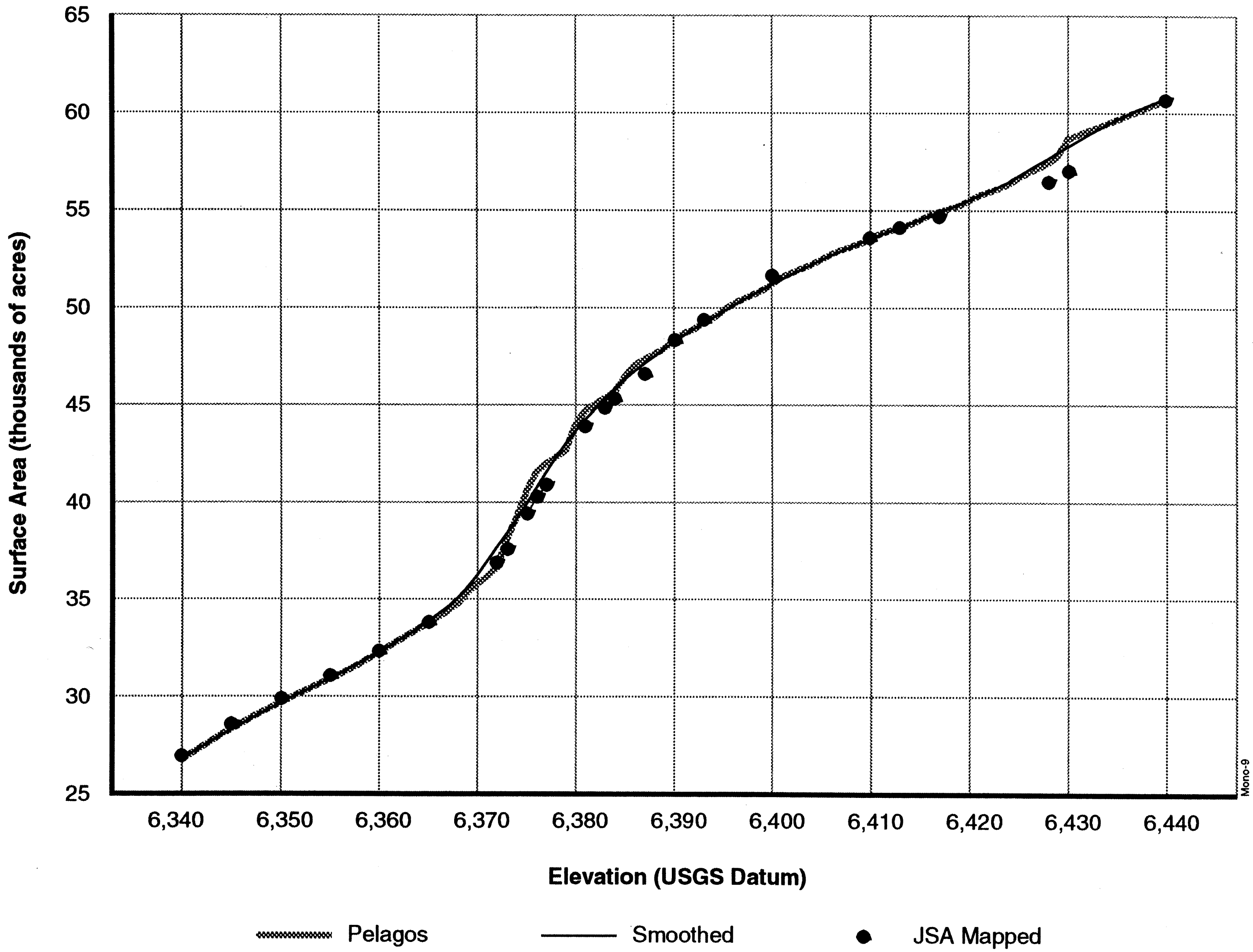
Table A-2. Monthly Evaporation Estimates for Mono Lake

Month	Monthly Water Budget[a]	Grant Pan[b]	Simis Ranch[c]
January	1.1	--	--
February	0.6	--	--
March	1.0	--	--
April	1.9	--	--
May	3.2	6.0	8.7
June	4.7	7.1	9.5
July	5.5	8.2	10.6
August	6.2	8.0	9.4
September	5.1	6.3	7.1
October	3.8	4.6	4.3
November	3.1	--	--
December	1.8	--	--
Annual	38.0	--	--

[a] Estimated as residual of lake volume change/area.

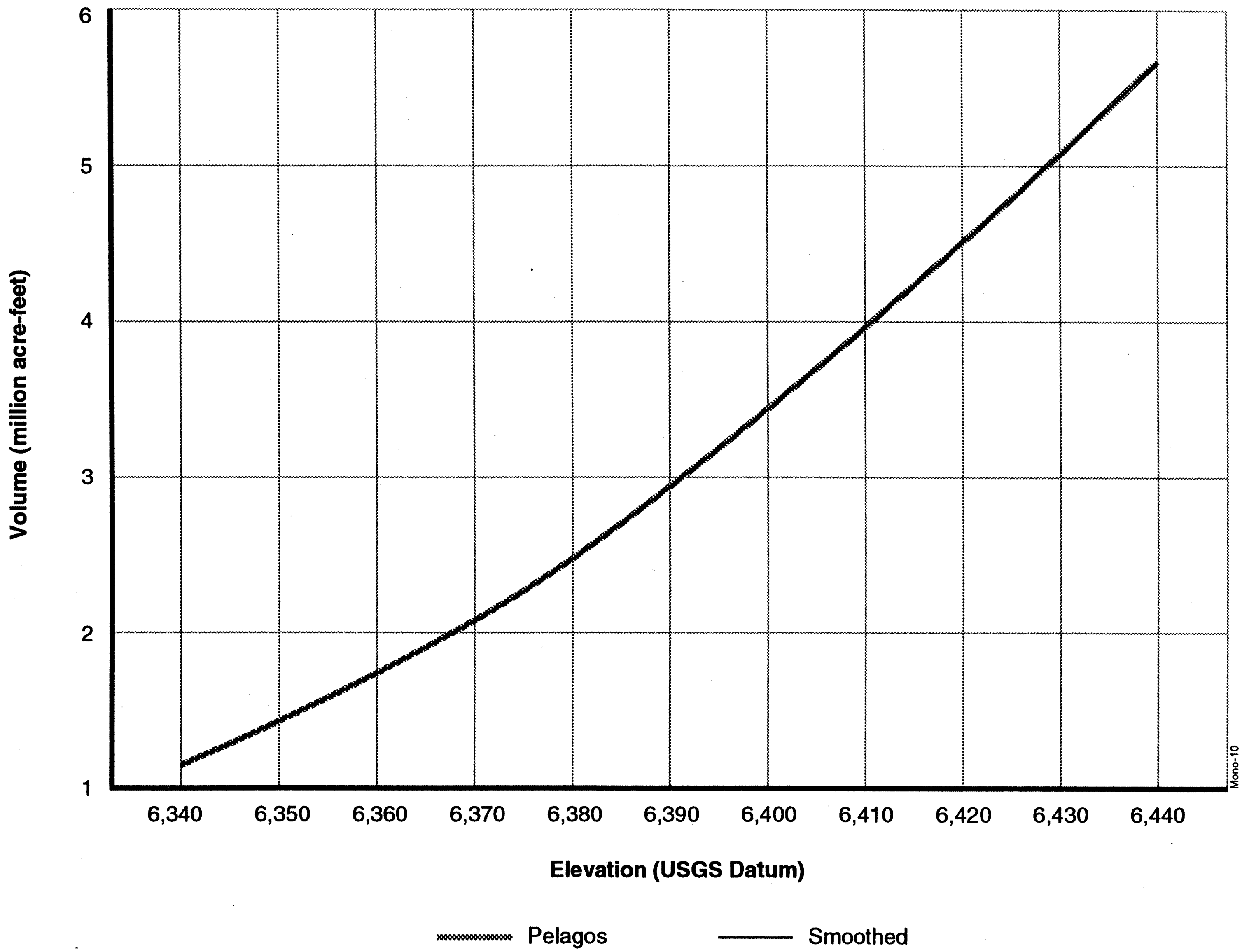
[b] LADWP land pan (1968-1989) and floating pan (1942-1969) data.

[c] Source: Data from 1980-1983 from Vorster 1985.



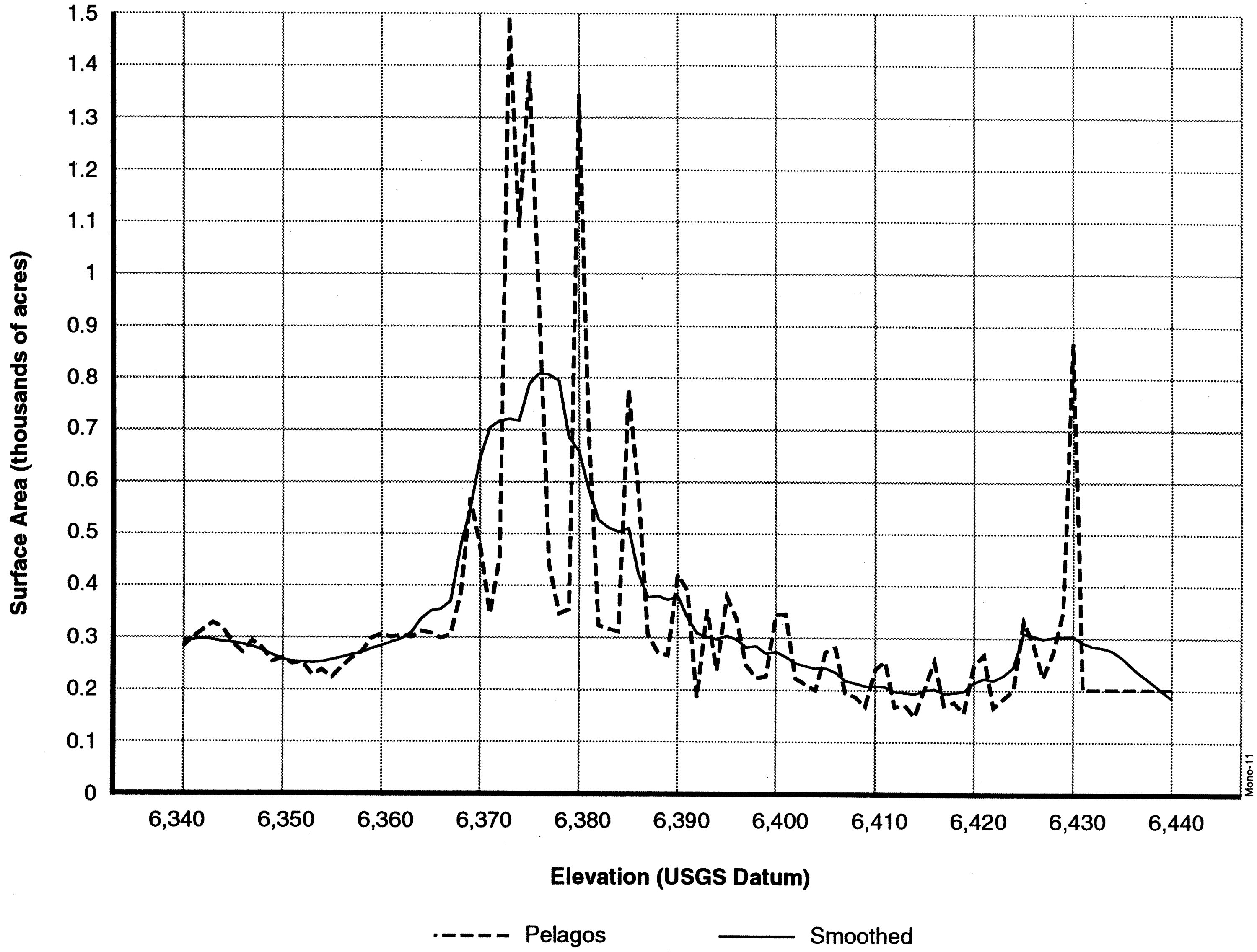
Source: Pelagos (1986) bathymetric survey and Pacific Western Aerial Surveys (1986) terrestrial photogrammetric survey for JSA - mapped data, see Appendix G

Figure A-1.
Lake Surface Area - Elevation Relationship for Mono Lake



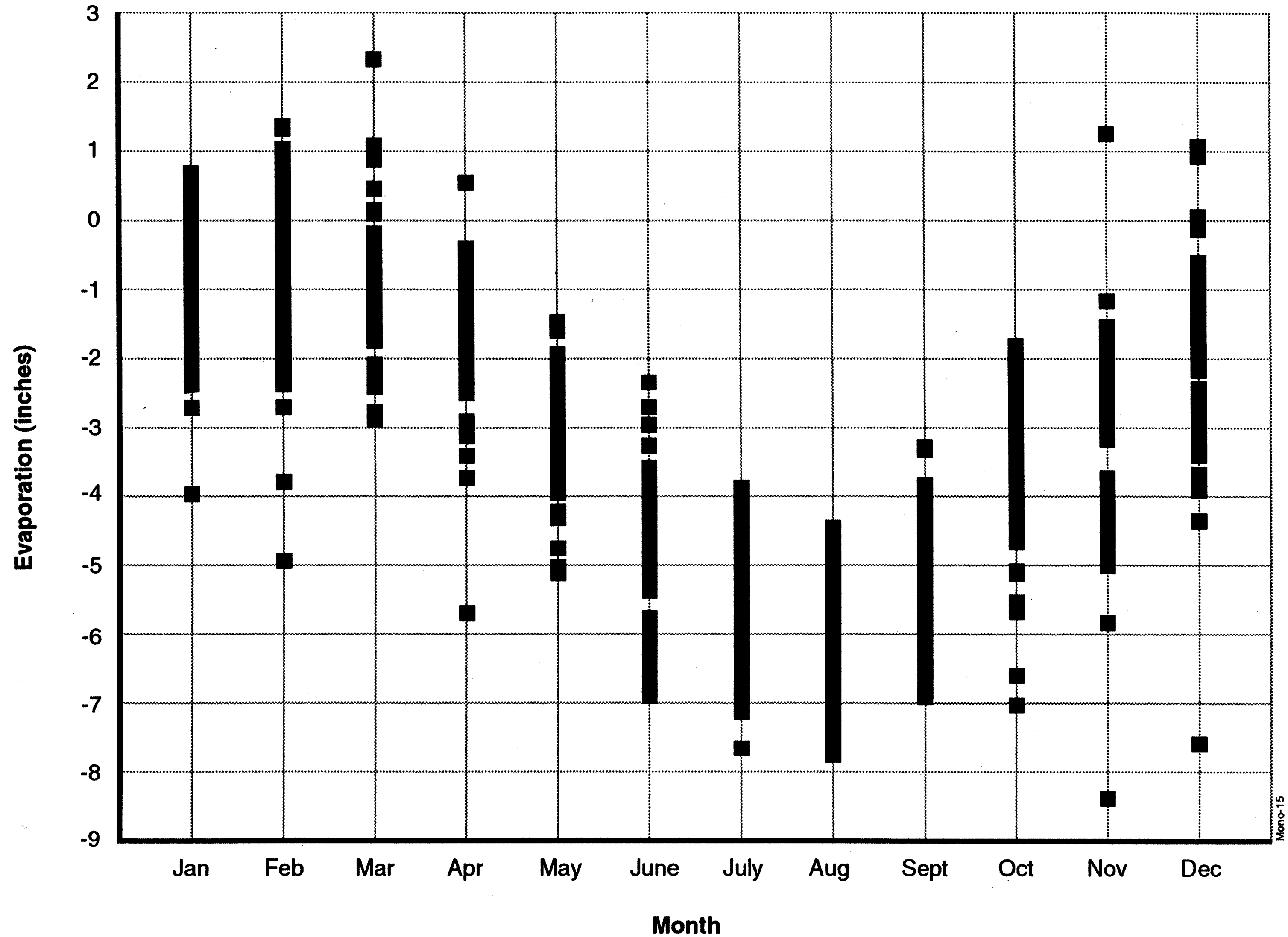
Source: Pelagos (1986) bathymetric survey and Pacific Western
Aerial Surveys (1986) terrestrial photogrammetric survey

Figure A-2.
Lake Volume - Elevation Relationship for Mono Lake



Source: Pelagos (1986) bathymetric survey and Pacific Western Aerial Surveys (1986) terrestrial photogrammetric survey

Figure A-3.
Lake Area Increments by Elevation for Mono Lake



Source: Based on LADWP monthly streamflow and lake level data, 1941-1989

Figure A-4.
Evaporation Estimates for Mono Lake

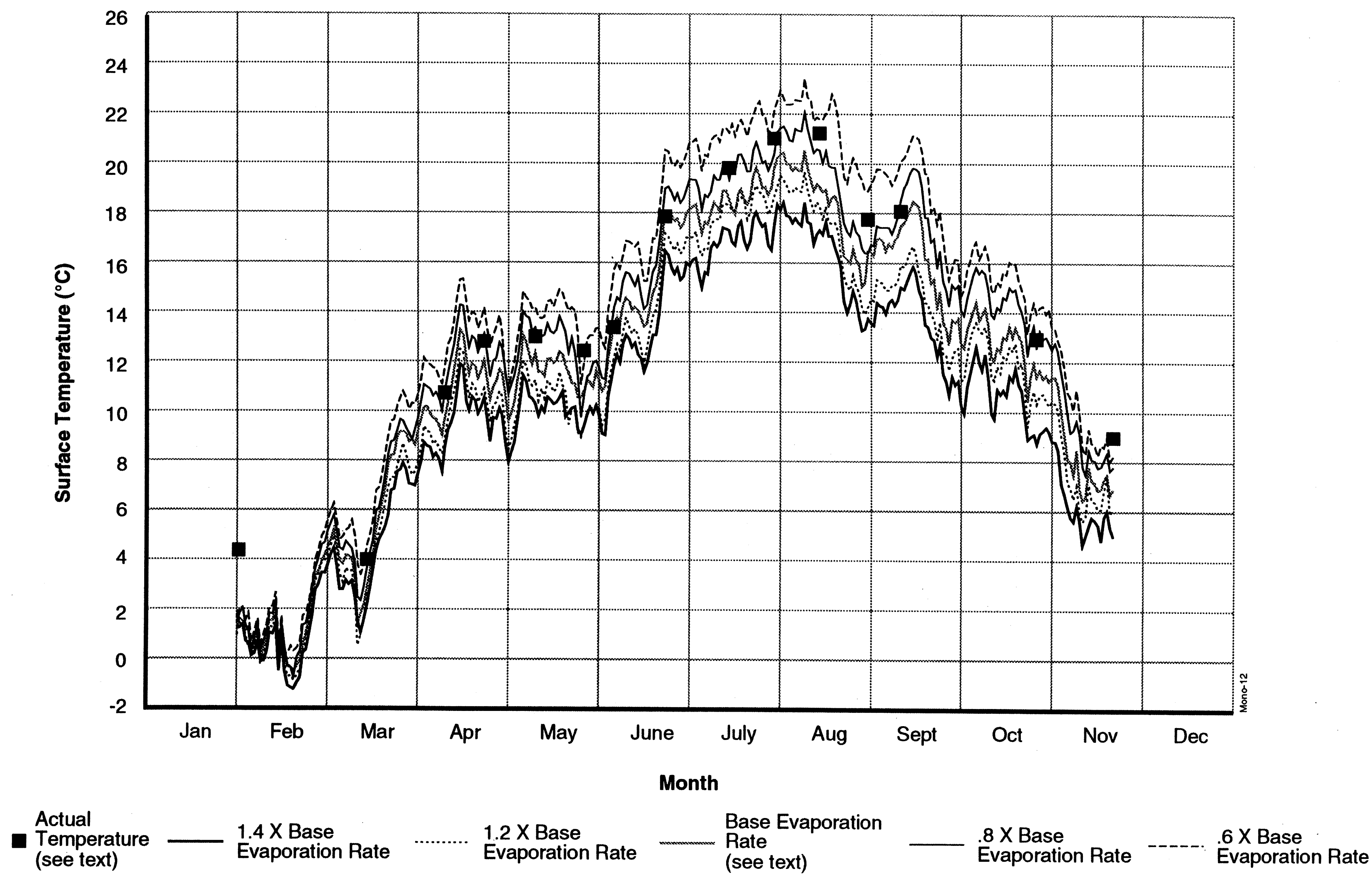


Figure A-5.
Effect of Evaporation Rate on Seasonal Temperature

MONO BASIN EIR

Prepared by Jones & Stokes Associates

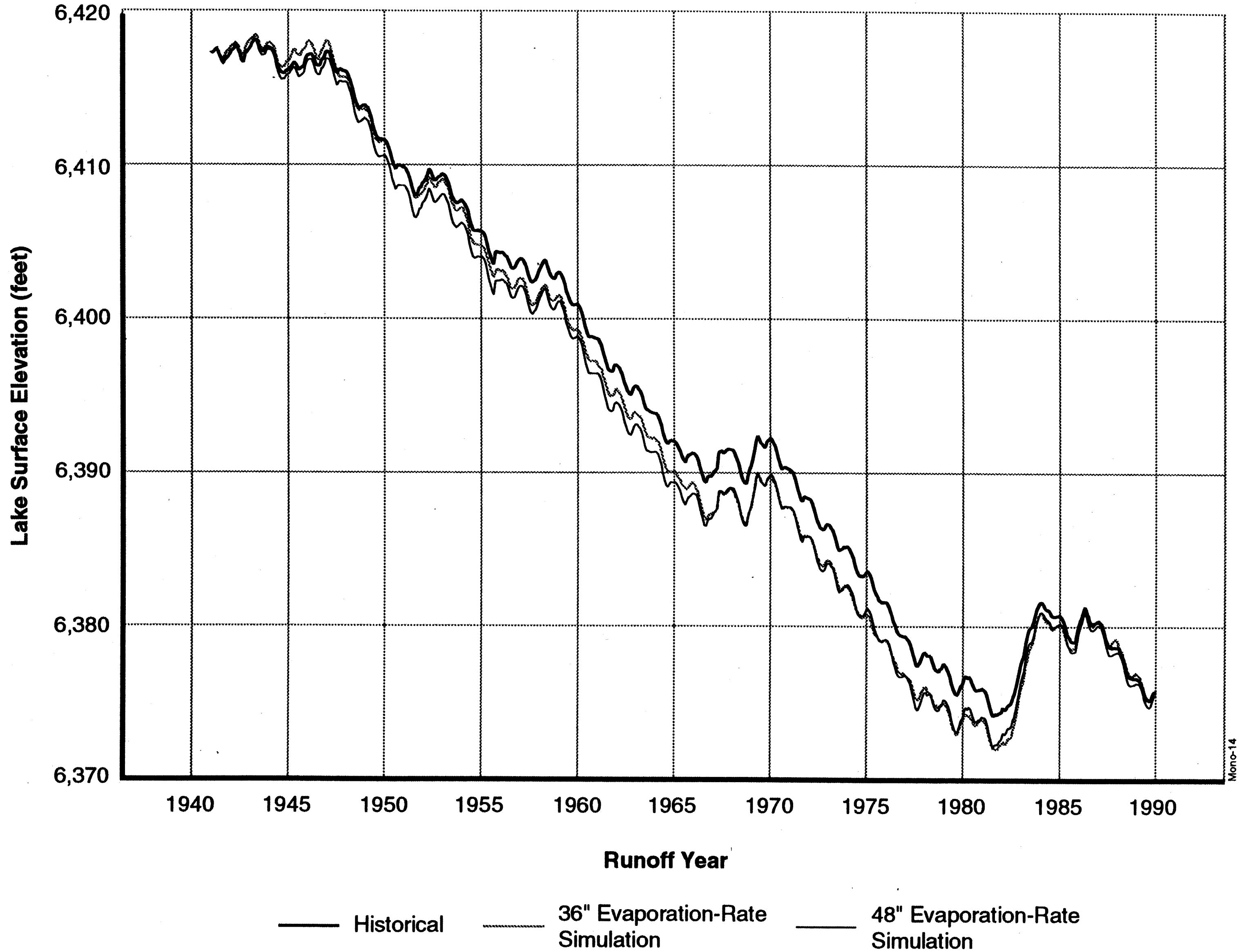


Figure A-6.
Historical and Simulated Lake Surface Elevation
Changes for Various Evaporation Rates

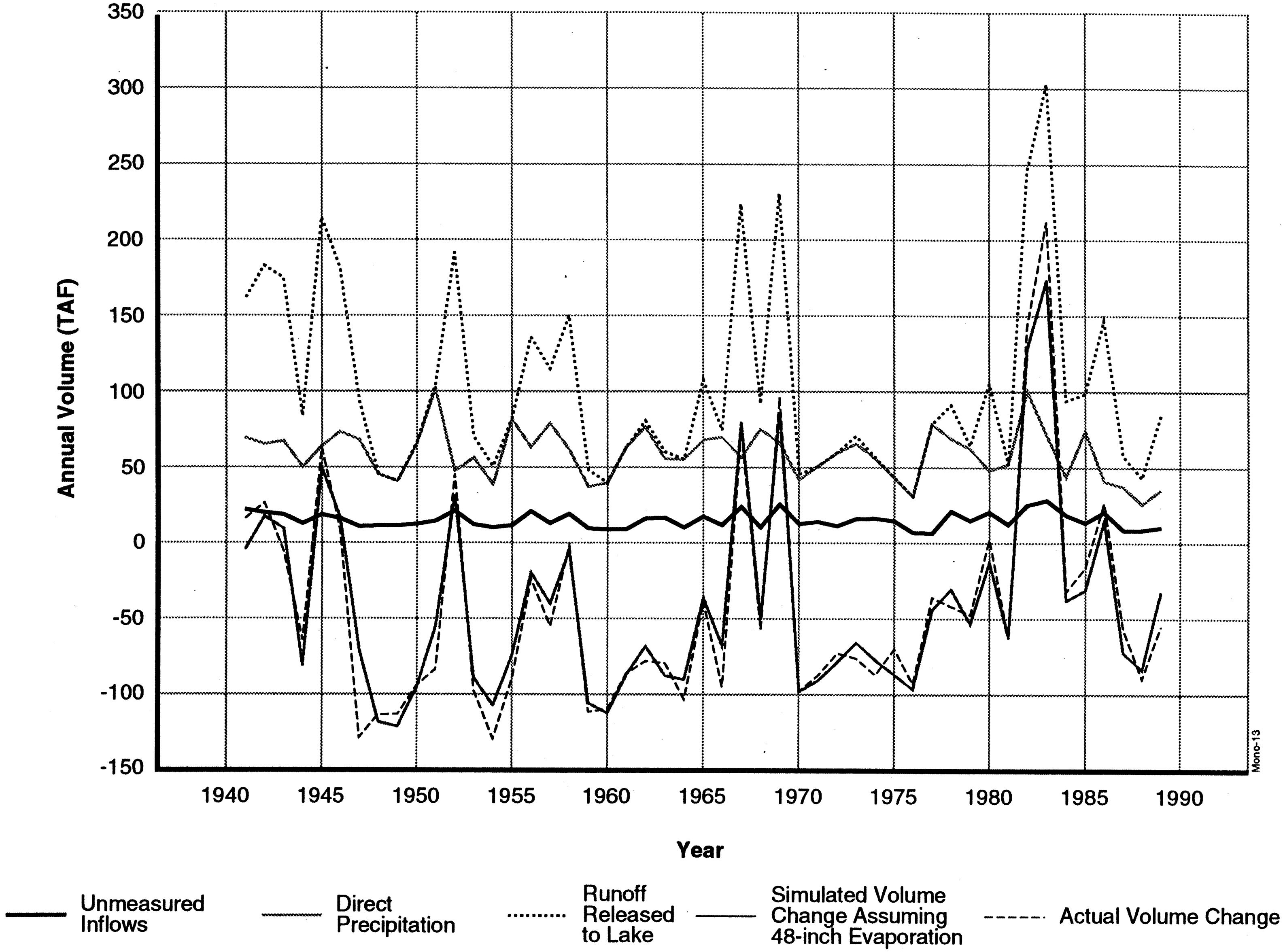
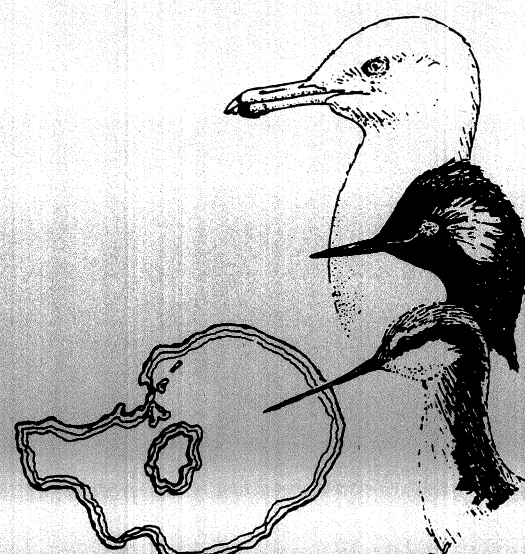


Figure A-7.
Annual Average Water Budget Terms

Appendix B. Common and Scientific Names of Animal Species Mentioned in the Report



Appendix B. Common and Scientific Names of Animal Species Mentioned in the Report

Common Name	Scientific Name
Invertebrates	
Mono brine shrimp	*Artemia monica*
Alkali fly	*Ephydra hians*
Mono checkerspot	*Euphydryas editha monoensis*
Apache silverspot butterfly	*Speyeria nokomis apacheana*
Mono Lake tick	*Argos monolakensis*
Salamanders, Toads, and Frogs (Amphibia)	
Mount Lyell salamander	*Hydromantes platycephalus*
Great Basin spadefoot	*Scaphiopus intermontanus*
Yosemite toad	*Bufo canorus*
Mountain yellow-legged frog	*Rana muscosa*
Turtles, Lizards, and Snakes (Reptilia)	
Sagebrush lizard	*Sceloporus graciosus*
Western aquatic garter snake	*Thamnophis couchi*
Birds (Aves)	
Common loon	*Gavia immer*
Horned grebe	*Podiceps auritus*
Eared grebe	*Podiceps nigricollis*
American white pelican	*Pelecanus erythrorhynchos*
Double-crested cormorant	*Phalacrocorax auritus*
Great blue heron	*Ardea herodias*
Snowy egret	*Egretta thula*
Black-crowned night-heron	*Nycticorax nycticorax*
White-faced ibis	*Plegadis chihi*
Snow goose	*Chen caerulescens*

Common Name	Scientific Name
Ross' goose	*Chen rossii*
Brant	*Branta bernicla*
Canada goose	*Branta canadensis*
Wood duck	*Aix sponsa*
Green-winged teal	*Anas crecca*
Mallard	*Anas platyrhynchos*
Northern pintail	*Anas acuta*
Blue-winged teal	*Anas discors*
Cinnamon teal	*Anas cyanoptera*
Northern shoveler	*Anas clypeata*
Gadwall	*Anas strepera*
American wigeon	*Anas americana*
Canvasback	*Aythya valisineria*
Redhead	*Aythya americana*
Bufflehead	*Bucephala albeola*
Hooded merganser	*Lophodytes cucullatus*
Common merganser	*Mergus merganser*
Red-breasted merganser	*Mergus serrator*
Ruddy duck	*Oxyura jamaicensis*
Turkey vulture	*Cathartes aura*
Osprey	*Pandion haliaetus*
Bald eagle	*Haliaeetus leucocephalus*
Northern harrier	*Circus cyaneus*
Sharp-shinned hawk	*Accipiter striatus*
Cooper's hawk	*Accipiter cooperii*
Northern goshawk	*Accipiter gentilis*
Swainson's hawk	*Buteo swainsoni*
Red-tailed hawk	*Buteo jamaicensis*
Rough-legged hawk	*Buteo lagopus*
Golden eagle	*Aquila chrysaetos*
American kestrel	*Falco sparverius*
Peregrine falcon	*Falco peregrinus*
American peregrine falcon	*Falco peregrinus anatum*
Prairie falcon	*Falco mexicanus*
Sage grouse	*Centrocercus urophasianus*
Mountain quail	*Oreortyx pictus*
Yellow rail	*Coturnicops noveboracensis*
Virginia rail	*Rallus limicola*
Sora	*Porzana carolina*

Common Name	Scientific Name
American coot	*Fulica americana*
Black-bellied plover	*Pluvialis squatarola*
Snowy plover	*Charadrius alexandrinus*
Semipalmated plover	*Charadrius semipalmatus*
Killdeer	*Charadrius vociferus*
Mountain plover	*Charadrius montanus*
Black-necked stilt	*Himantopus mexicanus*
American avocet	*Recurvirostra americana*
Greater yellowlegs	*Tringa melanoleuca*
Willet	*Catoptrophorus semipalmatus*
Spotted sandpiper	*Actitis macularia*
Long-billed curlew	*Numenius americanus*
Marbled godwit	*Limosa fedoa*
Ruddy turnstone	*Arenaria interpres*
Sanderling	*Calidris alba*
Semipalmated sandpiper	*Calidris pusilla*
Western sandpiper	*Calidris mauri*
Least sandpiper	*Calidris minutilla*
Baird's sandpiper	*Calidris bairdii*
Short-billed dowitcher	*Limnodromus griseus*
Long-billed dowitcher	*Limnodromus scolopaceus*
Common snipe	*Gallinago gallinago*
Wilson's phalarope	*Phalaropus tricolor*
Red-necked phalarope	*Phalaropus lobatus*
Pomarine jaegar	*Stercorarius pomarinus*
Bonaparte's gull	*Larus philadelphia*
Ring-billed gull	*Larus delawarensis*
California gull	*Larus californicus*
Western gull	*Larus occidentalis*
Caspian tern	*Sterna caspia*
Black tern	*Chlidonias niger*
Mourning dove	*Zenaida macroura*
Long-eared owl	*Asio otus*
Short-eared owl	*Asio flammeus*
Lesser nighthawk	*Chordeiles acutipennis*
Common nighthawk	*Chordeiles minor*
Common poorwill	*Phalaenoptilus nuttallii*
Vaux's swift	*Chaetura vauxi*
Calliope hummingbird	*Stellula calliope*

Common Name	Scientific Name
Rufous hummingbird	*Selasphorus rufus*
Belted kingfisher	*Ceryle alcyon*
Lewis' woodpecker	*Melanerpes lewis*
Downy woodpecker	*Picoides pubescens*
Hairy woodpecker	*Picoides villosus*
Northern flicker	*Colaptes auratus*
Western wood-pewee	*Contopus sordidulus*
Willow flycatcher	*Empidonax traillii*
Dusky flycatcher	*Empidonax oberholseri*
Gray flycatcher	*Empidonax wrightii*
Pacific-slope flycatcher	*Empidonax difficilis*
Say's phoebe	*Sayornis saya*
Ash-throated flycatcher	*Myiarchus cinerascens*
Cassin's kingbird	*Tyrannus vociferans*
Western kingbird	*Tyrannus verticalis*
Horned lark	*Eremophila alpestris*
Tree swallow	*Tachycineta bicolor*
Violet-green swallow	*Tachycineta thalassina*
Northern rough-winged swallow	*Stelgidopteryx serripennis*
Bank swallow	*Riparia riparia*
Cliff swallow	*Hirundo pyrrhonota*
Barn swallow	*Hirundo rustica*
Steller's jay	*Cyanocitta stelleri*
Scrub jay	*Aphelocoma coerulescens*
Pinyon jay	*Gymnorhinus cyanocephalus*
Black-billed magpie	*Pica pica*
Common raven	*Corvus corax*
Mountain chickadee	*Parus gambeli*
Plain titmouse	*Parus inornatus*
Bushtit	*Psaltriparus minimus*
White-breasted nuthatch	*Sitta carolinensis*
Pygmy nuthatch	*Sitta pygmaea*
Brown creeper	*Certhia americana*
Rock wren	*Salpinctes obsoletus*
Bewick's wren	*Thryomanes bewickii*
House wren	*Troglodytes aedon*
Marsh wren	*Cistothorus palustris*
Ruby-crowned kinglet	*Regulus calendula*
Blue-gray gnatcatcher	*Polioptila caerulea*

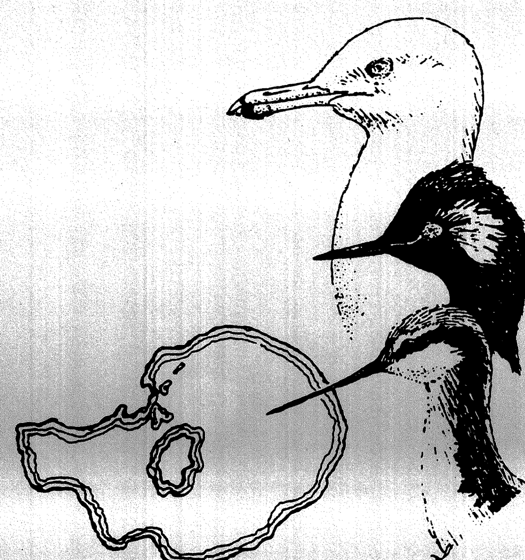
Common Name	Scientific Name
Black-tailed gnatcatcher	*Polioptila melanura*
Mountain bluebird	*Sialia currucoides*
Townsend's solitaire	*Myadestes townsendi*
Hermit thrush	*Catharus guttatus*
American robin	*Turdus migratorius*
Sage thrasher	*Oreoscoptes montanus*
Brown thrasher	*Toxostoma rufum*
American pipit	*Anthus rubescens*
Cedar waxwing	*Bombycilla cedrorum*
Loggerhead shrike	*Lanius ludovicianus*
European starling	*Sturnus vulgaris*
Solitary vireo	*Vireo solitarius*
Warbling vireo	*Vireo gilvus*
Orange-crowned warbler	*Vermivora celata*
Nashville warbler	*Vermivora ruficapilla*
Virginia's warbler	*Vermivora virginiae*
Yellow warbler	*Dendroica petechia*
Yellow-rumped warbler	*Dendroica coronata*
Black-throated gray warbler	*Dendroica nigrescens*
Townsend's warbler	*Dendroica townsendi*
Black-and-white warbler	*Mniotilta varia*
MacGillivray's warbler	*Oporornis tolmiei*
Common yellowthroat	*Geothlypis trichas*
Wilson's warbler	*Wilsonia pusilla*
Yellow-breasted chat	*Icteria virens*
Western tanager	*Piranga ludoviciana*
Black-headed grosbeak	*Pheucticus melanocephalus*
Luzuli bunting	*Passerina amoena*
Green-tailed towhee	*Pipilo chlorurus*
Rufous-sided towhee	*Pipilo erythrophthalmus*
California towhee	*Pipilo crissalis*
Chipping sparrow	*Spizella passerina*
Brewer's sparrow	*Spizella breweri*
Vesper sparrow	*Pooecetes gramineus*
Sage sparrow	*Amphispiza belli*
Savannah sparrow	*Passerculus sandwichensis*
Fox sparrow	*Passerella iliaca*
Song sparrow	*Melospiza melodia*
Lincoln's sparrow	*Melospiza lincolnii*

Common Name	Scientific Name
White-crowned sparrow	*Zonotrichia leucophrys*
Dark-eyed junco	*Junco hyemalis*
Red-winged blackbird	*Agelaius phoeniceus*
Western meadowlark	*Sturnella neglecta*
Yellow-headed blackbird	*Xanthocephalus xanthocephalus*
Brewer's blackbird	*Euphagus cyanocephalus*
Brown-headed cowbird	*Molothrus ater*
Cassin's finch	*Carpodacus cassinii*
House finch	*Carpodacus mexicanus*
Pine siskin	*Carduelis pinus*
American goldfinch	*Carduelis tristis*
Northern oriole	*Icterus galbula*
Mammals (Mammalia)	
Inyo shrew	*Sorex tenellus*
Water shrew	*Sorex palustris*
Vagrant shrew	*Sorex vagrans*
Spotted bat	*Euderma maculatum*
Townsend's big-eared bat	*Plecotus townsendii*
Pygmy rabbit	*Brachylagus idahoensis*
Nuttall's cottontail	*Sylvilagus nuttallii*
Western white-tailed hare	*Lepus townsendii townsendii*
Black-tailed hare	*Lepus californicus*
Sierra Nevada mountain beaver	*Aplodontia rufa californica*
Least chipmunk	*Tamias minimus*
Yellow-pine chipmunk	*Tamias amoenus*
Lodgepole chipmunk	*Tamias speciosus*
Belding's ground squirrel	*Spermophilus beldingi*
California ground squirrel	*Spermophilus beecheyi*
Golden-mantled ground squirrel	*Spermophilus lateralis*
Douglas' squirrel	*Tamiasciurus douglasii*
Western pocket gopher	*Thomomys mazama*
Panamint kangaroo rat	*Dipdomys panamintinus panamintinus*
Chisel-toothed kangaroo rat	*Dipodomys microps*
Great Basin pocket mouse	*Perognathus parvus*
Beaver	*Castor canadensis*
Western harvest mouse	*Reithrodontomys megalotis*

Appendix B. Continued

Common Name	Scientific Name
Deer mouse	*Peromyscus maniculatus*
Brush mouse	*Peromyscus boylii*
Pinyon mouse	*Peromyscus truei*
Bushy-tailed woodrat	*Neotoma cinerea*
Montane vole	*Microtus montanus*
Long-tailed vole	*Microtus longicaudus*
Sagebrush vole	*Lagurus curtatus*
Porcupine	*Erethizon dorsatum*
Coyote	*Canis latrans*
Sierra Nevada red fox	*Vulpes vulpes necator*
Ermine	*Mustela erminea*
Wolverine	*Gulo gulo*
American badger	*Taxidea taxus*
Bobcat	*Lynx rufus*
Mule deer	*Odocoileus hemionus*

Appendix C. California Gulls at Mono Lake Since 1900: Population Trends, Survivorship, and Reproduction Success



MONO BASIN EIR

Prepared by Jones & Stokes Associates

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Appendix C. California Gulls at Mono Lake since 1900: Population Trends, Survivorship, and Reproduction Success

POPULATIONS FROM 1900 TO 1940

Jehl et al. (1984, 1988) and Winkler and Shuford (1988) summarized the available information on Mono Lake's nesting California gulls since 1900 (Table C-1). These authors reviewed most of the same references contained in the incomplete historical record. They disagreed, however, on the reliability and interpretation of historical population estimates, especially the possible inferences regarding changes in the size and distribution of the gull colony in this century.

Dixon (1916) was apparently the first ornithologist to make quantitative censuses of the nesting gulls at Mono Lake. He estimated 1,000 pairs (about 2,000 adults) nesting along two long obsidian-like ridges on the north side of Paoha Island (Table C-1). Dixon (1916) also visited Negit Island but did not make reference to gulls nesting there. Based on Dixon's field notes, Grinnell and Storer (1924) characterized California gulls as "common in summer on Mono Lake, nesting on Paoha Island".

Dawson (1923) spent several days observing nesting California gulls on Paoha Island and estimated 250 pairs at the Lagoon Colony and about 600 pairs at the Black Rocks Colony (these colonies also were surveyed by Dixon [1916]) for a total of about 850 pairs (1,700 adults) (Table C-1). Dawson (1923) also visited the main colony on Negit Island, the largest at the lake at that time, but he did not estimate the number of gulls nesting there. He also observed an uncounted number of gulls nesting on the "outlying rock", which Jehl et al. (1984) identified as Little Tahiti Islet. Nichols (1938) reported that the Mono Lake colony was confined to Negit Island, and he estimated the total population at 3,000 adults.

Grinnell recorded a secondhand account of 60,000 nesting gulls at Mono Lake in his 1937 field notes (Table C-1). These notes also were reviewed by Winkler and Shuford (1988), who believed the secondhand nature of the account reduced its reliability because it was not based on Grinnell's personal observations. These authors, however, considered Grinnell's notes evidence that a sizeable colony probably nested at Mono Lake in the late 1930s.

Despite the few direct counts of the prediversion gull colony, the available observations provide evidence that at least a few thousand nesting gulls were present on Negit Island or Paoha Island before 1940 (Table C-1). Although it is much larger than Negit Island, Paoha Island was probably used less frequently by nesting gulls during this century because of the intermittent presence of humans, domestic goats, and coyotes (Jehl et al. 1984, McPherson pers. comm.).

POPULATIONS FROM 1941 TO 1975

The first postdiversion estimates of the California gull colony were made by Young (1952), who reported approximately 1,500 nesting birds restricted to about 3 acres on the northeast side of Negit Island (Table C-2). Young (1952), observing that his counts were lower than those of Dawson (1923), Grinnell and Storer (1924), and Nichols (1938) (Table C-2), believed that the population was declining. Young's (1952) comparisons of his estimates with those of Dawson (1923) have little meaning, however, because Dawson did not attempt to count the most populous colony on Negit Island.

Johnston (1956) conducted detailed studies of the reproductive physiology of California gulls at Negit Island, the only colony in the early 1950s. He did not attempt to make systematic censuses of their population, and his rough estimates ranged from 3,000 to 10,000 nesting adults during 1952 and 1953. Similarly, Johnston (1956) questioned Young's (1952) interpretation of gull population trends and indicated that it was unwise to speculate about the numbers in this colony until annual census data were available to replace the sporadic and perhaps inaccurate records that existed at that time.

Although Dawson (1923) reported an uncounted number of gulls on the "outlying rocks" of Negit Island in 1919, most of the highest Negit Islets emerged from the lake in the 1930s and these were mainly pinnacles. Not until the early 1960s did substantial areas of substrate suitable for nesting gulls become available (Stine 1992). The Negit Islets were apparently first colonized by large numbers of nesting gulls during the early or mid-1960s, but apparently no systematic counts of the California gull colony were made during this decade (Table C-2). Jurek (1972) made a rough estimate of 10,000 gulls in the vicinity of the colonies at Negit Island and the Negit Islets and estimated "uncounted thousands around the lake". He considered his estimate of 1,200 adults at Negit Island conservative because many birds were not visible, and he did not make a complete count there. Nesting gulls on the Negit Islets may have outnumbered those on Negit Island, but they were not counted (Jurek 1972).

Jurek (1973) estimated that 42,500 adult gulls were present during an aerial survey of Mono Lake in late August 1973. In most years, nesting California gulls depart from Mono Lake by early August, and Jurek's (1973) high count indicates an unusual influx of fall migrants, delayed breeding that year (Jehl et al. 1984), or possibly an overestimate.

Stallcup and Greenberg (1974) estimated 20,000-30,000 adult gulls at Mono Lake but their count was made from a mainland vantage point more than 4 miles from the nesting colony where most nesting gulls were not visible (Table C-2). Mangan (1974) also estimated about 20,000-30,000 breeding gulls, but he did not make separate counts of Negit Island and the Negit Islets. In 1975, however, Mangan (1975) and Heindel (1975) estimated only about

2,000 adult gulls on Negit Island; none appeared to be nesting on the Negit Islets (Table C-2).

POPULATIONS FROM 1976 TO 1988

Winkler et al. (1977) made the first attempts to census the lake's entire gull population from the ground and estimated about 51,000 nesting adults in early July 1976 (Table C-3). During this census, about two-thirds of the nesting birds were on Negit Island and about one-third were on the Negit Islets. With a total of more than 50,000 nesting gulls, the Mono Lake colony was one of the two largest in the world and supported about 20% of the global population and 95% of the California nesting population of this species (Winkler 1983a, Dennis M. Power Associates 1980). The world's largest concentration of nesting California gulls occurs at the Great Salt Lake, which supported a population of about 75,000-80,000 adults during most of the 1980s (Paul et al. 1990) and currently holds about 130,000 nesting gulls (Jehl pers. comm.).

The Mono Lake colony was not censused in 1977 or 1978, but Winkler estimated that the gull population was roughly constant from 1976 to 1978 because the density of nesting gulls and their distribution appeared to be similar in those years (Winkler and Shuford 1988). During this period, the breeding population was estimated at 40,000-50,000 adults and the population used both Negit Island and the Negit Islets (Winkler 1980a, 1983b). Negit Island was first land bridged to the mainland around November 1977. Because of concerns about the potential impacts of coyotes and other terrestrial predators on nesting gulls, government agencies blasted a channel between Negit Island and the mainland in 1978 (Winkler 1980b, Winkler and Shuford 1988).

In July 1979, nesting gulls were first observed on the Paoha Islets. About one-quarter of the lake's population nested there that year (Jehl 1991a; Court Testimony, Vol. XIII) (Table C-3). Efforts to protect Negit Island, including blasting channels and erecting predator fences, were unsuccessful, and canids (probably coyotes) crossed the land bridge, causing abandonment of the Negit Island colony and reducing the number of successfully reproducing gulls (Winkler 1980b, 1983b). In 1980, the number of nesting gulls remained about the same as 1979 and the proportions of the total population nesting on the Negit and Paoha Islets remained about the same (Winkler 1987, Winkler and Shuford 1988).

During 1981-1982, Mono Lake dropped to its lowest historical elevation of 6,372 feet (NAS 1987, CORI 1988). The major difference between the census results in the 2 years was the absence of reproduction on Twain and Java Islets in 1982 because of land-bridging to the mainland at the beginning of the year. Twain Islet was the most densely populated islet from 1979 until 1981, and Twain and Java Islets had supported an average of 40% of lakewide breeding population during that period (Winkler 1983b).

In 1983, long-term gull studies were initiated on the Paoha Islets by the Hubbs-Sea World Research Institute (HSWRI) (Jehl 1983) and on the Negit Islets by the Point Reyes

Bird Observatory (PRBO) (Shuford et al. 1984). These research teams shared information and had more comprehensive coverage of the entire Mono Lake gull population, which improved the overall estimates of breeding adults and their reproductive success. Since 1983, the size of Mono Lake's gull colony has been estimated by counting the total number of occupied nests on each island and islet and multiplying by two adults per nest (Jehl 1983, 1984b; Shuford et al. 1984).

Between 1983 and 1988, the estimated number of adult gulls nesting at Mono Lake ranged between about 44,000 and 50,000 (Table C-3). Negit Island was recolonized by nesting gulls in 1985 after resident coyotes were trapped and removed from the island (Shuford and Page 1985, Winkler and Shuford 1988). A few gulls also nested on Duck Islet (a peninsula of Paoha Island at lake elevations below 6,379.5 feet) in 1986 but not in subsequent years after it again became a peninsula (Table C-3). Numbers of nesting gulls on Negit Island increased every year between 1985 and 1989, but at their maximum of about 5,500 adults (in 1989), they represented only about 12% of Mono Lake's nesting population. During 1983-1988, the majority of gulls nested on the Negit Islets, and almost one-half of the lake's population was on Twain Islet; other Negit Islets that supported more than 1,000 nesting gulls in any year included Little Tahiti, Little Norway, Steamboat, Java, Spot, and Tie (Dierks 1990, 1991).

About one-third of Mono Lake's gull population nested on the Paoha Islets in 1983, but from 1984 through 1988 the Paoha Islets never supported more than about 15% of the total population (Table C-3). During these years, Coyote Islet consistently supported more than 1,000 nesting gulls; Anderson, Browne, and portions of McPherson Islet supported 500 or more birds in most years (Jehl 1989). Other Paoha Islets, including Brewer, Hoffman, Gull, Smith, Conway, Dawson, Whitney, Channel, Obsidian, and Winkler, were used intermittently by nesting gulls because rapidly changing lake levels and related erosional forces made them unavailable in many years (Jehl 1989).

Despite rapid changes in the lake's level and the distribution of potential nesting habitat during 1983-1988, Mono Lake's adult gull population remained relatively stable (i.e., between about 44,000 and 50,000 birds) during this period.

POPULATIONS FROM 1989 THROUGH 1992

Coyotes were present on Negit Island and Pancake Islet in 1989, limiting gull reproduction at those sites. Gulls nested without disturbance, however, on other islets and most were on the Negit Islets with Twain, Java, and Little Tahiti supporting the largest populations. More than 5,000 gulls also nested in small colonies on the outer "white rocks" areas on the eastern and southern shoreline of Negit Island (Dierks 1990). Similarly, more than 5,000 gulls nested on the Paoha Islets in 1989 (Jehl 1989).

In 1990, the number of nesting gulls was estimated at 61,500, the highest recorded at Mono Lake by that time (Dierks 1991, Jehl 1991b). The number of nesting gulls on the

Paoha Islets almost doubled from an estimated 2,682 in 1989 to 5,145 in 1990 (Jehl 1991b). Similarly, numbers of breeding gulls on most of the Negit Islets increased markedly from an estimated 16,641 in 1989 to 22,765 in 1990.

Gull numbers on Negit Island increased only slightly in 1990 compared to the previous year; Negit Island and Pancake Islet were the only two islands that were visited by coyotes that year (Dierks 1991). Pancake Islet was reinvaded by coyotes and other mainland predators in 1990; it supported 651 nests (down from 1,395 nests in 1989) in late May, when coyote tracks were first observed on that islet that year. In early July, Pancake Islet was totally abandoned; damaged eggshells also showed signs of canid predation, suggesting that coyotes had completely disrupted gull nesting (Dierks 1991).

In 1991, an estimated 43,520 adult gulls nested at Mono Lake and the Negit Islets and Negit Island supported 80% of the lake's breeding gulls. As in previous years, Twain Islet supported about one-half the nesting gulls at Mono Lake; Little Tahiti, Java, and Steamboat Islets also provided habitat for more than 1,000 adults. More than 1,500 gulls attempted nesting on land-bridged Negit Island, but they all abandoned the island by late May (see "Predation" below). Pancake Islet was connected to the mainland in 1991 and was not used by nesting gulls (Dierks and Shuford 1992). Approximately 8,884 gulls nested on the Paoha Islets in 1991; as in recent years, the largest colonies were on Browne, Coyote, and McPherson Islets (Jehl 1991b).

In 1992, the gull colony exceeded its 1990 high and an estimated 64,976 breeding adults were recorded at Mono Lake (Table C-3). More than 70% of the nesting gulls were on the Negit Islets; Twain Islet supported 31,792 adults, which represented almost 50% of the lake's breeding gulls that year (Shuford pers. comm.). Other Negit Islets supporting large numbers of nesting gulls included Little Tahiti (7,620), Little Norway (946), Steamboat (1,724), Java (2,080), and Spot (660) (Dierks and Shuford 1992).

Only four nests were found on Negit Island in 1992, and none was successful. The land bridge offered coyotes and other mainland predators easy access to the island and probably reduced its attractiveness to nesting gulls. Evidence of coyotes (i.e., fresh tracks and several recently preyed upon chick corpses) was found on Java Islet for the first time since 1982. Probably as a result of coyote predation, chicks on Java Islet had a low post-banding survival (percent of chicks banded in early July that fledged) and the rates on various Negit Islets were: Java (78%), Steamboat (95%), Krakatoa (90%), Little Norway (88%), Spot (88%), Little Tahiti (90%), and Twain (90%) (Shuford pers. comm.).

The Paoha Islets had unprecedented numbers of nesting gulls in 1992, when an estimated 18,566 adults were reported (Table C-3). This total represented more than 28% of the lake's population and included nearly twice as many breeding adults as were reported in 1990, the next highest yearly count. One pair of gulls tried unsuccessfully to nest on Paoha Island during the 1992 breeding season (Jehl pers. comm.).

REPRODUCTIVE SUCCESS FROM 1976 THROUGH 1992

Four techniques have been used to estimate gull reproductive success at Mono Lake, including the fenced plot, islet-by-islet, Lincoln index, and cooperative interagency census methods (Winkler 1983a, 1987). Only the fenced plot and islet-by-islet methods, however, have been widely used to report lakewide reproductive success since 1983 (Shuford pers. comm.). The fenced plot method involves direct counts of chicks in enclosures. This method is usually more accurate than the other techniques; however, the only long-term data set available using this method is from the Negit Islets (Shuford pers. comm.). The islet-by-islet method relies on the best estimates of reproductive success from each of the islands and islets derived from one of the three other methods mentioned above.

The first method used to estimate lakewide reproductive success, later known as the cooperative interagency census, was begun by Winkler in 1976 (Winkler 1983a). This technique employed censuses of chicks from a boat and had the advantages of rapid, lakewide coverage of the breeding colony and minimal disturbance of nesting birds (Winkler 1987). The main limitation of these censuses was the inability of observers to detect all chicks on islets of differing size and relief, which resulted in underestimates of the breeding adults and fledglings. Cooperative interagency counts were continued through 1987, however, to provide continuity with Winkler's (1983a) estimates of the number of fledged young that were derived using this method (Shuford pers. comm.). Shuford (1986) compared his estimates of fledging success in 1983-1986, which were derived from several largely independent methods of censusing, and found that they generated similar values.

Regardless of which method is used to derive the data, reproductive success is calculated by dividing the estimated number of fledged young in the entire colony by the number of breeding adults. The number of breeding adults early in the nesting season (e.g., the third week in May) is the most meaningful index of the adult breeding population (Winkler 1987). Late-season estimates (e.g., early July) of adult populations do not account for adults that initiated nesting but abandoned the effort (Winkler 1987). Thus, the fledging success per adult when applied to the entire colony is somewhat inflated because the total number of fledglings produced should be attributed to a smaller number of adults.

Based on reinterpretation of data originally presented by Winkler et al. (1977), fledging success of the Mono Lake gull colony was estimated at 0.52 in 1976 (Shuford pers. comm.). Systematic censuses of the gull colony were not conducted in 1977 and 1978, and no estimates of reproductive success are available for those years (Table C-3).

In 1979, mainland predators (probably coyotes) invaded Negit Island for the first time, and reproductive success for the Mono Lake colony was about half its calculated value in 1976 (Table C-3). Predators caused total reproductive failure on Negit Island that year but did not destroy the entire Mono Lake colony because many other gulls nested on the Negit and Paoha Islets (Winkler pers. comm.).

Winkler (1987) and Winkler and Shuford (1988) estimated the colony at relatively constant population sizes (i.e., between 40,000 and 50,000) from 1979 until 1982 but observed major differences in reproductive success in those years. In 1980, fledging success almost doubled compared to 1979, but 1981 and 1982 had the lowest reproductive success on record (Table C-3). High temperatures and possibly reduced food supplies were hypothesized to have caused high chick mortalities in 1981 (Winkler 1987). Twain and Java Islets were land bridged to the mainland late in 1981, and nesting gulls abandoned them in 1982. Total chick production in 1982 was about 43% lower than it had been the previous year. When adult gulls abandoned their nesting habitat on Twain and Java Islets, some of them apparently began preying on gull eggs from nests on other islets; some adult gulls whose nests had been destroyed also became "marauders" and probably increased overall nest predation even further (Winkler pers. comm.).

In winter 1982 and 1983, the elevation of Mono Lake increased by more than 8 feet due to extremely high runoff. In this period of lakewide changes, gull reproductive success increased from the values observed in the 1981 and 1982 breeding seasons (Table C-3). Lake levels continued to rise in 1984, but gull reproductive success decreased from the previous year. From 1985 until 1988, the lake's elevation remained above 6,378 feet and gull reproductive success was higher than that observed in the early 1980s (Table C-3).

Despite the presence of coyotes on Negit Island and Pancake Islet late in the season, gulls continued to reproduce successfully at Mono Lake in 1989 (Dierks 1990, Jehl 1989). Overall, reproductive success was high compared to the late 1970s and early 1980s (Table C-3). In 1990, the gull colony had the highest fledging success on record (Dierks 1991, Jehl 1991b). Lakewide reproductive success in 1991 declined from the previous year, and the three small colonies on Negit Island failed completely (see "Predation" below).

In 1992, fledging success was higher than in any previous year except 1990 (Table C-3). No clear explanation was apparent for the high fledging success reported at Mono Lake in 1992. Jehl and Shuford (pers. comms.) suspected it could have been due to the warm spring weather and an early brine shrimp hatch.

SURVIVORSHIP

Winkler (1987) analyzed 136 recoveries of gulls banded at Mono Lake between 1938 and 1985; the final pool included only records of birds that fledged and departed Mono Lake and that were recovered in reasonably fresh condition. In the past 20 years, sophisticated methods have been developed for estimating survival rates from band recovery data (Brownie et al. 1985). These new methods assume that large numbers of birds have been banded in all age classes in the same year and permit estimations of the age-specific survival and recovery rates of a larger population.

Unfortunately, the Mono Lake sample of band recoveries contained only one individual that had been banded as an adult; thus, it was not possible to use the new methods to estimate the age-specific survival rate of this population (Winkler 1987). A precise estimate of the adult and juvenile survival rates for the entire world population of this species was impossible using the new methods because fewer than 100 gulls banded as adults have been recovered dead in all the years of banding.

Due to the lack of adequate band recovery data, Winkler (1987) considered the distribution of the ages at death of all birds in the recovered sample, regardless of the year in which they were banded. By assuming that the interannual variation in survival rates was negligible, the population size was approximately stable, and the recovered sample was a random sample of the larger population, Winkler (1987) calculated a survival rate by estimating the rate at which the sizes of successive age classes dwindle. The mean survival rate over all age classes using these methods was 0.57.

Winkler (1987) also estimated survivorship of Mono Lake gulls by observing a population of color-banded adult gulls on Little Tahiti Islet from 1980 until 1982. By counting the number of marked gulls returning each year, he estimated the adult survival rate at 0.79. Winkler (1987) examined sources of bias to determine which value (e.g., 0.57 or 0.79) was the best estimate of gull survivorship. The estimate derived from the age structure assumed a relatively stable population, despite the fact that it was growing at an annual rate of about 5% from the early 1900s until the mid-1970s (Jehl et al. 1984). Population growth would have the effect of overrepresenting younger age classes in the sample but would be unlikely to affect the representation of older age classes.

Another source of bias in the life table analysis is the problem of band losses, which underrepresent older age classes and decrease their apparent survival rate (Winkler 1987). Recognizing the problems inherent in either approach to estimating survivorship, Winkler (1987) tentatively recommended survival rates of about 0.8 for adults and 0.6 for juveniles.

ESTIMATION OF POPULATION GROWTH RATE

Winkler (1987) used the estimates of survival rates and fecundity described in the preceding sections to produce a life table for the Mono Lake gull colony. The fecundity of this colony has been studied only since 1979, and even during this relatively short time fledging success has varied significantly (Table C-3). The life table must include a "typical" estimate of the number of fledglings produced per female in the population = m_x.

The Mono Lake colony has an unusually low clutch size, averaging only two eggs, which limits its potential production of offspring (Winkler 1985). Winkler (1987) used the 4 previous years of record (i.e., 1983 through 1986) and calculated that an individual on average produced only about 0.3325 offspring per reproductive season (sum of fledged chicks [61,201] divided by sum of adults early in the breeding season [184,078]). Fledging success has varied each year at Mono Lake, and average fecundity generally has increased in this colony since Winkler's (1987) analysis was conducted (Table C-3).

Given the uncertainties in the estimations of both fecundity and survivorship, Winkler (1987) presented his life table as a series of five options that depended on the initial assumptions. For each option, he tabulated the assumed survivorship and fecundity rates and calculated an overall population growth rate. A stable population would have a population growth rate of 1.0, and populations with growth rates less than 1.0 are shrinking; no population will persist for a long period with a growth rate of less than 1.0 without being constantly replenished by immigrants from other populations. Population growth rates for Winkler's (1987) five options ranged from a low of 0.661 to a high of 0.905, suggesting that the Mono Lake gull population was not sustaining itself with local recruits from the population.

Winkler (1987) also calculated the population growth rate of the population for a wide variety of survival rates and fecundities to determine how much these variables must be changed in order to predict a stable or increasing population. The results of these simulations suggest that the Mono Lake gull population will decline in the future (unless it is presently being supplemented by immigrants from other sites), or the values used for fecundity and survivorship are grossly underestimated (Winkler 1987).

Murray (1988) reviewed Winkler's (1987) life tables and concluded that an adequate analysis would require quality data on age-specific mortality and fecundity. Murray (1988) questioned the use of 0.3325 as an average annual fecundity value because it was calculated using the cooperative interagency census method. He recalculated fecundity rates using data gathered by other methods and concluded that the fenced plot method was the most reliable and yielded the highest m_x value (0.3953); those derived by the islet-by-islet method were closer to the fenced plots than they were to the interagency counts in 2 of 3 sample years. Murray also pointed out that Jehl and Stewart (1988) estimated 0.85 chicks per pair at nine fenced plots on the Paoha Islets in 1987; this converts to 0.445 chicks per adult, which may be a more realistic value of m_x.

Murray (1988) also questioned other aspects of Winkler's (1987) life table analysis, including the assumption of an 8-year life expectancy, the failure to include the effects of immigration in the model, and the calculations of finite rates of population increase. Winkler (1987) used an 8-year life expectancy because it was the oldest band recovery available, but this may be an unrealistically short life span for a bird of this size (Murray 1988). A life table that does not account for the effects of immigration underestimates the population's annual rate of growth. Finally, the range of values calculated by Winkler (1987) (i.e., 0.661 to 0.905) indicates a decline of between 34% and 10% for the Mono Lake gull colony. As presented by Winkler (1987), the population data from 1983 to 1986 indicated a slight increase, and Murray calculated on the basis of population size a value at 1.0318, representing an increase of about 3% per year.

Winkler's (1987) life table analysis and Murray's (1988) commentary received extensive discussion in court (Dodge, Goldsmith, Moskovitz, Court Testimony 1991, Vol. XXVII). Despite the attention these analyses have received in the literature and in court, important data are lacking for appropriate use of life tables to evaluate population changes of Mono Lake's gull colony. The lack of convincing data on age-specific survival and fecundity rates derived from marked populations of known age prevents the calculation of finite rates of population increase for this population. Even if such data existed, it may not be possible to calculate an average fecundity rate because fledging success is highly dependent on the incidence of land bridging and the subsequent invasions of coyotes and other mainland predators into formerly secure nesting islands.

If life tables are used to analyze population trends of the Mono Lake colony in the future, they should include fecundity and survivorship data derived from long-term studies (e.g., more than 10 years) to account for year-to-year variations that appear to be inherent in this population. If possible, such analyses also should consider the effects of immigration in overall population growth (Winkler pers. comm.).

FACTORS AFFECTING REPRODUCTIVE SUCCESS

The present status of gull nesting at Mono Lake is a complex interplay between several factors. Winkler (1987) described six factors that potentially could have major effects on the breeding productivity of gulls at Mono Lake, including predation, weather, parasites, food supply, nesting density, and habitat quality.

Predation

Predation and disturbance by great horned owls are known to have caused total reproductive failure on several small Paoha Islets and parts of larger islets in 1983 and 1984 (Jehl 1983, 1984b, 1991a; Court Testimony, Vol. XIII, p. 12; Court Testimony, Vol. XIV, pp. 4-7). Similarly, golden eagles and prairie falcons also prey on gulls at Mono Lake, but these avian predators typically visit colonies infrequently and are unlikely to reduce overall nesting success of large colonies (Jehl and Chase 1987, Winkler 1987). Although numerous examples exist of birds of prey disrupting gull nesting efforts, these predators appear to have had a negligible effect on the overall reproductive success of the Mono Lake colony or the entire nesting populations on large islets (Shuford 1985, Dierks 1990).

In contrast, mainland predators such as coyotes have had a major impact on the reproductive success of nesting gulls at Mono Lake, and studies from other areas have shown that canids can destroy nesting efforts if they gain access to gull colonies (Kadlec 1971). In 1979, coyotes crossed the land bridge to Negit Island and probably caused a complete nesting failure there. In 1982, Negit Island had already been abandoned and the coyotes crossed new land bridges to Twain and Java Islets and probably caused these colonies to fail (Winkler 1983b; Winkler and Shuford 1988; Jehl 1991a; Court Testimony, Vol. XIII, p. 12). In 1990, coyotes also were implicated in the abandonment of Pancake Islet (Dierks 1991). Gulls have made limited efforts to colonize Paoha Island in recent years (Jehl pers. comm.) and have failed, probably because several coyotes are resident on this island.

During April 23 and May 18-20, 1991, high coyote activity was observed on Negit Island, including fresh canid prints near two of three nesting groups and a sighting of an adult (Dierks and Shuford 1992). Nesting gulls abandoned Negit Island in late May (Shivik pers. comm.), and nests examined on July 10 contained eggs or downy carcasses of downy young, but not carcasses of feathered chicks (Dierks and Shuford 1992). The continued presence of coyotes on the island was suggested as the most likely reason for the abandonment by nesting gulls in 1991 (Dierks and Shuford 1992, Jehl pers. comm.). The presence of several decapitated adults, however, indicated that resident great horned owls probably also preyed on nesting adults (Jehl pers. comm.).

Twelve coyotes were fitted with radio collars in 1991 and monitored during the entire gull breeding season, including during winter gull arrival (October 20, 1990 to April 23, 1991), nesting and chick rearing (April 23 to July 26, 1991), and fledging and dispersal (July 26 to September 19, 1991) periods (Shivik and Crabtree 1992). Of the marked coyotes, three transient and one territorial individual visited the vicinity of Negit Island, primarily during the gull fledging and dispersal period (Shivik and Crabtree 1992). At least six adult coyotes (including marked and unmarked individuals) visited the island during the course of the study.

The high coyote activity in April and May corresponded with an abrupt decline in the number of crossings by marked individuals over the land bridge. Two or three coyotes resided on the island from April 23 until July 15 and probably excluded other coyotes during this period. A resident female was captured on Negit Island on July 3, and she remained on the island until July 15 before departing for the mainland. Coyote activity was evident on Negit Island for an additional 2 months after the gull abandonment occurred, suggesting that food supplies other than gulls could lead coyotes to take up residence there. Evidence of den digging suggested that coyotes also attempted to breed on the island (Shivik and Crabtree 1992).

Shivik and Crabtree (1992) found that coyotes in the study area ate many species of animals and adapted their diets to consume various available food sources. Rabbits were the primary prey ingested by coyotes during the winter gull arrival period and the fledging and dispersal period, and gulls were the primary food source during the nesting and chick rearing period. It should be noted, however, that gull biomass observed in scats does not directly translate to a predation rate; though gulls were known to have been killed by coyotes, some gulls may have been a scavenged food source.

Shivik and Crabtree (1992) found three adult gulls that were suspected of being eaten by coyotes, one of which showed direct evidence of being killed by a canid (e.g., canine punctures and subcutaneous hemorrhaging). Two eggs were found on Negit Island that appeared to have been eaten by coyotes (i.e., neat, incisor-like damage to an empty shell).

Egg shell fragments were found in six of 50 coyote scats collected on Negit Island from late April until early September (Shivik and Crabtree 1992). These eggs were not identified to species, but the following evidence suggests they were from gulls: no coyote activity was observed near artificial nests (stocked with chicken eggs) set out on Negit

Island, nests of territorial passerines in the study area would be difficult to find, and gull nests are clumped in colonies permitting access to many nests simultaneously. Shivik (pers. comm.) concluded, however, that data from marked coyotes and direct observations of predation events would be required to clearly identify the cause of abandonment by Negit Island's nesting gulls in 1991.

Most predation events probably occur at night when humans are least likely to observe them. For example, Emlen et al. (1966) observed that nocturnal visits by a raccoon were indirectly responsible for extensive egg and chick mortality at a colony of ring-billed gulls in Michigan. The raccoon caused very little nest destruction but incited panic flights, which caused breeding adults to leave their nests for up to 4 hours and eventually to abandon the nesting area. Thus, coyotes at Mono Lake need not prey on a large number of gulls to have a disruptive effect on nesting efforts.

Observations made in previous breeding seasons also suggest that coyotes played a role in the abandonment of the Negit Island nesting populations in 1991 (Dierks 1990, 1991; Dierks and Shuford 1992). After gulls recolonized Negit Island in 1985, the first coyotes were not observed until 1989. In 1990, coyotes were again evident during the breeding season; Negit Island was the only large island that did not experience a large gull population increase that year. Dierks (1991) considered coyote predation to be a factor in the low reproductive success on Negit Island in 1989 and 1990. In 1991, the initial breeding population was lower than in 1990, and the island was abandoned relatively early in the breeding season. In light of predator-induced abandonment of Negit Island in 1979, Java and Twain Islets in 1982, Pancake Islet in 1990, and low fledgling survival on Java Islet in 1992, it is probable that coyotes also caused the abandonment of Negit Island in 1991.

Coyotes do not require a physical land bridge to gain entry to a nesting island. Murphy (pers. comm. in Shivik and Crabtree 1992) observed a coyote swimming between Negit and Paoha Islands in 1990, and he watched an individual swimming as far as 20 meters to reach Negit Island in 1991. Similarly, a water depth of 1 foot over the imminent land bridges to Negit Island and Pancake Islet (at lake elevations of about 6,376.5 feet) and Java and Twain Islets (at lake elevations of about 6,373.5 feet) was insufficient to prevent coyote crossings in 1979 and 1982, respectively (Winkler 1987). Coyotes have been resident on Paoha Island for years, however, and have apparently not crossed the relatively narrow channels (e.g., less than 100 yards wide) to the closest Paoha islets (Jehl pers. comm.).

In studies of canid behavior elsewhere, Getz and Smith (1989) found that distances of 60-150 meters (200-500 feet) and water depths of 0.6-1 meter (2-3 feet) were required to reduce canid predation of waterfowl nests. Likewise, Giroux (1981) recommended a distance of at least 170 meters (560 feet) and a depth of approximately 0.7 meter (2.3 feet) to ensure a reliable deterrent to coyote crossings of open water.

Weather

Heat stress may have caused the extremely high rate of chick mortality observed in 1981 (Jehl and Jehl 1982, Mahoney and Jehl 1982). Winkler (1983b) hypothesized that a combination of heat stress and food shortages may have been responsible. Heat stress may also have been a factor in the low reproductive success observed in 1984 (Shuford et al. 1985), and Winkler (1983a) also found statistically significant correlations between chick mortalities and high temperatures.

Jehl (1983) reported a high rate of gull chick mortality on low-lying portions of the Paoha Islets following heavy storms; he observed that high waves washed chicks away or drenched them with saltwater, causing death from exposure. Storm-induced mortality was negligible on the rocky, steep-sided Negit Islets during 1983 (Shuford et al. 1984). Because most gulls nest on high, rocky areas where they are protected from waves and high winds (e.g., Negit Islets or higher terraces of the Paoha Islets), severe storms are unlikely to have major effects on gull reproductive success at Mono Lake.

Parasites

A tick species (*Argas monolakensis*) unique to Mono Lake (Schwan et al. 1992) carries the Kemerovo group virus and was first discovered under gull nests at Mono Lake in 1966 (Johnson and Casals 1972). High levels of tick infestation have subsequently been reported on California gull adults and chicks (Schwan and Winkler 1984). Ticks have been reported on Mono Lake gulls and correlations have been noted between chick mortalities and levels of tick infestation (Shuford et al. 1984; Shuford 1985, 1986; Dierks 1990). However, no specific documentation indicates whether ticks (or the virus they carry) have had a major effect on the reproductive success of the Mono Lake gull population in any year (Shuford 1985, Dierks 1991).

Food Supply

Invertebrate prey at Mono Lake, including alkali flies and brine shrimp, has accounted for more than 50% (by volume) of gull chick diets in all sampling years since 1976 (Winkler 1983a, 1983b; Mahoney and Jehl 1982; Jehl 1984b; Shuford et al. 1985; Shuford 1985, 1986; Strauss 1987; Dierks 1988, 1990, 1991). For example, in a recent PRBO study the food items that had been fed to chicks just before capture were brine shrimp (57.4%), alkali flies (36.7%), fish (3.2%), and human garbage (2.7%) (Dierks 1991). Studies from Great Salt Lake (Winkler 1983a, 1987), however, indicate that brine shrimp are the least preferred food for gulls. Studies of foraging behavior at Mono Lake suggested that gulls primarily foraged at nearby dumps (e.g., within 30 miles of the lake) in early spring, but switched to natural food as soon as it became available (Jehl 1985).

Preliminary studies of the foraging ecology of juvenile California gulls at Mono Lake in July and August 1991 suggested that submerged tufa shoals are an important feeding habitat (Elphick and Rubega pers. comms.). These observers suggest that more than 50% of all feeding attempts by juvenile gulls in this habitat were either on emerging alkali flies or floating pupae. Furthermore, foraging success rates were high because emerging adult and pupal forms of the alkali fly are relatively inactive and easy to capture at the water surface. A high proportion of juvenile gulls frequent inshore areas while foraging, and it seems likely that these areas represent an important source of concentrated food. Elphick and Rubega (pers. comms.) suggest that alkali flies may contribute significantly to the survival of postfledgling gulls and may constitute gull's preferred prey during this period.

Dietary studies of California gulls are incomplete, but studies of invertebrate prey organisms indicate that alkali flies have a higher caloric value and lipid content than brine shrimp (Herbst et al. 1984) and represent the most nutritionally important food source at Mono Lake. Boula (1986) and Boula and Jarvis (1984) found that alkali flies were the most important food source to migratory water birds at Abert Lake, Oregon. Similarly, Rubega (1992) found that red-necked phalaropes required alkali flies in their diet at Mono Lake and that they could not survive in laboratory trials when offered an exclusive diet of brine shrimp. These studies do not discuss the nutritional requirements of California gulls, but it is likely that the high lipid content and caloric value of alkali flies are important to developing juvenile gulls.

During 1981, many chick deaths occurred late in the season; Winkler (1987) suggested that heat stress and possibly food shortages may have limited gull reproductive success. In 1982, the lake remained at low levels and brine shrimp densities were extremely low during spring and early summer. In this period, the gulls appeared to take other prey such as cicadas (*Okanagana gibbera*, *O. cruentifera*, and *O. occidentalis*), which are infrequently abundant in Mono Basin (Winkler 1983b). Brine shrimp densities recovered by July 1982, and gulls resumed foraging on brine shrimp as their primary food source. Recovery of brine shrimp numbers this late in the nesting season, however, was of limited value to the majority of gull chicks that had already passed through the most energy-demanding period of their growth (Winkler pers. comm.). Thus, at the lowest historical lake level (6,372 feet), brine shrimp appeared to be sufficiently abundant, at least after early summer, to sustain the nesting gulls. Cicadas also were extremely abundant that year and supplemented the food supply during this period of low brine shrimp abundance (Winkler pers. comm.).

Nesting Substrate

Jehl (1984b) and Jehl et al. (1984) characterized the preferred gull nesting habitat at Mono Lake as open, rough terrain on relatively flat terraces that are protected from the highest waves. Jehl (pers. comm.) noted that gulls on the Paoha Islets will first occupy areas of rough or rugose substrate (e.g., tufa-encrusted areas, logs, and small boulders), which occur both on and above the wave-cut platforms. Once these areas are occupied, the nesting birds will begin using nonrugose substrates (e.g., open sandy areas). With few exceptions, nesting gulls will not occupy any areas on wave-cut platforms less than 8-12 inches above the water surface or on the windward sides of the islets. They also will not occupy the steep wave-cut slopes of these islets.

Jehl (1991a; Court Testimony, Vol. XIII, pp. 3-7) stated that gulls do not select nesting habitats with regard to temperature or shade. He noted that California gull colonies at other nesting sites avoid thick, high brush that may impair lateral visibility, and that the historical colony on Negit Island was an anomalous situation. Further, he feels that there is little relationship between vegetative density and reproductive success and stated that nesting gulls tend to select open areas first (Jehl 1991a; Court Testimony, Vol. XII, pp. 76-79).

Based on observations of gulls in other portions of their range, such as the Great Salt Lake, Winkler (pers. comm.) believes that gulls colonizing a site for the first time will always prefer open nesting sites because they feel safer there. He does not regard open nesting sites as preferable in all circumstances, especially during hot years on islands that are safe from predators. He feels that gulls selected greasewood habitats on Negit Island prior to 1979 either because they gradually moved there from open areas as they gained a sense of security or because when gulls first started nesting in the area little open habitat was available. The gulls probably avoid greasewood habitats now because, like gulls everywhere that have experienced predation due to recent land bridging, they avoid habitats with limited visibility.

Until 1979, Negit Island was one of the only stable nesting islands for California gulls in their entire range (the other major site is Gunnison Island at Great Salt Lake where they nest in brush) (Winkler pers. comm.). Since 1979, Negit Island has been no more reliably predator-free than in most other places that this species nests, and it is not reasonable to expect them to immediately recolonize this area after recent land bridging events. If the Negit Island land bridge had never formed, Winkler (pers. comm.) would have expected the gulls to nest at higher numbers in greasewood habitats than in any other area at Mono Lake. He also predicted that they would have higher nesting productivity at Negit Island greasewood habitats, especially during hot years.

Shuford believes California gulls have a hierarchical method of habitat choice (Shuford 1991a; Court Testimony, Vol. XIV, pp. 12-18). The first factor is the selection of a nesting island that is free of ground predators. Once on the island, Shuford testified that gulls select shoreline nest sites if appropriate nesting substrates are available because these sites are typically cooler and more easily defended from other gulls. The disadvantage of shoreline nest sites is that they are more vulnerable to destruction from high waves. Preferred nesting substrates appear to be rough surfaces (e.g., rocks, tufa crust, shrubs, or logs), and the gulls avoid sandy beaches lacking surface debris, even if they are near the shoreline. Habitat relief probably provides several benefits, including visual screening from adjacent, territorial gulls and predators and shade for chicks. Shade may be important during hot years (such as 1981) when adults leave their chicks for long periods late in the nesting season (Winkler 1987).

In addition to nesting in greasewood scrub habitats on Negit Island before it was land bridged, California gulls have been observed nesting in scrub habitats elsewhere in their range, including at Honey Lake Wildlife Area and at portions of the Great Salt Lake (Shuford pers. comm.). Similarly, Pugesek and Diem's (1983) studies of nesting California gulls in Wyoming suggested that older gulls preferred to nest in sites with shrub shelter at the center of the colony. In their 2-year study, however, they found no significant differences in reproductive success between gulls of the same age nesting in shrubby and nonshrubby habitats. They cautioned that because their study had a short duration it may not have revealed the advantages of shrubby sites that might be apparent during infrequent or intermittent heat waves. The selection of shrubby sites by older gulls suggests that these areas may provide a long-term reproductive advantage.

In most years, California gulls at Mono Lake, and apparently at the Great Salt Lake (Paul et al. 1990), appear to be highly adaptable in their choice of nesting substrates and can reproduce successfully in both greasewood and open, unvegetated substrates. Reproductive success in these two habitats at Mono Lake, however, has not been compared over a period of years because recent land bridging has not permitted long-term studies of the Negit Island population. Recent nesting success on islands without extensive shrubs (Dierks 1990, 1991; Jehl 1989, 1991a) does not provide sufficient evidence to conclude gulls never benefit from nesting in shaded habitats.

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Table C-1. Estimated Number of Adult California Gulls Nesting at Mono Lake between 1916 and 1938

Date of Visit	Approximate Lake Elevation	Mono Lake Total	Negit Island	Paoha Island	Negit Islets	Paoha Islets	Comments	Source
May 27-28 and July 3, 1916	6,426.5	2,000	0	2,000	?	NA	Visited Negit Islands but did not observe gulls there	Dixon 1916 Grinnell and Storer 1924
June 3-6, 1919	6,427.7	>3,400	P	1,700	P	NA	Did not count "most populous" colony on Negit Island; nesting also occurred on "outlying rock" that represented the crest of Little Tahiti Islet	Dawson 1923 Jehl et al. 1984
May 21, 1928	6,423.5	>4,000	>4,000	?	?	NA		W. M. Pierce[a]
Late 1920s or early 1930s	--	?	P	P	?	NA	The largest colony was on Negit Island and small numbers nested on Paoha Island	McPherson (pers. comm.)
Mid-1930s	6,420.0	Large colony	P	0	?	NA	Absent from Paoha Island throughout this period	McPherson (pers. comm.)
July 1, 1937	6,416.0	Large colony	P	?	?	NA	Colony site covered about 12 acres	E. F. Sechrist[a]
June 1937	6,416.0	60,000	?	?	?	NA	Unreliable estimate based on second-hand information	Grinnell (1937)
July 9-12, 1938	6,416.0	3,000	3,000	0	?	NA	Banded 510 half-grown young on Negit Island; Paoha Island not occupied	Nichols 1938

Notes: P = present but no population estimate available.
NA = not applicable. Paoha Islets were submerged during this period.

[a] Cited by Winkler and Shuford (1988) but not reviewed by Jones & Stokes Associates biologists.

Table C-2. Estimated Number of Adult California Gulls Nesting at Mono Lake between 1950 and 1975

Date of Visit	Lake Elevation (feet) (USGS Datum)	Mono Lake Total	Negit Island	Paoha Island	Negit Islets	Paoha Islets	Comments	Source
1950-1951	6,411-6,409	1,500	1,500	0	?	NA	Rough estimate; colony reported from a small area on the southeast side of Negit Island	Young 1952
June 18-19, 1952	6,408	5,000-10,000	P	?	?	NA	Rough estimate; no systematic counts made	D. W. Johnston[a]
May 16 and 29, 1953	6,409	3,000-6,000	P	?	?	NA	Rough estimate; no systematic counts made	D. W. Johnston[a]
1952-1953	6,408-6,409	3,000-5,000+	P	?	?	NA	Rough estimate; no systematic counts made	Johnston 1956
1958-1967	6,401-6,387	Large colony	P	?	?	NA		D. Banta and D. Mason[a]
1959, 1961-1963	6,401	?	P	?	?	NA	Banded 4,825 chicks on Negit Island	Gallup 1963, USFWS Bird Banding Laboratory
June 8, 1963	6,394	?	?	?	P	NA	No population estimates made	R. Quigley[a]
1966	6,389	?	?	?	P	NA	No population estimates made	H. Johnson and K. Lajoie[a]
June 21, 1972	6,385.4	>10,000	1,200	0	P	0	Rough estimate; uncounted thousands around the lake	Jurek 1972
June 26, 1973	6,383.9	Thousands	P	0	P	?		Anderson 1973
August 24, 1973	6,383.4	42,500	–	–	–	–	Aerial census of a postbreeding population of adults and young	Jurek 1973
1974	6,382	20,000-30,000	P	?	?	?	Rough estimate made from shore miles from colony where most breeding birds were not visible	Stallcup and Greenberg 1974
June 6, 1974	6,382.3	20,000-30,000	P	?	P	?	Rough estimate; did not estimate numbers on Negit Islets	Mangan 1974
May 25, 1975	6,380.6	>3,000	0	0	0	?	Rough estimate; gulls did not appear to be nesting on Negit Islets	Heindel 1975, Mangan 1975

Notes: P = present but no population estimate available.
NA = not applicable. Paoha Islets submerged during this period.

[a] Cited by Winkler and Shuford (1988) but not reviewed by Jones & Stokes Associates biologists.

Table C-3. Estimated Number (or Percentage) of Adult California Gulls Nesting at Mono Lake Since 1976

Date of Visit	Lake Level in July (feet) (USGS Datum)	Mono Lake Total	Negit Island	Paoha Island	Negit Islets	Paoha Islets	Estimated Number of Fledglings per Adult	Comments	Source
July 4, 1976	6,378.4	51,162	~65%	0	~35%	0	0.52	First attempted survey of the entire breeding population	Winkler et al. 1977, Winkler 1987
1977-1978	6,376.6-6,375.8	40,000-50,000[a]	P	0	P	0	No data	Gull population monitored but not censused; channel blasted	Winkler 1987
July 5, 1979	6,374.4	40,000-50,000[a]	0	0	~75%	~25%	0.22-0.27[b]	Invading coyotes caused a major nesting failure on Negit Island; predator fence erected	Winkler 1987
July 7, 1980	6,374.2	40,000-50,000[a]	<5%	0	~70%	~30%	0.40-0.51[b]	A few gulls nested on the eastern half of Negit Island	Winkler 1987
July 6, 1981	6,373.4	40,000-50,000[a]	<5%	0	~65%	~35%	0.03-0.04[b]	The number of nesting gulls on Negit Island increased	Winkler 1987, Jehl and Jehl 1981
July 6, 1982	6,372.4	40,000-50,000[a]	0	0	~50%	~50%	0.08-0.10[b]	Mainland predators caused the abandonment of Java and Twain Islets	Winkler 1987
May 29-June 21, 1983	6,377.6	45,116	0	0	29,114	16,002	0.32	Extremely high runoff caused the lake elevation to increase by more than 5 feet; Negit Island was separated from the mainland	Shuford 1985, Jehl 1983
May 24-31 and June 12, 1984	6,380.4	44,836	0	0	37,744	7,092	0.14	Erosion of Paoha Islets occurred because of rising lake levels; coyotes removed from Negit Island	Shuford 1985, Jehl 1984
May 23-27, 1985	6,379.5	44,570	184	4	38,080	6,302	0.40-0.42[c]	Negit and Paoha Islands recolonized by nesting gulls; some coyotes removed from Paoha Island	Shuford 1985, Jehl 1985
May 20-29, 1986	6,380.9	49,556	1,272	204	40,888	7,192	0.67-0.67[c]	Expanded use of Negit Island and Negit Islets	Shuford 1986, Jehl pers. comm.
May 21-25, April-August 1987	6,379.9	47,616	3,004	0	38,196	6,416	0.56-0.57[c]		Strauss 1987, Jehl and Stewart 1988
May 20-24, April-August 1988	6,378.2	45,002	4,074	0	35,262	5,666	0.51-0.54[c]		Dierks 1988, Jehl 1989
May 20-25, 1989	6,376.8	44,176	5,530	0	33,282	5,364	0.57-0.60[c]	Coyotes entered colonies on Negit Island and Pancake Islet	Dierks 1990, Jehl 1989
May 19-24, 1990	6,375.8	61,474	5,654	0	45,530	10,290	0.71-0.47[c]	Mainland predators entered colonies on Negit and Pancake Islets	Dierks 1991, Jehl 1991b

Table C-3. Continued

Date of Visit	Lake Level in July (feet) (USGS Datum)	Mono Lake Total	Negit Island	Paoha Island	Negit Islets	Paoha Islets	Estimated Number of Fledglings per Adult	Comments	Source
May 18-22, 1991	6,375.0	43,520	1,576	0	33,060	8,884	0.47-0.51[c]	Three small colonies attempted nesting on Negit Island but all failed; coyotes living on Negit Island; no nesting on Pancake Islet	Jehl 1991b, Dierks and Shuford 1992
May 20-24, 1992	6,374.5	64,976	8	2	46,400	18,566	0.66-0.68[c]	Coyotes entered Java Islet in late nesting season and fledglings there had much higher mortality than on other islets	Jehl and Shuford pers. comms.

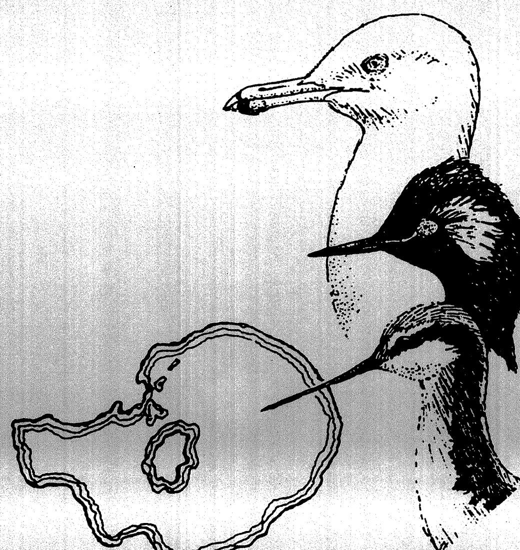
Note: P = present but no population estimate available.

[a] Rough estimates because no censuses were conducted during 1977 and 1978 and incomplete censuses were conducted from 1979 until 1982 (Shuford and Winkler pers. comms.).

[b] From 1979 until 1982, fledging success values varied, depending on whether 40,000 or 50,000 adults were used for the calculations (Shuford pers. comm.).

[c] From 1985 until 1992, the first fledging success value was based on the islet-by-islet method and the second value was based on the fenced plot method (see text).

Appendix D. 1991 Wildlife Habitat Inventory and Analysis



MONO BASIN EIR

Prepared by Jones & Stokes Associates

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Appendix D. 1991 Wildlife Habitat Inventory and Analysis

INTRODUCTION

In 1991, SWRCB consultants, Jones & Stokes Associates, conducted surveys to characterize the wildlife species inhabiting streamside, lakeshore, upland, and island habitats in Mono Basin, and floodplain habitats on the Upper Owens River. Surveys were conducted from May until October and were designed to identify wildlife responses associated with habitat changes that have occurred since diversions of Mono Lake's tributary streams began in 1941. Data derived in these studies also will be used to analyze future wildlife responses that could potentially occur with implementation of any of the proposed project alternatives.

OBJECTIVES

The objectives of conducting wildlife surveys were to:

- determine the prediversion and current status and habitat associations of birds, mammals, reptiles, and amphibians inhabiting wetland-dependent habitats of Mono Basin and the Upper Owens River;
- determine the occurrence of special-status species, including state and federally listed species and other species of special concern to DFG and USFWS in Mono Basin and the Upper Owens River; and
- estimate the changes that have occurred between prediversion and point-of-reference wildlife populations in Mono Basin and Upper Owens River.

STUDY AREAS

Studies were conducted in riparian, wetland, meadow, and upland habitats within Mono Basin and in riparian and meadow habitats along with the Upper Owens River. Wildlife surveys were conducted in the following study areas:

- Study Area 1: Lee Vining, Rush, Walker, and Parker Creeks (Figure D-1);

- Study Area 2: relicted shoreline habitats and open water areas adjacent to the Mono Lake shoreline at Simon Springs, Navy Beach, Lee Vining Tufa Grove, Black Point, DeChambeau Marsh, and mouths of Wilson, Lee Vining, and Rush Creeks (Figure D-2);

- Study Area 3: Paoha Island (Figure D-2); and

- Study Area 4: the portion of the Upper Owens River occurring on the Arcularius Ranch (Figure 3G-4, "Land Use").

STUDY TEAM

The study design was developed by Jones & Stokes Associates wildlife biologists. Bird surveys were conducted on Mono Lake tributary streams, lakeshore areas, and on the Upper Owens River by Jones & Stokes Associates wildlife biologists Dr. Edward Beedy, Marcus Rawlings, Emilie Strauss, and Daniel Taylor. Under the direction of Jones & Stokes Associates, Dr. Michael Morrison of UC Berkeley conducted bird, mammal, reptile, and amphibian surveys on Paoha Island and upland sites near Black Point. Also under direction of Jones & Stokes Associates, Dr. John Harris of Mills College and five of his undergraduate students conducted mammal, reptile, and amphibian surveys on Mono Lake tributary streams and lakeshore areas and on the Upper Owens River; Steven Clifton of Jones & Stokes Associates also assisted Dr. Harris with the mammal surveys.

METHODS

Standardized fixed-plot and plotless techniques were used to survey wildlife. Fixed-plot surveys were used to determine the occurrence of bird, mammal, reptile, and amphibian species on specific survey plots. Standardized plot surveys permitted direct comparisons of species richness, relative abundance, diversity, and habitat associations of species on different plots.

All survey plots were 1,000 square meters in area and most measured 20 meters by 50 meters. The only exceptions were in some riparian survey sites where riparian corridor widths of less than 20 meters limited plot width and increased plot length.

A habitat classification system was developed by project botanists; specific vegetation types are described in Chapter 3C, "Vegetation". Several habitat designations used in this section combined two or more of the habitat types identified in Chapter 3C, "Vegetation", (Table D-1) in cases where habitats were distinct vegetatively, but functionally provided similar values to wildlife. Eighty-eight survey plots were established in 19 habitat types in Mono Basin and Upper Owens River (Table D-2).

In addition to conducting systematic censuses on the study plots, the study team also recorded daily field notes of wildlife and habitat associations observed during plotless surveys. These surveys were made without space or time restrictions and recorded all wildlife species observed in each major habitat type occurring in Mono Basin and Upper Owens River. Plotless surveys involved systematic searches of specific habitat types and were used to document overall wildlife occurrence and habitat associations rather than the relative abundance of individual species.

Six habitat types, including riparian conifer forests, mature cottonwood-willow woodlands, stream channels, alkali flats, lakeshore areas, and open waters of Mono Lake were surveyed by plotless techniques elusively (Table D-2). Mature cottonwood-willow vegetation along Lee Vining, Rush, Parker, or Walker Creeks is currently restricted to a few small areas (Chapter 3C, "Vegetation"). For this reason, we made plotless surveys of mature cottonwood-willow vegetation along DeChambeau, Post Office, and Wilson Creeks, near the Mono County Park, and near DeChambeau Ranch to develop a species list for this habitat type.

Selection of Survey Plots

Before collecting field data, SWRCB consultants (including both botanists and wildlife biologists) conducted reconnaissance-level surveys to map polygons representing all riparian habitats on Rush, Lee Vining, Parker, and Walker Creeks, and the Mono Lake shoreline. Results of habitat mapping indicated that habitats were distributed unequally among the study areas and only a few polygons for some habitat types were present in specific drainages. Similarly, many polygons classified as the same habitat type had variable structural characteristics, such as percent canopy coverage and stand composition.

Because of this variability, SWRCB consultants selected all polygons of rare habitats (e.g., mature cottonwood-willow woodland) rather than using a stratified random approach. For common habitats (e.g., riparian willow scrub, recovering riparian, alkali dry meadow) several plots were systematically selected in each study area to ensure that all the major habitats and drainages were represented.

Plots were selected using the following guidelines:

- plots sampled the range of habitats occurring within each study area;
- plots sampled the range of structural variability (e.g., percent cover of various canopy layers) that occurred within each habitat type;
- lakeshore plots were located only in areas supporting large acreages of wetlands or meadows, and high-use public recreation areas (e.g., Danburg Beach, South Tufa, and parking areas along U.S. 395) were avoided.

Great Basin scrub plots were located along the tributary streams, north and northeast of Black Point, and on Paoha Island. Survey plots were placed at Black Point because Great Basin scrub habitats in this area closely resemble those present on Paoha Island (Morrison 1991) and lands near Black Point form the mainland side of a land bridge to Negit Island at lake elevations below about 6,376 feet.

Vegetation Surveys

In addition to the detailed vegetation mapping and classification conducted by project botanists (Chapter 3C, "Vegetation"), wildlife biologists characterized the vegetation at individual survey plots. At tree and shrub plots, the botanists visually characterized the dominant plant species, approximate percent cover, average height of vegetation layers, soil moisture (e.g., dry, moist, or saturated), the level of disturbance (e.g., grazing frequency, proximity to developed lands, or public recreational areas), and the state of vegetative vigor (e.g., increasing, stable, or declining). At meadow plots, the relative soil moisture and the total percent vegetative cover of dominant plants were estimated. In marsh habitats, the extent of soil saturation was noted and percent cover was estimated for vegetation less than and above 5 feet.

Wildlife Surveys

Specific field survey methods for birds, mammals, reptiles, and amphibians are discussed separately in the following sections.

Bird Surveys

A total of 415 surveys were conducted on 86 survey plots from May 16 through August 1, 1991 (Table D-2). Seventy-three of the plots were each surveyed five times over the survey period; the Great Basin scrub plots near Black Point and plots on Paoha Island were each surveyed 3 times each (Table D-2). Birds were detected and identified using visual and auditory cues. Guidelines for conducting bird surveys included the following:

- individual plots were surveyed for 7 minutes during the period from 0.5 hour before sunrise until 1000 hours;
- individual plots were surveyed at different times (e.g., early [0530-0700], mid-morning [0700-0830], and late morning [0830-1000]) to compensate for bias associated with bird activity periods;

- surveys were conducted only during fair weather; periods of rain, high winds, or extreme cold were avoided to eliminate sampling bias caused by reduced bird activity and detectability;

- birds observed flying over survey plots were recorded only if they made use of resources on the plot (e.g., swallows foraging for aerial insects above a plot were counted, but flocks of passing gulls were not).

Plotless surveys were conducted on the Upper Owens River because the narrow willow corridor was discontinuous along the meandering stream (Table D-2). Because the owners of Arcularius Ranch would not permit us to cross the channel, we surveyed all willow thickets and wet meadows on the south side of the river for approximately one-quarter mile as a single census area (about 1.5 acres). Wet meadow plots on Arcularius Ranch were surveyed using the same methods employed for plotless surveys in the other study areas.

From May 16 until October 21, 1991, and from November 9 to 11, 1992, approximately 30 daylong surveys were conducted with a spotting scope to search the Mono Lake shoreline and nearshore waters for shorebirds, wading birds, waterfowl, and other water birds.

Mammal Surveys

Mammal surveys were conducted from May 7 through July 20, 1991 on 66 survey plots (Table D-2). All lakeshore wetland plots were examined by Dr. John Harris to determine their likelihood of use by mammals. Dr. Harris concluded that plots with permanently saturated soils or standing water would receive little or no use by mammals; therefore, only seven of 27 lakeshore plots were surveyed. Due to difficulty of access, one mixed riparian scrub plot also was not surveyed for mammals.

Sherman live traps and pitfall traps were used to capture small mammals. Fifty-one plots were surveyed on three consecutive days using 36 live traps per plot (108 trap nights per plot). Paoha Island and Black Point plots (15 plots) were surveyed using 18 live traps per plot on three consecutive days (54 trap nights per plot).

Pitfall traps were used to determine occurrence of shrews, reptiles, and amphibians (see below). One pitfall trap was placed in each of 61 plots and was operated for a minimum of three consecutive days (Table D-2).

Large mammal surveys were conducted on 66 plots. Mammals observed on plots were recorded and plots were searched to locate tracks, scats, or other sign that would indicate use of the plots by larger species of mammals (Table D-2). One track plate or plot baited with cat food was placed at each of 59 plots to attract and record plot use by wide-ranging carnivores (Table D-2).

Reptile and Amphibian Surveys

In addition to the pitfall traps, plots were searched during the period of May 7-July 20, 1991, to locate reptiles and amphibians. Searches were conducted in conjunction with mammals surveys; therefore, surveys were limited to the 66 plots surveyed for mammals (Table D-2).

Analytical Methods

Wildlife Habitat Index Analyses

A wildlife habitat index (WHI) methodology was developed and applied to:

- quantify the relative value of each habitat type to wildlife,
- identify the probable effects on wildlife of diversions from Mono Lake's primary tributary streams that occurred from 1941 until the present, and
- quantify the potential future effects of each project alternative on wildlife.

The WHI is a habitat-specific value and is used to evaluate project impacts on wildlife in a manner similar to the USFWS's habitat evaluation procedures (HEP) methodology (U.S. Fish and Wildlife Service 1980). The method, however, differs significantly from HEP in that WHI is based on the observed wildlife species richness in each habitat type, rather than on modeled habitat values developed for a selected group of evaluation wildlife species.

A WHI value was determined for each habitat type in the study areas based on its combined species richness determined during the fixed-plot and plotless surveys. WHI values were calculated as the sum of the bird, mammal, reptile, and amphibian species observed in each habitat type divided by the total number of species observed in the four study areas. A habitat-specific WHI value was not calculated for ponds and lagoons because these habitats did not exist around the lakeshore during the 1991 field surveys. Similarly, specific bird census data on these habitats from the prediversion period were unavailable. Prediversion observations indicated that lakeshore ponds and lagoons attracted large concentrations of various duck and shorebird species (Banta and McPherson pers. comms.), but no attempt was made to quantify these migrant populations in the present analysis.

The relative species richness associated with each habitat in the four study areas was determined by calculating wildlife habitat units (WHUs). Habitat-specific WHUs were derived by multiplying the number of prediversion and 1991 acres by the WHI value for that habitat type. Prediversion acreage estimates were available for all habitats except for irrigated meadows in Study Area 4 and lakeshore scrub, meadow, and marsh habitats in Study Area 2. Irrigated meadows were not mapped in the prediversion period or during the

1991 field surveys (Chapter 3C, "Vegetation"). Thus, no attempt was made to calculate WHUs for this habitat. Similarly, wetland habitats around the lakeshore in Study Area 2 were not distinguishable on pre-1940 aerial photographs and their combined 356 acres were mapped as a single wetland type (Stine pers. comm.).

Lacking specific data, SWRCB consultants derived prediversion acreages for scrub, meadow, and marsh habitats in Study Area 2 by assuming that the proportions of individual habitats were similar under prediversion and current conditions. For example, the 206 acres of lakeshore willow scrub habitat mapped in 1991 represented about 4.1% of 5,034 vegetated acres around Mono Lake in that year; using this percentage, the prediversion lakeshore acreage for this habitat was estimated at 14.5 acres (i.e., 4.1% x 356 acres).

In addition to lakeshore willow scrub habitats, derived acreages for lakeshore mixed scrub, alkali wet and dry meadows, and short and tall emergent marsh habitats were used to calculate prediversion WHUs in Study Area 2. Throughout all the study areas, WHUs provided a quantitative basis for comparing the relative number of species associated with each surveyed habitat under prediversion and 1991 conditions.

Statistical Analyses

Vegetation, bird, and mammal data derived from the fixed plot surveys were subjected to statistical analyses using Biomedical Computer Programs-P (BMDP) (1992). Reptile and amphibian data were not included in these analyses due to their infrequent occurrence on the survey plots.

The independent variables, plot vegetation characteristics, were coded into discrete, ordered categories. For example, total percent vegetation coverage had four categories: 1 = 0-24%, 2 = 25-49%, 3 = 50-74%, and 4 = 75-100%. Relative cover in overstory, midstory, and understory, and dominant trees, shrubs, and herbaceous species were assigned to the same percentile categories. Vegetation vigor (e.g., establishing, mature, and decadent) and the site hydrology (e.g., standing water, saturated soil, and dry) were assigned to three categories.

The dependent variables were mean wildlife species densities and bird and mammal diversity values. Mean densities were calculated by dividing the total number of individuals of each species observed by the number of surveys over all plots. Species whose mean densities did not exceed 0.01 were omitted from the statistical analyses.

A measure of species diversity, the Shannon-Wiener Index (H'), was calculated on the mean densities of individual species observed on the plots. This index assumes equal sampling intensity on individual plots (Green 1979). For this reason, we did not include the bird data from the Paoha Island and Black Point survey plots in diversity calculations or other statistical analyses because only three, rather than five, surveys were conducted there. If no species were observed on an individual plot during the census period, the Shannon-Wiener index was set to zero.

For all statistical tests we assumed that vegetation and wildlife data gathered at individual plots were independent. This assumption was met by placing all survey plots at least 200 meters apart. For biological samples, non-normality of the error (or observation) distributions is common. In this analysis, we log-transformed H' values and individual bird densities to improve the normality of the data.

We used stepwise multiple regression analysis (BMDP 2R) to identify those vegetation variables that provide the best correlations with H'. This analysis selects the best correlative model by evaluating statistics (univariate F-statistics) for independent variables that are sequentially added or deleted to the model. (Addition and deletion sequences resulted in the same model in this analysis.) Independent variables in this analysis were individual layers, vegetation vigor, total percent cover, site hydrology, and the presence or absence of mature conifers.

We calculated univariate analyses of variance (ANOVAs) (specifically, BMDP 7D) to identify significant relationships between bird diversity and vegetation variables considered individually. We also applied a robust test to the equality of variance in our univariate ANOVAs by computing the absolute values of deviations from the group means (Brown and Forsythe 1974). After applying the Brown and Forsythe computations, significance criteria for the ANOVAs included: $P < 0.05$, moderately significant, $P < 0.01$, fairly significant, and $P < 0.001$ highly significant.

Individual correlations between bird and mammal species and vegetation variables were identified using multivariate regression and correlation analyses (BMDP 6R). Significant correlations between the mean densities of bird and mammal species and vegetation variables were identified by evaluating t-tests (two-tailed) of the regression coefficients.

RESULTS AND DISCUSSION

General Wildlife and Habitat Relationships

General results of the 1991 field surveys, the WHU calculations, and statistical analyses are presented and interpreted in the following sections. The characteristic species and relative importance of specific habitats to wildlife are described in a later section entitled "Specific Wildlife and Habitat Relationships."

Summary of Observations during the 1991 Field Surveys

A total of 193 vertebrate species were observed in the four study areas during the 1991 field surveys, including 161 bird, 29 mammal, two reptile, and one amphibian species (Table D-3). The highest species richness of birds and mammals was observed along tributary streams in Study Area 1 (116 species) and nearly 80 bird species were seen at the shoreline and nearshore waters of Mono Lake (Study Area 2). The Upper Owens River had the lowest species counts for all vertebrate taxa of the four study areas (Table D-3).

Combining data from both the fixed-plot and plotless surveys, conifer-broadleaf forests, cottonwood-willow woodlands, riparian willow scrub habitats, and the shores of Mono Lake supported the most bird species, and unvegetated floodplains and alkali flats supported the fewest (Table D-4).

The highest mammal species richness was encountered in riparian willow scrub habitats, but conifer-broadleaf forests, aspen groves, mixed riparian scrub, montane meadows, and great basin scrub habitats also supported at least 10 mammal species (Table D-4). Mature cottonwood-willow woodlands were not surveyed intensively for mammals due to the limited extent of this habitat in Study Area 1. Riparian conifer forest, stream channel, lakeshore willow scrub, alkali flat, and unvegetated shoreline habitats supported only one mammal species and no mammals were observed in short or tall emergent marshes in any of the study areas (Table D-4).

Two reptile species were observed in eight habitats and one amphibian, the western spadefoot, was noted exclusively in alkali wet meadows (Table D-4).

Habitats where a combined total of more than 40 bird, mammal, reptile, and amphibian species were observed included conifer-broadleaf forests, cottonwood-willow woodlands, aspen groves, riparian willow scrub (Study Area 1), and the shoreline of Mono Lake (Study Area 2) (Table D-4). These results suggest that habitats with dense tree or shrub cover along tributary streams, as well as the waters and shorelines of the lake, typically have the highest species richness within the four study areas.

Wildlife Habitat Values

Conifer-broadleaf forest, cottonwood-willow woodland, and riparian willow scrub habitats had the highest WHI values in the four study areas (i.e., WHI > 0.30), while unvegetated floodplains, alkali flats, lakeshore mixed scrub, and short and tall emergent marshes had the lowest (e.g., WHI < 0.10) values (Table D-5). Relative values of different wildlife habitats are discussed separately below for each study area.

Tributary Streams (Study Area 1). Between the prediversion period and 1991, acreages of riparian willow scrub, mixed riparian scrub, Great Basin scrub, and unvegetated floodplains increased in Study Area 1 (Table D-5). Major losses of acreage, however, occurred in cottonwood-willow woodlands and montane meadows, and moderate reductions also were found in conifer-broadleaf forests during this period. Conversion of riparian forests and montane meadows to scrub and unvegetated habitats resulted in an overall loss of more than 28 WHUs, or a 6% loss, in Study Area 1 in this time period (Table D-5).

Since diversion of Mono Lake's tributary streams began in 1941, the receding shoreline extended the channel of Lee Vining Creek by about 1,700 linear feet (0.32 mile) and that of Rush Creek by about 2,300 feet (0.44 mile) resulting in a combined increase of about 110 acres of new wildlife habitat for the two creeks (Chapter 3C, "Vegetation"). Changes in habitat acreages along Lee Vining and Rush Creeks were primarily due to increased channel length and the conversion of mature, riparian forests to scrub and unvegetated habitats resulting from stream dewatering and subsequent events (Table D-5).

In Study Area 1, the largest acreage increases occurred in arid, unvegetated floodplain and Great Basin scrub habitats and increases in WHUs were highest for these habitats (Table D-5). Moderate acreage increases also occurred, however, in certain water-dependent habitats with high WHI values, such as riparian willow scrub, especially along drainage ditches, irrigated pastures (e.g., Cain Ranch), and other artificially maintained wetland areas (Chapter 3C, "Vegetation").

Using the same WHI value to calculate both prediversion and current wildlife WHUs assumes that each habitat type supported a similar array of wildlife species in both time periods. Prediversion aerial photographs and wildlife surveys of Mono Lakes' tributary streams (e.g., those from Dixon 1915, 1916; Grinnell 1915; Taylor 1915) suggested that this assumption was valid for habitats such as mature conifer-broadleaf forests (i.e., above the diversion dam on Lee Vining Creek), aspen groves, riparian willow scrub, and montane meadows that were similar in structure and extent in both time periods. Cottonwood-willow woodlands were reduced by a greater acreage than any other habitat in Study Area 1 (Table D-5), and prediversion stands in Mono Basin probably supported more species than current early successional cottonwood habitats (Gaines 1988).

In prediversion years, cottonwood-willow woodlands formed broad riparian corridors of mature forest comprising about 50 and 160 acres along Lee Vining and Rush Creeks, respectively (Table D-6). Currently, only about 4 acres of narrow, regenerating cottonwood-willow woodlands are present along selected reaches of each creek. The extent of mature cottonwood-willow forests has been reduced by almost 93% on Lee Vining Creek and by more than 97% on Rush Creek (Table D-6).

Current cottonwood-willow woodlands along Lee Vining and Rush Creeks lack mature, multistoried vegetation (e.g., ground cover, shrub layer, saplings, and mature trees) that characterized prediversion riparian corridors (Chapter 3C, "Vegetation"). Narrow, discontinuous stands of small trees and shrubs offer fewer nesting, foraging, and resting opportunities habitat for wildlife than mature riparian corridors (Verner and Boss 1980). Bird distributional summaries of Mono Basin and the eastern Sierra Nevada (Gaines 1988, Hart and Gaines 1983) suggest that prediversion cottonwood-willow woodlands probably supported more species than any other terrestrial habitat. Thus, a simple multiplication of 1991 WHI values with prediversion acreages probably underestimates the overall wildlife values of this habitat lost during the diversion period. Moreover, the almost complete loss of mature riparian habitat along creeks in these areas resulted in virtual elimination of the riparian wildlife corridor that once connected the montane forests with the shores of Mono Lake.

Mono Lake Shoreline (Study Area 2). Wetland habitats occupied about 553 acres of Mono Lake's shoreline in the prediversion period, and 260 acres of shoreline (about 47%) consisted of pond and lagoon habitats (Table D-5). Derived prediversion estimates suggest that the remaining 293 vegetated acres probably consisted of a mixture of wet meadows, marshlands, and scrublands.

During the diversion period, the total acreage of Mono Lake's shoreline area increased by about 10,600 acres and lakeshore scrublands, alkali dry and wet meadows, short and tall emergent marshes, and alkali flats grew to their greatest probable extent (Table D-5). Exposure of vast areas of former lakebed sediments and subsequent colonization by marsh and upland vegetation created thousands of acres of new wildlife habitat and resulted in an overall increase of about 615 WHUs (Table D-5).

Wildlife habitats colonizing the shoreline during the diversion period were dominated by arid, sparsely vegetated uplands, dense marshlands, or unvegetated alkali flats. Alkali flats represent almost 50% of Mono Lake's current lakeshore acreage and had the lowest WHI value within the four study areas (Table D-5). Similarly, lakeshore scrub habitats, alkali wet and dry meadows, and short and tall emergent marshes had relatively low WHI values (i.e., < 0.15), indicating that they are used by relatively few species compared to many terrestrial habitats in Mono Basin (Tables D-4 and D-5).

Lakeshore willow and mixed scrub habitats are usually found in relatively small (a few acres or less), isolated patches around the lake. Their small size and isolation, together with a lack of fresh water and the presence of typically saline, saturated soils, limit the number of resident bird and mammal species that can occur there. WHI values are relatively low. Lakeshore scrub habitats are probably used by a variety of migratory birds passing over Mono Lake, however, offering important habitat for these species.

Due to their lack of fresh water and low wildlife cover, alkali and dry meadows have moderately low habitat values (i.e., WHI < 0.15) (Table D-5). These arid habitats are often dominated by sparse stands of saltgrass and are used by a few specialized species. Because of its large acreage, however, these habitats contribute about 70% of the new WHUs that have been created around the lakeshore during the diversion period. Wet meadows have grown by about 45 acres during the diversion period and added some new wildlife habitat within Study Area 2 (Table D-5). Wet meadows around Mono Lake currently do not support high numbers of birds or other wildlife; their use by ducks, shorebirds, and wading birds would probably increase, however, if sources of open water were available nearby.

Almost all of the prediversion ponds and lagoons were lost during the diversion period as the lake's elevation receded (Chapter 3C, "Vegetation"). In the absence of bird census data from ponds and lagoons in the prediversion period, it is impossible to calculate how loss of this habitat contributed to changes in wildlife use of Mono Basin. Clearly, the major concentrations of ducks and shorebirds that used to visit Mono Lake are no longer present (Banta, DeChambeau, and McPherson pers. comms.).

In addition to attracting a high number of bird species (i.e., high species richness), ponds and lagoons around Mono Lake served as concentration areas for a few of the most abundant duck, wading, and shorebird species; during fall migration the bird densities there were far higher than at any other habitat in Mono Basin (Banta and McPherson pers. comms.). Thus, an index based on resident species richness alone does not reflect the overall importance of ponds and lagoons to regional migratory water bird populations in the prediversion period.

Paoha Island (Study Area 3). The only source of fresh water on Paoha Island is the spring and surrounding marshland near the southeast shore of the island (Chapter 3C, "Vegetation"). Studies conducted on the island in 1991 suggested that short and tall emergent marsh vegetation associated with this spring have somewhat higher WHI values than similar mainland habitats (Morrison 1991). This difference may reflect the water needs of many bird and mammal species on the island that depend on this single source of water and may visit it frequently. In contrast, marsh-dependent species on the mainland have extensive acreages of similar habitats to choose from, and few areas offer sources of fresh water. The marsh at Paoha Island has increased by about 1.2 acres during the diversion period, representing a slight increase in its wildlife habitat value.

Upper Owens River (Study Area 4). The acreage of willow scrub habitat decreased by 12.4 acres along the Upper Owens River during the diversion period, which represents a loss of about 2 WHUs (Table D-5). Assuming that irrigated meadow habitat replaced the willow scrub habitat, a loss of only 0.7 WHUs occurred, which is a minor decrease in wildlife value along the Upper Owens River.

Wildlife and Habitat Diversity Relationships

The wildlife value of a specific habitat depends on its size, condition, structural characteristics, plant species composition, and continuity with adjacent habitats. Previous studies have identified correlations between the richness and diversity of bird communities and various vegetation measurements such as foliage height diversity (MacArthur and MacArthur 1961, Karr 1968, Karr and Roth 1971, Cody 1981), foliage volume (Balda 1969, Franzreb and Ohmart 1978, Szaro and Balda 1979, Larson 1981), or percent canopy closure (Whitmore 1975, Beedy 1981). Other workers, however, have found few correlations between bird communities and various measures of vegetative diversity, especially between habitats with similar structure (Tomoff 1974, Willson 1974, Rotenberry and Wiens 1980, Wiens and Rotenberry 1981, Beedy 1982). In general, taxonomic diversity of forests has not been predictive of avian community patterns (MacArthur and MacArthur 1961, Cody 1974, Beedy 1982).

Within the four study areas, our fixed-plot surveys included a broad array of habitats ranging from mature conifer-broadleaf forests to barren alkali flats. Measurable differences in the richness and diversity of wildlife communities and in the occurrence of individual species and wildlife-habitat associations are likely when ecologically and structurally dissimilar habitats are compared (Verner and Boss 1980, Weins and Rotenberry 1981, Zeiner 1990a).

Stepwise multiple regression and univariate ANOVA analyses of the wildlife plot data revealed significant relationships ($P < 0.05$) between bird species diversity (H') and the number of vegetative layers; percent cover of tall trees, shrubs, and low trees; and the degree of soil saturation (Table D-7). Univariate anovas also indicated a moderately significant relationship between mammal diversity and the percent cover of shrubs and low trees but not for the other vegetation variables (Table D-7).

Multivariate regression and correlation analyses were used to analyze relationships between 16 of the most common bird species and vegetation characteristics on the survey plots (Table D-8). Four species, including western wood pewees, house wrens, American robins, and warbling vireos, were significantly correlated with increased percent cover of tall trees. Similarly, seven species were correlated with conifer or aspen overstory or midstory vegetation, and six species were correlated with rose and snowberry midstory vegetation. These correlations probably do not represent a preference for specific plant species by birds; rather conifers, aspens, roses, and snowberries were frequently dominant species in the tree and shrub categories on the study plots. Significant correlations were not found with tall cottonwoods or willows, probably because only one study plot contained individuals of these species that exceeded 12 feet.

Percent cover of shrubs and low trees had a moderately significant correlation with mammal diversity (Table D-7). Nuttall's cottontails, Douglas' squirrels, lodgepole chipmunks, and deer mice had significant correlations with more than one vegetation variable (Table D-9). In general, however, fewer significant relationships between vegetation characteristics and individual mammal species were found than for bird species. This suggests that small mammals may select habitats based on microhabitat conditions that were not measured in this study.

Major Conclusions

Correlation analyses suggested that mature, multistoried habitats offer the greatest array of resources to wildlife, especially birds, along Mono Lake's tributary streams. Bird diversity and the abundance of many species were highest in moist forests with vertical layering and many tall trees. These conditions were typical of prediversion mature cottonwood-willow woodlands. The conversion of more than 200 acres of these woodlands along Lee Vining and Rush Creeks to arid Great Basin scrub and unvegetated floodplain habitats had the effect of replacing a high-value wildlife habitat with low- and moderate-value habitats. Elimination of this prediversion mature riparian corridor substantially diminished carrying capacity, disrupted the natural movement patterns of resident wildlife, and removed an important migratory stopover area for birds migrating through the arid Great Basin.

Creation of more than 10,600 acres of new habitat around the shoreline of Mono Lake has benefited specialized wildlife species, such as snowy plovers, that tolerate arid, saline conditions and a lack of fresh water. Most of the exposed lakeshore is now dominated by habitats with limited wildlife value, such as alkali flats, dry and alkaline meadows, sparsely vegetated uplands, and dense, brackish, or saline marshes. Together with this large habitat increase was the elimination of about 260 acres of pond and lagoon habitat around the lakeshore. These former wetland habitats attracted an abundance of ducks and shorebirds, but their value to other wetland-dependent wildlife is unknown. While the overall increase in wildlife value of existing lakeshore habitats can be estimated, eliminating ponds and lagoons resulted in a major but incalculable reduction in habitat conditions for ducks, shorebirds, and probably other wildlife. Thus, while the increase in habitat acreage benefits terrestrial wildlife, these benefits must be weighed against the detrimental effects of the losses of the aquatic habitats around Mono Lake.

Specific Wildlife and Habitat Relationships

Tributary Streams (Study Area 1)

Riparian Conifer Forest. Riparian conifer forests consist primarily of an association of lodgepole and Jeffery pine trees. These habitats were not mapped or surveyed systematically for wildlife because they occur primarily above the LADWP diversion points and would be unlikely to be affected by any of the alternatives. Incidental observations of wildlife associated with riparian conifer forests, however, were recorded during our field investigations but were not used to calculate WHI and WHU values for this habitat.

Twenty-eight species of birds and one mammal were observed in riparian conifer-forest during plotless surveys (Table D-4). Characteristic wildlife species included great horned owl, red-breasted sapsucker, hairy woodpecker, western wood pewee, brown creeper, Steller's jay, mountain chickadee, pygmy nuthatch, warbling vireo, western tanager, dark-eyed junco, and Douglas' squirrel.

Riparian conifer forest habitats generally support a greater diversity of plants and provide more overstory, midstory, and understory cover compared to adjacent, drier conifer habitats. Similarly, riparian conifer forests provide higher breeding, resting, and escape cover, and foraging values for more wildlife than adjacent uplands.

Conifer cones provide nuts that are fed on by many wildlife species, such as Douglas' squirrels, chipmunks, and Clark's nutcrackers. Bark surfaces provide favored habitats for several invertebrates, such as insects and arachnids, that are favored food sources for insectivorous species. Tree sap and cavities provided by conifers are favored nesting and feeding areas for woodpeckers. Cavities excavated by woodpeckers also provide nesting sites for several bird species that are incapable of excavating their own, such as western bluebirds.

Conifer-Broadleaf Forest. Riparian conifer-broadleaf forests were defined as habitats in which Jeffrey pine and cottonwood or aspen are codominant species. A total of 32.4 acres of riparian conifer-broadleaf forest was mapped on the upper reaches (i.e., upstream from U.S. 395) of Rush, Lee Vining, Parker, Walker Creeks (Table D-5). The density of riparian conifer-broadleaf forest canopy, midstory, and understory cover varied considerably between individual reaches (Chapter 3C, "Vegetation").

Eight plots were established in conifer-broadleaf habitats (Table D-2), and a total of 50 bird, 10 mammal, and one reptile species were observed there during our surveys (Table D-4). Species typically associated with this habitat include red-breasted sapsucker, calliope hummingbird, western wood pewee, mountain chickadee, house wren, Townsend's solitaire, warbling vireo, Nuttall's cottontail, least chipmunk, lodgepole chipmunk, long-tailed vole, mule deer, and sagebrush lizard (Table D-4).

This habitat provides the greatest diversity of plant species and vegetative structure of the habitat types currently existing in Study Area 1. In addition to understory and midstory layers, conifer-broadleaf forests usually provide a multilayered overstory canopy with mature conifers as the tallest species.

This habitat attracts wildlife associated with conifers as well a deciduous trees. Conifers and deciduous trees provide cavities and support a variety of insects for food. Lands adjacent to this habitat are often unforested; therefore, wildlife, such as brown creepers and nuthatches, that normally are not present in lower elevation habitats frequent these sites.

Conifer-broadleaf forest had the third highest WHI value among surveyed habitats, and only mature cottonwood-willow woodlands and riparian willow scrub habitats support more wildlife species (Table D-5). Among surveyed habitats, conifer-broadleaf forests have the most tall trees and vertical layering; both vegetation variables are significantly correlated with bird diversity (Table D-7). Current conifer-broadleaf forests in the Mono Lake Basin are probably structurally similar to prediversion forests, but the loss of almost 20 acres of this habitat has resulted in some reduced wildlife habitat value in Study Area 1 (Table D-5).

Cottonwood-Willow Woodland. Cottonwood-willow woodlands are dominated by black cottonwoods that may be codominant with willows or aspens in some locations. Most of the 39.8 acres of cottonwood-willow woodland in Study Area 1 is on Rush and Lee Vining Creeks (Table D-6). Most currently existing stands are narrow, discontinuous, and lacking in mature trees (Chapter 3C, "Vegetation").

More than 200 acres of mature cottonwood-willow woodland have been lost from Rush and Lee Vining Creeks since diversions began (Table D-6). Before 1941, cottonwood-willow woodland was a dominant cover type occurring as broad, continuous, and multilayered stands (Stine 1991, Chapter 3C, "Vegetation"). After years of dewatering and recent rewatering, this habitat now occurs as small disjunct clumps and most stands are associated with cobbley floodplain deposits. These sparsely vegetated areas are dominated by cottonwood trees standing less than 30 feet tall. Most stands contain decadent trees or saplings that have resprouted in response to recent rewatering of stream channels.

Three plots were established in early successional stages of this habitat type (Table D-2), and 17 bird and four mammal species were observed there (Table D-4). An additional 47 bird and one mammal species, however, were observed in cottonwood-willow woodlands outside Study Area 1 during plotless surveys of riparian stands along DeChambeau, Post Office, and Wilson Creeks and stands of mature cottonwood near the Mono County Park. These additional bird species increased the WHI index value of this habitat from that derived from fixed plots located in sparsely vegetated, early successional stands on Lee Vining and Rush Creeks.

Characteristic species observed in cottonwood-willow habitats of Mono Basin included great horned owl, long-eared owl, downy woodpecker, hairy woodpecker, dusky flycatcher, Steller's jay, violet-green swallow, mountain chickadee, brown creeper, house wren, American robin, cedar waxwing, blue-gray gnatcatcher, warbling vireo, solitary vireo, Wilson's warbler, yellow warbler, MacGillivray's warbler, western tanager, lazuli bunting, rufous-sided towhee, song sparrow, northern oriole, deer mouse, long-tailed vole, and mule deer (Table D-4).

The prediversion value of this habitat to wildlife is probably not reflected by its current WHI value derived from both fixed-plot and plotless surveys. None of the extant stands of cottonwood-willow woodland in Mono Basin offer the length, width, or habitat structure present on the lower reaches of Lee Vining and Rush Creeks under prediversion conditions (Chapter 3C, "Vegetation"). The diversity of wildlife associated with cottonwood-willow habitats would be expected to increase significantly as recovering stands gradually become more extensive, mature, and continuous.

Mature cottonwood-willow habitats in good condition would support several layers of vegetation and provide important nesting and foraging habitat for many resident and migratory wildlife species. Historically, cottonwood-willow woodlands often occurred as wide bands of vegetation that provided a near continuous corridor of wooded habitat from higher elevation conifer-broadleaf forests to the lakeshore terrace (Chapter 3C, "Vegetation"). Stand continuity allows secretive species that are intolerant of open habitats to move along the length of the corridor, and wider stands provide more protection from disturbance by humans and more movement of predators than narrower stands.

Aspen Groves. This habitat is dominated by aspen trees but may include a few Jeffery pine and/or cottonwood trees. The current total of 11.3 acres of aspen represented a slight decline from the prediversion acreage (Table D-5). Aspen is present on all the diverted creeks, and the largest stands occur above the diversion structures on Lee Vining, Walker, and Parker Creeks.

Aspen stands may be supported hydrologically by springs, seeps from snow saturation, or streamflows (Chapter 3C, "Vegetation"). Only those groves associated with surface streams, however, were considered riparian habitats in this study. Aspen stands usually provide dense overstory cover and may support a mixed midstory of young aspen trees and riparian and Great Basin scrub species. Riparian aspen groves along Parker and Walker Creeks often had evidence of disturbance such as grazing, firewood clearing, and camping areas.

Four wildlife survey plots were established in aspen groves (Table D-2). Eighteen bird, 10 mammal, and one reptile species were observed during the fixed-plot surveys and 16 additional bird species were observed in this habitat during plotless surveys (Table D-4). Species using aspen stands included rufous hummingbirds, red-breasted sapsuckers, western wood pewees, tree swallows, white-breasted nuthatches, house wrens, mountain bluebirds, yellow warblers, western tanagers, northern orioles, Nuttall's cottontails, least chipmunks, Douglas' squirrels, Panamint kangaroo rats, bushy-tailed wood rats, and sagebrush lizards.

Aspen stands provide important wildlife habitat in Mono Basin, especially since mature cottonwood-willow woodland and other broad-leaved habitats are currently scarce. Aspen stands, however, tend to have dense overstory cover and reduced understory vegetation compared to mature cottonwood-willow habitats.

Despite their increased cover of tall trees, aspen groves in Study Area 1 had a lower WHI value than riparian willow scrub habitats (Table D-5). In general, habitats with tall trees and several vertical layers support higher bird diversities (Table D-7). Within Study Area 1, however, riparian scrub habitats occupied far greater acreage and varied more widely in other vegetation characteristics (e.g., percent cover, age class, understory composition, and soil saturation) than aspen habitats.

Riparian Willow Scrub. Willows are the dominant woody vegetation in this habitat; however, a subdominant component of rose, buffaloberry, or other shrubs also may be present. A total of 207.1 acres of willow scrub currently exists in the study area, representing more than 20 acres of new habitat since the prediversion period (Table D-5). Willow scrub is present on all the diverted streams and is uncommon only on Lee Vining Creek (Chapter 3C, "Vegetation").

Riparian willow scrub habitats vary in structural characteristics depending on site location. Decadent, impenetrable thickets are common in areas that have been dewatered during the past 50 years. Very young, sparse stands supporting little or no understory vegetation are establishing adjacent to recently rewatered channels and deltas on Lee Vining and Rush Creeks. Open-canopied, mature stands with meadow understorys are common on more stable, meandering reaches of the creeks, especially above U.S. 395.

Nine survey plots were established on willow scrub habitats on the tributary streams (Table D-2). A total of 19 bird, 15 mammal, and two reptile species were observed during the fixed-plot surveys, and 28 additional bird species were observed during nonsurvey periods (Table D-4). Species present in willow scrub habitat include long-eared owls, Pacific-slope and ash-throated flycatchers, mountain bluebirds, American robins, yellow warblers, McGillvray's warblers, rufous-sided towhees, fox sparrows, song sparrows, Brewer's blackbirds, vagrant shrews, Belding's ground squirrels, Great Basin pocket mice, pinyon mice, long-tailed voles, porcupines, mule deer, and western aquatic garter snakes.

Riparian willow scrub habitats provide high-quality nesting, escape, feeding, and resting cover required by many wildlife species. Because willow scrub in Mono Basin most often occurs within open habitats, such as meadows, irrigated pastures, and unvegetated floodplains, this community provides vertical structure and cover for wildlife that otherwise would not be present.

The WHI value of riparian willow scrub was second highest, and only cottonwood-willow woodlands had a larger value (Table D-5). Willow scrub habitats had four more mammal species than any other habitat type. The diversity of mammals was probably greater because adjacent habitats were typically open (e.g., meadows and unvegetated floodplains), and mammals were attracted to the shade and cover of willow scrub habitats. Bird species richness values recorded in this habitat were probably also increased due to its relatively large acreage (Table D-5); proportionally more time was spent there than in other scrub and forested habitats during the 1991 field surveys.

Mixed Riparian Scrub. Mixed riparian scrub is dominated by rose or buffaloberry shrubs growing in association with willows, young cottonwoods, or other upland shrubs. A total of 82.0 acres of this habitat currently exists on Rush, Lee Vining, Parker, and Walker Creeks and represents more than 60 acres of new habitat since 1941 (Table D-5).

This habitat usually occupies complex hydrologic sites in which soil moisture changes with minor changes in floodplain elevation (Chapter 3C, "Vegetation"). Mixed riparian scrub generally supports a dense canopy that, depending on the dominant species, can range from approximately 3 feet to over 15 feet in height.

Seven plots were established in mixed riparian scrub habitats along Walker and Rush Creeks (Table D-2). A total of 21 bird, 10 mammal, and one reptile species were observed there during the fixed-plot surveys, and six additional bird and one mammal species were observed during plotless surveys (Table D-4). Species observed in mixed riparian scrub habitat included bushtits, yellow warblers, green-tailed towhees, song sparrows, American goldfinches, Brewer's blackbirds, Nuttall's cottontails, Great Basin pocket mice, deer mice, bushy-tailed woodrats, ermine, bobcat, coyotes, and sagebrush lizards.

Mixed riparian scrub provides wildlife cover values similar to those described for riparian willow scrub. Because it often occupies somewhat drier sites, however, mixed riparian scrub habitats appear to have somewhat lower wildlife habitat value than streamside willow thickets.

Unvegetated Floodplain. This habitat category consists primarily of stream deposits dominated by large cobbley substrates supporting less than 10% herbaceous or woody cover. More than 270 acres of this habitat currently exist in the study area, representing an increase of almost 180 acres from the prediversion period (Table D-5).

In Study Area 1, these habitats are primarily located on Lee Vining and Rush Creeks and were created by floodflows that deposited gravel and cobble or exposed stream deposits through channel incision (Chapter 3C, "Vegetation").

One survey plot was established on sparsely vegetated stream cobble (Table D-2) and five bird, two mammal, and one reptile species were observed during the fixed-plot surveys. Additional bird and mammal species were observed in this habitat during the plotless surveys and representative species in this habitat were killdeer, spotted sandpiper, violet-green swallow, cliff swallow, Brewer's blackbird, Panamint kangaroo rat, water shrew, deer mouse, and coyote (Table D-4).

This habitat provides foraging and loafing habitat for a few species of wildlife. Gravels and sands along these creeks support invertebrates and ruderal vegetation that frequently grows there and provides foraging and resting cover for wildlife. Many California gulls, eared grebes, ducks, and a few other species of waterbirds frequent the deltas of Lee Vining, Rush, and Wilson Creeks to drink, loaf, and forage on exposed gravel bars. Open stream deposits adjacent to channels also allow access to water for large mammals such as mule deer. Aside from alkali flats and tall emergent marshes, however, the WHI value of unvegetated floodplain habitat was the lowest recorded in any of the study areas (Table D-5).

Montane Meadow. For the purposes of wildlife analyses, montane meadows included wet meadows, upland meadows, and irrigated pasturelands (Table D-1). These habitats were considered as a single habitat type during the fixed-plot surveys because different types were difficult to distinguish due to past land use practices such as altered water regimes and grazing. Also, wet meadows and irrigated pasturelands are similar structurally and in their functional wildlife habitat values. Montane meadows in Mono Basin are managed primarily to produce livestock forage and are grazed in late spring to fall (Chapter G, "Land Use").

Almost 500 acres of montane meadows exist in Study Area 1, representing a loss of 92 acres from the prediversion period (Table D-5). Under current conditions, unirrigated meadows are usually small areas dominated by forbs, rushes, sedges, or grasses. Most of these meadows support plant species adapted to drier soils, however, inclusions of wet meadow plant communities may occur within drier meadow types near springs, seeps, and creek banks. Irrigated pastures are similar in character to montane meadows, but are more extensive and have a larger component of grass species (Chapter 3C, "Vegetation").

Most irrigated pasturelands in Mono Basin are located on the Cain Ranch between Rush and Walker Creeks upstream from U.S. 395 and to the north of the lake near Mono County Park and at Conway and DeChambeau Ranches. Montane meadows provide foraging areas and cover for wildlife species associated with herbaceous habitats. Generally, ungrazed meadows and pastures provide greater cover and forage values than those that are grazed (Medin and Clary 1990). Due to its low stature and relative lack of wildlife cover, however, the WHI value of montane meadow habitat is relatively low compared to shrub- or tree-dominated habitats (Table D-5).

Eight plots were located in montane meadow habitats (Table D-2), and a total of nine bird, 11 mammal, and one reptile species were observed there during the fixed-plot surveys. Eight additional bird species were observed in montane meadow habitats during plotless surveys (Table D-4). Characteristic species observed in this habitat included tree swallows, violet-green swallows, mountain bluebirds, Brewer's blackbirds, black-tailed hares, least chipmunks, Belding's ground squirrels, coyotes, mule deer, and sagebrush lizards.

Recovering Riparian Areas. Areas ecovering riparian areas were defined as stream reaches where historical woody vegetation was lost due to dewatering and where young vegetation is growing in response to recent rewatering. These areas would be expected to increase in extent and condition with continuing streamflows (Chapter 3C, "Vegetation").

Five survey plots were defined as recovering riparian areas (Table D-2). Two of these plots were dominated by mixed riparian scrub, two had reverted to montane meadows, and one was an unvegetated floodplain. Twelve bird, nine mammal, and one reptile species were observed on these plots. Eight additional bird and one mammal species were observed during nonsurvey periods (Table D-4). Representative wildlife species in recovering riparian areas included northern rough-winged swallows, cliff swallows, Bewick's wrens, mountain bluebirds, Brewer's blackbirds, water shrews, Nuttall's cottontails, least chipmunks, Great Basin pocket mice, sagebrush voles, and mule deer (Table D-4).

Recovering riparian areas provide foraging and cover values for wildlife species that are associated with the early successional stages of herbaceous, shrub, and woodland riparian habitats. WHI values were not calculated for these habitats, however, because the early stage of succession made it difficult to determine what the mature vegetation on the plot would be. Thus, recovering riparian areas define an early successional condition rather than a habitat type.

Stream Channels. Stream channels include flowing water, channel banks, and point bar deposits. Incidental observations were made of 10 bird and one mammal species using stream channels in Study Area 1 (Table D-4). Species observed using stream channels included great blue herons, black-crowned night herons, mallards, gadwalls, killdeer, spotted sandpipers, belted kingfishers, American dippers, and water shrews. American dippers are unique to stream channel habitats within the study areas.

Stream channels are required habitat elements for some species because they provide water for drinking and bathing, foraging habitat for some species (e.g., ducks and belted kingfishers that feed on aquatic plants or animals), and escape cover for aquatic birds and mammals. Channel banks and point bars provide loafing and foraging areas for some shorebirds and waterbirds. Exposed cut banks also provide nesting substrates for some species, such as northern rough-winged swallows.

Fixed-plot surveys were not conducted in stream channels; therefore, WHI and WHU values were not calculated for this habitat.

Great Basin Scrub. Great Basin scrub habitat occupies arid sites and is dominated by sagebrush, rabbitbrush, bitterbrush, and other upland shrubs (Chapter 3C, "Vegetation"). Great Basin scrub is the dominant nonforested upland habitat in Mono Basin, surrounding the inventoried wetland and riparian habitats. Currently, more than 900 additional acres of this habitat exist along Mono Lake's diverted tributary streams, representing an increase of more than 140 acres since the prediversion period.

Five Great Basin scrub plots were established in the vicinity of Black Point and a total of nine bird, nine mammal, and one reptile species were observed during the fixed-plot surveys; an additional 20 bird and two mammal species were observed during nonsurvey periods (Table D-4). Species observed in Great Basin scrub habitats during surveys included sage grouse, pinion jays, sage thrashers, green-tailed towhees, Brewer's sparrows, black-tailed hares, least chipmunks, Panamint kangaroo rats, chisel-toothed kangaroo rats, montane voles, and sagebrush lizards.

Great Basin scrub provides nesting, escape, and resting cover, and forage for many species of wildlife not associated with water-dependent habitats. Thus, the WHI value of Great Basin scrub in Study Area 1 is higher than montane meadows and unvegetated floodplains but lower than most habitats dominated by shrubs and trees along the tributary streams (Table D-5). The combination of increasing acreage and a relatively high WHI value result in an increased WHU value for this habitat in Study Area 1 over the diversion period. Similar to other widespread habitats in Mono Basin (e.g., riparian willow scrub), SWRCB consultants spent proportionately more time surveying Great Basin scrub habitats than less common scrub types (e.g., mixed riparian scrub and lakeshore willow scrub), which probably increased the species counts for this habitat.

Lakeshore Habitats (Study Area 2)

Lakeshore Willow Scrub. Lakeshore willow scrub habitats are uncommon in Mono Basin and occur as relatively small (i.e., a few acres or less), isolated patches near lakeshore springs and seeps. A total of 210 acres of this habitat occurs in Study Area 2 (Table D-5), and the largest stands currently exist near Danberg Beach and at the mouth of Wilson Creek. This represents an increase of about 180 acres compared to prediversion conditions (Table D-5).

Lakeshore willows occupy moist sites that are not permanently saturated year-round. They are usually monotypic inclusions in surrounding wetland or meadow habitats. Due to its isolation and habitat structure, lakeshore willow scrub habitat offers similar wildlife habitat values to the lakeshore mixed-scrub areas described below.

Five species of birds were observed during fixed-plot surveys of lakeshore willows, and 13 additional species were observed during plotless surveys of this habitat (Table D-4). Mammal species were not censused in this habitat because most plots were wet during the field surveys. Birds observed nesting in lakeshore willow scrub included house wrens, yellow warblers, song sparrows, red-winged blackbirds, and Brewer's blackbirds. This habitat probably also is used by a variety of migrant flycatchers, warblers, vireos, sparrows, and other songbirds. The structural wildlife values provided by lakeshore willows are similar to those described for riparian willow scrub. Lakeshore sites, however, do not provide habitat for wildlife species requiring large, continuous patches of willows, stream banks, deposits, or flowing water. The WHI value of lakeshore willow scrub, similar to other lakeshore habitats is low compared to tree-dominated habitats along tributary streams (Table D-5).

Lakeshore Mixed Scrub. Lakeshore mixed scrub habitat is uncommon and occurs as small isolated patches near lakeshore springs and seeps, such as those near the Lee Vining Tufa Grove. Most of the 26 acres mapped of this habitat type are composed of willow and typical Great Basin shrub species (Table D-5). This habitat was not distinguishable on prediversion aerial photographs, but the extent of lakeshore scrub habitats appeared to be limited in this period (Stine pers. comm.).

Mixed-scrub habitats occupy lakeshore sites that are hydrologically complex. Abrupt spatial changes in soil moisture on these sites results in a mix of water-tolerant shrubs, such as willows, growing in close association with species adapted to drier soil conditions, such as rabbitbrush. Stands of lakeshore mixed scrub generally occur as inclusions in surrounding wetland, meadow, or Great Basin scrub habitats (Chapter 3C, "Vegetation").

The estimated WHI value of this habitat is slightly lower than that of lakeshore willow scrub (Table D-5), possibly because lakeshore mixed-scrub habitats occupy less acreage and received a lower sampling intensity. Wildlife species observed on surveys included house wrens, European starlings, yellow warblers, Brewer's sparrows, savannah sparrows, song sparrows, red-winged blackbirds, brown-headed cowbirds, Nuttall's cottontails, and California ground squirrels (Table D-4).

The structural characteristics and wildlife values of lakeshore mixed scrub are similar to those described for riparian mixed scrub. Lakeshore mixed scrub habitats are, however, generally composed of fewer shrub species than riparian mixed scrub habitats (Chapter 3C, "Vegetation"). Wildlife species that use mixed scrub habitats only in association with streambanks, deposits, or flowing water would not frequent this habitat.

Alkali and Dry Meadows. Alkaline and dry meadows occupy recently exposed lake terrace sites and are dominated by saltgrass, rushes and other salt-tolerant species. A total of about 3,920 acres of these habitats currently exist around the lake, representing an increase of more than 3,786 acres from prediversion conditions (Table D-5). Dry meadows are widely distributed around the lakeshore, and they are usually associated with alkaline soils that depend on rain and snowfall for moisture (Chapter 3C, "Vegetation").

Six alkali and dry meadow plots were established around the lakeshore (Table D-2). Nine bird and five mammal species were observed there during the fixed-plot surveys (Table D-4), and eight additional bird species were observed during plotless surveys (Table D-4). Typical species observed in alkali and dry meadows included horned larks, violet-green swallows, savannah sparrows, red-winged blackbirds, Brewer's blackbirds, black-tailed hares, Panamint kangaroo rats, deer mice, and coyotes.

Alkaline and dry meadows provide foraging areas and cover for a few wildlife species associated with saline, herbaceous habitats. Wildlife habitat values are reduced because vertical structure, vegetative diversity, and sources of fresh water are lacking in this habitat. Thus, despite their large increase in acreage from the prediversion period, alkaline and dry meadow habitats around Mono Lake provide some cover, but offer limited foraging opportunities or water; consequently, their use by wildlife is limited. The WHI value of these habitats were slightly higher than that of lakeshore scrub habitats (Table D-5), possibly because its acreage is so much greater, and because SWRCB consultants spent proportionately more time surveying these areas than other lakeshore habitats.

Wet Meadow. Wet meadows occupy recently exposed lake terraces that are watered by springs, seeps, and groundwater. Wet meadows are dominated by sedges, rushes, or grasses in various combinations (Chapter 3C, "Vegetation"). A total of 51 acres of wet meadow habitats occur around the lakeshore, representing an increase of more than 44 acres from prediversion conditions (Table D-5). Among the lakeshore wetland habitats surveyed, alkali wet meadows supported the greatest diversity of plant species (Chapter 3C, "Vegetation"). Presumably, this is because wet meadows occupy sites with water and soils that vary widely in salinity and alkalinity. For the wildlife analysis, fresh, brackish, and saline marshes were considered as a single habitat type.

Seven wet meadow plots were established (Table D-2). Twelve bird and one mammal species were observed there during the fixed-plot surveys, and eight additional bird, two mammal, and one amphibian species were recorded during plotless surveys (Table D-4). Species observed in alkali wet meadow habitat included killdeer, Wilson's phalaropes, horned larks, violet-green swallows, cliff swallows, savannah sparrows, red-winged blackbirds, western meadowlarks, Brewer's blackbirds, montane voles, and Great Basin spadefoots.

Despite their large acreage (Table D-5), high plant diversity, and variable hydrological conditions, alkali wet meadows, like alkali dry meadows, receive limited wildlife use. Wet meadows typically have higher cover than dry meadows because dominant plants generally grow taller and denser. Wet meadows that hold standing water also provide habitat for some wading birds and shorebirds but few mammals, resulting in a relatively low WHI value for this habitat.

Short Emergent Marsh. Short emergent marsh is dominated by alkali bulrush and sedges that are less than 3.5 feet in height. Stands are dense, and often have 100% cover. Short emergent marshes occupy sites that support seasonally saturated soils (Chapter 3C, "Vegetation"). A total of about 933 acres of short emergent marshes occur around the lakeshore, representing an increase of almost 815 acres from prediversion conditions (Table D-5).

A total of nine plots were located at short emergent marsh habitats on lower lakeshore terraces of extensive wetland areas at Simon Springs, Warm Springs, and at the DeChambeau Marsh. Due to the presence of standing water or saturated soils, these plots were judged to be unsuitable habitat for small mammals (Harris pers. comm.) and were surveyed only for birds (Table D-2). Seventeen bird species were observed during in fixed-plot and plotless surveys of short emergent marshes, including killdeer, American avocets, Wilson's phalaropes, soras, marsh wrens, violet-green swallows, savannah sparrows, red-winged blackbirds, yellow-headed blackbirds, and Brewer's blackbirds (Table D-4).

Short emergent marshes around Mono Lake currently provide limited wildlife habitat value. The dense vegetation typically lacks open water areas that are attractive to ducks and other common marsh inhabitants. Because vegetation is short, it does not provide the nesting structure favored by herons, blackbirds, and other species that frequent tall emergent habitats.

Around the Mono Lake shoreline, this habitat occurs in broad expanses and contains inclusions of alkali meadow and tall marsh habitats. The most concentrated use of this habitat by wildlife probably occurs at the edges of tall and short emergent marshes and meadow habitats where the marsh is available as escape cover and the higher vegetation can be used for perching. Probably due to the lack of open, ponded water nearby, the WHI value of short emergent marshes is low, even compared to other lakeshore wildlife habitats (Table D-5).

Tall Emergent Marsh. Tall emergent marshes were defined as wetland habitats dominated by hardstem bulrush and/or cattail greater than 3.5 feet and that attain heights greater than 6 feet. Tall emergent marsh is associated primarily with permanent springs and seeps on the lower lakeshore terraces, and the largest areas are located at Simon Springs, Warm Springs, the DeChambeau Marsh, and at scattered locations along the western shoreline (Chapter 3C, "Vegetation"). Approximately 55 acres of tall emergent marshes currently exist around Mono Lake, representing an increase of 48 acres from prediversion conditions (Table D-5).

Tall emergent marshes around the lakeshore frequently attain 100% coverage and generally occur as inclusions within short emergent marshes. Unlike prediversion conditions around the lakeshore, tall emergent marshes with areas of ponded, open water are rare. Seven species of birds were observed during fixed-plot surveys, and three additional bird and one amphibian species were observed during plotless surveys of this habitat (Table D-4). Plots were not surveyed for mammals or reptiles due to the presence of standing water or permanently saturated soils. Reconnaissance-level surveys revealed the presence of Great Basin spadefoot larvae in smaller areas of open water near tall emergent marshes at Simon Springs (Simon pers. comm.).

Bird species associated with tall emergent marshes around the lakeshore included Virginia rails, American coots, Wilson's phalaropes, marsh wrens, common yellowthroats, song sparrows, red-winged blackbirds, and yellow-headed blackbirds (Table D-4). Tall emergent marshes are important nesting habitat and hiding cover for Virginia rails, marsh wrens, red-winged blackbirds, and yellow-headed blackbirds. Tall cattails and bulrushes provide structure and cover required by some species. At Mono Lake, however, the diversity of wildlife associated with tall marsh habitats is limited because of the lack of open water, saline conditions, and the high density of stands. The relative lack of fresh or brackish open water near the lakeshore reduces the value of this habitat to ducks, grebes, herons, egrets, and other birds that typically frequent tall marshes in the Great Basin. Thus, similar to short emergent marshes, tall marshes were found to have a low WHI value in Mono Basin (Table D-5).

Alkali Flats. Alkali flats are defined as relicted lake bottomlands that are encrusted with alkali salts that support virtually no vegetation (Chapter 3C, "Vegetation"). The current estimate of 5,959 acres represents an increase of 100% from the prediversion period. We did not conduct fixed-plot surveys in this habitat but did spend many days walking across alkali flat areas along the western, northern, and eastern shorelines of Mono Lake.

Only a few snowy plovers, horned larks, and coyotes were observed in alkali flat areas. California gulls and common ravens, both snowy plover nest predators, also occasionally forage in this habitat type (Page et al. 1983). Because alkali flats are devoid of vegetation, they provide virtually no cover or forage for most wildlife species. Snowy plovers, which construct nests on unvegetated shoreline substrates, often nest on alkali flats (Page et al. 1983). Despite the large increase in alkali flat acreage around the lakeshore, the low WHI value results in an increase of only about 50 WHUs within Study Area 2.

Mono Lake Lakeshore. Lakeshore areas include the shoreline and adjacent near-shore water areas of Mono Lake. In shoreline areas watered by tributary streams, springs, or seeps, adjacent lands often support alkali wet meadows or marsh habitats. Unwatered shoreline areas are typically unvegetated or may support salt grass meadows (Chapter 3C, "Vegetation"). Recently exposed shoreline areas with shallow gradients (located primarily on northern and eastern shorelines) are unvegetated, salt encrusted alkali flats.

Approximately 30 person-days were spent observing birds along the shoreline of Mono Lake. Areas where repeated surveys were made included Danburg Beach; the mouths of Wilson, Lee Vining, and Rush Creeks; from the mouth of Lee Vining Creek to the Lee Vining tufa grove; Navy Beach; Simon Springs; and Warm Springs. Three half days also were spent observing Mono Lake's birds from a boat. Spring and fall shoreline surveys also been conducted by the Point Reyes Bird Observatory (PRBO) since 1989 (Strauss and Shuford pers. comms.).

Forty-eight species of birds were observed during Jones & Stokes Associates and PRBO surveys (Table D-4). The most common species observed in shoreline areas included eared grebes, California gulls, killdeer, American avocets, spotted sandpipers, western sandpipers, and least sandpipers. Thousands of Wilson's phalaropes and red-necked phalaropes also were observed from a boat in the northeast sector of the lake.

The lake shoreline is used as loafing, feeding, and watering sites by a variety of water and shorebirds. Water and shorebirds frequent lakeshore areas because the open terrain allows predators to be more readily detected and the proximity of the lake provides a nearby refuge from terrestrial predators.

Shorelines offer the highest densities of alkali flies and many shorebirds, gulls, and other water birds gather there to forage. Adult alkali flies congregate in large rafts on or immediately adjacent to the shore (Chapter 3E, "Aquatic Productivity"). This readily available food source can attract large numbers of phalaropes, gulls, grebes, and shorebirds.

Some of the most important lakeshore areas are those adjacent to freshwater inflows to the lake. Freshwater available at these sites allow species that feed on alkali flies or brine shrimp to reduce the salt load ingested when these invertebrates are fed upon. Species not adapted to highly saline conditions, such as ducks, also may use freshwater inflows as bathing areas to remove crusted salt from feathers and feet or to seek relief from irritation caused by the lake's high salt and alkali content. California gulls also make frequent use of freshwater deltas, especially at Lee Vining, Rush, and Wilson Creeks.

Standardized plot surveys were not conducted along Mono Lakes shoreline; therefore, WHI and WHU values were not calculated for this habitat.

Ponds and Lagoons. In the prediversion period, about 260 acres of ponds and lagoons around Mono Lake's shoreline included those at DeChambeau Marsh (6 acres), near Bridgeport-Cottonwood Beach (29 acres), at Black Point (4 acres), near dunes along the northern shoreline (175 acres), near the Wilson-Mill Creek deltas (3 acres), and at the Rush Creek delta (38 acres) (Chapter 3C, "Vegetation"). During the early diversion period, large ponded areas formed behind natural berms at Simon Springs and lakeshore ponds were created for duck hunting using water diverted from Rush Creek (Stine pers. comm.). As the lake's elevation receded and the water table dropped, however, freshwater ponds gradually dried up and by about the early 1960s most of them were gone (Banta and Stine pers. comms.).

Aside from a 0.5-acre pond near the mouth of Wilson Creek, lakeshore ponds and lagoons currently are absent from Mono Lake's shoreline (Chapter 3C, "Vegetation"). Because these habitats no longer exist, it was not possible to conduct wildlife surveys there or to calculate their WHI values.

Mono Lake Open Water. At elevation 6,376.8 feet, Mono Lake provides approximately 39,000 acres of open water habitat to migrating birds. Due to extensive previous research on waterbirds of Mono Lake, specific surveys were not conducted to determine wildlife use of open water areas. Sixteen species of birds, however, were recorded incidental to other survey work. In addition to the abundant eared grebes, California gulls, Wilson's phalaropes, and red-necked phalaropes, less common species, such as Caspian terns, Bonaparte's gulls, Canada geese, mallards, northern shovelers, common mergansers, ruddy ducks, redheads, buffleheads, American wigeons, northern pintails, gadwalls, and green-winged teals were observed in open waters of Mono Lake during the 1991 field investigations (Table D-4).

The high salt and alkali content of Mono Lake exceeds the tolerance limits of most invertebrates. However, through the spring and summer months, the lake produces enormous amounts of brine shrimp and alkali flies that provide a food source for large numbers of migratory birds (Chapter 3E, "Aquatic Productivity"). The lake's large expanse of open water also provides resting areas safe from terrestrial predators for seasonally resident and migratory water birds.

Standardized surveys were not conducted in open water; therefore, WHI and WHU values were not calculated for this habitat.

Paoha Island (Study Area 3)

Ten survey plots were established in Great Basin scrub and short emergent marsh habitats on Paoha Island (Table D-2). A total of 42 bird and four mammal species were observed fixed-plot and plotless surveys on the island during the 1991 surveys (Table D-4).

Great Basin Scrub. Great Basin scrub is the most abundant habitat type on Paoha Island and is dominated by greasewood and spiny hop-sage. Seven Great Basin scrub plots were established and surveyed for bird, mammal, reptile, and amphibians (Table D-2) and a total of 11 bird and three mammal species were observed on fixed-plot surveys. An additional 15 bird and one mammal species were observed during plotless surveys (Table D-4). Species observed in scrub habitats on Paoha Island included horned larks, violet-green swallows, sage thrashers, Brewer's sparrows, Brewer's blackbirds, house finches, black-tailed hares, deer mice, montane voles, and coyotes.

Great Basin scrub provides nesting, escape, and resting cover and forage for many species of wildlife not associated with water-dependent habitats. Probably due to the isolation of Paoha Island, WHI values of Great Basin scrub habitats there are lower than in similar Great Basin scrub habitats located on the mainland (Table D-5). Although more species of birds used Great Basin scrub habitat on Paoha Island than on the mainland, mainland areas supported more species of mammals and reptiles (Table D-4). The acreage of Great Basin scrub habitat within the study area was not determined; therefore, WHUs were not calculated for this habitat.

Short Emergent Marsh. Although small areas of tall emergent marsh exist on Paoha Island, only short emergent marshes were examined during the fixed-plot surveys. Short emergent marsh is limited to the southeast shore of Paoha Island and is composed of soft rush, three-square bulrush, saltgrass, foxtail barley, and fivehook (Morrison 1991). Stands are dense, generally approximating 100% cover, and average 2.5-3.5 feet in height.

Three plots were established and surveyed in short emergent marsh habitats (Table D-2), and 14 bird and three mammal species were observed during fixed-plot surveys (Table D-4). Seven additional species of birds were observed during plotless surveys of short emergent marshes. No reptiles or amphibians were located on Paoha Island. Species associated with short marsh habitat include violet-green swallows, common yellowthroats, Wilson's warblers, song sparrows, red-winged blackbirds, western meadowlarks, and yellow-headed blackbirds, deer mice, montane voles, and coyotes.

Springs supporting emergent marshes near the southeast side of Paoha Island are the only sources of fresh water, and they are an important resource to most species of terrestrial wildlife inhabiting the island. Surprisingly, the WHI value of short emergent marsh habitat on Paoha Island was higher than similar mainland habitats (Table D-4). It is possible that the springs attract especially high numbers of birds compared to mainland areas because other sources of freshwater are lacking on the island.

Upper Owens River (Study Area 4)

Surveys were conducted on the Arcularius Ranch located on the Upper Owens River. Five survey plots were established in irrigated meadow habitat (Table D-2). A plotless survey was conducted along a 1/4-mile stretch of willows and wet meadows along the river (about 1.5 acres).

Riparian Willow Scrub. Willows occur as discontinuous islands of habitat adjacent to the Upper Owens River primarily upstream from the East Portal. Willows are mature and usually open canopied, with an understory of meadow or irrigated pasture. Downstream from the East Portal, willows become sparse and are composed primarily of decadent shrubs.

A total of 3.7 acres of riparian willow scrub habitat currently exist on the Arcularius Ranch, representing a decline of about 12.4 acres since 1944 (Table D-5); these areas are now irrigated meadow and stream channel habitats Seven plotless surveys were made for birds, mammals, reptiles, and amphibians along the Upper Owens River from the East Portal to the Arcularius Ranch headquarters (Table D-2), and one mammal and 33 bird species were observed there (Table D-4). Common species observed included black-crowned night-herons, mourning doves, dusky flycatchers, house wrens, hermit thrushes, warbling vireos, yellow warblers, Wilson's warblers, MaGillvray's warblers, Lincoln's sparrows, and western harvest mice.

Owens River riparian willow scrub provides wildlife values similar to those described for riparian willow scrub in Mono Basin. Perhaps due to its limited acreage and frequent visitation by anglers and cattle, the WHI value for willow scrub habitats of the Upper Owens River was about half the value calculated for similar habitats in Mono Basin.

Irrigated Meadow. Irrigated meadows dominate the floodplain on the Arcularius Ranch and are composed of a mix of sedges and grasses (Chapter 3C, "Vegetation"). The relative abundance of grasses and sedges is determined by soil moisture; wetter sites support a greater proportion of sedges than drier sites (Chapter 3C, "Vegetation"). Acreages of irrigated meadows were not calculated, but qualitative estimates suggest that acreages and land uses were similar under both prediversion and current conditions.

Five plots were surveyed in irrigated meadows on the Upper Owens River (Table D-2). Nine bird and five mammal species were observed there, and seven additional species of birds were observed using these habitats during plotless surveys (Table D-4).

Typical species observed in irrigated meadows of the Arcularius Ranch included killdeer, common snipe, spotted sandpipers, cliff swallows, red-wing blackbirds, yellow-headed blackbirds, Brewer's blackbirds, vagrant shrews, Belding ground squirrels, western harvest mice, and deer mice.

Irrigated meadows provide habitat values similar to those described for montane meadows in Study Area 1. Upper Owens River meadows are irrigated more heavily than those in Mono Basin; therefore, meadows there typically have more lush vegetation and standing water than those in Mono Basin (Chapter 3C, "Vegetation").

The WHI value of irrigated meadows along the Upper Owens River were similar to those of montane meadows in Mono Basin (Table D-5). The WHI value is lower on irrigated meadows because fewer mammal species used meadows on the Upper Owens River than used montane in Mono Basin. The number of mammal species using irrigated meadows was probably lower than for montane meadows because most irrigated meadow plots were flooded or supported saturated soils during portions of the study period.

Stream Channels. Stream channels include flowing water, channel banks, and point bar deposits. Within the study area, the Upper Owens River occupies a single, meandering channel. Eleven species of birds and one species of mammal were observed during plotless surveys (Table D-4), and characteristic species included snowy egrets, Canada geese, mallards, northern pintails, American wigeons, American avocets, belted kingfishers, yellow-headed blackbirds, and beavers.

Stream channels provide water for drinking and bathing and foraging habitat for some species of wildlife. Gravel and sand bars harbor invertebrates and ruderal vegetation that frequently grows on these sites provide seeds for forage. Waterfowl and shorebirds that use tributary channels also loaf on exposed gravel bars.

Surveys were not conducted in stream channels; therefore, WHI and WHU values were not calculated for this habitat.

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Table D-1. Wildlife Habitats and Equivalent Vegetation Communities

Wildlife Habitat Designation	Plant Community Equivalent
Riparian conifer forest	Jeffery pine woodland Pinyon pine woodland
Conifer-broadleaf forest	Conifer-broadleaf forest
Cottonwood-willow woodland	Cottonwood-willow woodland
Aspen woodland	Aspen
Riparian willow scrub	Willow scrub
Mixed riparian scrub	Mixed riparian scrub
Unvegetated floodplain	Unvegetated channel Unvegetated floodplain Unvegetated upland
Montane meadow	Meadow
Lakeshore willow scrub	Wetland willows
Lakeshore mixed scrub	Riparian mixed scrub
Dry meadow	Dry meadow - saltgrass Dry meadow - Nevada bulrush Dry meadow - Baltic rush Dry meadow - mixed
Alkali meadow	Alkali meadow - saltgrass Alkali meadow - Nevada bulrush
Wet meadow	Wet meadow - mixed
Short emergent marsh	Marsh - threesquare Marsh - mixed Marsh - alkali bulrush
Tall emergent marsh	Marsh - tule Marsh - cattail
Great Basin scrub	Great Basin - greasewood Great Basin - sagebrush Great Basin - bitterbrush Great Basin - rabbitbrush
Irrigated meadow	Wet meadow - mixed

Table D-2. Summary of Survey Effort by Habitat Type

Habitat Type by Survey Location	Bird Surveys			Mammal Surveys							Reptile and Amphibian Surveys		
	Fixed Plot Surveys			Sherman Live Traps		Pitfall Traps		Track Plates and Pads			Pitfall Traps		
	No. of Plots	No. of Surveys	No. of Plotless Surveys	No. of Plots	No. of Trap Nights	No. of Plots	No. of Trap Nights	No. of Plots	No. of Days	No. of Plots Sign Searched	No. of Plots	No. of Trap Nights	No. of Plots Sign Searched
Mono Lake tributaries (Study Area 1)													
Riparian conifer forest	0	0	0	0	0	0	0	0	0	0	0	0	0
Conifer-broadleaf forest	8	40	0	8	864	8	24	8	24	8	8	24	8
Cottonwood-willow woodland	3	19	0	3	324	3	9	3	9	3	3	9	3
Aspen	4	20	0	4	432	4	12	4	12	4	4	12	4
Riparian willow scrub	9	46	0	8	864	8	24	8	24	8	8	24	8
Mixed riparian scrub	7	38	0	6	648	6	18	6	18	6	6	18	6
Unvegetated floodplain	1	5	0	1	108	1	3	1	3	1	1	3	1
Montane meadow	8	42	0	8	864	8	24	8	24	8	8	24	8
Recovering riparian[a]	5	25	0	5	540	5	15	5	15	5	5	15	5
Stream channels	0	0	0	0	0	0	0	0	0	0	0	0	0
Mono Lake shoreline (Study Area 2)													
Lakeshore willow scrub	1	6	0	0	0	0	0	0	0	0	0	0	0
Lakeshore mixed scrub	1	5	0	1	108	1	3	1	3	1	1	3	1
Alkali and dry meadows	6	32	0	4	432	4	12	4	12	4	4	12	4
Wet meadow	6	32	0	2	216	2	6	2	6	2	2	6	2
Short emergent marsh	9	45	0	0	0	0	0	0	0	0	0	0	0
Tall emergent marsh	3	15	0	0	0	0	0	0	0	0	0	0	0
Alkali flats	0	0	0	0	0	0	0	0	0	0	0	0	0
Mono Lake lakeshore	0	0	20	0	0	0	0	0	0	0	0	0	0
Mono Lake open water	0	0	0	0	0	0	0	0	0	0	0	0	0
Paoha Island (Study Area 3)													
Short emergent marsh	3	9	0	3	162	3	51	3	9	3	3	51	3
Great Basin scrub	12	36	0	12	648	8	59	5	15	12	8	59	12
Upper Owens River (Study Area 4)													
Riparian willow scrub	0	0	7	1	108	1	3	1	3	1	1	3	1
Irrigated meadow	5	25	0	5	540	5	15	5	15	5	5	15	5
Stream channels	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	86	415	27	66	6,318	62	263	59	177	66	62	263	66

[a] Recovering riparian not included in summary totals.

Table D-3. Numbers of Species Observed during Surveys of Mono Basin and Upper Owens River

Location	Bird	Mammal	Reptile	Amphibian	Total
Mono Lake tributaries (Study Area 1)	92	24	2	0	118
Mono Lake shoreline (Study Area 2)	79	8	0	1	88
Paoha Island (Study Area 3)	58	12	1	0	71
Upper Owens River (Study Area 4)	51	6	0	0	57
Study area subtotals[a]	150	29	2	1	182
Additional species observed in Mono Basin[b]	11	0	0	0	11
Additional species observed in the Upper Owens River basin[b]	12	0	0	0	12
Total all species observed[a]	161	29	2	1	193

[a] Species observed in more than one study area were counted only once in the subtotal and total.

[b] Additional species observed outside specific study areas but within Mono Basin and Upper Owens River areas (see text).

Table D-4. Species Observed in Each Habitat Type

Species	Study Area 1										Study Area 2									Study Area 3			Study Area 4				
	Conifer Forest	Conifer Broadleaf Forest	Cottonwood-Willow Woodland	Aspen	Riparian Willow Scrub	Mixed Riparian Scrub	Unvegetated Floodplain	Montane Meadow	Recovering Riparian	Stream Channel	Lakeshore Willow Scrub	Lakeshore Mixed Scrub	Dry Meadow	Wet Meadow	Short Emergent Marsh	Tall Emergent Marsh	Alkali Flat	Lake Shoreline	Lake Open Water	Short Emergent Marsh	Island Great Basin Scrub[a]	Mainland Great Basin Scrub[b]	Riparian Willow Scrub	Irrigated Meadow	Stream Channel	Observed in Mono Basin[c]	Observed in the Upper Owens River[d] Basin
Amphibians																											
Great basin spadefoot														O													
Reptiles																											
Sagebrush lizard		X		X	X	X	X	X	X													X					
Western aquatic garter snake					X																						
Birds																											
Common loon																										O	
Eared grebe																			O								
American white pelican																										O	O
Double-crested cormorant																										O	
Great blue heron					O																		X	O	O		
Great egret																									O		
Snowy egret																									O		
Black-crowned night-heron										O								O					X				
White-faced ibis																		O									
Brant																		O									
Canada goose																		O	O								
Wood duck																										O	
Green-winged teal																		O	O								O
Mallard			O							O					O			O							O		
Northern pintail										O			X					O	O								
Cinnamon teal																		O							O		
Northern shoveler																			O							O	
Gadwall										O				O				O	O	O							
American wigeon																		O	O	X					O		
Redhead																			O								
Bufflehead																			O								
Common merganser										O									O								
Ruddy duck																			O								
Turkey vulture																										O	O
Osprey																			O						O		
Bald eagle																											O
Northern harrier														O	O			O				O					
Cooper's hawk			O																			O					
Red-tailed hawk			O	O	O			O					O	O										O			
Rough-legged hawk																										O	
Golden eagle													O	O				O									
American kestrel	O		O		O	X		O	O				O		O												
Prairie falcon																						O					
Sage grouse																						O					
Virginia rail															O	O				X							
Sora															O												
American coot																O		O	O	O							

	Study Area 1										Study Area 2									Study Area 3			Study Area 4				
Species	Conifer Forest	Conifer Broadleaf Forest	Cottonwood-Willow Woodland	Aspen	Riparian Willow Scrub	Mixed Riparian Scrub	Unvegetated Floodplain	Montane Meadow	Recovering Riparian	Stream Channel	Lakeshore Willow Scrub	Lakeshore Mixed Scrub	Dry Meadow	Wet Meadow	Short Emergent Marsh	Tall Emergent Marsh	Alkali Flat	Lake Shoreline	Lake Open Water	Short Emergent Marsh	Island Great Basin Scrub[a]	Mainland Great Basin Scrub[b]	Riparian Willow Scrub	Irrigated Meadow	Stream Channel	Observed in Mono Basin[c]	Observed in the Upper Owens River[d] Basin
Black-bellied plover																				X				O		O	
Snowy plover																	O	O									
Semipalmated plover																		O[e]									
Killdeer					X	X	X	O	X	O	X		O	X	X			O[e]		X				X			
Black-necked stilt																		O									
American avocet													X	O	X			O		O					O		
Greater yellowlegs																		O[e]									
Lesser yellowlegs																		O[e]									
Willet																		O									
Spotted sandpiper			X		X		X		X	O	O							O						X			
Long-billed curlew								O										O[e]									
Marbled godwit																		O[e]									
Ruddy turnstone																		O[e]									
Sanderling																		O[e]									
Semipalmated sandpiper																		O[e]									
Western sandpiper																		O[e]									
Least sandpiper																		O[e]			O						
Baird's sandpiper																		O[e]									
Short-billed dowitcher																		O									
Long-billed dowitcher																								O			
Common snipe														O				O		O				X			
Wilson's phalarope														X	X	X		O	O								
Red-necked phalarope																		O	O								
Pomarine jaegar																			O								
Bonaparte's gull																		O									
California gull																		O	O								O
Caspian tern																		O	O		O		O				
Mourning dove			O					O					O									O					
Great horned owl	O		O																								
Long-eared owl			O		O																						
Common nighthawk						X			X	O				X													O
Common poorwill																										O	
Vaux's swift																										O	
Calliope hummingbird		X	X																								
Rufous hummingbird			O	O																					O		
Belted kingfisher		O	O							O															O		
Lewis' woodpecker																										O	
Red-breasted sapsucker	O	X	O	X																			X				
Downy woodpecker		X	O		O																						
Hairy woodpecker	O	X	X	O	O																						
Northern flicker	O	X	O	X	O				O		O							O			O	O		O			
Willow flycatcher			O		O																						

Table D-4. Continued

	Study Area 1										Study Area 2									Study Area 3			Study Area 4				
Species	Conifer Forest	Conifer Broadleaf Forest	Cottonwood-Willow Woodland	Aspen	Riparian Willow Scrub	Mixed Riparian Scrub	Unvegetated Floodplain	Montane Meadow	Recovering Riparian	Stream Channel	Lakeshore Willow Scrub	Lakeshore Mixed Scrub	Dry Meadow	Wet Meadow	Short Emergent Marsh	Tall Emergent Marsh	Alkali Flat	Lake Shoreline	Lake Open Water	Short Emergent Marsh	Island Great Basin Scrub[a]	Mainland Great Basin Scrub[b]	Riparian Willow Scrub	Irrigated Meadow	Stream Channel	Observed in Mono Basin[c]	Observed in the Upper Owens River[d] Basin
Western wood-pewee	O	X	X	X	O	O																	X				
Dusky flycatcher	O	X	X	X	O															X	O		X				
Grey flycatcher									O													O	X				
Pacific-slope flycatcher			O		O													O				O					
Say's phoebe																					O	O					
Ash-throated flycatcher			O		O																						
Cassin's kingbird																					X						
Western kingbird																					O						
Horned lark							O	O					X	X			O	O			X	X					
Tree swallow		X	O	X	O			X			O												X				
Violet-green swallow		X	X	O	X	X	X	X	X			X	X	X	X	X		O		X	X	X		X			
Northern rough-winged swallow						X		X	X						X												O
Cliff swallow			O			X	X		X				O	X	X						O		X	X			
Barn swallow																										O	O
Stellar's jay	O	X	X	X																			X				
Scrub jay		O	O																								
Pinyon jay																						X					
Clark's nutcracker	O	O		O																							
Black-billed magpie		O	O		X	X			O		O							O				O					O
Common raven			O								O			O				O				O		X			
Mountain chickadee	O	X	O	O	O																	O					
Plain titmouse		O	O																								
Bushtit		O	X		O	X																					
Red-breasted nuthatch				O																							
White-breasted nuthatch	O	O	O	X																							
Pygmy nuthatch	O	O		O																							
Brown creeper	O	X																									
Rock wren																					X	O					O
Bewick's wren			O		O	X			X		O									O		O					
House wren	O	X	X	X	X	O						X											X				
Marsh wren													X		X	X											
American dipper										O																	
Ruby-crowned kinglet		O	O																		O						
Blue-gray gnatcatcher			O																		O	O					
Mountain bluebird				X	X			X	X												O	O					
Townsend's solitaire	O	O																									
Hermit thrush		O	O		O																		O				
American robin		X	X	X	X	X																	X				
Sage thrasher																					X	X					
Brown thrasher		O																									
American pipit																		O		O							
Cedar waxwing			X																								
Loggerhead shrike													O									X					

	Study Area 1										Study Area 2									Study Area 3			Study Area 4				
Species	Conifer Forest	Conifer Broadleaf Forest	Cottonwood-Willow Woodland	Aspen	Riparian Willow Scrub	Mixed Riparian Scrub	Unvegetated Flood-plain	Montane Meadow	Recovering Riparian	Stream Channel	Lake-shore Willow Scrub	Lake-shore Mixed Scrub	Dry Meadow	Wet Meadow	Short Emergent Marsh	Tall Emergent Marsh	Alkali Flat	Lake Shore-line	Lake Open Water	Short Emergent Marsh	Island Great Basin Scrub[a]	Mainland Great Basin Scrub[b]	Riparian Willow Scrub	Irrigated Meadow	Stream Channel	Observed in Mono Basin[c]	Observed in the Upper Owens River[d] Basin
European starling		X	X	O				X			X	X		X									X				
Solitary vireo	O	O	O																								
Warbling vireo	O	X	X	X	O																		O				
Orange-crowned warbler		O	O		O	O																					
Nashville warbler		O	O																								
Yellow warbler		X	X	X	X	X			X		X	X											X				
Yellow-rumped warbler	O	O	O			O														O	O		X				
Black-throated gray warbler			O																		O						
Townsend's warbler			O																		O		O				
Black-and-white warbler		O		X	O																		O				
MacGillivray's warbler		X	O		X	O																	O				
Common yellowthroat															O	O				X							
Wilson's warbler	O	X	O	O	O	X														X	X		O				
Yellow-breasted chat																							X				
Western tanager	O	X	O	O	O																						
Black-headed grosbeak	O	X	O	O	O																		O				
Luzuli bunting			O	O	O	O																					
Green-tailed towhee	O	O	O		X	X			O		O											X	O				
Rufous-sided towhee		O	X	X	X	X			O		O											O	O				
Chipping sparrow	O	O	O		O																O						
Brewer's sparrow					X	X		X			O	X									X	X					O
Vesper sparrow					X																	O					
Sage sparrow																						X					
Savannah sparrow					X			O			O	X	X	X	X	X		O		X				O			
Fox sparrow			O	O	X	X			O												X	O					O
Song sparrow		X	X	O	X	X		O	X		O	X		O				O		X			X				
Lincoln's sparrow		O	O	O										O									O				
White-crowned sparrow		O			O																O		O				
Dark-eyed junco	O	X	O																								
Red-winged blackbird		O	O		X	X		X			X	X	X	X	X	X		O		X			X	X			
Western meadowlark					O			X	O				O	X						X		O					
Yellow-headed blackbird													X	X	X	X		O		X			X	X	O		
Brewer's blackbird	O	O		X	X	X	X	X	X		X	X	X	X	X	X		O		X	X	X	X	X			
Brown-headed cowbird	O	X	X	X	X	X			X		O	X									X		X	O			
Northern oriole	O	X	O	X																							
Cassin's finch		X	O	X																							
House finch			O		O																X		X				
American goldfinch						X																					
Mammals																											
Water shrew							O		O	O																	
Vagrant shrew					X																			X			
Nuttall's cottontail		X		X	X	X		X	X		O	X										O					
Black-tailed hare						O		X	X				X								X	X					
Least chipmunk		X	X	X	X			X	X													X					

Species	Study Area 1: Conifer Forest	Study Area 1: Conifer Broadleaf Forest	Study Area 1: Cottonwood-Willow Woodland	Study Area 1: Aspen	Study Area 1: Riparian Willow Scrub	Study Area 1: Mixed Riparian Scrub	Study Area 1: Unvegetated Floodplain	Study Area 1: Montane Meadow	Study Area 1: Recovering Riparian	Study Area 1: Stream Channel	Study Area 2: Lakeshore Willow Scrub	Study Area 2: Lakeshore Mixed Scrub	Study Area 2: Dry Meadow	Study Area 2: Wet Meadow	Study Area 2: Short Emergent Marsh	Study Area 2: Tall Emergent Marsh	Study Area 2: Alkali Flat	Study Area 2: Lake Shoreline	Study Area 2: Lake Open Water	Study Area 3: Short Emergent Marsh	Study Area 3: Island Great Basin Scrub[a]	Study Area 3: Mainland Great Basin Scrub[b]	Study Area 4: Riparian Willow Scrub	Study Area 4: Irrigated Meadow	Study Area 4: Stream Channel	Observed in Mono Basin[c]	Observed in the Upper Owens River[d] Basin
Yellow-pine chipmunk				X																							
Lodgepole chipmunk		X																									
Belding's ground squirrel					X			X																X			
California ground squirrel		X										X										X					
Golden-mantled ground squirrel												X															
Douglas' squirrel	O	X	X	X																							
Pocket gopher				X	X	X		X																			
Panamint kangaroo rat				X	X		X		X				X									X					
Chisel-toothed kangaroo rat																						X					
Great Basin pocket mouse		X			X	X		X	X													X					
Beaver																									O		
Western harvest mouse																							X	X			
Deer mouse		X	X	X	X	X	X	X	X				X							X	X	X		X			
Brush mouse																						X					
Pinyon mouse					X																						
Bushy-tailed woodrat		X		X	X	X																					
Montane vole					X			X					X	X						X	X	X					
Long-tailed vole		X	X	X	X	X																					
Sagebrush vole								X	X																		
Porcupine					X																						
Coyote					X	X		X	X				X	O			O			X	O	O					
Ermine						X																					
Bobcat						X																					
Mule deer		X	O	X	X	X		X	X															X			
Total number of species observed during fixed plot surveys	0[e]	37	21	29	36	32	8	21	22	0[e]	5	13	14	13	11	7	0[e]	0[e]	0[e]	17	14	19	22	14	0[e]	0	0
Total number of species observed incidental to surveys	28	24	47	16	28	7	2	8	9	11	13	0	8	11	6	3	3	48	18	7	16	22	11	7	12	11	12
Total number of species observed	28	61	68	45	64	39	10	29	31	11	18	13	20	24	17	10	3	48	18	24	30	41	33	21	12	11	12

Notes: X = Observed during fixed-plot surveys.
O = Incidental observation made in habitat during 1991.

[a] Island habitat.
[b] Habitat located on mainland adjacent to Black Point.
[c] Species observed in Mono Basin, but not in study areas.
[d] Point Reyes Bird Observatory 1991 survey data (Strauss pers. comm.).
[e] Fixed-plot surveys were not conducted in these habitats.

Table D-5. Wildlife Habitat Indices (WHI), Acreages, and Wildlife Habitat Unit (WHU) Values under Prediversion and 1991 Conditions

Study Area/ Habitat Type	WHI Value	Prediversion Acres	Prediversion WHUs	1991 Acres	1991 WHUs	Change Acres	Change WHUs
Tributary streams (Study Area 1)							
Conifer-broadleaf forest	0.34	51.5	17.5	32.4	11.0	-19.1	-6.5
Cottonwood-willow woodland	0.38	220.9	83.9	39.8	15.1	-181.1	-68.8
Aspen woodland	0.25	12.6	3.2	11.3	2.8	-1.3	-0.4
Riparian willow scrub	0.36	186.8	67.2	207.1	74.6	20.3	7.4
Mixed riparian scrub	0.21	20.3	4.3	82.0	17.2	61.7	12.9
Unvegetated floodplain	0.05	91.7	4.6	270.9	13.5	179.2	8.9
Montane meadow	0.16	591.0	94.6	499.0	79.8	-92.0	-14.8
Great Basin scrub[a]	0.23	776.0	178.5	918.6	211.3	142.6	32.8
Subtotal		1,950.8	453.8	2,061.1	425.3	110.3	-28.5
Mono Lake shoreline (Study Area 2)							
Lakeshore willow scrub	0.10	26.6[b]	2.7	210.0	21.0	183.4	18.3
Lakeshore mixed scrub	0.07	3.3	0.2	26.0	1.8	22.7	1.6
Dry meadow	0.12	79.2	9.5	2,397.0	287.6	2,317.8	268.6
Wet meadow	0.13	6.4	0.8	51.0	6.6	44.6	5.8
Alkali meadow	0.12	52.8	6.3	1,521.0	182.5	1,468.2	176.2
Short emergent marsh	0.09	117.6	10.6	933.0	84.0	815.4	73.4
Tall emergent marsh	0.05	7.0	0.4	55.0	2.8	48.0	2.4
Alkali flat	0.01	0.0	0.0	5,959.0	59.6	5,959.0	59.6
Ponds and lagoons	--[c]	260.0	--[c]	1.0	--[c]	-259.0	--[c]
Subtotal		552.9	30.5[c]	11,153.0	526.0	10,600.1	605.9
Paoha Island (Study Area 3)							
Short emergent marsh	0.13	.8	0.1	2.0	0.3	1.2	0.2
Tall emergent marsh	0.05	.2	0.01	1.0	0.04	0.8	0.03
Subtotal		1.0	0.1	3.0	0.3	2.0	0.2
Upper Owens River (Study Area 4)							
Riparian willow scrub	0.18	16.1[d]	2.9	3.7	0.7	-12.4	-2.2
Irrigated meadow	0.12	--[d]	--[d]	--[d]	--[d]	--[d]	--[d]
Subtotal		16.1	2.9	3.7	0.7	-12.4	-2.2

[a] Great Basin scrub WHI values in Study Area 1 are extrapolated from Great Basin scrub survey data collected from Black Point in Study Area 3.

[b] Prediversion acreages for Study Area 2 were calculated by multiplying the total lakeshore acreages by the proportions of each habitat type under point.-of-reference conditions.

[c] WHI values were not calculated for ponds and lagoons because none existed at the point of reference.

[d] Prediversion point-of-reference acreages are lacking for irrigated meadows habitat.

Table D-6. Acreages of Mature Cottonwood-Willow Forest with Mid- and High-Canopy Foliage

Creek	1940	1991	Percent Change
Lee Vining	53.3	3.9	-92.6
Rush	159.9	4.1	-97.4
Parker	0.1	0.0	0.0
Walker	0.0	0.0	0.0
Total	213.3	8.0	-96.3

Note: Includes all trees higher than 12 feet.

Table D-7. Stepwise Multiple Regression Coefficients and P-Values of Univariate Analyses of Variance of Bird Diversity versus Plot Vegetation Characteristics

	Number of Layers	Percent Total Cover	Percent Cover Tall Trees	Percent Cover Shrubs and Low Trees	Soil Saturation
Bird diversity (H')					
Regression coefficients	0.261	-1.444	0.147	0.0212	0.412
P-values	0.004**	0.068	0.001***	0.026*	0.027*
Mammal diversity (H')					
Regression coefficients	--	--	--	0.436	--
P-values	--	--	--	0.015*	--

Note: Only significant correlations are presented: [t-test (two-tailed) for regression coefficients: * = $P < 0.05$; ** = $P < 0.01$; *** = $P < 0.001$].

Table D-8. Correlation Coefficients of Bird Species Mean Density with Habitat Variables

Species	More Layers	Saturated Soil	Higher Percent Cover of Tall Trees	Higher Percent Cover of Shrubs and Low Trees	Conifer Overstory	Aspen Overstory	Conifer Midstory	Aspen Midstory	Willow Midstory	Rose and Snowberry Midstory	Scirpus Less than 5 Feet	Scirpus over 5 Feet	Typha
Red-breasted sapsucker						0.542**		0.513*					
Western wood-pewee	0.573**		0.594**		0.584**	0.765**	0.549*	0.659**		0.614**			
Tree swallow					0.588**	0.645**				0.500*			
Mountain chickadee					0.627**		0.525*	0.679**					
Brown creeper							1.000***						
House wren	0.606**		0.661**		0.634**	0.837**			0.502*		0.717**		
Marsh wren												0.953***	0.789***
American robin			0.581**		0.572**	0.678**				0.566*			
Warbling vireo			0.508*		0.598**	0.694**	0.556**	0.504*		0.644**			
Yellow warbler				0.521*									
Savannah sparrow		0.538*											
Song sparrow				0.536*									
Red-winged blackbird		0.539**											
Yellow-headed blackbird											0.523*		
Brown-headed cowbird										0.562*			

Note: Only significant correlations are presented: [t-test (two-tailed) for regression coefficients: * = $P < 0.05$; ** = $P < 0.01$; *** = $P < 0.001$].

Table D-9. Correlation Coefficients of Mammal Species Mean Density with Habitat Variables

Species	More Layers	Saturated Soil	Higher Percent Cover of Tall Trees	Higher Percent Cover of Shrub and Low Trees	Conifer Overstory	Aspen Overstory	Willow Overstory	Rose and Snowberry Overstory	Aspen Midstory	Willow Midstory	Rose and Snowberry Midstory	Grasses	Saltgrass	Juncus	Carex
Nuttall's cottontail				0.491*			0.625*								
Black-tailed hare													0.582*		
Least chipmunk															
Lodgepole chipmunk					0.438*				0.514*						
Belding's ground squirrel												0.494*			
California ground squirrel															
Douglas' squirrel	0.555*		0.707***		0.854***	0.889**			0.756**	0.538*	0.764**				
Gopher spp.															
Great Basin pocket mouse								0.587*							
Western harvest mouse		0.541*													
Deer mouse	0.520*													-0.503*	-0.543*
Bushy-tailed woodrat										0.645**					
Montane vole															
Long-tailed vole															
Ermine															

Note: Only significant correlations are presented [t-test (two-tailed) for regression coefficients: * = P < 0.05; ** = P < 0.01; *** = P < 0.001]

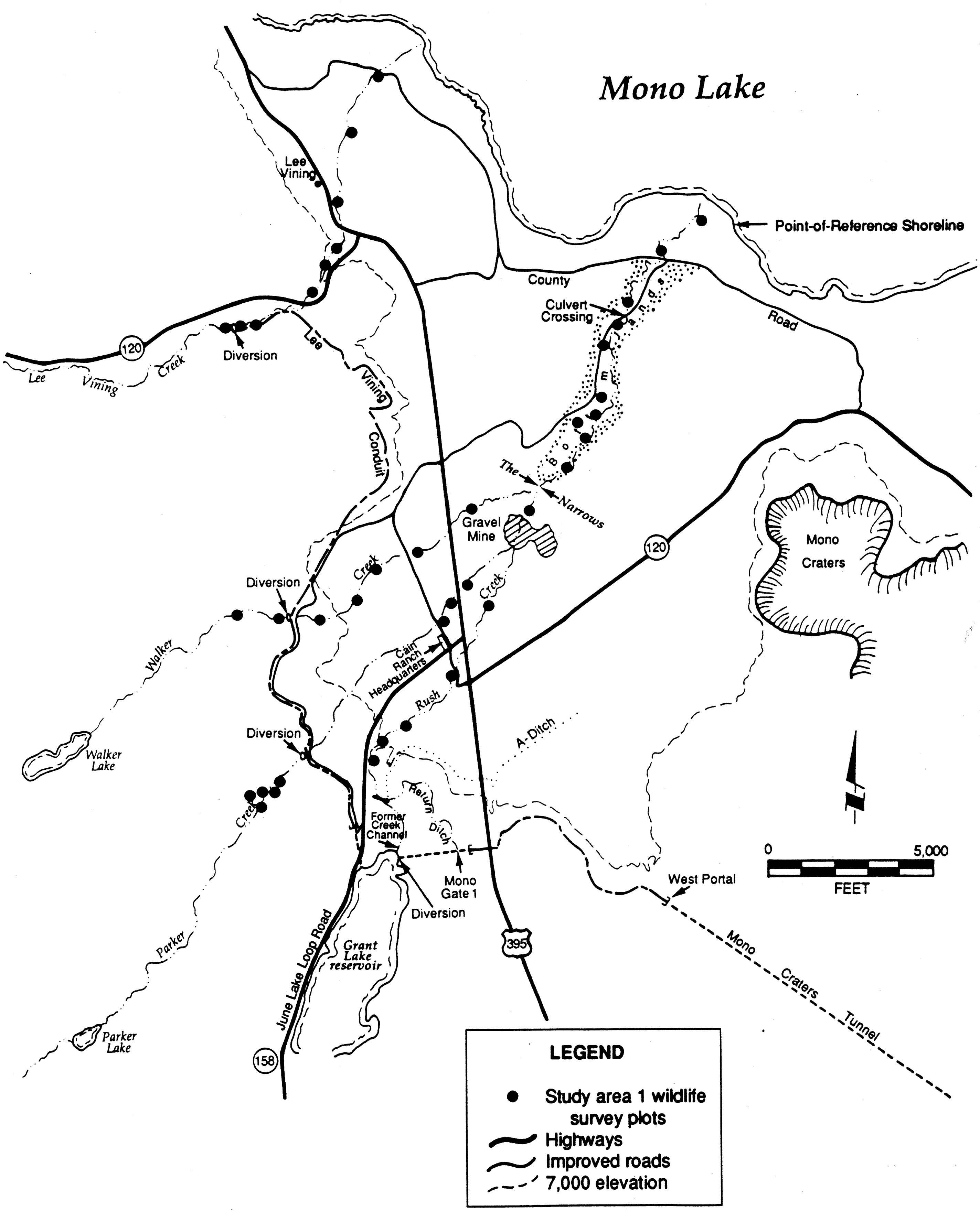


Figure D-1.
Wildlife Survey Plots along Diverted Tributary Streams

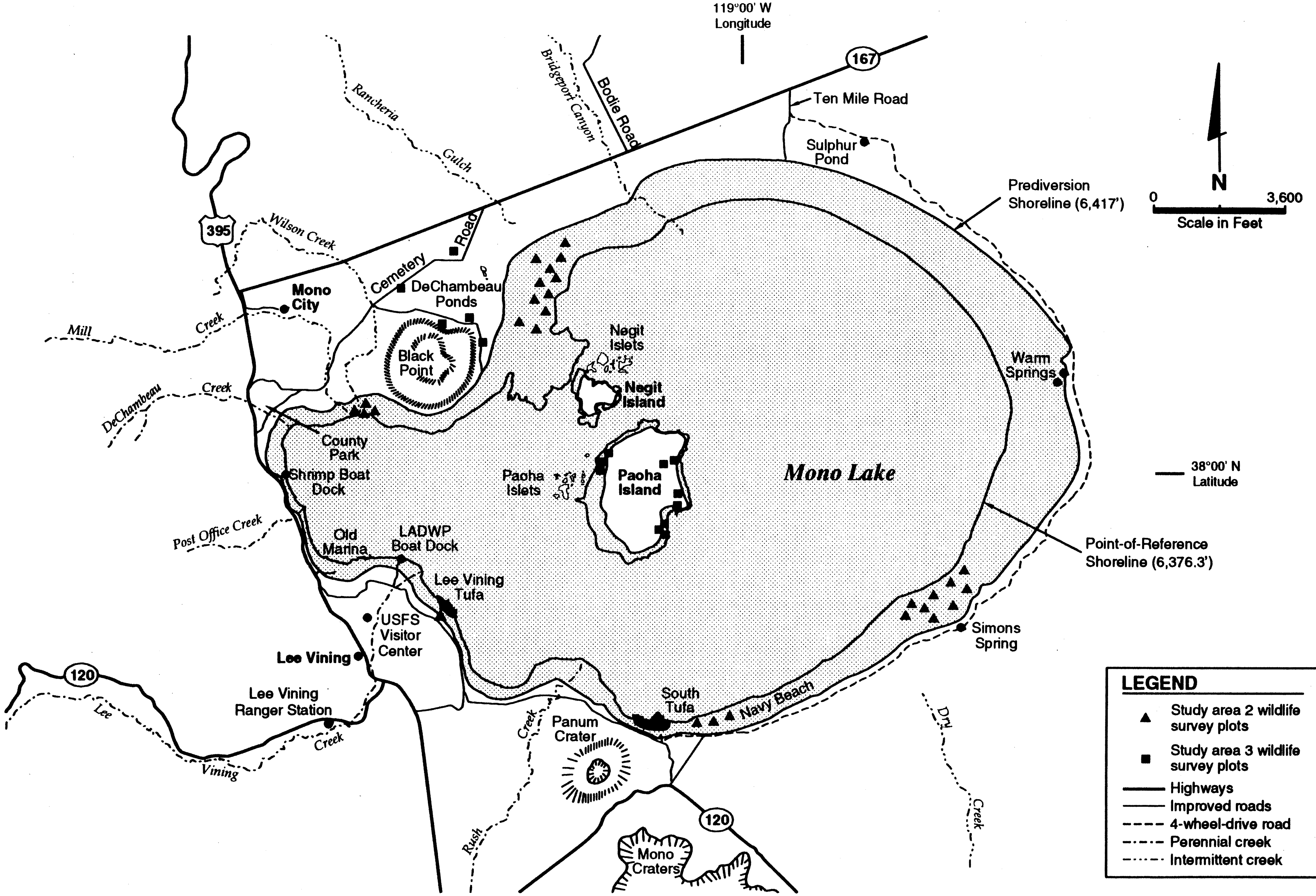
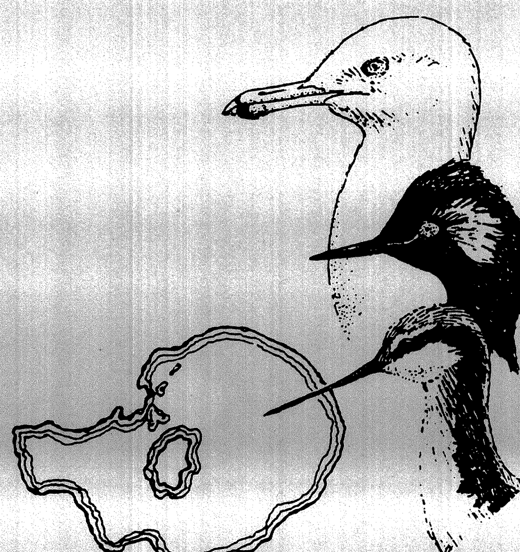


Figure D-2.
Wildlife Survey Plots at Mono Lake

Appendix E. Special-Status Wildlife Species in Mono Basin and Upper Owens River Basin



MONO BASIN EIR

Prepared by Jones & Stokes Associates

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Appendix E. Special-Status Wildlife Species in Mono Basin and Upper Owens River Basin

Thirty-nine special-status wildlife species have been observed or have potential to occur in Mono Basin or along Upper Owens River in Long Valley (the project areas) (Table E-1). This section describes the prediversion status, historical changes during Los Angeles Department of Water and Power (LADWP) water diversions, and the current status of these species. Sources of information consulted include Jones & Stokes Associates 1991 habitat survey data, pertinent literature, California Department of Fish and Game's (DFG's) Natural Diversity Data Base (NDDB), and discussions with knowledgeable individuals.

Special-status species are animals that are legally protected under state and federal Endangered Species Acts or other regulations, and species that are considered sufficiently rare by the scientific community to qualify for such listing. These wildlife types fall into the following categories:

- animals listed or proposed for listing as threatened or endangered under the federal Endangered Species Act (50 CFR 17.11 [listed animals] and various notices in the Federal Register [proposed species]);
- animals that are Category 1 or 2 candidates for possible future listing as threatened or endangered under the federal Endangered Species Act (54 Federal Register 554, January 6, 1989);
- animals listed or proposed for listing by the State of California as threatened or endangered under the California Endangered Species Act (14 CCR 670.5);
- animal species of special concern to the California Department of Fish and Game (Remsen 1978, California Department of Fish and Game 1991 [birds] and Williams 1986 [mammals]);
- animals listed as sensitive by the local U.S. Forest Service region (Forest Service Manual 2670) or U.S. Bureau of Land Management resource area.

Invertebrates

Two special-status invertebrate species occur within the project areas. The Mono Lake brine shrimp is a candidate (Category 1) for federal listing as threatened or endangered due to its unique occurrence at Mono Lake; its status is discussed in more detail elsewhere in this report (Chapter 3E, "Aquatic Productivity").

The Apache silverspot butterfly, which occurs in the project area, has been redesignated by U.S. Fish and Wildlife Service (USFWS) as a Category 3c species and is no longer considered a special-status species (Ngano pers. comm.).

Mono Checkerspot Butterfly

Status: Federal Candidate (Category 2)

The Mono checkerspot is a rare subspecies of the Editha checkerspot (Garth and Tilden 1986). The Mono checkerspot occurs on the east side of the Sierra Nevada, and Mono County is the center of its distribution. Larval food plants include dwarf plantain and several other plant species in the Scrophulariaceae family (Garth and Tilden 1986).

Prediversion Conditions and Changes. The status of the Mono checkerspot prior to diversions is unknown; however, the species was reported as being common prior to the early 1970s (Ngano pers. comm.).

Status at Point of Reference. Rangewide, populations are considered scarce (Garth and Tilden 1986), and the species has not been reported in Mono Basin during the past 20 years (Ngano pers. comm.). Jones & Stokes Associates did not conduct surveys to determine the status of this subspecies; however, no Mono checkerspots or their preferred larval food plants were observed during the 1991 botanical or wildlife surveys.

Amphibians

One special-status amphibian, the Mount Lyell salamander (status: DFG Species of Special Concern, Federal Category 2), occurs at the headwaters of Rush Creek (Natural Diversity Data Base 1991). However, suitable habitat for this species does not occur within the project areas. Mountain yellow-legged frogs and Yosemite toads (both Federal Category 2 Candidates) occur at high elevations of Yosemite National Park, but neither species is known to occur in Mono Basin (Zeiner et al. 1990c).

Birds

Twenty-two of the 27 special-status bird species that have been recorded or potentially occur within the project areas are described in this section. The common loon, double-crested cormorant, and white-faced ibis are not known to nest within the project areas (Gaines 1988). Because the breeding, rather than wintering, areas of these species are considered sensitive (California Department of Fish and Game 1990), they are not addressed in this section. The status of California gulls and snowy plovers at Mono Lake is presented in Chapter 3F.

American White Pelican

Status: DFG Species of Special Concern

American white pelicans winter along the coast and in the Central Valley and formerly nested at large lakes throughout much of California. In California, white pelican nesting areas are now limited to Clear Lake in the Klamath Basin (Zeiner et al. 1990a) and at Honey lake Wildlife Area when water levels are sufficiently high to create nesting islands (Shuford pers. comm.). The loss of nesting colonies is attributed primarily to the destruction of nesting islands and breeding habitat, although human disturbance of colonies and pesticide contamination may also be factors affecting this species.

Prediversion Conditions and Changes. The prediversion status of American white pelicans in the project areas is unknown; however, they probably occurred in the project area during migration (Grinnell and Miller 1944). Numbers of pelicans using the project area may have increased as a result of the construction of Lake Crowley reservoir. White pelicans using Lake Crowley reservoir probably nest at Pyramid Lake in Nevada (Tillemans pers. comm.) and, because the project areas are situated between Lake Crowley reservoir and Pyramid Lake, white pelicans occur regularly in Mono Basin (Jehl and Shuford pers. comms.).

Status at Point of Reference. American white pelicans occur occasionally at Mono Lake and Grant Lake Reservoir (Gaines 1988), but they are common transients at Lake Crowley reservoir (Tillemans pers. comm.). Over 200 pelicans were observed at the DeChambeau ponds in 1984, and over 500 at Lake Crowley reservoir in 1987, using it as a migratory stopover (Gaines 1988). Possibly due to recent drought conditions, approximately 100 nonbreeding white pelicans have summered at Lake Crowley reservoir (Tillemans pers. comm.). Currently, American white pelicans are regular and sometimes common transients through the Owens Valley and Mono Lake and may stay for months at local reservoirs (Jehl pers. comm.). Their numbers in Mono Basin probably vary in direct proportion to the size of the Pyramid Lake colony (Jehl pers. comm.). The number staying to feed in summer and fall has almost surely increased with construction of Lake Crowley reservoir, which has a fish stocking program (Jehl pers. comm.).

Osprey

Status: DFG Species of Special Concern

Ospreys occur as breeding residents and migrants along the east side of the Sierra Nevada. The osprey is piscivorous and requires lakes or large streams that support fish (Zeiner et al. 1990a).

Osprey populations have declined in California since the 1940s because of pesticide contamination, habitat destruction, and disturbance during the breeding season (Remsen 1978). Currently, however, their numbers appear to be increasing in the state (Gould and Jurek 1988).

Prediversion Conditions and Changes. The historical status of ospreys is unknown; however, this species is not known to have nested in Mono Basin prior to the diversion of tributaries (Gaines and Mandelbaum pers. comms.) Thus, ospreys probably have always been uncommon in Mono Basin and Upper Owens River.

In Mono Basin, reduced or discontinued streamflows and channel incision have reduced the quantity and quality of Mono Basin's introduced brown trout fishery (Chapter 3D, "Fisheries Resources"). Therefore, the quality of the stream foraging habitat has been significantly reduced. The created fishery at Grant Lake reservoir, however, may have benefited this species. The nearly total loss of large cottonwood trees on Rush and Lee Vining Creeks below the U.S. Highway 395 crossings (Chapter 3E, "Vegetation") has eliminated potential nesting and perching structures from these areas and may explain why a currently nesting pair selected its tufa tower nesting site near Navy Beach. Jehl (pers. comm.), however, pointed out that rock towers are used by ospreys nesting on the offshore Baja California islands, and for this reason tufa towers should not be considered unusual nest sites for this species.

Osprey have benefited from construction of Lake Crowley reservoir, which created higher quality osprey foraging habitat than previously existed (Tillemans pers. comm.).

Augmentation of flows to Upper Owens River in itself probably has not had a substantial effect on the river's fishery (see Chapter 3D, "Fisheries Resources"). Due to the creation of Lake Crowley reservoir and angler interest, DFG and other organizations have implemented management actions (e.g., stocking the river with fish) that has enhanced Upper Owens River's fishery; therefore, the quality of osprey foraging habitat below East Portal has probably increased since diversions began.

Status at Point of Reference. Ospreys prey on fish and occur as rare summer residents or as transients in both Mono Basin and the Upper Owens River Basin (Gaines 1988).

A pair of ospreys has nested on an exposed tufa tower near Navy Beach every year since 1984, but it is unknown whether the same individuals were present each year (Carle pers. comm.). The nesting ospreys fledged no young from 1984 through 1988; however, in 1989, 1990, and 1992, two young were successfully fledged, and one bird was fledged in 1991 (Carle pers. comm.). These ospreys apparently forage along lower Rush Creek and the lakes near the June Lake Loop. The created fishery at Grant Lake reservoir may have benefited this species.

On Upper Owens River, ospreys are most common in late summer and early fall (Tillemans pers. comm.). The Owens River provides suitable osprey foraging habitat; however, trees suitable for nesting and perching (e.g., large snags and dead-top trees) are lacking along most of the river's course.

Bald Eagle

Status: Federal-Listed Endangered, State-Listed Endangered

Bald eagles winter in both Mono and the Owens River Basins (Gaines 1988). This species generally winters near lakes or large streams and rivers supporting abundant fish, its preferred prey; they also forage on waterbirds and carrion. Large trees or snags adjacent to foraging areas that provide a wide field of view are preferred hunting perches (Zeiner et al. 1990a).

The numbers and distribution of bald eagles breeding in California has declined significantly since the late 1800s (Jurek 1990). Losses are attributed to habitat destruction, hunting, human disturbance, and pesticide contamination. California's bald eagle population is probably recovering as evidenced by a significant increase in the number of occupied bald eagle breeding territories observed since 1970 (Jurek 1990).

Prediversion Conditions and Changes. Prior to diversions of its primary streams (especially larger streams such as Rush Creek), preferred bald eagle habitat was more abundant in Mono Basin, but the status of the bald eagle population at that time is unknown. Reduced or discontinued streamflows and channel incision have reduced the quantity and quality of the basin's fishery (see Chapter 3D, "Fisheries Resources") and stream foraging habitat for bald eagles. The created fishery at Grant Lake reservoir, however, may have benefited this species. The nearly total of loss of large cottonwood trees on Rush and Lee Vining Creeks below the U.S. Highway 395 crossings (see Chapter 3C, "Vegetation") has eliminated potential hunting and resting perches from these areas.

Bald eagles have benefited from construction of Lake Crowley reservoir, which created higher quality bald eagle habitat than previously existed (Tillemans pers. comm.).

Augmentation of flows to Upper Owens River probably had little or no overall effect on the river's fishery (see Chapter 3D, "Fisheries Resources"). Due to the creation of Lake Crowley reservoir and angler interest, DFG and other organizations have implemented management actions (e.g., stocking the river with fish) that has enhanced the Owens River fishery; therefore, the quality of bald eagle foraging habitat below East Portal has probably increased.

Status at Point of Reference. Bald eagles are locally uncommon to common winter residents and transients in both Mono and Owens River Basins (Gaines 1988).

Gaines and Mandelbaum (pers. comms.) observed up to five individual bald eagles in the winter of 1984-1985 roosting and foraging for fish on lower Rush Creek. Bald eagles also forage at Grant Lake reservoir and other freshwater lakes in the basin that support a sufficient fishery (Gaines 1988). Bald eagles may be present in Mono Basin from November through April (Hart and Gaines 1983); they probably leave in years sufficiently cold to freeze lakes and streams, which eliminates access to a favored food source (Gaines and Mandelbaum pers. comm.).

Bald eagles also winter in Upper Owens River valley. Five bald eagles were observed on Upper Owens River in the winter of 1990 and one in 1991 (Tillemans pers. comm.). Eighteen bald eagles were counted in the winter of 1978, 17 in the spring of 1987, and six in the winter of 1991 at Lake Crowley Reservoir (Gaines 1988, Tillemans pers. comm.).

Northern Harrier

Status: DFG Species of Special Concern

Northern harriers occur as a residents, winter residents, and migrants throughout much of the state (Zeiner et al. 1990a). Northern harriers prefer to construct nests on the ground near the edges of marshes or in grasslands; they forage in open habitats and feed primarily on small mammals, birds, reptiles, and amphibians (Zeiner et al. 1990a).

Resident breeding populations have declined throughout most of the state since at least the early 1940s. Conversion of wetland and grassland habitats for agriculture and urban development is thought to be the primary cause for statewide population declines (Remsen 1978).

Prediversion Conditions and Changes. The number of harriers breeding in Mono Basin today is thought to have substantially declined since the LADWP diversions (Remsen 1978). Gaines (1988) attributes population declines to loss of grasslands caused by over-grazing, water diversions, and reservoir and recreational development.

Augmentation of Owens River flows has probably not affected northern harrier population densities or distribution because the vegetation is similar to prediversion conditions (Chapter 3C, "Vegetation").

Status at Point of Reference. A small population of northern harriers nests in Mono Basin (Remsen 1978). Northern harriers occur in the project areas as uncommon summer residents and common winter residents and fall migrants (Gaines 1988). Suitable nesting habitat exists in the extensive marshlands and meadows around the lakeshore. However, the highly saline and saturated soils associated with these habitats make them unattractive to small mammals (Harris pers. comm.), and they are relatively unproductive foraging areas for harriers and other raptors.

Northern harriers are known to nest along Upper Owens River (Gaines 1988). Suitable nesting and foraging habitat for this species is present, and harriers were observed on numerous occasions during 1991 surveys.

Sharp-Shinned Hawk

Status: DFG Species of Special Concern

The sharp-shined hawk occurs as a migrant or winter resident throughout most of California (Zeiner et al. 1990a). Its breeding distribution is poorly documented, and few nesting records exist for the east slope of the Sierra Nevada (Gaines 1988). This species prefers to breed in coniferous or deciduous woodland habitats. Sharp-shinned hawks prey primarily on small birds and forage in wooded or scrub habitats and adjacent open areas (Zeiner et al. 1990a).

The status of the breeding population is unknown but is thought to have declined statewide and has probably been extirpated in some regions (Remsen 1978).

Prediversion Conditions and Changes. Change in population status or distribution of this species is unknown; however, reduction of riparian forest habitats in Mono Basin have resulted in the loss of about 200 acres of potential nesting and foraging habitat (Appendix D).

Augmentation of Owens River flows has probably not affected the sharp-shinned hawk's population or distribution because vegetation is similar to prediversion conditions (Chapter 3C, "Vegetation").

Status at Point of Reference. Sharp-shinned hawks are uncommon to rare and may be present year around in Mono and Upper Owens River Basins (Airola et al. 1980, Gaines 1988).

Sharp-shinned hawk nesting has not been documented in Mono Basin; however, year-long observations of this species indicate some breeding probably occurs (Gaines 1988). Approximately 85 acres of conifer-broadleaf forest, cottonwood-willow woodland, and aspen woodland located primarily along Lee Vining and Rush Creeks upstream from U.S. Highway 395, is potential nesting and foraging habitat for this species (Appendix D).

Riparian willow and mixed scrub habitats and conifer forests in Mono Basin are also potential foraging habitat.

Preferred nesting habitat is absent from Upper Owens River, but willow thickets adjacent to the river channel are potential foraging habitat for this species.

Cooper's Hawk

Status: DFG Species of Special Concern

Cooper's hawks occur throughout most of California. This species prefers to nest in second-growth conifers or broadleaved evergreen forests (Zeiner et al. 1990a). Riparian aspen groves are currently the most important Cooper's hawk breeding habitats in Mono Basin (Shuford pers. comm.). Cooper's hawks forage in broken woodlands and adjacent habitats, and prey primarily on small birds (Zeiner et al. 1990a).

As a breeding species, the Cooper's hawk has declined throughout California and loss of riparian habitats, human disturbance at nest sites, and perhaps pesticide contamination may have contributed to its decline (Remsen 1978).

Prediversion Conditions and Changes. Reduction of riparian forests on Lee Vining and Rush Creeks has resulted in the loss of about 200 acres of potential nesting and foraging habitat in conifer-broadleaf forests, cottonwood-willow woodlands, and aspen woodlands (Appendix D). Cooper's hawks historically nested along lower Rush Creek and are thought to have been extirpated as a nesting species from this area (Gaines and Mandelbaum pers. comms.).

Augmentation of Owens River flows has probably not affected Cooper's hawk population density or distribution because vegetation is similar to prediversion conditions.

Status at Point of Reference. Cooper's hawks are year-long residents in Mono and Upper Owens River Basins (Zeiner et al. 1990a), and nesting Cooper's hawks have been documented in Mono Basin (Gaines 1988). Approximately 25 acres of potential nesting habitat occurs within the project area. One Cooper's hawk was observed foraging near Black Point during the Jones & Stokes Associates 1991 field surveys, but its nesting status was not determined.

Suitable nesting habitat for this species is absent from Upper Owens River project area.

Northern Goshawk

Status: Federal Category 2, DFG Species of Special Concern

Goshawks occur as a breeding and wintering species along the east slope of the Sierra Nevada from Plumas County south to northern Inyo County (Zeiner et al. 1990a). This species is most closely associated with mature conifer forests and prefers to select nest trees in the densest portions of stands located near water (Zeiner et al. 1990a). On the Inyo National Forest, northern goshawks primarily breed in Jeffrey and lodgepole pine forests. Gaines (1988), however, mentioned aspen groves as potential nesting habitat in Mono Basin, and in Great Basin regions of Nevada preferred nest sites are located in dense, mature aspen stands (Herron et al. 1985). Goshawks generally forage in wooded habitats and prey primarily on small mammals and birds (Zeiner et al. 1990a), but they also forage in open, sagebrush scrub in winter (Gaines 1988).

Prediversion Conditions and Changes. Goshawk populations have probably not been significantly affected by water diversions from Mono Basin or augmentation of Upper Owens River since the acreage of aspen habitats in these areas remains almost unchanged from the prediversion period (Chapter 3C, "Vegetation").

Status at Point of Reference. Goshawks are year-long residents and are known to breed in Mono and Upper Owens River Basins (Gaines 1988, Airola ed. 1980). Fragmented forests within the project area appear to be marginal nesting habitat for this species. However, riparian woodlands and shrublands provide potential foraging and roosting habitat for wintering and migrant goshawks.

Swainson's Hawk

Status: State-Listed Threatened

Swainson's hawks are uncommon summer residents and migrants in California where they typically nest in isolated large trees or shrubs within open habitats (Sharp 1986). This species forages in open grasslands, fields, and pastures and preys primarily on small mammals, birds, large insects, reptiles, and amphibians (Zeiner et al. 1990a).

Breeding populations have declined significantly throughout the state and this species has been extirpated from some regions (Sharp 1986). Conversion of grasslands and pasturelands to croplands is thought to be a major factor in the decline of this species, but other possible factors include human disturbance at nest sites, pesticide contamination, and loss of South American wintering habitat (Remsen 1978).

Prediversion Conditions and Changes. The change in Swainson's hawk populations from prediversion conditions in both Mono and Upper Owens River Basins is unknown. Population declines documented in other portions of the state indicate, however, that populations also may have declined in the project areas (Remsen 1978).

Status at Point of Reference. Hart and Gaines (1983) listed the Swainson's hawk as a very rare breeding species in Mono Basin. During the Jones & Stokes 1991 field surveys Swainson's hawks were not observed in the Mono or Upper Owens River Basins. One Swainson's hawk, however, was observed in June 1991 north of Mono Lake at Bridgeport, California.

Gaines (1988) reported that one to two pairs of Swainson's hawks nested along the Owens River. In recent years six to eight pairs of Swainson's hawks have been reported nesting in cottonwood trees or tall willow shrubs in the Upper Owens River Basin (Tillemans pers. comm.).

Golden Eagle

Status: DFG Species of Special Concern

The golden eagle occurs throughout most of California as a resident, migrant, or wintering species (Zeiner et al. 1990a). Golden eagles forage over open terrain and feed primarily on rabbits and rodents (Zeiner et al. 1990a); they have also been reported foraging on nesting gulls at Mono Lake (Jehl pers. comm.). This species nests on cliff faces with suitable ledges or in large trees in open areas (Zeiner et al. 1990a).

Prediversion Conditions and Changes. Golden eagle populations probably have not been significantly affected by water diversions from Mono Basin or augmentation of Upper Owens River. Areas with permanently saturated soils do not support small mammals (Harris pers. comm.); therefore, within Mono Basin, prey populations may have increased on meadows that became drier due to dewatering. However, reduction of riparian forests on Lee Vining and Rush Creeks has resulted in the loss of potential nest and roost sites for this species. Jehl (pers. comm.) surmised that the increase in Mono Lake's gull colony may have benefited this species.

Status at Point of Reference. Golden eagles are permanent residents in Mono and Upper Owens River Basins (Zeiner et al. 1990a). They have been recorded nesting in Mono Basin (Hart and Gaines 1983), and a pair is known to nest in the Rush Creek bottomlands (Banta pers. comm.). A pair of eagles was observed at the mouth of Lee Vining Creek during the Jones & Stokes Associates 1991 field surveys, but the pair's nesting status was not determined.

Peregrine Falcon

Status: Federal-Listed Endangered, State-Listed Endangered

Peregrine falcon populations declined throughout their range in the lower 48 states, primarily due to pesticide contamination (King 1981). During the past two decades, however, restrictions on pesticides and captive breeding programs have allowed peregrine falcon populations to recover in some portions of the United States (Johnsgard 1990).

Peregrines prey primarily on birds and prefer to nest and forage near wetlands, lakes, and rivers (Zeiner et al. 1990a).

Prediversion Conditions and Changes. Peregrine falcons formerly nested near the mouth of Lundy Canyon in Mono Basin (Gaines 1988), and circumstantial evidence indicated that a pair probably nested on Negit Island in 1916 (Dixon 1916). Evidence from feeding sites indicate the pair fed heavily on eared grebes (Grinnell and Storer 1924).

Peregrine falcon populations were unaffected by contamination from chlorinated hydrocarbon pesticides, such as DDT, at the time diversions were initiated (Gaines 1988). Due to their dramatic rangewide declines by the 1960s, however, falcons were probably more common in the Mono and Owens River Basins prior to the diversions than today.

Redistribution of water in both basins has changed the number and distribution of waterbirds, the peregrine falcon's primary prey species. The effects of this change on their prey availability cannot be determined due to historical and current rarity of this species in the project area.

Status at Point of Reference. The peregrine falcon is rare in Mono Basin and occurs as a summer resident or migrant (Gaines 1988). Peregrine falcons were observed along Rush Creek in August and October 1984 (Gaines and Mandelbaum pers. comms.). Jehl (pers. comm.) observes this species approximately once every 2 years and feels their frequency in Mono Basin has probably increased during the past 5 years.

The status of wild peregrine falcons in the Owens River Basin is probably similar to Mono Basin; however, approximately 10 peregrine falcons have been successfully reintroduced at Lake Crowley reservoir, and these birds have fledged 15-20 "hacked" young over the last 3 years (Tillemans pers. comm.). Although nesting is suspected in the Owens River gorge and possibly above Grant Lake reservoir on Rush Creek, no confirmed eyries have been found at either location (Tillemans pers. comm.).

Prairie Falcon

Status: DFG Species of Special Concern

In California, the prairie falcon occurs as an uncommon resident and migrant species closely associated with open habitats (Zeiner et al. 1990a). This species nests on cliff ledges and preys primarily on small mammals (Zeiner et al. 1990a).

Reproductive success of prairie falcons nesting on the periphery of the Central Valley was found to be extremely low during surveys conducted from 1969 to 1972 (Remsen 1978). The cause of poor reproduction is unknown, but pesticide contamination, human disturbance at nest sites, shooting, and collection of young birds by falconers are cited as possibilities (Remsen 1978).

Prediversion Conditions and Changes. Prairie falcons probably have not been significantly affected by the LADWP diversions. Nesting sites for this species (ledges on cliff faces) were unaffected by the diversions and, because prairie falcons forage in many habitat types, it is unlikely that dewatering of Mono Basin or augmentation of flows to Upper Owens River would have reduced the area of available foraging habitat.

Status at Point of Reference. Prairie falcons occur as uncommon residents and migrants in Mono Basin and Upper Owens River (Gaines 1988, Tillemans pers. comm.). East of the Sierra Nevada, prairie falcons forage in meadow and upland scrub habitats and along the edges of Mono Lake and other small lakes and ponds (Gaines 1988).

Sage Grouse

Status: DFG Species of Special Concern

Sage grouse are uncommon residents of Great Basin scrub and meadow habitats east of the Cascade Range and the Sierra Nevada (Zeiner et al. 1990a). Sage grouse require sagebrush for cover and in winter forage almost exclusively on sagebrush (Autenrieth et al. 1982). In other seasons, sage grouse prefer to forage on meadows for forbs and insects (Zeiner et al. 1990a).

Sage grouse populations have declined throughout their range in California. Major factors attributed to population declines include eradication of sagebrush to increase livestock forage, and over-grazing and subsequent deterioration of meadows. Over-hunting and hunting on leks (breeding display sites) in the early part of the century may have contributed to population declines. Human disturbance at active leks can also cause reduced reproductive success (Remsen 1978).

Prediversion Conditions and Changes. Sage grouse were common to abundant in Mono Basin in the 19th century and have since been extirpated from most of the basin (Gaines 1988).

The prediversion status of sage grouse on Upper Owens River is unknown; however, trends throughout the western United States indicate populations probably have declined since the early part of this century (Johnsgard 1973).

Status at Point of Reference. Sage grouse are considered to be a rare breeding species within Mono Basin (Hart and Gaines 1983). One sage grouse was observed in Great Basin scrub habitat on the Cain Ranch during 1991 wildlife surveys.

Sage grouse occur along the length of Upper Owens River and several leks are located near the river's course (Tillemans pers. comm.). Meadows adjacent to the Owens

River would provide forage for this species in late summer and early fall when forbs become an important dietary component (Johnsgard 1973).

Mountain Quail

Status: Federal Category 2

Mountain quail are common to uncommon residents of montane habitats throughout California (Zeiner et al. 1990a). This species inhabits mountainous terrain supporting dense stands of brush and migrates downslope from high elevation areas prior to the first winter snowfalls.

Prediversion Conditions and Changes. The prediversion status of the mountain quail is unknown. Because mountain quail typically occupy dense stands of upland scrub species, this species has probably been largely unaffected by stream diversions in Mono Basin or augmentations to Owens River flows.

Status at Point of Reference. Mountain quail are an uncommon summer resident at higher elevations and a rare winter resident at lower elevations in Mono Basin (Gaines 1988). No mountain quail were observed in Mono Basin during the 1991 surveys. Breeding mountain quail in other parts of the Great Basin, however, are restricted to scrub habitats within walking distances of water (Shuford pers. comm.).

Mountain quail probably make little or no use of Upper Owens River because typical habitats frequented by this species are not present there.

Yellow Rail

Status: DFG Species of Special Concern

Historically, yellow rails wintered at wetlands along the California coast but the state's only confirmed nesting was at a few locations in Mono County (Grinnell and Miller 1944). Their preferred breeding habitat is in freshwater marshes with low, sparse, emergent vegetation (Cogswell 1977).

Prediversion Conditions and Changes. Breeding rails were reported nesting in freshwater wetlands in Long Valley in the early part of this century (Grinnell and Miller 1944). Several yellow rail nests were found near Bridgeport Lake Reservoir, located north of Mono Basin, in the 1930s (Gaines 1988).

Yellow rail populations have declined or the species may have been extirpated from Long Valley since the diversions began (Remsen 1978). The primary reason for these losses, however, is thought to be the degradation of freshwater wetlands caused by grazing although loss of nesting habitat occurred when Lake Crowley reservoir was filled (Remsen 1978).

Status at Point of Reference. Yellow rails are currently considered to be extremely rare transients in Mono Basin and Upper Owens River (Gaines 1988). Surveys conducted in the 1970s failed to locate this species in Long Valley (Remsen 1978); however, Gaines (1988) reported one observation of a yellow rail in a wet meadow at the Mono Lake county park in July 1985. Stream diversions, reductions in spring flows, and grazing reduced the availability of yellow rail habitat in Mono Basin (Gaines and Shuford pers. comms.).

Black Tern

Status: Federal Category 2

Black terns occur at freshwater emergent wetlands during spring and summer in the Central Valley and northeastern plateau area of California. Black terns were formerly common within their range, but numbers in California have been declining primarily due to loss or degradation of wetland habitats (Zeiner et al. 1990a).

Prediversion Conditions and Changes. Prediversion status of black terns is unknown, although Grinnell and Miller (1944) report observations of this species at Mono Lake in the early 1920s.

Status at Point of Reference. Small numbers of migratory black terns regularly visit Mono Basin (Gaines 1988). Gaines (1988) reported a peak count of 12 birds at Mono Lake in 1976.

The status of black terns on the Owens River Valley is probably similar to Mono Basin. This species has been observed at Lake Crowley reservoir (Gaines 1988). However, because suitable habitat is not present, it is unlikely the species would occur on Upper Owens River.

Because black terns do not nest in the project areas and occur only as migrants through Mono and Upper Owens River Basins (Gaines 1988), it is unlikely the status of this species has been affected by diversions.

Long-Eared Owl

Status: DFG Species of Special Concern

Long-eared owls occur in California as uncommon residents or winter visitors. They require riparian forests or thickets for nesting and roosting and prefer to forage in open habitats where they prey primarily on small rodents and occasionally birds (Zeiner et al. 1990a). Although riparian thickets adjoining meadow foraging grounds are this species' primary nesting habitats in California, long-eared owls also breed in conifer and broadleaved evergreen forests. Productive foraging areas with suitable nest sites nearby are probably their key elements of habitat selection (Shuford pers. comm.).

Population declines were noted in the 1940s, and the owl may have been extirpated from some portions of its historic range (Remsen 1978). The cause for this species' decline is not fully understood, although loss of low elevation riparian habitats throughout the state may be a major factor (Remsen 1978).

Prediversion Conditions and Changes. Long-eared owls are considered uncommon east of the Sierra Nevada; however, their numbers may have been higher in the early part of this century. In Mono Basin, seven pairs were reported to have bred along Walker Creek in 1916 (Grinnell and Storer 1924). Gaines (1988) cites water diversions and conversion of woodlands to pasture as possible causes for this species' current rarity on Walker Creek. Gaines and Mandelbaum (pers. comms.) considered the long-eared owl to have been a rare nesting species on lower Rush Creek prior to diversion and as having been extirpated as a nesting species in this area by 1985. A total of about 200 acres of potential roosting and nesting habitat has been lost in Mono Basin since diversions began (Appendix D).

Prediversion habitat conditions on Upper Owens River for this species are similar to those observed today.

Status at Point of Reference. Long-eared owls are an uncommon breeding and rare wintering species on the east side of the Sierra Nevada (Gaines 1988). At Mono Lake, long-eared owls have nested in dense stands of buffaloberry near Simon's Spring (Gaines 1988). Approximately 85 acres of potential nesting and roosting habitat currently exist along diverted tributary streams.

Long-eared owls also occur on Upper Owens River and their status is probably similar to Mono Basin (Tillemans pers. comm.). Approximately 4 acres of riparian willow scrub provides potential nesting and roosting habitat for this species on Upper Owens River, which represents a loss of about 12 acres from the prediversion period.

Short-Eared Owl

Status: DFG Species of Special Concern

In California, short-eared owls occur as uncommon residents or winter migrants in suitable grasslands and wetlands (Zeiner et al. 1990a). This species prefers to nest and roost in dense herbaceous vegetation and forages for small mammals, birds, reptiles, and other prey items in open habitats (Zeiner et al. 1990a).

Breeding populations of this species have declined throughout California and have been extirpated from some localities. The major factor attributed to declining nesting populations are conversion of wetland and grassland habitats for agricultural uses and deterioration of these habitats due to over-grazing (Remsen 1978).

Prediversion Conditions and Changes. The prediversion status of this species is unknown; however, Grinnell and Miller (1944) report records of nesting in 1934 at June Lake in Mono Basin and in 1943 at Lake Crowley reservoir. Short-eared owls may have been extirpated as a breeding species on the east slope of the Sierra Nevada (Gaines 1988).

Populations of short-eared owls in Mono Basin are thought by some to have declined significantly (Gaines 1988, Remsen 1978). Potential short-eared owl roosting, nesting, and foraging habitat in Mono Basin (e.g., alkali meadows, dry meadows, wet meadows, and marshlands) has increased by about 4,500 acres since diversions began (Appendix D). The relatively low prey densities of these highly saline wetlands, however, probably reduces their attractiveness to short-eared owls and other raptors.

Short-eared owl populations on Upper Owens River probably have declined as indicated by general declines in this species' populations on the east side of the Sierra Nevada (Gaines 1988). Prediversion habitat conditions on Upper Owens River for this species are similar to those observed today.

Status at Point of Reference. Short-eared owls are considered a rare summer visitor and fall transient in Mono Basin and Upper Owens River (Gaines 1988). Gaines (1988) reported only four observations of short-eared owls in Mono Basin between 1976 and 1986. No short-eared owls were observed during 1991 surveys; however, approximately 5,000 acres of potential foraging, nesting, and roosting habitat currently occurs within the basin.

The status of short-eared owls on Upper Owens River is probably similar to Mono Basin (Tillemans pers. comm.). Short-eared owls were not observed during 1991 surveys; however, potential foraging, nesting, and roosting habitat for this species occurs in irrigated pastures of the Upper Owens River.

Willow Flycatcher

Status: State-Listed Endangered, USFS Sensitive Species

Willow flycatchers nest and roost in dense willow thickets and forage over meadows or water bordering willows (Zeiner et al. 1990a). Their numbers and distribution have declined throughout most of California, and most summer resident populations now occur only in the Sierra Nevada (Harris et al. 1988). Population declines have been attributed to loss of willow habitat, brown-headed cowbird nest parasitism, and heavy grazing of willows (Remsen 1978, Harris et al. 1988, Sanders and Flett 1989).

Prediversion Conditions and Changes. Grinnell and Storer (1924) reported this species' occurrence in the vicinity of Mono Lake. Although prediversion status of willow flycatchers is unknown, willow flycatchers were probably more common in Mono Basin prior to the diversions (Gaines 1988). Reduced or discontinued streamflows and spring flows, and channel incision caused by the diversions have reduced the quantity and quality of willow-meadow habitats associated with affected streams. Other factors, such as brown-headed cowbird nest parasitism and hedging of willows by livestock, may also have adversely affected willow flycatchers throughout their range in California (Sanders and Flett 1989). Approximately 92 acres of potential montane meadow habitat has been lost within the basin since diversions began.

The acreage and distribution of willows on Upper Owens River has changed little since augmentation of flows, and populations of willow flycatchers probably have not been affected by the project. However, hedging of willows by livestock and brown-headed cowbird nest parasitism may have reduced the quality of habitat for this species (Sanders and Flett 1989).

Status at Point of Reference. The willow flycatcher is a locally rare summer resident in Mono Basin and along Upper Owens River (Gaines 1988).

In Mono Basin, a territorial male was observed near the LADWP diversion on Lee Vining Creek in July 1986 (Natural Diversity Data Base 1991). Gaines and Mandelbaum (pers. comms.) reported in 1985 that willow flycatchers may have been extirpated as a breeding species on lower Rush Creek. One willow flycatcher was observed in riparian willow scrub habitat on upper Parker Creek during the Jones & Stokes field survey, but it was not present in subsequent surveys, suggesting that it did not breed in the area. Approximately 500 acres of potential willow flycatcher habitat occurs within Mono Basin project areas, but these are unoccupied by nesting birds.

Willow flycatchers have been reported to occur in suitable habitat on Upper Owens River (Tillemans pers. comm.), but none were observed during 1991 surveys of this area. Approximately 3.7 acres of potential willow flycatcher habitat was mapped on the Upper Owens River. Willows do not occur on Upper Owens River downstream from the Arcularius Ranch. Because willows on the Upper Owens River have declined by about 12 acres during the diversion period, less habitat is currently available for nesting willow flycatchers and most of the remaining acreage is in poor condition and probably would not support this species. In this area, willows occur as scattered clumps of mature or decadent plants that have been hedged by cattle. Even if this habitat acreage were restored, however, it is unlikely that willow flycatchers would breed there because the presence of livestock would continue to promote nest parasitism of this species by brown-headed cowbirds (Sanders pers. comm.).

Bank Swallow

Status: State-Listed Threatened

Bank swallows occur as uncommon migrants and locally as uncommon summer residents in California (Zeiner et al. 1990a). Inland bank swallow populations nest in cavities excavated in vertical banks or cliffs adjacent to, and formed by, streamcourses (Zeiner et al. 1990a).

Bank swallows have been extirpated from as much as 50% of their former range in California (Humphrey and Garrison 1986). The primary factor related to this species' decline is the loss of nesting banks and cliffs resulting from bank protection and other river control practices in the Central Valley (Remsen 1978); such activities have not occurred in Mono Basin or on Upper Owens River.

Prediversion Conditions and Changes. The status of bank swallow populations prior to diversions is unknown in Mono and Upper Owens River Basins due to a lack of historical records (Gaines 1988).

Potential bank swallow nesting habitat may have increased on lower Rush Creek since diversions began. Dropping lake levels coupled with periods of high flows in the late 1960s severely incised lower Rush Creek, creating extensive cliff faces that, depending on the type of substrate exposed, may be suitable for nesting.

Status at Point of Reference. Gaines (1988) considered the bank swallow as a rare migrant in Mono Basin; however, an active nesting colony was located near DeChambeau ponds in 1986 (Natural Diversity Data Base 1991). No bank swallows were observed there during 1991 wildlife surveys.

Bank swallows are a rare transient along Upper Owens River; however, Gaines (1988) reported a nesting colony of approximately 2,000 individuals at Lake Crowley reservoir. This colony is still active, but its current size is unknown (Tillemans pers. comm.).

Loggerhead Shrike

Status: Federal Category 2

Loggerhead shrikes occur throughout much of California and are common residents and winter visitors. This species occupies open terrain that supports scattered shrubs, trees, or fence posts for perches (Zeiner et al. 1990a).

Prediversion Conditions and Changes. The prediversion status of the loggerhead shrike is unknown; however, Grinnell and Miller (1944) described this species as common east of the Sierra Nevada. Loggerhead shrikes typically occupy open terrain, such as sparse sagebrush scrub and pinion-juniper woodland habitats (Zeiner et al. 1990a); therefore, the species probably has been largely unaffected by stream diversions.

Status at Point of Reference. Loggerhead shrikes are an uncommon summer and rare winter species in Mono Basin (Gaines 1988). Loggerhead shrikes were infrequently observed in Great Basin scrub and alkali dry meadow habitats in Mono Basin during the 1991 surveys.

The status of the loggerhead shrike in Upper Owens River Basin is probably similar to Mono Basin although, within the project area, habitats preferred by this species are lacking.

Virginia's Warbler

Status: DFG Species of Special Concern

Virginia's warblers occur as rare, irregular summer residents or migrants on the east slope of the southern Sierra Nevada (Gaines 1988, Zeiner et al. 1990a). Only a few nesting records for this species, which inhabits open woodland and riparian habitats, have been reported in California (Remsen 1978, Zeiner et al. 1990a).

Prediversion Conditions and Changes. Prediversion status of Virginia's warbler populations in Mono Basin and on Upper Owens River is unknown; however, because this species currently occurs only irregularly and in small numbers in California, it is unlikely Virginia's warblers have been significantly affected by the LADWP diversions.

Status at Point of Reference. Virginia's warblers have been observed irregularly in Mono Basin. Gaines (1988) reported observations of three singing males in upper Lee Vining Canyon in 1975, and one in 1976 and one in 1985 from Mono Lake.

Observations have not been reported from along Upper Owens River; however, its occurrence is probably irregular and similar to that reported for Mono Basin.

Yellow Warbler

Status: DFG Species of Special Concern

The yellow warbler occurs as a summer resident throughout much of California and it breeds in riparian woodland and shrub habitats (Zeiner et al. 1990a).

The distribution and number of yellow warblers in California have declined significantly in recent decades. The primary factors affecting this decline include losses of riparian habitat and nest parasitism by brown-headed cowbirds (Remsen 1978). Brown-headed cowbird populations have expanded significantly with development of lands for agricultural and livestock production (Gaines 1988, Zeiner et al. 1990a).

Prediversion Conditions and Changes. Prediversion status of yellow warblers is largely unknown; however, Grinnell and Storer (1924) reported yellow warblers as a common summer resident in the Mono Lake area.

Within Mono Basin, reduced or discontinued streamflows and spring flows and channel incision have reduced the quantity and quality of riparian woodland and shrub habitats associated with affected streams. Approximately 200 acres of mature cottonwood-willow woodlands habitat has been lost since diversions began (Appendix D). Because riparian habitat was more extensive and cowbirds less common than today, yellow warbler populations were probably larger in Mono Basin prior to the diversions.

Yellow warbler numbers may have declined on Upper Owens River due to increases in brown-headed cowbird populations. However, the acreage and distribution of willow on Upper Owens River is unchanged, and populations of yellow warblers probably have not been affected by augmented streamflows in this area.

Status at Point of Reference. Yellow warblers are common summer residents on the east slope of the Sierra Nevada (Gaines 1988).

In Mono Basin, yellow warblers were uncommon to common in riparian woodland and shrub habitats surveyed in 1991. Yellow warblers have been reported nesting in Lee Vining Canyon, Walker Creek, and the Mono Lake County Park (Gaines 1988). Gaines and Mandelbaum (pers. comms.) reported yellow warblers absent as a nesting species on lower Rush Creek in 1985; however, the species was frequently encountered during the 1991 nesting season. No nests were found, but the persistence of territorial males in this area suggested that breeding there was likely. Approximately 290 acres of potential yellow warbler nesting habitat in conifer-broadleaf forest, cottonwood-willow woodland, and riparian willow scrub are present within Mono Basin project areas (Appendix D). However, yellow warbler populations were probably larger in Mono Basin prior to diversions than today because riparian habitats were more extensive and brown-headed cowbirds were less common.

Yellow-Breasted Chat

Status: DFG Species of Special Concern

The yellow-breasted chat was once a fairly common summer resident of riparian woodlands throughout California (Grinnell and Miller 1944).

Changes from Prediversion Conditions. Currently, this species is rare or absent from much of its former breeding range in the state, including Mono Basin, due to destruction of riparian habitats, and possibly other factors such as parasitism by brown-headed cowbirds (Remsen 1978).

Status at Point of Reference. Yellow-breasted chats were not observed in Mono Basin during the 1991 field surveys (Appendix D) but a singing male was reported near the shrimp plant in 1976 (Winkler pers. comm.). A single individual was also observed in riparian habitat on the Arcularius Ranch in 1991 (Appendix D), suggesting that small numbers probably continue to migrate through the western Great Basin. Currently, only about 4 acres of suitable riparian nesting habitat exist for this species along the Upper Owens River. The extent of the yellow-breasted chat's preferred cottonwood-willow breeding habitat was reduced by about 200 acres in Mono Basin during the diversion period (Appendix D), which probably had adverse effects on this species.

Approximately 3.7 acres of riparian willow scrub habitat occurs on Upper Owens River, mostly upstream from East Portal. Riparian woodland habitats are not present on Upper Owens River, and willows do not occur below the Arcularius Ranch. Observations of territorial male yellow warblers on the Arcularius Ranch in 1991 suggest this species nests there; however, suitable riparian habitat for this species is limited.

Mammals

Nine special-status species of mammals occur or could occur within the project areas (Table E-1). The Sierra Nevada red fox and California wolverine would not be affected by the diversions or proposed alternatives because preferred habitats are located at elevational zones outside of the affected area (Harris 1991). Sensitive roosting habitats (e.g., caves, rock crevices, and mine tunnels) for the spotted bat and Townsend's big-eared bat would not be affected by the diversions or proposed alternatives (Harris pers. comm.).

Inyo Shrew

The Inyo shrew is not considered a special-status species throughout its California range; however, within Mono Basin, it is considered to be locally rare (Harris pers. comm.).

The Inyo shrew occurs on the east side of the Sierra Nevada in Mono and Inyo Counties. This species prefers riparian habitats although it may occur in pinon-juniper forest or Great Basin scrub habitats (Zeiner et al. 1990b).

Changes from Prediversion Conditions. Effects of diversions on this species are unknown; however, loss of riparian vegetation on Lee Vining and Rush Creeks may have reduced the amount of potential habitat available for Inyo shrews.

Status at Point of Reference. The status of this species in Mono and Upper Owens River Basins is unknown; however, it is presumed to be rare (Harris 1982). Zeiner et al. (1990b) excludes Mono Basin from this species' range; however, Harris (1982) reported an occurrence of this shrew near Lee Vining. An occurrence of Inyo shrews at the Mono Lake County Park was also recorded in 1988 (Harris pers. comm.).

Pygmy Rabbit

Status: Federal Category 2, DFG Species of Special Concern

Pygmy rabbits are associated with Great Basin scrub habitats and occur in northeastern California and Mono County (Williams 1986). Preferred habitat for this species includes dense stands of big sagebrush, rabbitbrush, and greasewood (Harris 1991). Big sagebrush is the primary forage for the pygmy rabbit, although grasses and forbs are consumed during some periods of the year (Zeiner et al. 1990b).

The status of pygmy rabbit populations is unknown; however, their distribution is limited and patchy within their geographic range (Williams 1986). A preference for the densest patches of Great Basin scrub within larger stands of sagebrush may account for the spotty distribution of this species (Harris pers. comm.).

Prediversion Conditions and Changes. The prediversion status of pygmy rabbit populations is unknown; however, populations probably have not been significantly affected by the diversions in Mono Lake or Owens River Basins (Harris 1991). Upland habitats preferred by this species remained either stable or increased slightly as a result of dewatering.

Status at Point of Reference. Pygmy rabbits occur in the Mono Basin project area and the Upper Owens River Basin (Harris 1982, Zeiner et al. 1990b).

Within Mono Basin, pygmy rabbits were observed at several locations. They have been observed in riparian scrub habitats adjacent to Mono Lake; however, riparian scrub is probably not required for this species (Harris 1991).

Pygmy rabbit occurrence in the Upper Owens River Basin is probably similar to that described for Mono Basin (Harris pers. comm.).

White-Tailed Hare

Status: DFG Species of Special Concern

In California, the white-tailed hare is a resident of the east slope of the Sierra Nevada (Zeiner et al. 1990b). This species is associated primarily with upland habitats and feeds on grasses, forbs, and buds, bark, and twigs of shrubs (Zeiner et al. 1990b).

White-tailed hare populations have declined significantly throughout their range. Declines are attributed to changes in the quantity and quality of habitat caused primarily by livestock grazing and to competition with expanding black-tailed hare populations (which may have been triggered by grazing) (Harris 1982, Williams 1986).

Prediversion Conditions and Changes. The prediversion status of white-tailed hares is unknown; however, they probably have not been significantly affected by changes in flow regimes in Mono or Owens River Basins. Upland habitats preferred by this species probably have remained either stable or increased slightly as a result of dewatering; however, dewatering may have resulted in some loss of potential foraging meadows in Mono Basin.

Status at Point of Reference. White-tailed hares occur in the Mono Basin project area and the Upper Owens River Basin (Harris 1982; Zeiner et al. 1990b).

On the eastern slope of the Sierra Nevada, this species' summer range extends above 8,000 feet in elevation. White-tailed hares occur in the project area primarily in winter and spring. Among the wetland and riparian habitats inventoried in 1991, meadows are probably the most important for this species (Harris 1991).

White-tailed hares are probably more common in the Upper Owens River Basin than in the Mono Basin (Harris pers. comm.).

Mountain Beaver

Status: Federal Proposed Endangered

In California, the mountain beaver occurs in the Sierra Nevada, as well as the Cascade and Klamath Ranges. This species is associated with dense, moist riparian thickets and feeds on a variety of forbs, shrubs, and twigs (Harris 1991). Mountain beavers occur in Mono Basin, but are not known to occur on Upper Owens River (Zeiner et al. 1990b, Tillemans and Harris pers. comms.).

Prediversion Conditions and Changes. The prediversion status of mountain beavers in the project areas is unknown. In Mono Basin, reduced or discontinued streamflows and spring flows and channel incision have reduced the quantity and quality of riparian woodland and scrub habitats associated with affected streams. Approximately 188 acres of potential mountain beaver habitat has been lost in cottonwood-willow habitats (Table 3F-7). Loss of riparian vegetation linking lakeside riparian habitat to suitable habitat at higher elevations may have been a factor in isolating this population (Harris 1991).

The acreage and distribution of potential mountain beaver habitat on Upper Owens River has probably not changed with augmentation of flows.

Status at Point of Reference. The status of the population around Mono Lake is unknown; however, mountain beavers at Mono Lake appear to be geographically isolated from other populations. Harris (1991) reported five observations of this species in Mono Basin from 1976 to 1990. These sightings were associated with thickets of willow or mixed scrub habitats adjacent to springs or streams. Approximately 300 acres of potential mountain beaver habitat currently exists in riparian scrub areas of Mono Basin.

Approximately 3.7 acres of potential habitat for this species is located on Upper Owens River, most of which occurs above East Portal.

American Badger

Status: DFG Species of Special Concern

The badger's range extends throughout California, except the extreme northwestern coastal areas (Zeiner et al. 1990b). Badgers occur in a variety of habitats; however, a sufficient food supply, friable soils for burrowing, and relatively open and uncultivated areas appear to be primary requirements (Williams 1986). Badgers are carnivorous, feeding primarily on burrowing rodents.

Badger populations and distribution have declined significantly in California over the last century and the chief causes are thought to be habitat loss due to development of urban and agricultural lands, poisoning of prey populations, and badger control programs (Williams 1986).

Prediversion Conditions and Changes. Prediversion status of badger populations in Mono Basin and Upper Owens River is unknown; however, populations probably have not been significantly affected by the diversions.

In Mono Basin, prey populations may have increased in meadows that became drier. Upland habitats preferred by this species probably have remained either stable or increased slightly as a result of dewatering.

Status at Point of Reference. Badgers occur in Mono Basin project area and the Upper Owens River Basin (Harris 1982; Zeiner et al. 1990b).

On east slope of the Sierra Nevada, preferred habitat includes perennial grasslands and low canopy stages of sagebrush and bitterbrush (Harris 1991). Badgers occur in Mono Basin from the lakeshore up to 10,000 feet in elevation (Harris 1982). Within the project area, meadows supporting populations of ground squirrels or pocket gophers would provide suitable badger foraging habitat (Harris 1991).

Badgers are common in the Upper Owens River Basin (Tillemans pers. comm.), and habitat preferences are probably similar to that described for Mono Basin.

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Table E-1. Special-Status Wildlife Species Occurring or Having the Potential to Occur in the Mono Lake Basin or Upper Owens River Areas

Species	Status[a] Federal/State	Habitat	Distribution
Invertebrates			
Mono brine shrimp *Artemia monica*	C1/--	Permanent hypersaline water	Known only from Mono Lake
Mono checkerspot *Euphydryas editha monoensis*	C2/--	Associated with riparian habitats	East side of the Sierra Nevada; distribution centered in Mono County
Amphibians			
Mount Lyell salamander *Hydromantes platycephalus*	C2/SSC	Uses granite crevices high in the Sierra Nevada associated with grasses, alpine willow (*Salix anglorum*), heather (*Phyllodoce brewerii*), and scrubby white-bark pine (*Pinus albicaulis*)	Found along the crest of the Sierra Nevada from Sonora Pass south to Twin Lakes and Sillimon Gap in Sequoia National Park
Birds			
Common loon *Gavia immer*	--/SSC	Large bodies of deep water with a healthy fish population	Primarily winters in California, but an occasional year-round resident; found along the coast and large inland bodies of water
American white pelican *Pelecanus erythrorhynchos*	--/SSC	Uses freshwater lakes with islands for breeding; inhabits river sloughs, freshwater marshes, salt ponds, and coastal bays the rest of the year	The largest nesting colony is at Great Salt Lake; winters along the California coast from southern Sonoma County south to San Diego County, the Salton Sea, and Mexico, inland from the San Francisco Bay through the Delta region, and areas in King, Kern, Riverside, and Imperial Counties; summers in Plumas, Modoc, and Siskiyou Counties
Double-crested cormorant *Phalacrocorax auritus*	--/SSC	Uses rocky coastlines, beaches, inland ponds, and lakes; needs open water for foraging, and nests in riparian forests or on protected islands	Winters along the entire California coast and inland over the Coast Ranges and over the Northcoast Range into the Central Valley from Tehama to Fresno Counties; a permanent resident along the coast from Monterey to San Diego Counties, along the Colorado River, Imperial, Riverside, Kern, and King Counties, and the islands off of San Francisco; summers in Siskiyou, Modoc, Lassen, Shasta, Plumas, and Mono Counties; also breeds in the San Francisco Bay Area and in Yolo and Sacramento Counties

Table E-1. Continued

Species	Status[a] Federal/State	Habitat	Distribution
White-faced ibis *Plegadis chichi*	C2/SSC	Prefers freshwater marshes with tules, cattails, and rushes, but may nest in trees and forage in flooded agricultural fields	Found as resident and winter populations on the Salton Sea, as well as isolated areas in Imperial, San Diego, Ventura, and Fresno Counties; breeds at Honey Lake in Lassen County and near Woodland in Yolo County; winters in Merced County and along the Sacramento River in Colusa, Glenn, Butte, and Sutter Counties
Osprey *Pandion haliaetus*	--/SSC	Nests in snags or cliffs near the ocean, large lakes, or rivers with abundant fish populations	Nests along the north coast from Marin to Del Norte Counties, east through the Klamath and Cascade Ranges, and the northern tip of the Sacramento Valley; important breeding population at Lake Almanor, Plumas County, and small numbers elsewhere in Plumas, Butte, Yuba, Tuolumne, and Madera Counties; also nests at Lake Tahoe, Mono Lake in Mono County, Tinnemaha Lake in Inyo County, and Lake Isabella in Kern County; winters along the coast from San Mateo to San Diego Counties
Bald eagle *Haliaeetus leucocephalus*	E/E	In western North America, nests and roosts in coniferous forests within 1 mile of a lake, reservoir, river, or the ocean	Nests in Siskiyou, Modoc, Trinity, Shasta, Lassen, Plumas, Butte, Tehama, Lake, and Mendocino Counties and in the Lake Tahoe Basin; winter range includes the rest of California except the southeastern deserts, very high altitudes in the Sierra, and east of the Sierra south of Mono County
Northern harrier *Circus cyaneus*	--/SSC	Uses marshes, meadows, and seasonal and agricultural wetlands	Found as either a permanent or winter resident over all of California, except in the Klamath, Cascade, and Sierra Nevada Ranges
Sharp-shinned hawk *Accipiter striatus*	--/SSC	Uses dense canopy ponderosa pine or mixed conifer forest as well as riparian habitats	Found as permanent resident in the Sierra Nevada, Cascade, Klamath, and Northcoast Ranges at mid-elevations, as well as along the coast in Marin, San Francisco, San Mateo, Santa Cruz, and Monterey Counties; winters over the rest of the state except very high elevations

Table E-1. Continued

Species	Status[a] Federal/State	Habitat	Distribution
Cooper's hawk *Accipiter cooperi*	--/SSC	Nests primarily in riparian forests dominated by deciduous species; also nests in densely canopied forests from digger pine-oak woodland up to ponderosa pine; forages in open woodlands	Found in all parts of California except high altitudes in the Sierra Nevada; winters in the Central Valley, southeastern desert regions, and plains east of the Cascade Range; permanent residents occupy the rest of the state
Northern goshawk *Accipiter gentilis*	C2, FS/SSC	Nests in red fir, Jeffrey pine, and lodgepole pine forests	Found as permanent resident on the Klamath and Cascade Ranges, the Northcoast range from Del Norte to Mendocino Counties, and the Sierra Nevada range south to Kern County; winters in Modoc, Lassen, Mono, and northern Inyo Counties
Swainson's hawk *Buteo swainsoni*	--/T	Nests in oaks or cottonwoods in or near riparian habitats; forages in grasslands, irrigated pastures, and grain fields	Uses the lower Sacramento and San Joaquin Valleys, the Klamath Basin, and Butte Valley; most nesting occurs in Yolo County
Golden eagle *Aquila chrysaetos*	--/SSC	Nests on cliffs, escarpments, or large oaks; forages over annual grasslands	Found as permanent resident over most of California; only uses high altitude areas in the Sierra Nevada in summer and the Central Valley only in winter
American peregrine falcon *Falco peregrinus anatum*	E/E	Nests and roosts on protected ledges of high cliffs, usually adjacent to lakes, rivers, or marshes that support large populations of birds	Found as permanent resident on the Northcoast and Southcoast Ranges; may summer on the Cascade and Klamath Ranges south through the Sierra Nevada to Madera County; winters in the Central Valley south through the Transverse and Peninsular Ranges and the plains east of the Cascade Range
Prairie falcon *Falco mexicanus*	--/SSC	Nests on cliffs or escarpments adjacent to dry, open terrain, uplands, marshes, or seasonal agricultural wetlands	Found as permanent resident on the Southcoast, Transverse, Peninsular, and northern Cascade Ranges; the southeastern deserts; Inyo-White mountains, Modoc, Lassen, and Plumas Counties; and the foothills surrounding the Central Valley; winters in the Central Valley; along the coast from Santa Barbara to San Diego Counties; and in Marin, Sonoma, Humboldt, Del Norte, and Inyo Counties

Table E-1. Continued

Species	Status[a] Federal/State	Habitat	Distribution
Sage grouse *Centrocercus urophasianus*	--/SSC	Dependent on sage-brush (*Artemisia tridentata*) for food and cover; restricted to flat plains or rolling hills	Occupies the plains east of the Cascade Range and the eastern Sierra from Alpine to northern Inyo County
Mountain quail *Oreortyx pictus*	C2/--	Montane scrublands supporting dense shrub cover	Permanent resident in most California mountain ranges
Yellow rail *Coturnicops noveboracensis*	--/SSC	Found from freshwater marshlands to brackish marshes and coastal saltmarshes	Historical nests in Mono County east of the Sierra Nevada and formerly Marin County on the coast; winter records also on the coast from Humbolt to Orange Counties
Black tern *Chlidonias niger*	C2/--	Freshwater emergent wetlands	Found as spring and summer resident in the Central Valley and northeastern plateau areas of California
Western snowy plover *Charadrius alexandrius nivosus*	C2/SSC	Found on coastal beaches above the normal high tide limit, inland shores of salt ponds, and alkali or brackish inland lakes	Nests at inland lakes, including Mono Lake and salt evaporation ponds in the San Joaquin Valley, throughout northwestern, central, and southern California; winters along the coast from Del Norte to San Diego Counties, with some areas supporting permanent populations
California gull *Larus californicus*	--/SSC	Forages in a variety of habitats, including beaches, mudflats, freshwater and alkali marshes, rivers, lakes, and urban areas; nests colonially on islands isolated from mainland predators	Winters along the Pacific coast from British Columbia to Mexico; in the interior of California, it frequents the Sacramento River Delta and Central Valley, the plains east of the Cascade Range, northern Plumas and southwestern Mono Counties, the Lake Tahoe Basin, the Transverse and Peninsular ranges, and the Salton Sea; nests at Great Basin lakes and at South San Francisco Bay; largest California breeding colony is at Mono Lake

Species	Status[a] Federal/State	Habitat	Distribution
Long-eared owl *Asio otus*	--/SSC	Found in dense riparian stands of willows, cottonwoods, live oaks, or conifers; uses adjacent open lands for foraging; nests in abandoned crow, hawk, or magpie nests	Found as permanent resident east of the Cascade Ranges from Placer County north to the Oregon border, east of the Sierra Nevada from Alpine to Inyo Counties, along the coast from Sonoma to San Luis Obispo Counties, and eastward over the Northcoast Range to Colusa County; winters throughout the Central Valley, Mojave and Colorado deserts, and the Inyo-White Mountains; summers along the eastern rim of the Central Valley and Sierra foothills from Tehema to Kern Counties
Short-eared owl *Asio flammeus*	--/SSC	Uses freshwater and saltwater marshes, low land meadows, and irrigated alfalfa fields; needs dense tules or tall grass for nesting and daytime roosts	Found as permanent residents along the coast from Del Norte to Monterey Counties, although very rare in summer north of San Francisco Bay, in the Sierra Nevada north of Nevada County, the plains east of the Cascades, and Mono County; winters on the coast from San Luis Obispo to San Diego Counties, the Central Valley from Tehema to Kern Counties, the eastern Sierra Nevada from Sierra to Alpine Counties, the Channel Islands, and Imperial County; small isolated populations also nest in the Central Valley
Willow flycatcher *Empidonax traillii*	FS/E	Uses riparian areas with abundant willows in wet meadows	Summer range includes a narrow strip along the eastern Sierra from Shasta to Kern Counties, another strip along the western Sierra from El Dorado to Madera Counties, and a small population in San Diego County
Bank swallow *Riparia riparia*	--/T	Nests in bluffs or banks adjacent to water where the soil consists of sand or sandy loam to allow digging	Nesting areas include the plains east of the Cascade Range south through Lassen County, northern Siskiyou County, along the Sacramento River from Tehema to Sacramento Counties, and in the Owens Valley; there are also small populations near the coast from San Francisco to Monterey Counties
Loggerhead shrike *Lanius ludovicianus*	C2/--	Open terrain with scattered shrubs, trees, or other suitable perching structures	Common resident and winter visitor in lowland and foothill areas throughout most of California

Table E-1. Continued

Species	Status[a] Federal/State	Habitat	Distribution
Virginia's warbler *Vermivora virginiae*	--/SSC	Desert mountains with open stands of pinon pine and white fir; scattered shrubs required for ground cover	There are five breeding populations in California: one on the border of Mono and Inyo Counties and four in San Bernardino County
California yellow warbler *Dendroica petechia brewsteri*	--/SSC	Nests in riparian areas dominated by willows, cottonwoods, sycamores, or alders or in mature chaparral; may also use oaks, conifers, and urban areas near streamcourses	Nests over all of California except the Central Valley, the Mojave Desert region, and high altitudes in the Sierra Nevada; winters along the Colorado River and in parts of Imperial and Riverside Counties; there are two small permanent populations in San Diego and Santa Barbara Counties
Yellow-breasted chat *Icteria virens*	--/SSC	Nests in dense riparian habitats dominated by willows, tall weeds, blackberry vines, and grapevines	Uncommon migrant in California; nests in a few locations with appropriate habitat such as Sweetwater Creek, Eldorado County, and along the Russian River in Sonoma County
Mammals			
Inyo shrew *Sorex tenellus*	--/--	Riparian scrub and woodland, pinion-juniper woodland, and Great Basin scrub; prefers damp, shaded conditions near water	Known only from Mono and Inyo Counties in California
Spotted bat *Euderma maculatum*	C2/--	Arid deserts and open pine forests set in rocky terrain; roosts mainly in rock crevices	Found in eastern and southern California, the central Sierra Nevada, and the Sierra Nevada foothills, bordering the San Joaquin Valley; they probably occur in other portions of the state where habitat is suitable
Townsend's western big-eared bat *Plecotus townsendii townsendii*	C2/SSC	Uses caves, tunnels, mines, and buildings for roosts; very sensitive to disturbance; may abandon a roost after one visit	Found throughout California except subalpine and alpine habitats in the Sierra Nevada; details of distribution are not well known
Pygmy rabbit *Brachylagus idahoensis*	--/SSC	Associated with tall, dense, shrub habitats; digs burrows; sage brush is an important food source	Great Basin portions of Modoc, Lassen, and Mono Counties
Western white-tailed hare *Lepus townsendii townsendii*	--/SSC	Uses open meadows and flat-topped hills with scattered brush or open stands of trees for cover	Crest and eastern slope of the Sierra Nevada from the Oregon border to Tulare and Inyo Counties

Table E-1. Continued

Species	Status[a] Federal/State	Habitat	Distribution
Sierra Nevada mountain beaver *Aplodontia rufa californica*	PE/--	Prefers dense, moist riparian thickets	Riparian habitats in Mono Basin, especially near the lake shore
Sierra Nevada red fox *Vulpes vulpes necator*	FS, C2/T	Red fir and lodgepole pine forests generally from 5,000 to 8,400 feet; associated with mountain meadows	Cascade Range east to the Sierra Nevada then south to Tulare County
Wolverine *Gulo gulo*	C2/T	Sighted in a variety of habitats from 1,600 to 14,200 feet; most common in open terrain above timberline and subalpine forests	Klamath and Cascade Ranges south through the Sierra Nevada to Tulare County
American badger *Taxidae taxus*	--/SSC	Uses open areas with scattered shrubs and trees for cover and loose soil for digging	Found all over California except for the northwestern corner in Del Norte County and parts of Humboldt and Siskiyou Counties

[a] Status explanations (see the "Definitions of Special-Status Species" in Chapter 3F, "Wildlife", for citations):

Federal

E = listed as endangered under the federal Endangered Species Act.

PE = proposed for listing as endangered under the federal Endangered Species Act.

C1 = Category 1 candidate for federal listing. Category 1 includes species for which USFWS has on file enough substantial information on biological vulnerability and threat to support proposals to list them. Species that are possibly extinct are indicated with an asterisk (*).

C2 = Category 2 candidate for federal listing. Category 2 includes species for which USFWS has some biological information indicating that listing may be appropriate but for which further biological research and field study are usually needed to clarify the most appropriate status. Species that are possibly extinct are indicated with an asterisk (*). Category 2 species are not necessarily less rare, threatened, or endangered than Category 1 species or listed species; the distinction relates to the amount of data available and is therefore administrative, not biological.

FS = U.S. Forest Service sensitive species (Pacific Southwest Region).

-- = no listing.

State

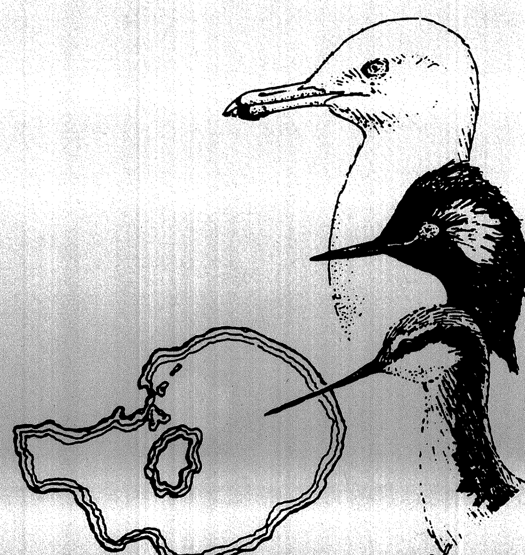
E = listed as endangered under the California Endangered Species Act.

T = listed as threatened under the California Endangered Species Act.

SSC = species of special concern.

-- = no listing.

Appendix F. Vegetation and Substrate Classification and Description



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Appendix F. Vegetation and Substrate Classification and Descriptions

CLASSIFICATION METHODS

Introduction

Vegetation in the study area is diverse because of the wide geographic and elevational ranges encompassed and the variety of geologic and hydrologic conditions in the area. A habitat classification system was developed for identifying and mapping vegetation types that are the basic units of analysis and comparison in this EIR. The classification and maps were used to document past changes and predict future changes in type, structure, quality, function, and value of vegetation in the study area.

For this evaluation, vegetation in the study area is classified into a three-level hierarchy as described by Paysen et al. (1980). The highest level of the hierarchy, "formation", is determined by the dominant growth form of the dominant species (i.e., tree, shrub, or herb). The next level, "subformation", is based on vegetation structure and site hydrology (e.g., upland or riparian, wet or dry). Subformations include one or more "series", each defined by its dominant species.

The classification methods described below are applicable to 1940 and 1989 vegetation, although vegetation conditions and extent changed significantly during this period.

Geographic place names used in this text, including named lake-fringing wetlands, are described in Chapter 3C, "Vegetation". The scientific names of plant species cited below and in Chapter 3C are provided in Table F-1.

Classification Methods for Tributary Streams

Woody vegetation is the focus of the riparian impact assessment and thus is classified in greater detail than herbaceous vegetation along the streams. The classification is based on qualitative observations upstream and downstream of the diversion sites on the four tributary streams in 1990-1991 and a review of available literature (Taylor 1982, Jones & Stokes Associates 1993).

Existing vegetation was initially mapped from 1990 and 1987 aerial photographs onto detailed topographic maps (scale 1:1,200; contour interval 2 feet; from May 1991 aerial photographs). The draft maps were checked and corrected in the field during summer 1991, after which final maps were produced and planimetered. Prediversion vegetation was similarly mapped from 1929 and 1940 aerial photographs, but historical vegetation could not be field-checked directly. Remnants of prediversion vegetation were sometimes indicative of prediversion conditions.

Vegetation was mapped as polygons of uniform composition and condition. Composition was defined in terms of dominant woody species; condition was characterized in terms of canopy cover, canopy layering, overall vigor, and response to rewatering. Minimum polygon sizes were influenced by patch isolation and density. Isolated patches of dense vegetation were mapped in polygons as small as about 0.1 acre. Contiguous polygons of sparse vegetation were at least 0.3 acre in size. Methods used to characterize riparian vegetation condition are described further in the "Methods" section of Chapter 3C, "Vegetation".

Classification Methods for Lake-Fringing Wetlands

Lake-fringing wetlands were classified based on previous studies (e.g., Dummer and Colwell 1985, Hargis 1986) and field studies conducted for this evaluation. Reconnaissance surveys provided information on vegetation types and dominant species needed to develop a preliminary classification.

After a classification scheme was devised, the vegetation of the relicted lakebed below the 1940 highstand was mapped. Mapping was conducted in the field using 1:6,000-scale color aerial photographs taken on May 6, 1991. Over 95% of all mapped wetland vegetation polygons were verified in the field. Nonwetland series were mapped using a combination of field survey and aerial photograph interpretation.

Classification of lake-fringing wetlands at the subformation level in the herbaceous formation is critically important because each subformation reflects underlying hydrogeologic differences. Subformations are distinguished primarily based on the structure of the dominant species (e.g., emergent aquatic, terrestrial herbaceous perennial, or annual), a breakdown that reflects underlying differences in presence of surface water and the timing and duration of saturation of upper soil layers.

DESCRIPTIONS

Vegetation of tributary streams, the Mono Lake shoreline, and the Upper Owens River was classified into three formations, nine subformations, and 31 series. The classification is presented in Table F-2, with dominant species listed by series. Several upland series found adjacent to or interspersed with riparian and wetland habitats are included in the classification.

Forest and Woodland Formation

The forest formation is dominated by trees (woody plants with one or a few main stems) that provide at least 10% areal cover. The canopy varies from dense with interlocking or overlapping trees (i.e., a forest), to sparse with mostly separate trees (i.e., a woodland). Forest and woodland vegetation in the study area is divided into riparian and upland subformations.

Riparian Forest and Woodland Subformation

This subformation includes three series that occur on the banks and floodplains of streams.

Conifer-Broadleaf Series. This series is codominated by various combinations of pine, cottonwood, and aspen. Jeffrey pine and black cottonwood are most abundant on alluvial substrate. Lodgepole pine and aspen are most abundant on glacial till substrate. Willows are common in this series but may be restricted to streambanks in areas of dense conifer cover. Streambanks and floodplains support moderate to dense herbaceous vegetation, except where the topsoil has been eroded or where the shade is too heavy.

Cottonwood-Willow Series. This series is dominated by black cottonwoods in the tree layer and coyote and arroyo willows in the shrub layer. Mountain rose may be codominant with willows in the shrub layer. Pines are usually absent, but a few scattered individuals may be present. Streambanks and floodplains support moderate to dense herbaceous vegetation, except where the topsoil has been eroded.

Aspen Series. This series is dominated by aspen. Aspens are usually tall trees, but some stands are short and shrubby. Willows, cottonwoods, and conifers are usually sparse or absent, except where aspen joins other vegetation types. Aspen is typically clonal, with many stems united by a common root system. Large stands may include several clones, while small stands may consist of a single clone. Aspens stands may be strictly riparian (along a stream) or occur at hillside seeps well above a stream or floodplain.

Upland Forest and Woodland Subformation

This subformation includes the following two series that occur in uplands outside the riparian zones.

Jeffrey Pine Series. This nonriparian community is dominated by Jeffrey pine, with a sparse understory of upland shrubs (usually sagebrush, bitterbrush, or rabbitbrush) and grasses (usually cheat grass, Indian rice grass, or squirreltail grass). This is the most common upland forest adjacent to riparian vegetation on the tributary streams.

Pinyon Pine Series. This nonriparian community is dominated by single-leaf pinyon trees and sagebrush and bitterbrush shrubs. This series is most common on dry canyon slopes high above the riparian zone but grows near the riparian zones in Lee Vining Canyon between Highway 120 and U.S. 395.

Scrub Formation

This formation is dominated by shrubs (woody plants with several main stems) that provide at least 10% cover. Trees may be present but generally provide less than 10% cover. Scrub vegetation in the study area is divided into a riparian and wetland subformation and upland subformations.

Riparian and Wetland Scrub Subformation

This subformation includes three series associated with tributary streams and the relicted lakebed of Mono Lake. Vegetation in this subformation depends on surface water or shallow groundwater and is considered wetland by the U.S. Fish and Wildlife Service (USFWS) (Cowardin et al. 1979).

Willow Scrub Series. This series is dominated by dense thickets of shrubby willows. One or more willow species contribute at least 50% of the canopy cover. Along tributary streams and the Upper Owens River, the distribution of willow species is controlled primarily by soil moisture. Coyote willow is the most drought-tolerant species and is commonly the only willow on irrigated pastures, hillside seeps, or floodplains away from the active low-flow channels. Arroyo willow and yellow willow are occasional to locally common on banks and bars along active stream channels. Geyer willow is locally abundant along sinuous, low-gradient stream reaches beside wet, sedge-series meadows. Mountain rose is typically interspersed among the willows but has less low cover than the willows. Cottonwood and aspen trees are absent, but scattered individuals or small clusters are occasionally present.

Willow scrub along the Mono Lake shoreline is dominated by mixed or pure stands of coyote, arroyo, and red willow interspersed with occasional mountain rose. It develops at springs and seep discharge points that are reliable sources of fresh water and where the soil has been most heavily leached.

Mixed Riparian Scrub Series. Mixed riparian scrub is a composite of two plant communities having similar hydrologic affinities. The rose community is dominated by dense thickets of mountain rose. The buffalo berry community is dominated by stands of buffalo berry. Mountain rose usually occurs in the buffalo berry community. Willows, rabbitbrush, or sagebrush are often present in both communities but provide less than half of the woody cover. Cottonwoods, aspens, and conifers are rare or absent.

Great Basin Scrub Subformation

This subformation includes five upland scrub series. These series are the most prevalent vegetation types in lower portions of the study area and dominate all nonriparian and nonwetland areas along the streams and around Mono Lake.

Sagebrush Scrub Series. This series is dominated by basin sagebrush occasionally interspersed with some bitterbrush and desert peach. The herbaceous layer contains wild buckwheat, Indian rice grass, squirreltail grass, and many other native herbs.

Bitterbrush Scrub Series. This series is dominated by bitterbrush heavily interspersed with basin sagebrush.

Rabbitbrush Scrub Series. The rabbitbrush scrub series is locally common at some meadow margins and below the historical high lake level of 6,428 feet. Rabbitbrush is represented in the study area by two species: *Chrysothamnus nauseosus* subsp. *albicaulis* frequents meadow margins, while subsp. *consimilis* dominates the relicted lakebed. On the lakebed, this series supports drought- and salinity-tolerant herbs, such as salt grass, Douglas sedge, and Baltic rush, in the herbaceous layer.

Greasewood Scrub Series. This series is an open-canopied scrub dominated by greasewood, occasionally interspersed with some rabbitbrush. It develops on saline-alkali soil of the relicted lakebed and often contains salt grass, Baltic rush, or Nevada bulrush as understory herbaceous species.

Hopsage Scrub Series. This series is dominated by hopsage interspersed with rabbitbrush and greasewood. It occurs only on Paoha Island above the 6,428-foot elevation contour.

Herbaceous Formation

This formation includes vegetation dominated by grasses, sedges, rushes, bulrushes, and forbs (broad-leaved herbs), with at least 10% total cover. Trees and shrubs may occur at locally dry sites and meadow margins but generally provide less than 10% cover.

The herbaceous formation in the study area includes five subformations and 18 series (Table F-2) distinguished by hydrology and vegetative structure. Marshes include vegetation that is emergent from ponded water. Wet meadows and alkali meadows are periodically flooded and have soil saturated at or near the surface for extended periods during the summer growing season. Dry meadows are dominated by phreatophytes that tap shallow groundwater at depths that appear to be too great to sustain wet meadows or alkali meadows. Wet and dry meadows commonly intergrade along the tributary streams and in extensively irrigated areas such as Cain Ranch. The forb subformation includes both wetland and nonwetland vegetation dominated by broad-leaved forbs.

Marsh Subformation

Marshes are dominated by aquatic vegetation that grows emergent from water for most or all of the growing season. Some marshes along the Mono Lake shoreline were flooded in midsummer 1991 but were dry by early fall. Seasonal drying may be natural or related to the ongoing 6-year drought. Groeneveld (1991) documented depressed groundwater levels in piezometers installed in the lake-fringing wetlands. Stine (pers. comm.) reports lower spring activity associated with the drought at some locations. Marshes in the project area are classified into four series: tule, cattail, threesquare, and mixed.

Tule and Cattail Marsh Series. Tule marshes consist of pure or nearly pure swards of common tule. Cattail marshes are dominated by mixed or pure stands of narrow- and broad-leaved cattail. Both series occur in lake-fringing wetlands in relatively small patches at spring discharge points or in basins and shallow lagoons formed behind beach berms.

Threesquare Marsh Series. Threesquare marshes are dominated by pure stands of threesquare occasionally interspersed with Cooper's rush or common spike-rush.

Mixed Marsh Series. Mixed marshes are dominated by several species, including threesquare, Cooper's rush, common and Parish's spike-rush, common monkeyflower, and a variety of sedges (e.g., lesser-panicled sedge, Nebraska sedge, and beaked sedge). Mixed marshes often consist of subunits, each dominated by one or a few of the above species. Subunits were not separately recognized because they form an interwoven mosaic, and individual units lacked obvious hydrologic or edaphic differences.

Riparian Meadow and Pasture Subformation

Meadows in this subformation occur in the floodplains of streams, at hillside seeps or springs, and in irrigated areas. The vegetation is generally a dense turf dominated by perennial sedges, rushes, and grasses, intermixed with lesser amounts of forb cover. Species dominance varies along moisture gradients, and several vegetation series are commonly intermixed in a complex mosaic. Pastures that have been irrigated for many decades contain essentially the same vegetation series that occur in natural meadows.

Sedge Meadow Series. This series is dominated by beaked sedge, wooly sedge, clustered field sedge, or Nebraska sedge. These meadows are often saturated to the surface or shallowly flooded for extended periods. Scattered willows may occur in these meadows.

Rush Meadow Series. Meadows closer to the middle of the moisture gradient are dominated by Baltic rush, Nevada rush, Kentucky bluegrass, clustered field sedge, or Nebraska sedge. Scattered coyote willow or other willows may occur in these meadows. Other locally common species may include Missouri iris, Nevada bluegrass, dandelion, curly dock, sorrel, and other forbs.

Douglas Sedge Meadow Series. The driest meadows are often dominated by drought-tolerant Douglas sedge. This series occurs at the margins of natural meadows, in pastures where irrigation has ceased, and where channel incision or gully erosion has caused water tables to drop.

Mixed Riparian Meadow and Pasture Series. This series is a cumulative category for meadows that includes two or more of the above series in a small area and vegetation transitional between these and other herbaceous series.

Wet Meadow Subformation

Meadows in this subformation occur along the western shore of Mono Lake. Soil of wet meadows is flooded by runoff during early summer and saturated to the surface by groundwater or flowing spring water for a significant portion of the growing season. These meadows are similar to the riparian meadows and pastures described above, but dominant species vary along salinity gradients and moisture gradients. Some wet meadows in the study area contain scattered willows.

Mixed Wet Meadow Series. Wet meadows support a diverse mixture of species characteristic of mid-elevation eastern Sierra meadows. Mixed wet meadows along the west shore of Mono Lake are dominated by beaked sedge, wooly sedge, clustered field sedge, and Nebraska sedge interspersed with a variety of grasses and forbs. Typical species include Nevada rush, Missouri iris, Kentucky bluegrass, alkali-marsh butterweed, basin goldenrod, small-flower Indian-paintbrush, rabbit's-foot grass, Nevada bluegrass, forget-me-not, willow-herb, helleborine, foxtail barley, Nuttall's alkali grass, and cut-leaf water parsnip.

Dry Meadow Subformation

Meadows in this subformation occur around the shores of Mono Lake. Dry meadows support herbaceous vegetation dominated by sparse to dense stands of grass, sedge, rush, and bulrush species. Dry meadows are never saturated at the soil surface for extended periods (i.e., for periods of 1 or more consecutive weeks) during the growing season but may temporarily flood or have soil saturated at or near the surface for short durations after heavy rainfall or briefly during peak snowmelt runoff.

Dry meadows are dominated by phreatophytes that draw on shallow groundwater too deep to sustain the types of wet meadow vegetation in the region. They develop on well-drained sand and gravel substrate. Groundwater supporting this vegetation may be from a zone of soil saturation (i.e., where free water occupies all soil pore space), from the zone of capillary rise above the water table, or from soil moisture trapped from infiltrated rainfall and runoff. Groundwater may be available on a seasonal or year-round basis. Clayey lacustrine deposits observed 5-10 feet below dry meadows could serve as barriers to downward infiltration by trapping and storing seasonal rainfall on which the deep-rooted dry meadow species can draw. Dry meadows at these sites lacked any other apparent water source. Dry meadows can apparently withstand seasonal soil moisture deficits because the dominant species have adaptations for drought tolerance (i.e., small leaves, leathery epidermis, and deep roots).

Dry meadows have apparently replaced some wet meadows along the Mono Lake shoreline as springs and seeps have dried. Elsewhere on the relicted lakebed, they cover extensive areas around the dry edges of marshes and wet meadows. They also dominate areas between the major lake-fringing wetlands below the 6,390-foot-elevation contour and form a near-continuous band of sparse vegetation around the lakebed above the 6,390- to 6,400-foot elevation. In the latter instance, dry meadows often have a spotty to moderately dense rabbitbrush or greasewood overstory.

The dry meadow subformation includes four series associated with sites having different depths to groundwater or variations in frequency and duration of periodic flooding and near-surface soil saturation. The series, in order from wet to dry, are mixed, Baltic rush, Nevada bulrush, and salt grass.

Mixed Dry Meadow Series. Mixed dry meadows are generally observed in relatively mesic sites, often near wet or alkali meadows. They are dominated by salt grass, Baltic rush, Nevada bulrush, and Douglas sedge interspersed with forbs such as dandelion, bassia, tumbleweed, mentzelia, and mealy rosettes.

Baltic Rush, Nevada Bulrush, and Salt Grass Dry Meadow Series. These three series are each dominated by pure or near-pure stands of the species for which they are named. In most instances, each contains small amounts of the species found in mixed dry meadows. Salt grass is the most abundant dry meadow series around Mono Lake, reflecting its tolerance for saline-alkali soil (Prodgers and Inskeep 1991; Brotherson and Rushforth 1985, 1987), aggressive colonization capabilities (Brotherson and Rushforth 1985), and tolerance for seasonal aridity.

Alkali Meadow Subformation

Meadows in this subformation occur around Mono Lake on saline-alkali soil where groundwater saturates the soil surface throughout most or all of the summer-fall growing season. The high salt level in alkali meadows is attributable to their prior submergence in Mono Lake and inadequate leaching by freshwater after lake recession. Salinity also may be maintained by soil efflorescence, a process by which salt-laden groundwater is drawn upward by capillary action. The water potential gradient formed by evaporation from the soil surface and transpiration by plants continuously draws water upward. Salts concentrate at the surface as water evaporates or is absorbed by plants. A salt residue accumulates over time, forming a thick surface crust. In the extreme cases, such as along the north beach where groundwater is extremely salty and contains phytotoxins, surface salt accumulations preclude vegetation (Rogers, Driess, and Groeneveld 1992). Elsewhere, less salty groundwater and freshwater flushing combine to leach salts below toxic levels.

The alkali meadow subformation in the study area contains four series: salt grass, Nevada bulrush, grassy, and mixed.

Salt Grass Alkali Meadow Series. Salt grass alkali meadows are characterized by dense, nearly pure salt grass turfs, with occasional species of the mixed alkali marsh series intermixed. This series is presently best developed on beach terraces near unvegetated playa shorelines around the northern and eastern shores of Mono Lake.

Nevada Bulrush Alkali Meadow Series. Extensive Nevada bulrush monocultures have established on low beach terraces near the lake-fringing playas along the northern and eastern shores. This series is best developed on gently sloped terraces immediately below seeps and springs emanating from beach berms. Unlike salt grass alkali meadows, the soil surface in these areas is leached by surface runoff, and thus the salt crust does not develop.

Grassy Alkali Meadows. Grassy alkali meadows support a mix of two or more perennial grasses to the near exclusion of forbs, rushes, or sedges. This series occupies low terraces above the unvegetated playa around the lakeshore. It develops as narrow bands on partially leached relicted lakebed around the west shore and forms large stands on the north shore at the DeChambeau Embayment, Bridgeport Creek, and Sierra escarpment wetlands. Typical dominants are foxtail barley, Nevada bluegrass, alkali muhley, Nuttall's alkali grass, and salt grass.

Mixed Alkali Meadow Series. Mixed alkali meadows consist of a diverse assemblage of halophytes dominated by several grass species and bulrush interspersed with a variety of forbs. This series is associated with a variety of sites with saline-alkali soil where soil efflorescence may predominate.

Typical dominants are Nevada bulrush, salt grass, foxtail barley, and alkali muhley. Other characteristic species include Cooper's rush, alkali bulrush, small-flowered Indian paintbrush, marsh and seaside arrowgrass, intermountain pyrrocoma, lesser-panicled sedge, Pursh and Torrey seepweed, Nevada blue-eyed grass, rabbit's-foot grass, and arrowscale.

Forb Subformation

The herbaceous subformation consists of series that are dominated by annual forbs. In the study area, the forb subformation includes both wetland and nonwetland series.

Nonwetland forb series occupy sites where the upper soil layers are not influenced by groundwater or concentrated surface runoff but often occur close to wetlands. Two nonwetland series are described for the Mono Basin EIR: mixed dry forb and bassia. Many other nonwetland forb series also are present in Mono Basin and Long Valley.

Wetland forb series are associated with tributary streams on floodplains and associated springs. They lack mature woody vegetation and topsoil that is protected by a meadow turf. Two wetland series are described for this EIR: mixed wet forb and watercress. Many other wetland forb series also are present in Mono Basin and Long Valley.

Mixed Dry Forb Series. Mixed dry forb series develop on well-drained sands and gravels around Mono Lake that support a sparse, mostly annual vegetation of mentzelia, willow buckwheat, tumbleweed, bassia, mealy rosettes, and tequilia.

Bassia Series. This series is dominated by pure or nearly pure stands of bassia. It occupies well-drained, sandy alkali soil near alkali meadows or dry meadows.

Mixed Wet Forb Series. The mixed forb series is dominated by lupine, bouncing-bet, or sweet-clover. Rushes, grasses, and wormwood also are often numerous. This series has developed since rewatering occurred on gravel and cobble bars along the flood-scoured stream channels.

Watercress Series. This series formerly occurred at springs in the Rush Creek bottomlands that have been reduced or eliminated by reducing irrigation in Pumice Valley, at Cain Ranch, and in other areas.

Unvegetated Habitats

The study area includes 13 habitats that lack appreciable plant cover. Plant cover of "unvegetated" habitats is less than 2% of the land surface. These habitats are included because they encompass substantial acreages in the project area and because some are important to wildlife or have implications for other issues, such as air quality and visual resources.

Channels

Channels include the bed, and sometimes the banks, of the main low-flow channel in each tributary stream.

Floodplains

Floodplains include gravel bars, overflow channels, and other surfaces along the tributary streams that are periodically scoured by high flows or have topsoil that has been removed by severe flood events.

Unvegetated Uplands

Unvegetated uplands include roads, graded areas, buildings and parking lots, and sheep bedding areas along the tributary streams.

Alkali Lakebeds

Alkali lakebeds include some areas that were exposed during lake recession. They are characterized by a surface layer of salts deposited by efflorescence (see previous discussion). Wind can remove or precipitation and runoff during the wet season can temporarily dissolve the surface layer, which will reform during the next dry period, assuming groundwater conditions remain favorable. Not all areas mapped as alkali lakebed qualify as wetlands based on the USFWS definition (Cowardin et al. 1979). Although groundwater was likely near the surface at all alkali lakebed areas sometime in the past, it has since drained from some areas as the lake level has dropped.

Tufa

The tufa mapping unit is reserved for unvegetated tufa towers and tufa cemented beaches found at scattered sites around the lake.

Sand

The sand mapping unit is used for all unvegetated sand flats, except those composed of material eroded from Black Point. Sand is mapped around portions of the entire Mono Lake shoreline.

Black Point Sand

Black Point sand is used for beaches composed of sand eroded from Black Point. Black Point is eroded by Mono Lake when the lake rises to elevations above 6,400 feet. Long-shore drift carries these sands and deposits them in a band above the 6,400-foot-elevation contour around the northern margin of the lake from east of Black Point to Warm Springs.

Lagoon

Lagoons are internally drained depressions that pond water. A lagoon basin forms behind littoral embankments created by wave action and long-shore drift. Lagoons flood because their highly permeable embankments permit the near shore water table to infiltrate the berm and pond in the lagoon bottom. Most lagoons receive fresh groundwater that is moving through shallow aquifers toward the lake from upslope catchments. Lagoons are too salty to support wetland vegetation. Although nearly absent during the point of reference, an extensive lagoon area existed before diversions began.

Large lagoons formed on the Lee Vining and Rush Creek deltas and in depressions in the sand dunes north of the lake. Smaller linear lagoons also formed at various locations around the shoreline where beach slopes were too steep to allow wider lagoons to form.

Lagoons in dune fields north of the lake ponded water before LADWP diversions. These lagoons were not present on the 1956 aerial photographs when the lake stood at 6,402 feet. They apparently cease ponding when the lake drops below 6,405 feet (Stine 1993). Diatom remains suggest that these lagoons were brackish, containing a mix of fresh-water and saltwater (Stine 1993). The lagoons contain salt accumulations more than 2 feet deep, indicating extensive efflorescence of salts from underlying brackish saltwater and/or periods of brackish water inundation followed by evaporation.

Gravel

This category was used in lakeshore mapping for the unvegetated portions of the Lee Vining, Rush, and Wilson Creek deltas with gravel and cobble surfaces. This category includes some beachrock areas (i.e., tufa-encrusted gravel [Stine 1993]).

Developed

This category is used in lakeshore mapping for areas converted to pavement, buildings, or other developments.

Open Water

This category designates the unvegetated portions of ponds.

Negit Island

Negit Island is composed of dacite rock. Previously inundated portions of the island and its islets are encrusted with tufa and thus required a separate mapping category.

Barren Rock

Areas of exposed bedrock were mapped as barren rock.

Barren Basin

Barren basins are interdunal depressions where water from direct precipitation or surface runoff ponds. These ephemeral features are most common along the north shoreline above the historical highstand of 6,428 feet.

Beachrock

Cobble deposits on deltas and colluvial slopes below the Sierra Nevada develop a tufa coating under some circumstances. Tufa-coated cobbles are referred to as beachrock.

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Table F-1. Common and Scientific Names of Plant Species in Mono Basin and Surrounding Area

Common Name	Scientific Name
Alkali bulrush	*Scirpus robustus*
Alkali-marsh butterweed*	*Senecio hydrophilus*
Alkali muhley	*Muhlenbergia asperifolia*
Arrowscale	*Atriplex phylostegia*
Arroyo willow	*Salix lasiolepis*
Baltic rush	*Juncus balticus*
Basin goldenrod	*Solidago spectabilis*
Bassia	*Bassia hyssopifolia*
Beaked sedge	*Carex rostrata*
Bitter cherry	*Prunus emarginata*
Black cottonwood	*Populus trichocarpa*
Bodie Hills draba*	*Draba quadricostata*
Buffalo berry	*Shepherdia argentea*
Cattail	*Typha latifolia*
Cheat grass	*Bromus tectorum*
Clustered field sedge	*Carex praegracilis*
Common spike-rush	*Eleocharis macrostachya*
Cooper's rush	*Juncus cooperi*
Coyote willow	*Salix exigua*
Creek dogwood	*Cornus stolonifera*
Curly dock	*Rumex crispus*
Cut-leaf water parsnip*	*Berula erecta*
Dandelion	*Taraxacum officinale*
Desert peach	*Prunus andersonii*
Douglas sedge	*Carex douglasii*
Forget-me-not	*Myosotis*
Foxtail barley	*Hordeum jubatum* sp.
Fremont cottonwood	*Populus fremontii*
Geyer willow	*Salix geyeriana*
Helleborine	*Veratrum californicum*
Hopsage	*Grayia spinosa*
Indian rice grass	*Oryzopsis hymenoides*
Intermountain pyrrocoma	*Pyrrocoma lanceolata*
Jeffrey pine	*Pinus jeffreyi*
Kentucky bluegrass	*Poa pratensis*
Lesser-panicled sedge	*Carex diandra*
Lodgepole pine	*Pinus contorta* ssp. *murrayana*
Lombardi poplar	*Populus lombardii*
Long Valley milk-vetch*	*Astragalus johannis-howelii*
Lupine	*Lupinus* spp.
Marsh arrowgrass	*Triglochin concinna* var. *debilis*

Table F-1. Continued

Common Name	Scientific Name
Mealy rosettes	*Tiquilia plicata*
Mentzelia	*Mentzelia*
Missouri iris	*Iris missouriensis*
Mono buckwheat*	*Eriogonum ampullaceum*
Mono Lake lupine*	*Lupinus duranii*
Mono milk-vetch*	*Astragalus monoensis*
Mountain rose	*Rosa woodsii*
Nebraska sedge	*Carex nebrascensis*
Nevada blue-eyed grass	*Sisyrinchium halophilum*
Nevada bluegrass	*Poa nevadensis*
Nevada bulrush	*Scirpus nevadensis*
Nevada rush	*Juncus nevadensis*
Northern cottonwood	*Populus deltoides*
Nuttall's alkali grass	*Puccinellia nuttalliana*
Pacific willow	*Salix lasiandra*
Parish's spike-rush	*Eleocharis parishii*
Pursh seepweed	
Quaking aspen	*Populus tremuloides*
Rabbit brush	*Chrysothamnus nauseosus* subsp. *albicaulis* and subsp. *consimilis*
Rabbit's-foot grass	*Polypogon monspeliensis*
Red willow	*Salix laevigata*
Saltgrass	*Distichlis spicata*
Sandbar willow	*Salix hindsiana*
Saponaria	*Saponaria officinalis*
Seaside arrowgrass	*Triglochin maritimus*
Sedge	*Carex* sp.
Small-flowered Indian paintbrush	*Castilleja exilis*
Sorrel	*Rumex acetosella*
Squirreltail grass	*Sitanion hystrix*
Threesquare	*Scirpus pungens*
Tonopah milk-vetch*	*Astragalus pseudiodanthus*
Torrey seepweed	*Suaeda torreyana*
Tule marsh	*Scirpus acutas*
Tumbleweed	*Salsola tragus*
Utah monkeyflower*	*Mimulus glabratus* var. *utahensis*
Water birch	*Betula occidentalis*
Watercress	*Rorippa nasturtium-aquaticum*
Western birch	*Betula occidentalis*
White cottonwood	*Populus*
White fir	*Abies concolor*
Willow buckwheat	*Eriogonum vimineum*
Willow-herb	*Epilobium* sp.

Table F-1. Continued

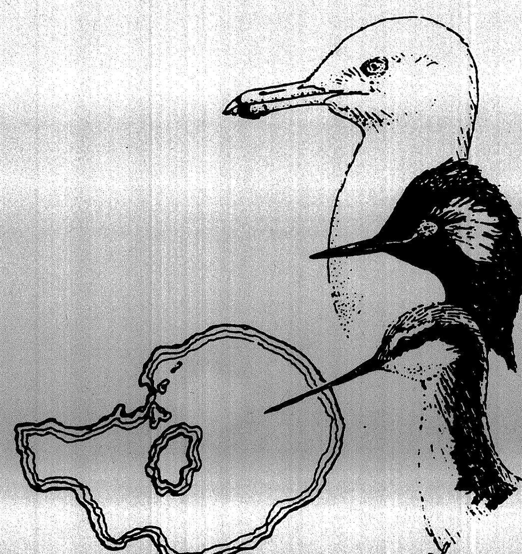
Common Name	Scientific Name
Woolly sedge	*Carex lasiocarpa*
Wormwood	*Artemisia ludoviciana*
Yellow willow	*Salix lutea*

* Special-status species on the site.

Table F-2. Hierarchical Vegetation Classification of the Tributary Streams, Mono Lake Shoreline, and Upper Owens River

Formation	Subformation	Series	Dominant Species
Forest	Riparian forest	Conifer-hardwood forest	
		Cottonwood-willow forest	
		Aspen forest	
	Upland forest	Jeffrey pine forest	
		Pinyon pine forest	
Scrub	Riparian and wetland scrub	Willow scrub	*Salix* spp. (e.g., *S. lasiolepis*, *S. exiguia*, *S. laevigata*)
		Mixed riparian scrub	*Salix* spp. (often *S. exigua*) and *Shepardia argentea, rosa woodsii*
	Great Basin scrub	Sagebrush scrub	*Artemisia tridentata, Chrysothyamnus nauseousus* subsp. *albicaulis, Prunus andersonii*
		Bitterbrush scrub	*Purshia tridentata*
		Rabbitbrush scrub	*Chrysothamnus nauseuosus* subsp. *albicaulis*
		Greasewood scrub	*Sarcobatus vermiculatus, Chrysothamnus nauseuosus* subsp. *consimilis*
Herbaceous	Marsh	Tule marsh	*Scirpus acutas*
		Cattail marsh	*Typha latifolia*
		Threesquare marsh	*Scirpus pungens*
		Mixed marsh	*Scirpus pungens, Eleodaris macrostachya, Juneus cooperi, Canex*
	Wet meadow	Mixed wet meadow	*Canex* spp., *Juncus cooperi, J. nevadensis, Senecio triangularis, Castillija exilis*
		Pasture wet meadow	*Poaprofensis, P. nevadensis, Juncus balfieus, Carex praegracilis, Taraxacum officinale*
	Dry meadow	Saltgrass dry meadow	*Distidilis spicata*
		Baltic rush dry meadow	*Junas balticus*
		Nevada bulrush dry meadow	*Scirpus nevordensis*
		Mixed dry meadow	*Distichlis spicata, Juncus balticus, Scirpus nevadensis, Carex douglasii*
	Alkali wet meadow	Saltgrass alkali meadow	*Distichlis spicata*
		Grassy alkali meadow	*Distichlis spicata, Por nevadensis, Muhlenbergia asperifolia, Hoodeum jabatum*
		Nevada bulrush alkali meadow	*Scirpus nevadensis*
		Mixed alkali meadow	*Distichlis spicata, Scirpus nevadensis, Hordeum jubatum, Haplopappus lanceolatus, Puccinellis nuttalliana*
	Forb	Mixed dry forb	*Solsoa depressa, Eriogonum vimineum, Mentzelia dispersa, Psathyrotes annua*
		Bassia forb	*Bossia hyssipifolia, Solsda depressa*
		Water cress	
		Mixed wet forb	

Appendix G. Mono Lakebed Contours and Lake Surface Areas Developed by SWRCB Consultants



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Appendix G. Mono Lakebed Contours and Lake Surface Areas Developed by SWRCB Consultants

A set of contours depicting the bed of Mono Lake was generated by SWRCB consultants (Jones & Stokes Associates) through a computer-aided drafting system (AutoCAD) for use in impact analysis and to create maps for the EIR (Table G-1). These contours are more accurate and should therefore supersede earlier topographic depictions of lakeshore lands developed for 7.5-minute topographic maps by the U.S. Geological Survey and Pacific Western Aerial Surveys (1986). The 7.5-minute topographic maps that cover Mono Lake include Mount Dana, 1988; Lundy, 1986; Negit Island, 1986; Lee Vining, 1986; Mono Mills, 1986; and Sulphur Pond, 1986.

The digital data set of all contours shown on Table G-1, except those in brackets, has been verified as complete and closed; the data were exported to a geographic information system (ARCINFO) for acreage calculations and for overlay on environmental data sets. Those in brackets are control contours used in interpolation of some of the other contours. Note that the contour set includes one for each of the nominal alternatives and intermediate contours useful in evaluating the fluctuating lake levels of the alternatives.

The source of each contour is given in Table G-1. The control contours were derived from aerial photographs of the lake at known lake levels; both shorelines and strands of former, known-elevation shorelines were digitized. This empirical method of developing contours is more accurate than using conventional photogrammetric techniques, evidenced by horizontal discrepancies of up to 2,000 feet between contours from photogrammetric surveys (U.S. Geological Survey 7.5-minute topographic maps, from 1982 aerial photographs, and Pacific Western Aerial Surveys [1986] from same photographs) and locations of lakeshores of corresponding elevations compiled herein.

Bathymetric contours from a ship-based sounding survey (Pelagos 1986) are also included in Table G-1, ranging from 6,320 ft to 6,365 ft. The 6,365-ft contour was modified in a few places to avoid conflict with the well-established 6.372.7-ft contour (rectified lakeshore used on U.S. Geological Survey 7.5-minute quadrangle maps).

The AutoCAD data set also includes the Universal Transverse Mercator grid, selected roads, and spot elevations determined by LADWP surveyors.

The procedures to prepare these contours were developed by SWRCB staff and consultants (Jones & Stokes Associates), LADWP staff, and Dr. Scott Stine on August 23, 1991.

Lake surface acreages have been computed for each of these contours through ARCINFO. These data appear in Table G-2. Additional acreages for lake surfaces at each whole foot increment have been estimated through linear interpolation. These data are available in Lotus 1-2-3 spreadsheet format from SWRCB consultants.

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Pelagos Corporation. 1986. Executive summary, a bathymetric and geologic survey of Mono Lake, California. San Diego, CA.

Table G-1. Mono Lakebed Contours

Contour Elevation	Source
6440	USGS contour
6430	Interpolated
6428	Historic highstand strand on 1991 aerial photos
6417	Interpolated (prediversion lake level)
6413	Interpolated
6410	Interpolated (nominal alternative)
{6401.5	Black Point strand on USGS orthophotoquads; present only in northeast portion of lake}
6400	USGS contour, adjusted to avoid conflicts with 6389.7 and 6401.5
6393	Interpolated
6390	Interpolated, except for closed contour in island bridge area from Stine's historic photographs (nominal alternative)
{6389.7	Upper strand on 1991 aerial photographs}
6387	Interpolated
6383.5	Interpolated (nominal alternative)
6381.3	Lower strand on 1991 aerial photographs
{6379.6	Shoreline on USGS orthophotoquads; west half of lake}
{6378.5	Shoreline on USGS orthophotoquads; east half of lake}
6377	Shoreline segment near land bridge from satellite photograph (January 28, 1977); remainder interpolated (nominal alternative)
6376.3	Interpolated (point of reference)
6375.1	Shoreline on 1991 Aerial Photometrics photographs
6372.7	Shoreline on USGS topographic quadrangle
6372	Interpolated (nominal alternative)
6365	From 1:12,000 Pelagos bathymetry maps
6360	From 1:12,000 Pelagos bathymetry maps
6355	From 1:12,000 Pelagos bathymetry maps

Table G-1. Continued

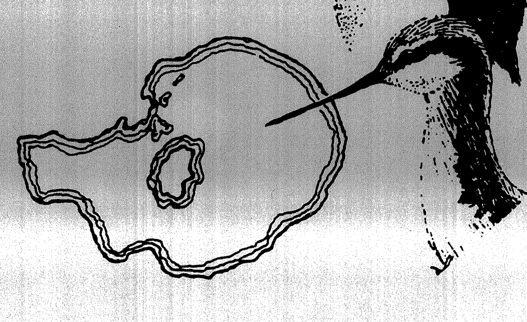
Contour Elevation	Source
6350	From 1:12,000 Pelagos bathymetry maps
6345	From 1:12,000 Pelagos bathymetry maps
6340	From 1:12,000 Pelagos bathymetry maps
6330	From 1:12,000 Pelagos bathymetry maps
6320	From 1:12,000 Pelagos bathymetry maps

Table G-2. Mono Lake Surface Areas

Contour Elevation	Lake Surface Area
6440	60,674
6430	57,004
6428	56,433
6417	54,698
6413	54,115
6410	53,626
6400	51,635
6393	49,402
6390	48,295
6387	46,597
6383.5	45,111
6381.3	44,121
6377	40,876
6376.3	40,594
6375.1	39,509
6372.7	37,318
6372	36,859
6365	33,831
6360	32,283
6355	30,920
6350	29,650
6345	28,277
6340	26,805
6330	24,029
6320	21,319

Source: New contours developed from lakeshores and strand lines on various aerial photographs; see Table G-1. Acreages from ARCINFO.

Appendix H. Drought Analysis



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Appendix H. Drought Analysis

Droughts in the Historical Period

Runoff data for the diverted tributary streams are available for 1895 to 1992, a period of 98 years. Two major droughts occurred in this period (Table H-1).

The drought beginning in 1987, persisting for six snowpack years through fall 1992, has involved average runoff in the diverted tributary streams of 60% of the long-term average of "normal" runoff in Mono Basin. It is the most intense drought of record. A longer drought persisted 13 years from 1923 through 1935. It consisted of diverted-stream runoff averaging 74% of normal runoff, including several years of near-normal runoff. The most intense portion of the earlier drought lasted 7 years (1923-1935) with average runoff of 65% of normal. Normal runoff in this appendix is the average runoff during the period 1941-1989, which is used in the aqueduct operations model; however, this average runoff is close to the average runoff for the longer period 1895-1987.

Analysis of the 1987-1992 Drought

During the 1982-1992 drought, the average runoff during this period has been 60% of the historical average. Similarly, precipitation at Cain Ranch has been about 63% of the historical average. These values can be used to adjust the water balance model for Mono Lake described in Chapter 2 and Appendix A for extreme drought conditions. Annual runoff, precipitation, and changes in the lake surface elevation and volume observed during this period are given in Table H-2. The table also shows annual "residual" terms (see Appendix A) needed to balance water inflows and evaporation with the observed changes in volume. The average of this term is about 69% of the historical average described in Appendix A, presumably reflecting reduced groundwater inflows during drought conditions.

The revised water balance equation for Mono Lake simulating a drought of this intensity can be developed from data in Table H-2 as follows:

Annual change in lake volume	= +	Diverted stream runoff
	+	Other estimated stream runoff
(60% of normal runoff)	+	Precipitation on lake surface
	-	Evaporation from lake surface
	+	Average residual for drought years (principally groundwater inflow)

= + (74,324 af) x (release factor)
+ (0.228) x (74,324 af)
+ (0.57 ft) x (lake surface acreage)
- (4.00 ft) x (lake surface acreage)
+ (23,421 af)

where the "release factor" is the fraction of runoff in the four diverted tributaries that is released to the lake.

This relationship accurately simulates the average decline in lake surface elevation of Mono Lake from 1987 to 1992.

Estimating Probabilities of Future Drought Intensities and Durations

Within the recent 50-year historical record, dry years having about 60% of normal runoff or less have occurred about 10% of the total years (see Chapter 2, "Project Alternatives and Points of Reference", and Chapter 3A, "Hydrology"). Thus, the probability that in any given year runoff will be 60% of normal would appear to be 0.10 (10%). If the runoff of any given year is independent of that of the previous year, the probability of 6 consecutive years of such low runoff is therefore one in one million (i.e., 0.10 raised to the 6th power). This result contrasts sharply with the fact that 6-year and 7-year droughts of about this intensity have occurred in the 100-year period of record (Table H-1). The probability of such events being initiated in any future year would therefore be two in 100 (2%). This incongruity demonstrates that dry years are not randomly distributed, but that they do occur as sequences, or "droughts".

For purposes of impact assessment, a drought duration having a 1% annual probability of being initiated is appropriate. The occurrence of two droughts of 60-65% of normal runoff in 100 years suggests that a longer drought has a 1% chance of occurring. To estimate this duration, an analysis of cumulative frequencies of dry-year sequences over the past 98 years is needed.

Table H-3 shows all sequences of 2 or more years that have been "dry" in that the average runoff in the sequence has been 69% or less of normal runoff. The data set involves some shorter periods of more intense drought than the data set of the two prolonged, major droughts considered so far. Table H-4 summarizes the dry-year sequence data.

The data summary shows that the number of dry-year sequences has an inverse relationship to the duration of the sequence. It also shows that the average fraction of normal runoff is fairly constant, about 60%, for all dry-year sequence durations, although it does increase somewhat as duration increases.

The relationship of probability of occurrence to length of sequence can be evaluated by fitting the data in Table H-5 to an exponential curve. An exponential relationship allows for the fact that probabilities of long duration droughts never reach zero, but become vanishingly small. A least-squares fit of the data employing a logarithmic transformation results in the following relationship:

$$P = 40.67 \times \exp(-0.4702 \times \text{length})$$

where

P = probability (in %) of a dry-year sequence of a particular length (in years) of occurring

Based on this relationship, the length of a sequence of dry years having a 1% chance of being initiated in any given year (and having average runoff of about 60-65% of normal) is 8 years.

Predicting Minimum Lake Levels from Prolonged Droughts

Based on the above analyses, the minimum lake level under each lake-management alternative during drought having a 1% chance of occurring can be estimated. The water balance equation previously presented for a drought period having 60% of normal runoff can be applied for 8 years to lake elevations beginning at the median lake level for each alternative, once dynamic equilibrium is attained. The simulations begin at the median levels of the alternatives to avoid simulating droughts even longer than the selected scenarios.

The minimum lake levels attained under each lake management alternative for this drought scenario after 6- and 8-year periods are shown in Table H-5. Tables H-6 through H-12 show the simulations for each alternative on a year-by-year basis.

As the simulations indicate, the amount of lake surface elevation decline during a prolonged drought depends on the target lake level. The highest elevation alternative would be subject to 8-year declines of up to 11 feet, while the lowest target lake level alternative would decline only 4-5 feet. This difference is because of the lower evaporative losses associated with lower lake levels; when lake level is low but diversions are curtailed, the lake surface tends to rise rapidly. At the higher lake elevations, this tendency diminishes.

The No-Restriction Alternative would entail a large lake surface elevation decline of about 16 feet. This is because diversions would continue throughout the drought period.

Table H-1. Droughts in the Historical Period

1923-1935			1987-1992		
Year	Fraction Normal Runoff[a]	Accumulated Deficit from Normal Runoff	Year	Fraction Normal Runoff	Accumulated Deficit from Normal Runoff
1923	0.91	0.09	1987	0.56	0.44
1924	0.55	0.54	1988	0.56	0.88
1925	0.92	0.62	1989	0.73	1.15
1926	0.72	0.90	1990	0.48	1.67
1927	1.05	0.85	1991	0.64	2.03
1928	0.75	1.10	1992	0.64	2.39
1929	0.59	1.51			
1930	0.62	1.89	Average	0.60	
1931	0.44	2.45			
1932	0.97	2.48			
1933	0.65	2.83			
1934	0.50	3.33			
1935	0.95	3.38			
Average	0.74[a]				

[a] Normal runoff is 123.5 TAF/yr.

[b] Average for 1928-1934 7-year subset is 0.65, with an accumulated deficit of 2.48.

Table H-2. 1987-1992 Drought History

Water Year[a]	Elevation (ft)	Change in Elevation (ft)	Area[b] (ac)	Average Area (ac)	Change in Volume (af)	Diverted Stream Runoff (af)	Fraction of Normal Runoff (%)	Lake Releases (af)	Other Runoff[c] (af)	Direct Precipitation[d] (in)	Precipitation Volume (af)	Evaporation Volume[e] (af)	Residual[f] (af)
1987	6,380.40		43,904										
		-1.57		43,400	-68,137	69,127	56.0	23,114	15,761	7.97	28,825	-173,598	37,761
1988	6,378.83		42,895										
		-1.90		42,185	-80,152	68,856	55.8	15,882	15,699	4.87	17,120	-168,740	39,887
1989	6,376.93		41,475										
		-1.00		41,071	-41,071	90,061	73.0	71,370	20,534	7.50	25,669	-164,284	5,640
1990	6,375.93		40,667										
		-0.76		40,360	-30,674	59,782	48.4	59,782	13,630	6.95	23,375	-161,440	33,979
1991	6,375.17		40,053										
		-0.60		39,815	-23,889	78,718	63.8	78,718	17,948	6.75	22,396	-159,260	16,309
1992	6,374.57		39,577										
		-0.77		39,280	-30,246	79,400[h]	64.3	79,400	18,103	6.85[i]	22,422	-157,120	6,949
1993	6,373.80[g]		38,983										
Average						74,324	60.2			6.82[j]			23,421[k]
Normal						123,405	1.000			11.00			33,780

[a] Water years begin on April 1 of the year stated.
[b] From Pelagos and Pacific Western Aerial Surveys data.
[c] 22.8% of diverted stream runoff, based on average for 1941-1989.
[d] At Cain Ranch.
[e] 48 inches per year assumed.
[f] Lake releases + other runoff + precipitation volume - evaporation - change volume.
[g] Estimate based on September 23, 1992 elevation and average elevation change from September 1 to April 1 in last 2 years.
[h] Projected by LADWP.
[i] Assumed, using average of 2 previous years.
[j] Average direct precipitation (6.82 inches) is 0.57 feet or 63% of the historical average.
[k] The average residual (23,421 af) is 69% of the historical average.

Table H-3. Dry Year Sequences, 1895-1992

Year	Percent of Normal Runoff	Percent of Normal Runoff Averages with Preceding Years					
		2 Years	3 Years	4 Years	5 Years	6 Years	7 Years
1928	75						
1929	59	67					
1930	62	60	65				
1931	44	53	55	60			
1932	97	>69	68	66	67		
1933	65	>69	69	67	65	67	
1934	50	58	>69	64	64	63	65
1953	73						
1954	62	68					
1959	59						
1960	58	59					
1961	60	59	59				
1976	47						
1977	44	46					
1987	56						
1988	56	56					
1989	73	65	62				
1990	48	61	59	58			
1991	64	56	62	60	59		
1992	64	64	59	62	61	60	

Notes: Includes sequences of 2 or more years having average runoff of 69% of normal or less (i.e., "dry" years).

Table H-4. Summary of Dry Year Sequences

Sequence Length (yrs)	Number of Sequences	Average Percent of Normal Runoff	Probability of Initiation Each Year[a] (%)
2	13	59	13.26
3	9	62	9.18
4	7	62	7.14
5	5	63	5.10
6	3	63	3.06
7	1	65	1.02

[a] Number of sequences divided by the length of the period of record, 98 years (1895-1992).

Table H-5. Minimum Lake Levels for the Alternatives during Prolonged Drought

Duration	Alternatives						
	No Restriction	6,372-Ft	6,377-Ft	6,383.5-Ft	6,390-Ft	6,410-Ft	No Diversion
0 yrs	6,352.4	6,374.9	6,379.1	6,385.7	6,391.6	6,410.8	6,427.4
6 yrs	6,340.3	6,371.0	6,374.1	6,379.3	6,384.7	6,403.3	6,419.1
8 yrs	6,336.5	6,370.4	6,373.1	6,377.8	6,382.8	6,400.8	6,416.4
Total decline	15.9	4.5	6.0	7.9	8.8	10.0	11.0

Note: Assumed runoff is 60% of normal and assumed precipitation is 63% of normal; see Table H-2.

Table H-6. Drought Simulation - No-Restriction Alternative
60% of Normal Runoff

Year	Starting Elevation (ft)	Release Factor	Lake Area (acres)	Change in Volume (af)	Change in Elevation (ft)	Ending Elevation (ft)
0	6,352.42	0	30,263	-63,266	-2.091	6,350.33
1	6,350.33	0	29,734	-61,454	-2.067	6,348.26
2	6,348.26	0	29,193	-59,602	-2.042	6,346.22
3	6,346.22	0	28,627	-57,663	-2.014	6,344.21
4	6,344.21	0	28,048	-55,681	-1.985	6,342.22
5	6,342.22	0	27,463	-53,677	-1.955	6,340.27
6	6,340.27	0	26,885	-51,698	-1.923	6,338.34
7	6,338.34	0	26,315	-49,746	-1.890	6,336.45
8	6,336.45					

Note: Beginning elevation is median at dynamic equilibrium.

Table H-7. Drought Simulation - 6,372-Ft Alternative
60% of Normal Runoff

Year	Starting Elevation (ft)	Release Factor	Lake Area (acres)	Change in Volume (af)	Change in Elevation (ft)	Ending Elevation (ft)
0	6,374.88	0.25	39,821	-77,415	-1.944	6,372.94
1	6,372.94	1	38,366	-16,690	-0.435	6,372.50
2	6,372.50	1	38,049	-15,604	-0.410	6,372.09
3	6,372.09	1	37,753	-14,590	-0.386	6,371.70
4	6,371.70	1	37,472	-13,628	-0.364	6,371.34
5	6,371.34	1	37,214	-12,745	-0.342	6,371.00
6	6,371.00	1	36,970	-11,909	-0.322	6,370.68
7	6,370.68	1	36,745	-11,139	-0.303	6,370.37
8	6,370.37					

Note: Beginning elevation is median at dynamic equilibrium.

Table H-8. Drought Simulation - 6,377-Ft Alternative
60% of Normal Runoff

Year	Starting Elevation (ft)	Release Factor	Lake Area (acres)	Change in Volume (af)	Change in Elevation (ft)	Ending Elevation (ft)
0	6,379.13	0.25	43,098	-88,637	-2.057	6,377.07
1	6,377.07	1	41,587	-27,720	-0.667	6,376.41
2	6,376.41	1	41,055	-25,898	-0.631	6,375.78
3	6,375.78	1	40,546	-24,155	-0.596	6,375.18
4	6,375.18	1	40,061	-22,494	-0.561	6,374.62
5	6,374.62	1	39,616	-20,970	-0.529	6,374.09
6	6,374.09	1	39,198	-19,539	-0.498	6,373.59
7	6,373.59	1	38,833	-18,289	-0.471	6,373.12
8	6373.12					

Note: Beginning elevation is median at dynamic equilibrium.

Table H-9. Drought Simulation - 6,383.5-Ft Alternative
60% of Normal Runoff

Year	Starting Elevation (ft)	Release Factor	Lake Area (acres)	Change in Volume (af)	Change in Elevation (ft)	Ending Elevation (ft)
0	6,385.74	0.25	46,624	-100,711	-2.160	6,383.58
1	6,383.58	1	45,588	-41,421	-0.909	6,382.67
2	6,382.67	1	45,126	-39,838	-0.883	6,381.79
3	6,381.79	1	44,672	-38,284	-0.857	6,380.93
4	6,380.93	1	44,214	-36,715	-0.830	6,380.10
5	6,380.10	1	43,729	-35,055	-0.802	6,379.30
6	6,379.30	1	43,209	-33,274	-0.770	6,378.53
7	6,378.53	1	42,689	-31,493	-0.738	6,377.79
8	6,377.79					

Note: Beginning elevation is median at dynamic equilibrium.

Table H-10. Drought Simulation - 6,390-Ft Alternative
60% of Normal Runoff

Year	Starting Elevation (ft)	Release Factor	Lake Area (acres)	Change in Volume (af)	Change in Elevation (ft)	Ending Elevation (ft)
0	6,391.57	0.5	48,760	-89,445	-1.834	6,389.74
1	6,389.74	1	48,145	-50,177	-1.042	6,388.69
2	6,388.69	1	47,749	-48,821	-1.022	6,387.67
3	6,387.67	1	47,367	-47,513	-1.003	6,386.67
4	6,386.67	1	46,987	-46,211	-0.983	6,385.68
5	6,385.68	1	46,598	-44,879	-0.963	6,384.72
6	6,384.72	1	46,167	-43,403	-0.940	6,383.78
7	6,383.78	1	45,689	-41,766	-0.914	6,382.87
8	6,382.87					

Note: Beginning elevation is median at dynamic equilibrium.

Table H-11. Drought Simulation - 6,410-Ft Alternative
60% of Normal Runoff

Year	Starting Elevation (ft)	Release Factor	Lake Area (acres)	Change in Volume (af)	Change in Elevation (ft)	Ending Elevation (ft)
0	6,410.83	1	53,706	-69,220	-1.289	6,409.54
1	6,409.54	1	53,439	-68,306	-1.278	6,408.26
2	6,408.26	1	53,171	-67,388	-1.267	6,407.00
3	6,407.00	1	52,904	-66,473	-1.256	6,405.74
4	6,405.74	1	52,625	-65,518	-1.245	6,404.49
5	6,404.49	1	52,327	-64,498	-1.233	6,403.26
6	6,403.26	1	52,030	-63,481	-1.220	6,402.04
7	6,402.04	1	51,730	-62,453	-1.207	6,400.83
8	6,400.83					

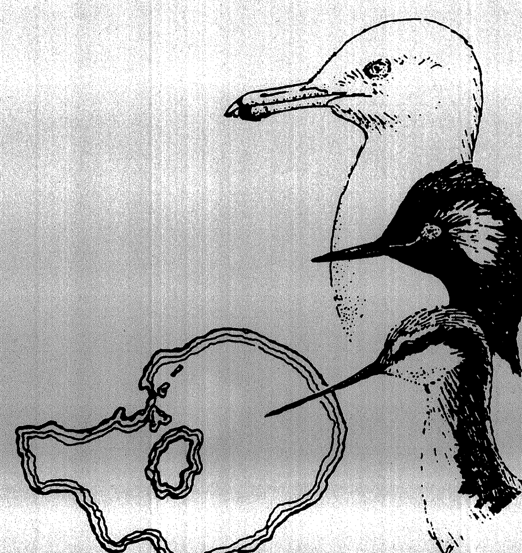
Note: Beginning elevation is median at dynamic equilibrium.

Table H-12. Drought Simulation - No-Diversion Alternative
60% of Normal Runoff

Year	Starting Elevation (ft)	Release Factor	Lake Area (acres)	Change in Volume (af)	Change in Elevation (ft)	Ending Elevation (ft)
0	6,427.44	1	57,498	-82,205	-1.430	6,426.01
1	6,426.01	1	57,069	-80,736	-1.415	6,424.60
2	6,424.60	1	56,636	-79,253	-1.399	6,423.20
3	6,423.20	1	56,254	-77,945	-1.386	6,421.81
4	6,421.81	1	55,934	-76,849	-1.374	6,420.44
5	6,420.44	1	55,632	-75,815	-1.363	6,419.07
6	6,419.07	1	55,333	-74,791	-1.352	6,417.72
7	6,417.72	1	55,065	-73,874	-1.342	6,416.38
8	6,416.38					

Note: Beginning elevation is median at dynamic equilibrium.

Appendix I. Natural History of the Mono Lake Alkali Fly



MONO BASIN EIR

Prepared by Jones & Stokes Associates

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Appendix I. Natural History of the Mono Lake Alkali Fly

This appendix presents a discussion of the life history of the Mono Lake alkali fly and the physical and biological constraints that determine the fly's abundance and distribution in Mono Lake.

CLASSIFICATION AND TAXONOMY

The Mono Lake alkali fly (*Ephydra hians* Say) was first described and classified by Say in 1830 as belonging to the shore and brine fly family Ephydridae, in the true fly order Diptera. Brine flies (*Ephydrids*) are often the most abundant benthic and shore inhabitants of saline aquatic habitats throughout the world (Herbst 1986).

The genus *Ephydra* inhabits extreme environments such as acidic thermal springs, alkaline saline lakes, tidal splash pools, and coastal marshes, but individual species often are adapted to particular habitat types (Herbst 1990a). For example, *Ephydra thermophilia* is present only in acidic hot springs in Yellowstone National Park, while *Ephydra cinerea* is found in the Great Salt Lake in Utah (Herbst 1986). The Mono Lake alkali fly, as its common name implies, is specifically adapted to alkaline habitats. The species inhabits many other alkaline saline lakes and ponds in North America (Herbst 1990b).

LIFE HISTORY

The Mono Lake alkali fly has a typical insect life cycle, developing from egg to larva before pupating and metamorphosing into an adult reproducing insect (refer to Figure 3E-3 in Chapter 3E, "Aquatic Productivity"). The life cycle begins as a mated female fly crawls underwater to lay her eggs individually on benthic algal mats or substrate close to shore. The eggs remain on the bottom mainly because they are heavier than Mono Lake water, although the female fly may further assist by tucking her eggs into the algal mat. The opalescent, non-sticky eggs are football-shaped and are approximately 0.6-1.0 mm long and about 0.2 mm wide (Herbst pers. comm.). Hatching success depends on salinity and temperature. The eggs hatch in 1-3 days into tiny larvae (first instars) (Herbst 1986).

The larvae undergo a series of distinct development phases (categorized as first, second, and third instars) and shed, or molt, the old skin (cuticle) between phases. Average Mono Lake alkali fly instar dry weight and size increase exponentially: first instars weigh 0.02 mg and are 1.0-3.5 mm long, second instars weigh 0.20 mg and are 3.5-5.5 mm long, and third instars weigh approximately 2.9 mg and are 5.5-12.0 mm long (Herbst 1990b, Herbst pers. comm.). Larval development ranges from 4 weeks to more than 5 months, depending on temperature, salinity, and food quantity and quality. Laboratory studies show that the growth and development at 20°C usually require 4 days for first instars, 7 days for second instars, and 14 days for third instars (Herbst pers. comm.) (refer to Figure 3E-4 in Chapter 3E, "Aquatic Productivity"). In Mono Lake, where water temperatures are often lower than 20°C, development times may be longer.

When ready to pupate, the mature larva attaches itself by means of clamp-like clawed caudal prolegs to a protected underside of a rock, where it is relatively safe from dislodgment by turbulent water. The larva encases itself in a puparium, where the nonfeeding, inactive pupa undergoes complete structural change and emerges as an adult alkali fly within 1-3 weeks, depending on temperature (Herbst 1986). At 20°C, pupation time is 13 days. The pupae range in length from 8 to 10 mm and average 1.95 mg dry weight. The puparium with the pupa fills with air during pupation and will float if dislodged.

When the adult Mono Lake alkali fly emerges from the puparium, it ascends to the water surface enclosed in an air bubble developed in the puparium. It spends the remainder of its life along the lake shore grazing on algal and detrital food sources and procreating (Herbst 1986, Herbst pers. comm.). Normal adult life span is 10-14 days, but overwintering adults may survive for months. Food is essential to successful reproduction, and adult flies are capable of submerging to gain access to high-quality benthic algae. Mating of the densely aggregated adults seems to be random with no precopulatory behavioral displays (Herbst 1986). Fecund female flies produce a daily average of approximately 10 eggs over a period of 2 weeks (Herbst 1992). The females submerge to deposit their eggs in the benthic algal mats, thus completing the life cycle.

Length of adult flies in Mono Lake ranges from 4.2 to 6.3 mm and averages 4.8 mm (Herbst 1990b). Adults from Mono Lake are consistently smaller than adult flies of the same species found in Abert Lake (Oregon), Pyramid Lake (Nevada), and Carson Sink Ponds (Nevada), which are saline inland waters with lower salinities than Mono Lake (Herbst 1990b). Laboratory rearing of alkali flies from different geographic locations indicates that body size is determined by both environmental and genetic components (Herbst 1990b).

Pupation and metamorphosis are high energy-consuming processes. The Mono Lake alkali fly reaches its highest caloric content as a third instar and early pupa; mature larvae contain 12.4 calories per individual, whereas pupae and adults contain only 11.2 and 7.2 calories per individual, respectively (Herbst 1986). Dry weight of the emerging adult is only approximately 1.3 mg, less than half the weight of the pupating larva. Larvae must reach a certain body weight and caloric content to ensure successful pupation and emergence (Herbst 1986, 1990b). Pupal mortality increases rapidly at pupal widths (dorso-ventral width between 3rd and 4th prolegs) below 1.7 mm, and pupae have little chance of survival at widths below 1.5 mm (Figure I-1) (Herbst pers. comm.).

Mono Lake alkali fly have few predators or competitors, and their numbers are limited mainly by food availability and physical constraints. Dislodgment of larvae and pupae brought on by storm-generated waves or currents are probably the main cause of mortality. Larvae and pupae use clawed prolegs to cling to hard surfaces to prevent being swept away to the middle of the lake or the shore, where they are exposed to starvation, predation, or parasitism (Herbst 1986).

EFFECTS OF ENVIRONMENTAL FACTORS ON DEVELOPMENT, SURVIVAL, AND REPRODUCTION

Temperature

Ambient temperature strongly affects temporal and spatial patterns of abundance of the Mono Lake alkali fly. Temperature is a major regulator of many life cycle processes of the fly, such as hatching, growth, development, pupation, metamorphosis, and egg laying.

Low ambient temperatures slow metabolic processes and increase development time and mortality. If temperatures drop below a certain threshold, development ceases altogether (Herbst 1988). Inactive, nonfeeding lifestages involving much structural development, such as the pupal and egg lifestages, are especially sensitive to low temperatures. Pupae cannot develop or survive long at water temperatures below 5°C (refer to Figure 3E-5 in Chapter 3E, "Aquatic Productivity") (Herbst 1988). Because winter temperatures in Mono Lake regularly drop below 5°C, pupae presumably suffer high winter mortalities. Eggs also perish at these ambient temperatures, but eggs are not generally exposed to cold water because adult flies do not produce eggs during winter. All larval instars can survive the near zero temperatures, however, and overwintering populations consist mainly of slowly growing second and third instars (Herbst 1988, 1990a).

Increasing water temperatures in spring (March-April) cause rapid growth and development of the overwintering larvae and increase rates of development and survival of the pupae. Development time of pupae in the laboratory decreased more than five-fold as temperature was raised from 10°C to 25°C (Figure I-2). As a result of increasing rates of growth and development, the alkali fly population increases exponentially during spring (refer to Figure 3E-6 in Chapter 3E, "Aquatic Productivity") (Herbst 1986). The population remains abundant through summer, until declining temperatures and shortened photo-period in autumn cause adult flies to cease laying eggs (Herbst 1988). Pupal densities are highest in early autumn (August-September). Population density drops rapidly in October when cooling temperatures cause high mortalities of all lifestages.

Body size of developing larvae and adult alkali flies exhibit seasonal cycles. The flies are largest in early spring and smallest in autumn (Figure I-3) (Herbst 1988). These seasonal variations in body size may be due to temperature-induced changes in fly metabolism or to seasonality of food quality (Herbst 1986). Large flies have less lipid reserves than smaller flies, however, so fly caloric value does not vary much seasonally.

The growing season available to the Mono Lake alkali fly is short due to the lake's high-altitude location and cool ambient temperature. However, the fly develops and reproduces rapidly, producing 1-3 generations in a season (Herbst 1988).

Alkali fly larvae and pupae are most abundant in water less than 3 feet deep and are rarely found below the thermocline, where temperatures are too cold for growth and development (Herbst and Bradley 1990). Littoral temperatures exhibit greater extremes than pelagic temperatures because shallow depths respond more quickly to heating and cooling. Selected littoral-benthic areas may freeze in winter and heat up to 40°C in summer (Herbst 1986, Herbst pers. comm.). Diel temperature fluctuations also are higher in shallow water than in the middle of the lake. Selected shallow areas of Mono Lake, such as Black Point Tufa Shoals, are more sheltered from wind and waves, resulting in higher water temperatures and a longer growing season.

Salinity

High salinities osmotically desiccate aquatic organisms because body fluids are less saline than the surrounding saltwater. The osmoregulatory mechanisms employed by the egg are unknown (NAS 1987). The larva maintains osmotic homeostasis by excreting salt through specialized organs in addition to using unknown mechanisms, whereas the developing pupa is protected from osmotic desiccation by the puparium (Herbst 1986).

The alkali fly is well adapted to high salinities, but the bioenergetic costs of osmotic regulation reduce the total energy available for growth and development (Herbst 1986). High salinities have a marked negative effect on larval growth and development rates, larval survivorship, and pupation success (Figures I-4 and I-5) (Herbst 1986, Bradley 1991). Hatching success and pupal weight also are negatively affected. At salinities above 150 grams per liter (g/l) the detrimental effects of osmotic stress become insurmountable (Herbst 1986). The early instars are particularly sensitive to high salinities (Herbst 1990b).

High salinity further affects the alkali fly by reducing algal primary productivity and, possibly, quality (Herbst 1992). As food availability declines, alkali fly growth and development rates decrease correspondingly, resulting in smaller pupae and adults, higher mortality, and less reproductive success (Herbst 1986, 1992). Increased energy must be spent on foraging, and it becomes more difficult for the larvae to meet the high osmoregulatory costs (Herbst 1990b).

Alkalinity

As in most alkaline saline lakes, alkalinity at Mono Lake is caused primarily by large concentrations of carbonate and bicarbonate ions (Herbst 1986). The carbonate and bicarbonate ions make up a constant 40% of the total dissolved solids of Mono Lake water, so alkalinity is linearly related to salinity. Although lakes exist worldwide supporting insect communities at salinities much higher than those found at Mono Lake, none is as alkaline (NAS 1987).

The combination of high salinity and high alkalinity is very difficult for most species to adapt to, yet Mono Lake alkali fly larvae survive better in alkaline salt water than in non-alkaline salt water of the same osmotic concentration (Herbst 1986). The larvae have a very unusual physiological adaptation for dealing with high concentrations of carbonate and bicarbonate ions accumulating in their blood. The lime gland, a kidney-like gland that in other insects commonly removes nitrogen wastes, in Mono lake alkali fly larvae also is used partially to remove carbonate ions from the blood. Within specialized lime gland tubules, excess carbonate ions are precipitated with calcium, forming calcium carbonate or limestone, which is stored inside the lime gland until metamorphosis occurs (Herbst pers. comm.). Larvae probably have a dietary need for calcium, as Mono Lake has extremely low calcium concentrations (Herbst pers. comm.). In Mono Lake, most calcium is bound as calcium carbonate and other minerals because carbonate and bicarbonate concentrations in the lake are so high. Tufa formations consist mostly of precipitated calcium carbonate.

Substrate

Mono Lake's shoreline is open and windswept. Storm-generated waves and undertows easily sweep away larvae and pupae not firmly attached to or sheltered by rocks. Once adrift in the lake or cast ashore, the larvae and pupae are likely victims of predators, desiccation, and parasitism. Wave action also shifts benthic sands and muds, potentially burying larvae and pupae. To survive these conditions, the alkali fly must have access to rocky surfaces or vegetation to which it can cling, especially during pupation.

The alkali fly's benthic-littoral habitat can be classified, based on attachment potential, as consisting of soft or hard substrate types (refer to Table 3E-1 and Figure 3E-8 in Chapter 3E, "Aquatic Productivity"). Mud, sand, and gravel are included in the soft substrate category, with mud predominant. Littoral sands and occasional gravels encircle Mono Lake above elevations of approximately 6,365 feet (Stine 1992). Tributary creeks are the main sources of littoral deposits of silt, sands, and gravels, but shoreline erosion also contributes some material. Benthic algal and detrital mats covering mud and sands flourish chiefly where the shoreline is somewhat sheltered from wind and waves. Although numerous larvae forage in the algal and detrital mats, soft substrate offers less shelter from waves and no firm attachment sites.

Densities of alkali fly larvae and pupae are much higher on hard substrates than on soft substrates (refer to Table 3E-2 in Chapter 3E, "Aquatic Productivity"). Soft substrate close to tufa has been found to be much more densely populated than soft substrate far removed from tufa areas (Little et al. 1989). Possible explanations of the higher densities near tufa include greater recruitment, reduced wave action, more accumulated detritus, and the presence of more nutritious food (Little et al. 1989).

Hard substrate types consist of tufa-covered pumice blocks, free-standing tufa, beach-rock, bedrock, and mudstone. Mudstone is the most extensive of the hard substrates in terms of total acreage (refer to Table 3E-1 in Chapter 3E, "Aquatic Productivity"), but is considered a poor-quality hard substrate habitat because its surface is relatively soft and does not contain sheltering micro-crevices (Herbst pers. comm.). Most of Paoha Island consists of compacted and uplifted mudstone, as do the Paoha Islets and submerged slump-blocks to the north, east, and west of Paoha Island.

Scattered tufa-covered pumice blocks are the second most extensive hard substrate. The tufa-covered blocks are good habitat for the Mono Lake alkali fly larvae and pupae because their roughly textured surfaces provide good foothold and shelter from waves. Most pumice blocks are more than 3 feet across and are found up to an elevation of 6,390 feet in drifts mainly in northern and western portions of Mono Lake.

The pumice blocks are evidence of a volcanic eruption occurring when lake elevation was 6,390 feet. The eruption pitched the blocks into Mono Lake, and southeasterly winds and currents carried the blocks, which were buoyant due to enclosed gas bubbles, to the northern and western shores where they slowly became waterlogged and sank. The pumice blocks vary in size and areal density (Stine 1992).

Tufa-coated bedrock of volcanic origin is found on the Negit islets, on several points on Paoha Island, and along earthquake faults on the lake floor (Stine 1992). It is the third most abundant type of hard substrate in terms of total acreage and provides good habitat for the Mono Lake alkali fly. Because of the steepness of the bedrock areas, only a small portion is within the littoral zone (CORI 1988).

Scattered solitary tufa towers, continuous tufa bulwarks, and other free-standing tufa types constitute a small but important hard substrate habitat type. These tufa substrates occur primarily on the southern portion of the lake at elevations ranging from 6,300 to 6,400 feet and consist of calcite and aragonite (two forms of calcium carbonate) and other mineral deposits precipitated where fresh spring water from lake bottom orifices mixed with saline lake water (Stine 1992). Some tufa originates from the mineral, gaylussite (Herbst and Bradley 1990). Tufa forms slowly everywhere on the lake bottom, and submerged hard objects such as vegetation often become encrusted with tufa over time. Tufa formation rates are much more rapid where springs supply a constant influx of calcium ions, which is the limiting ingredient for tufa in Mono Lake.

Tufa of all types is the most suitable habitat for aquatic lifestages of the Mono Lake alkali fly. Field studies found third instar larvae and pupae in far greater densities on tufa than on any other hard or soft substrate (Little et al. 1989, Herbst 1992). The preference of alkali fly larvae and pupae for tufa has several plausible explanations. Tufa provides superior attachment sites because of its rough surface. Vertical towers have deeper crevices than any other substrate, sheltering larvae and pupae from waves and bird predators (Little et al. 1989). Towers are elevated above the lake bottom, protecting early lifestages from burial or abrasion by shifting bottom sands (Little et al. 1989). Tufa also serves as a growth site for algae.

Beachrock is a hard substrate habitat consisting of tufa-cemented sands, gravels, and cobbles, found mainly on the deltas of Mill and Lee Vining Creeks and other smaller tributaries. Beachrock formed when calcium containing fresh water mixed with carbonate rich lake water, resulting in calcium carbonate precipitating and cementing rocks and gravels together. Today much of the beach rock habitat is covered with littoral sands. Although beachrock provides good habitat for the Mono Lake alkali fly, it is of little importance because of its limited distribution (Little et al. 1989).

Submerged vegetation such as grasses and bushes also can provide good attachment sites for larvae and pupae. Density of larvae and pupae in areas of submerged vegetation is about half of that on tufa (Herbst 1990a). Vegetation can persist for up to 10 years before deteriorating (Herbst 1990b).

Food

The feeding niche of the Mono Lake alkali fly can best be described as that of a scraper-gatherer, herbivore-detritivore (Herbst 1986). Throughout all lifestages, food sources consist of benthic algae composed mainly of diatoms (especially *Nitzschia frustrulum*), filamentous green algae (especially *Ctenocladus circinnatus*), blue-green algae (especially *Oscillatoria*) and perhaps various bacteria and protozoa associated with detritus (Herbst 1986). No food is required during the egg and pupa lifestages, but food is essential for the larvae and adult fly. The adult fly is capable of submerging to gain access to high-quality benthic algae.

Reduced access to food or poor nutritional value of food results in high mortality, slow growth, prolonged development time, smaller size at maturity, and reduced reproductive success in the alkali fly (Herbst 1986). Dietary studies indicate that various lifestages thrive on food high in diatoms and blue-green algae, and that the green alga, *Ctenocladus*, is of less nutritional value to the alkali fly (Herbst 1986). No research has been conducted to investigate the importance of bacteria and protozoa in the diet.

Food may well be a limiting factor for the alkali fly, especially on crowded preferred habitat such as tufa. Pupal and adult body size decrease from spring through autumn (Figure I-3), possibly due to limited food resources resulting from an increasing fly population during this time period (Herbst 1986).

Physical factors affecting food availability during summer are primarily depth and nutrient supply (Herbst and Bradley 1989). Benthic algae standing crop decreases with depth, as light penetration decreases, so shallow waters have better food availability for the Mono Lake alkali fly. Low ammonium concentrations limit production of planktonic algae in spring and summer (see Chapter 3E, "Aquatic Productivity") and probably also may limit production of benthic algae (Herbst and Bradley 1989). Some Mono Lake benthic algae are nitrogen fixers and therefore contribute nitrogen to the aquatic ecosystem (Herbst pers. comm.).

Interspecific Competition, Diseases, and Predation

The Mono Lake alkali fly faces no serious competition from other species and is by far the most abundant macro-invertebrate present in the benthic-littoral habitat. Potential insect predators and competitors of the fly cannot survive in Mono Lake because salinity and alkalinity are too high. The high salinity and alkalinity also reduce parasitism and diseases.

Under low salinity conditions, mortality of the alkali fly from predators and parasites can be quite high. Beetles, damselfly larvae, and tabanid and dolichopodid larvae prey on alkali fly larvae in saline lakes with lower salinities, such as Walker and Pyramid Lakes in Nevada (Herbst 1986).

In Lake Abert, Oregon, 60-70% of alkali fly pupae dislodged and swept ashore in heaps (windrows) were parasitized by a small wasp, *Urolepis rufipes* (Herbst 1986). Adult flies are preyed on by tiger beetles, damselflies, robber flies, and other predaceous terrestrial insects, in addition to birds.

Birds, primarily gulls, phalaropes, and grebes, are the primary predators of the Mono Lake alkali fly. As discussed earlier, the lifestage with the greatest caloric value per individual is the mature third instar, followed by the pupa, and it is not surprising that these lifestages are the preferred prey for birds. Pupae and third instars also are the most accessible lifestages for birds, because large quantities are continually dislodged by waves and either swept out to the middle of the lake by wind and currents (classified as drift) or washed ashore in windrows. In either case, the pupae and larvae are fairly helpless, exposed, and easy to detect because of their size. Some birds eat adult flies congregated on the shore.

Nutritional value of larvae or pupae in drift and especially windrows declines rapidly with time because they quickly become desiccated, parasitized, and decomposed. Birds have constant access to freshly dislodged larvae and pupae during most of the summer because drift and windrows are continuously generated. Surveys of open water drift indicate that about 1 metric ton of larvae and pupae can be found floating on the lake in summer (Herbst 1992).

The seasonal distribution of drift follows that of the alkali fly productivity (Figure I-6) (Herbst 1992). Drift is uncommon in winter, increases in spring through summer, peaks in August, then sharply declines as temperatures drop in autumn (Herbst 1992). Windrow abundance presumably follows the same seasonal pattern as drift. August was the month when Kuzedika Paiute Indians historically gathered pupae and larvae for food at Mono Lake by seining the nearshore water. This harvest constituted an important part of the Kuzedika's diet.

Drift and windrows are not uniformly distributed in Mono lake. Drift is concentrated where currents converge or upwelling occurs, facilitating foraging by birds. The highest larval and pupal densities observed in drift samples were 10-20 individuals per square meter. Some water birds can further concentrate food by paddling around in circles, which creates upwelling currents.

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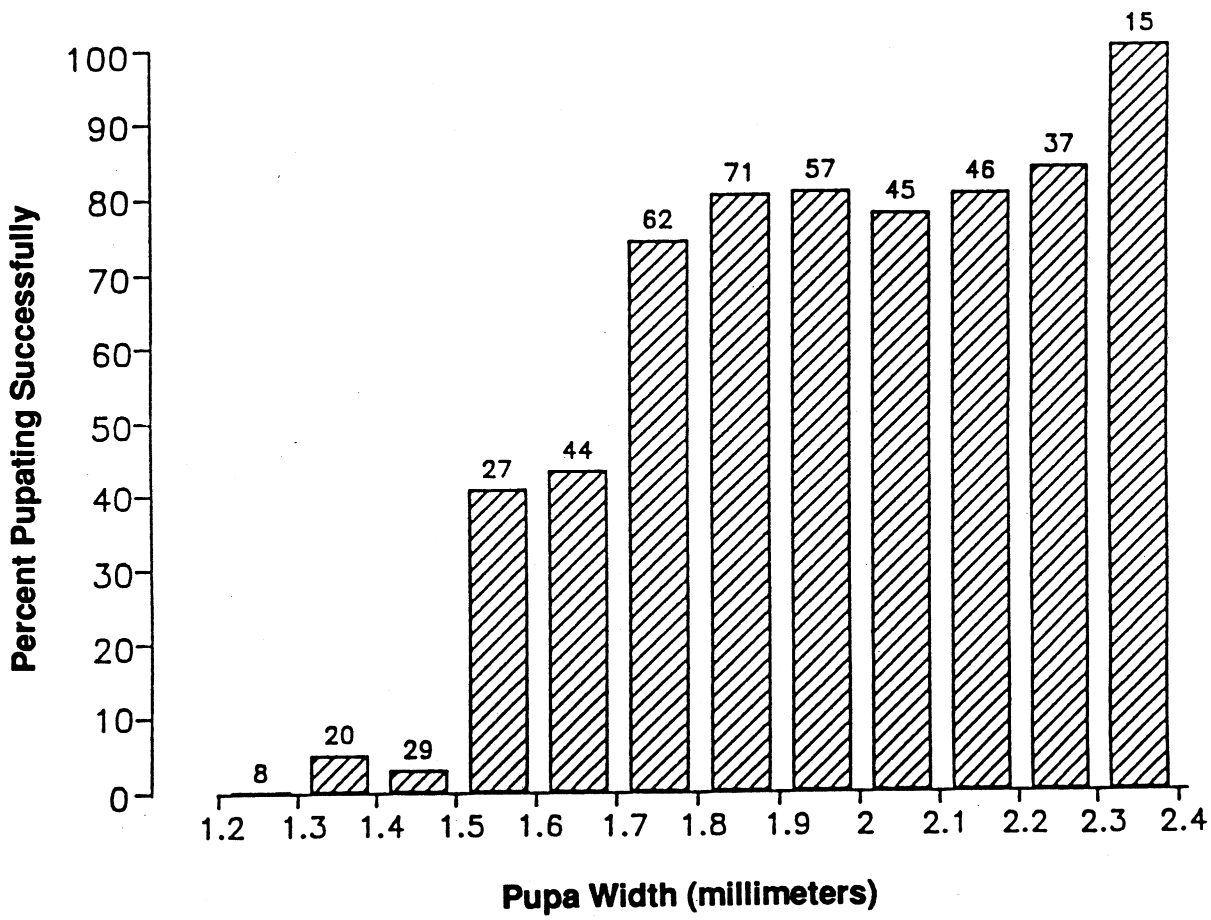


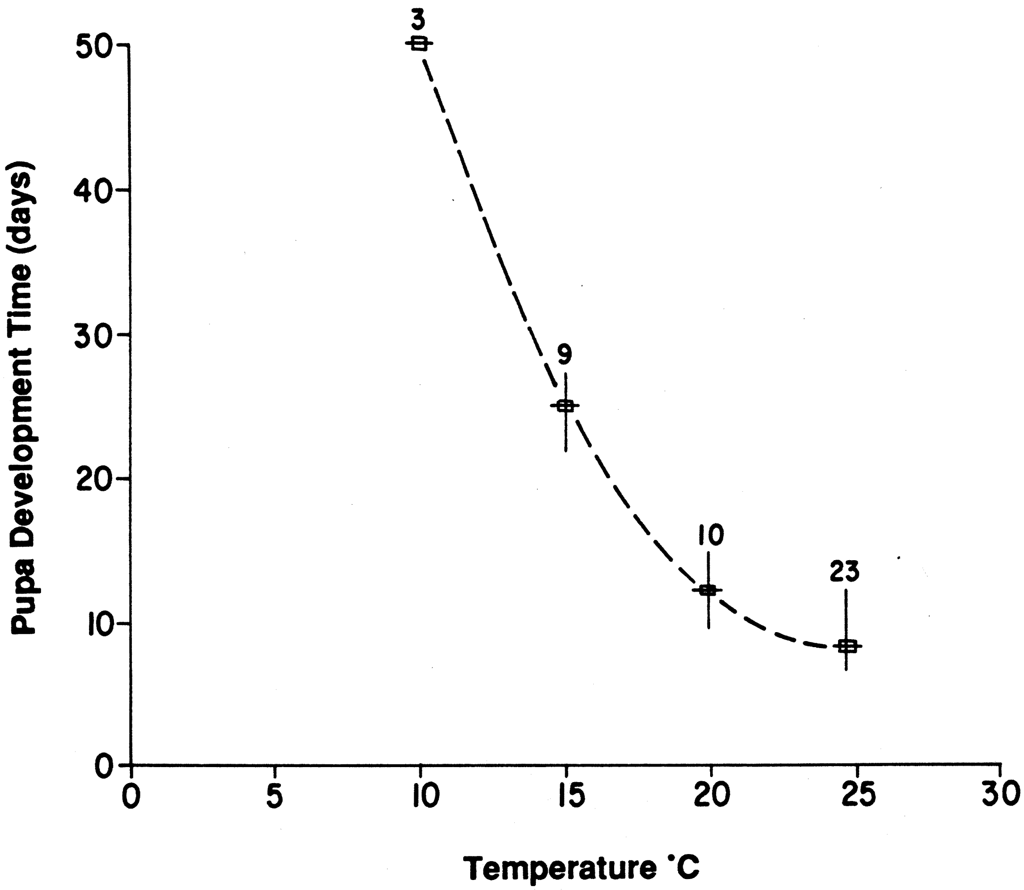
Note: Numbers above each bar indicate the sample sizes.

Source: Herbst 1990b

Figure I-1.
Percent of Mono Lake Alkali Fly Pupae of Different Widths Successfully Pupating to Adults

MONO BASIN EIR

Prepared by Jones & Stokes Associates

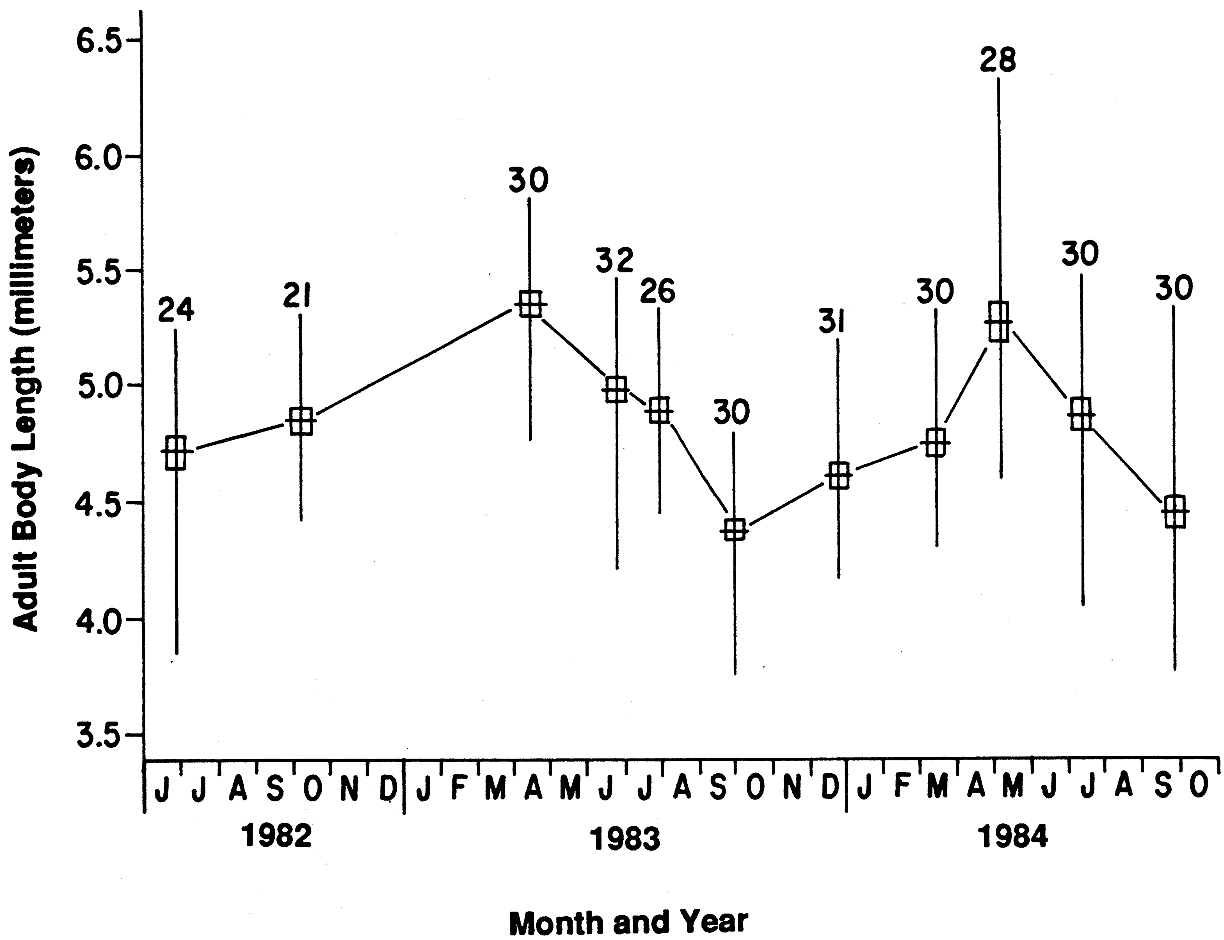


Notes: Boxes represent one standard error above and below the mean.
Vertical lines represent the range.
Numbers above each range line indicate the sample sizes.

Source: Adapted from Herbst 1986

Figure I-2.
Development Time of Mono Lake Alkali Fly Pupae as a Function of Temperature

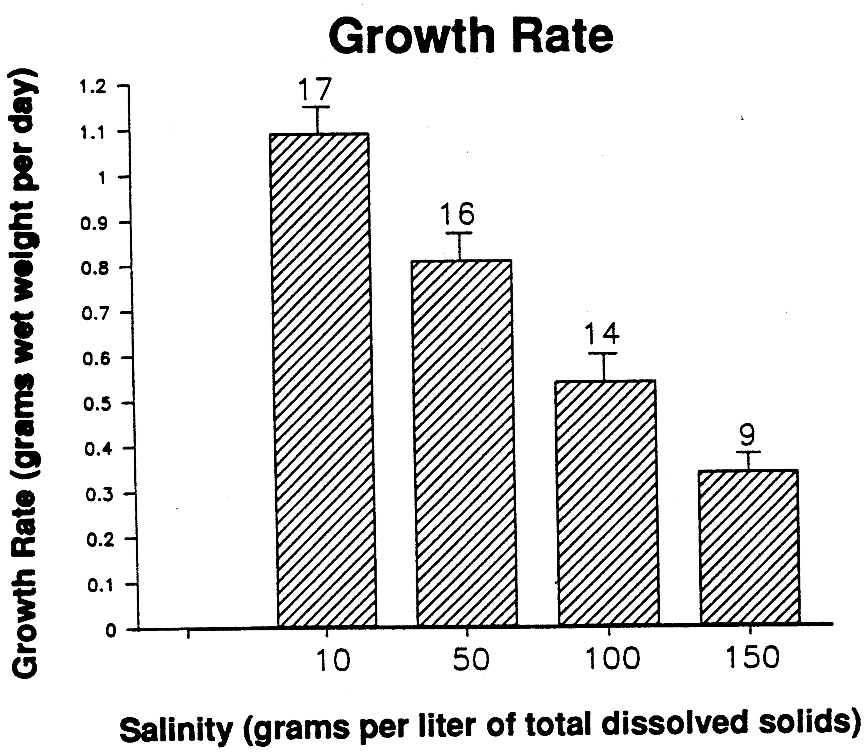
MONO BASIN EIR
Prepared by Jones & Stokes Associates

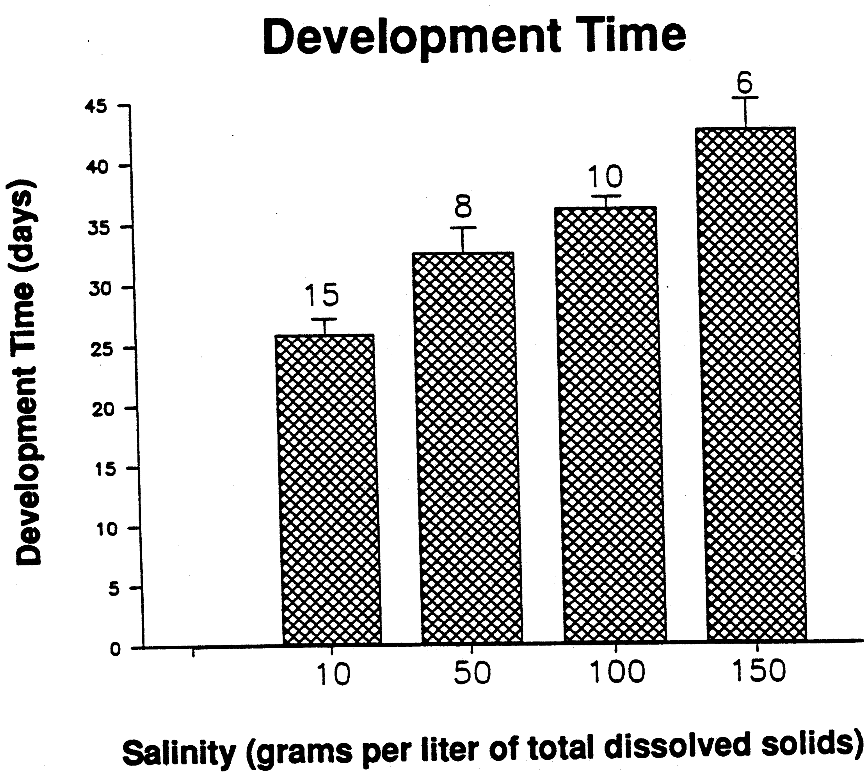


Notes: Boxes represent one standard error above and below the mean.
Vertical lines represent the range.
Numbers above each range line indicate the sample sizes.

Source: Adapted from Herbst 1986

Figure I-3.
Mean Body Lengths of Adult Mono Lake Alkali Flies in Different Months, June 1982 - September 1984

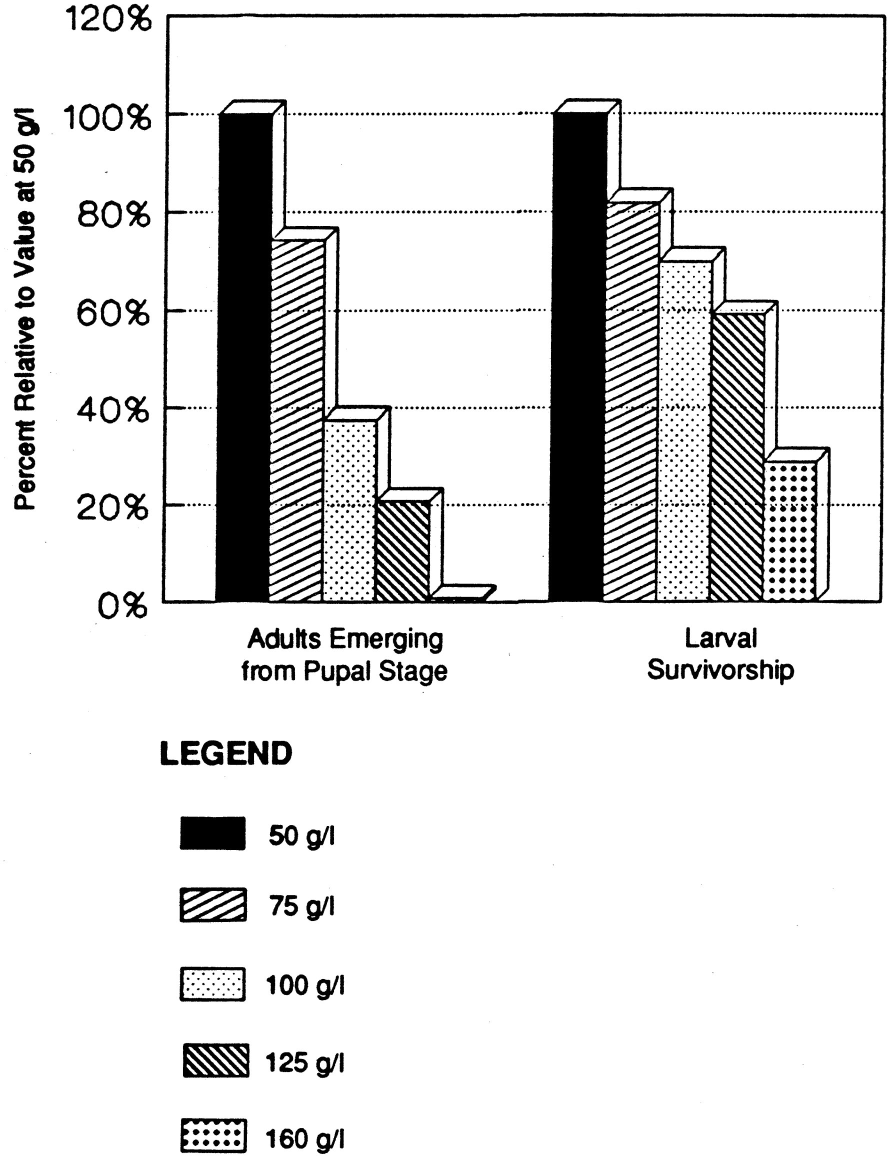




Notes: Height of bar indicates the mean. Height of "T" above the bar represents one standard error above the mean. Numbers above each bar indicate the sample sizes.

Source: Adapted from Herbst 1992

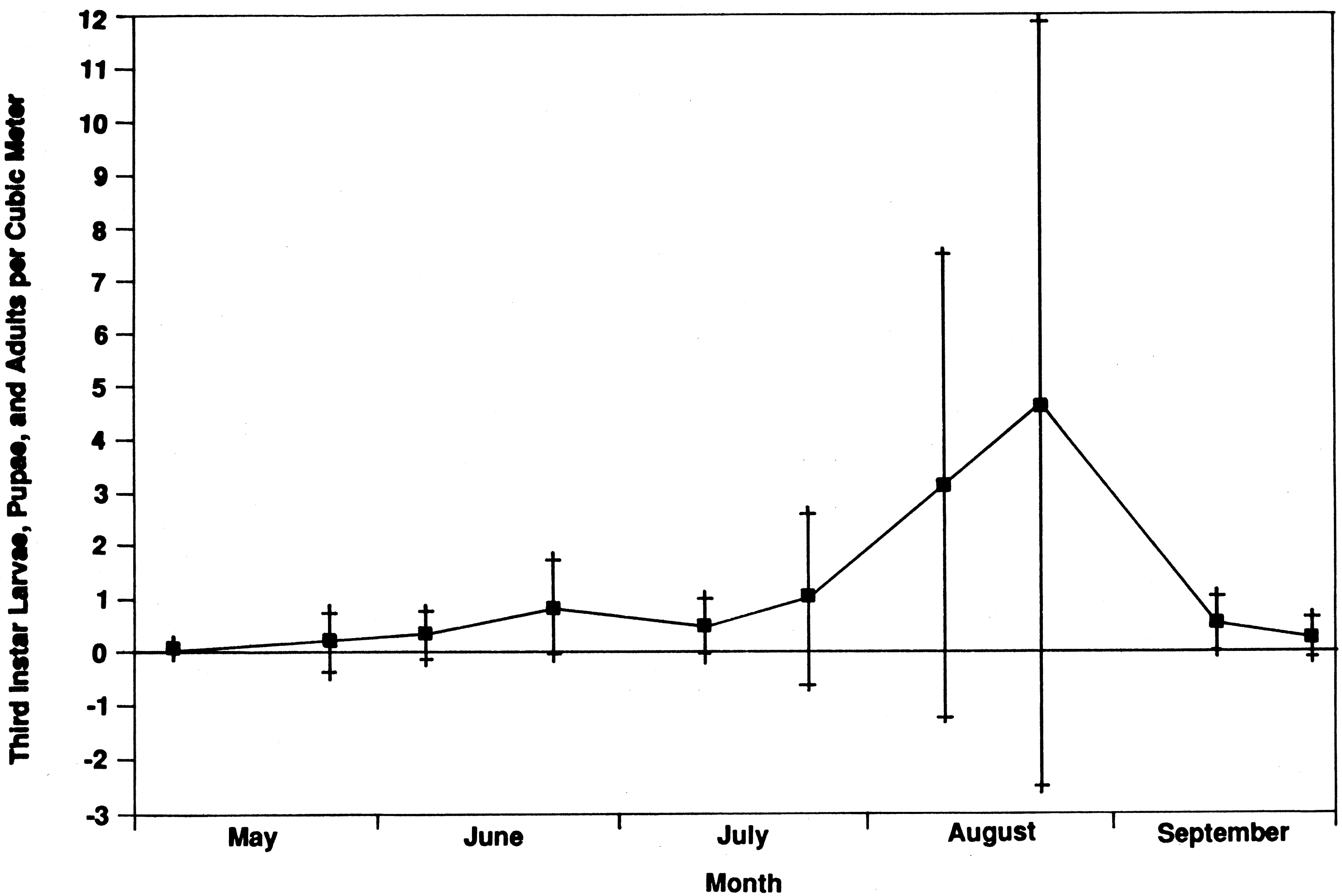
Figure I-4.
Effect of Four Salinities on Growth and Development of Third Instar Larvae of the Mono Lake Alkali Fly in Microcosm Experiments



Note: Microcosm experiments were conducted at five salinities, and the percent emergence of adults and percent survivorship of larvae at the four highest salinities were compared to the percent emergence and survivorship at the lowest salinity (50 g/l). Percentages in the graph are relative, not absolute, percentages.

Source: Adapted from Herbst 1992

Figure I-5.
Relative Emergence and Survivorship of Mono Lake Alkali Fly at Various Salinities

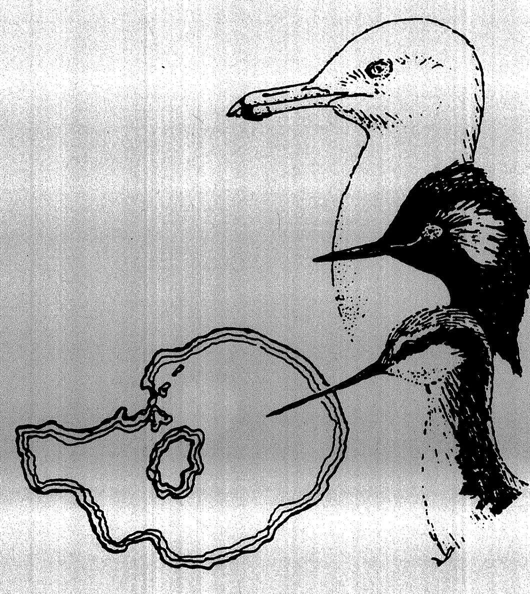


Note: Vertical lines represent one standard deviation above and below the mean.

Source: Adapted from Herbst 1992

Figure I-6.
Mean Numbers of Third Instar Larvae, Pupae, and Adults in Open Water Drift of Mono Lake in 1991

Appendix J. Natural History of the Mono Lake Brine Shrimp



MONO BASIN EIR

Prepared by Jones & Stokes Associates

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Appendix J. Natural History of the Mono Lake Brine Shrimp

This appendix presents a discussion of the life history of the Mono Lake brine shrimp and the physical and biological constraints that affect the shrimp's abundance and distribution in Mono Lake.

CLASSIFICATION AND TAXONOMY

The genus, *Artemia*, has a worldwide distribution. All *Artemia* were formerly considered to belong to a single species, *Artemia salina* (Barigozzi 1974, 1980), but the genus has recently been divided into several closely related species, including the Mono Lake brine shrimp, *Artemia monica* Verrill (Bowen et al. 1980).

Artemia are crustaceans of the order Anostraca, which includes fairy shrimp and brine shrimp. Most anostracans are filter-feeding herbivores inhabiting environments such as temporary pools and saline lakes in which few other animals can survive. The group's success in such environments may be due in part to a flexible reproductive physiology (Browne 1992). Many anostracans, *Artemia monica* included, produce live young when growth conditions are good and produce dormant cysts when conditions are unfavorable (Barnes 1963, Lenz 1982). Anostracans generally tolerate predation and competition poorly and, perhaps for this reason, are rarely found in marine habitats or in freshwater lakes and streams (Zaret 1980).

Though *A. monica* is similar to other *Artemia* species in many respects, Mono Lake differs from habitats of other *Artemia* species. Conditions in Mono Lake are relatively constant, whereas most *Artemia* are found in lakes and pools exhibiting large daily or seasonal variations of temperature, salinity, and dissolved oxygen (Lenz 1984). Mono Lake is deep and contains water perennially, whereas many *Artemia* species inhabit shallow, temporary lakes. Consistent with this difference, cysts produced by *A. monica* are less resistant to dehydration that those of other *Artemia* species. Also, *A. monica* cysts sink, while those of other species are buoyant (Lenz 1980). Mono Lake has a unique water chemistry and other *Artemia* species do not survive well in Mono Lake water (Bowen et al. 1980).

LIFE HISTORY

The life cycle of the Mono Lake brine shrimp, like that of other anostracans, is complex. Development proceeds through seven instars of nauplii larvae, four juvenile instars, and one or more adult instars. Generally, two generations are produced per year: a spring generation originating from overwintering cysts (diapause eggs) produced during the previous summer and fall, and a summer generation originating ovoviviparously (live birth) from adults of the spring generation. In some years, a small third generation of unknown origin (cysts or live birth) appears in autumn (Jellison et al. 1989a, 1991).

Hatching of the spring generation occurs from January to May and the first adults usually appear in May (Lenz 1984). The females reproduce ovoviviparously for about a month, giving rise to the summer generation. In June, adult females of the spring generation switch from ovoviviparous to oviparous (cyst) reproduction, producing cysts that settle to the lake bottom until the following year (Jellison et al. 1989b). The summer generation matures in July and August and primarily reproduces oviparously (Lenz 1984).

Cyst production rates were measured *in situ* in 1986 and 1987 by means of sediment traps and were estimated for 1983 to 1987 from data on the abundance of oviparous adult females and their average fecundity (cyst brood size and frequency of brood production) (Dana et al. 1990). The sediment trap data indicated that annual cyst production was 3.4 million cysts per square meter (cysts/m^2) in 1986 and 7.3 million cysts/m^2 in 1987 (Figure J-1). The data on adult female abundance and fecundity indicated that from 1983 to 1987 annual cyst production ranged between 2.4 million cysts/m^2 (in 1986) and 5.1 million cysts/m^2 (in 1987) (Figure J-1).

The estimates of annual cyst production greatly exceeded estimates of abundance of first instar nauplii produced in the following spring. This difference was partly due to the absence of oxygen in sediments as a result of chemical stratification. Cysts in anoxic sediments generally do not hatch (see below), and from 1984 through 1988 sediment oxygen concentrations were less than 1 milligram per liter (mg/l) in 51-58%, by area, of sediments (Dana et al. 1990). However, even when annual cyst production for 1983 to 1987 was estimated for oxygenated sediments only, numbers of first instars produced in the following spring ranged from 2.00% to 2.82% of cyst production (Jellison et al. 1990). In 1983, first instar production was estimated as only 0.33% of cyst production (Jellison et al. 1990). These results indicate that mortality is very high for cysts or recently hatched first instars.

Time of development, which is strongly affected by temperature (see below), is about 2 days at 20°C for each of the 12 preadult instars, for a total development time of 24 days from hatching to adult (Jellison et al. 1989a). In development experiments designed to mimic Mono Lake conditions, total development time (time from hatch to sexual maturity) for the spring generation averaged 57 days under conditions of high food supply (i.e., ambient algal density during spring) and 62 days under conditions of low food supply, and total development time for the summer generation with low food supply (i.e., ambient algal density during summer) averaged 24 days (Figure J-2) (Jellison et al. 1989a). The shorter development time of the summer generation was due to the higher summer water temperatures.

Survivorship to adulthood in the development experiments was 46% for the spring/ high food treatment, 30% for the spring/low food treatment, and 51% for the summer treatment (Figure J-3) (Jellison et al. 1989a). The average daily mortality rates for the three treatments were calculated to be 1.2%, 1.8%, and 2.2%.

EFFECTS OF ENVIRONMENTAL FACTORS ON DEVELOPMENT, SURVIVAL, AND REPRODUCTION

Temperature

Ambient temperature greatly affects rates of development of Mono Lake brine shrimp and is a major determinant of seasonal variations in shrimp production. Regression of development time on temperature explained 80% of the variation in development times in the brine shrimp development experiments and yielded the equation $DT = 285.7T^{-1.658}$, where DT is development time per instar (days), and T is temperature (°C) (Jellison et al. 1989a). As noted above, the summer generation of shrimp develops much more quickly than the spring generation because of the higher summer water temperatures. Water temperatures in the upper mixed layer in Mono Lake are generally about 5°C-15°C in spring and about 15°C-20°C in summer (Jellison et al. 1990).

Effect of temperature on reproductive output of the brine shrimp was difficult to assess, in part because effects of temperature were confounded with those of food supply. Brood size was a function of adult body size, with larger females producing larger broods (Jellison et al. 1989b), and body size of the summer generation of shrimp was less than that of the spring shrimp. However, the smaller body size of the summer shrimp could be due to the low level of food available during summer as well as to the higher temperatures (Jellison et al. 1989a). In any case, multiple regression analysis using field data indicated that food density alone explained most of the variation in brood size (see below).

Multiple regression on field data also indicated that the proportion of ovigerous (egg-bearing) females increased with female body length and with temperature (measured 15 days earlier). The regression equation is $P = -132.2709 + 4.4697T_{-15} + 12.0176L$, where P is the arcsine transform of proportion of ovigerous females, T_{-15} is temperature (°C) 15 days earlier, and L is female body length (millimeters). The arcsine transformation was applied to the proportions data to normalize them. Multiple regression indicated that the proportion of females reproducing ovoviviparously decreased with temperature and female body length. Temperature accounted for 78% of the variation (Jellison et al. 1989b). The regression equation is $P = 231.8900 - 7.9920T - 8.3994L$, where P is the arcsine transform of proportion of ovoviviparous females, T is temperature (°C).

Data from various sources indicated that interbrood duration is negatively related to temperature (Jellison et al. 1989b). Thus, shrimp in the summer generation produce broods more frequently than shrimp in the spring generation.

Data from the development experiments and field data indicated that the nauplii survived very poorly at water temperatures below 6°C. Brine shrimp from the Great Salt Lake also perish at temperatures below 6°C (Relyea 1937). Water temperatures fall below 6°C during winter in Mono Lake, so survival of the population from year to year depends primarily on the cysts.

Cysts of Mono Lake brine shrimp require 3 months of dormancy in cold (<5°C) water to hatch (Dana 1981, Thun and Starrett 1986). Following this obligate period of dormancy, time required for hatching of the cysts in the development experiments was negatively related to temperature (Figure J-4) (Dana et al. 1992). Regression of mean number of days to hatching (D) on temperature (T, °C) explained 93% of the variation in mean number of days to hatching and yielded the equation, $D = 139T^{-1.317}$. At a salinity of about 100 g/L of total dissolved solids, which is close to the present salinity of Mono Lake, mean number of days to hatching fell from 42 days to 3 days as temperature rose from 2.5°C to 20°C.

Salinity

High salinities osmotically desiccate aquatic organisms because body fluids are less saline than the surrounding saltwater. Even at sublethal salinities, metabolic costs of osmoregulation reduce the energy available for growth and development. Brine shrimp species accommodate high salinities by active transport of ions and water through the gut and excretion of ions across the branchiae (gills) into the water (Dana et al. 1992). The nauplii have a special neck organ that secretes salts.

Two different bioassay experiments in which Mono Lake brine shrimp were raised at salinities ranging from 76 to 192 g/L total dissolved solids indicated that salinity affects survival, growth, reproduction, and cyst hatching of the shrimp (Starrett and Perry 1985, Dana and Lenz 1986). Present salinity of Mono Lake is about 100 g/L. Regression analyses combining data from these studies and others were used to derive salinity response curves of a number of life history characteristics (Table J-1) (Figures J-6 to J-14) (Dana et al. 1992).

The effect of salinity on cyst hatching may have important effects for the survival of the Mono Lake population. Percent of cysts that failed to hatch rose steadily over the range of salinities tested in the bioassays (Table J-1) (Figure J-5) (Dana et al. 1992). No cysts hatched at a salinity of 160 g/l. Drinkwater and Crowe (1991) showed that cysts do not hatch at a salinity of 140 g/l, which suggests that survival of the brine shrimp population would be jeopardized if Mono Lake salinity was increased to this level. The time required for hatching also increased with salinity (Table J-1) (Figure J-6) (Dana et al. 1992).

Effect of salinity on survival of Mono Lake brine shrimp instars was determined for naupliar instars and for adults, but not for juveniles. Percent survival of nauplii was constant at salinities below about 130 g/l and decreased with salinity at higher values (Table J-1) (Figure J-7) (Dana et al. 1992). Survivorship of adults may have been negatively related to salinity over the full range of salinities tested, but the results at lower salinities showed a good deal of scatter (Table J-1) (Figure J-8) (Dana et al. 1992).

Salinity affected mean length and weight of the shrimp (Dana et al. 1992). Mean lengths and dry weights of adults, juveniles, and naupliar instars 6 and 7 decreased with increasing salinity (Table J-1) (Figure J-9). Mean length of instars 1-5 did not vary significantly with salinity. Dry weight (DW) in milligrams of the shrimp were estimated from lengths (L) in millimeters using the regression equation, $DW = 0.0057L^{2.296}$.

Total development time, measured as days from hatch to production of first brood of eggs was strongly related to salinity. Total development time at 20°C increased from about 40 days to about 70 days as salinity increased from 76 to 159 g/l (Table J-1) (Figure J-10). The percent of ovigerous females, the frequency of brood production, size of the first and size of subsequent broods, and percent of females reproducing oviparously all decreased with increasing salinity (Table J-1) (Figures J-11 to J-14).

Results of the salinity bioassays demonstrated that increasing salinity has several direct negative effects on Mono Lake brine shrimp production. Furthermore, except for survival of nauplii, the effects were continuous over the entire range of salinities tested (i.e., there were no salinity ranges with no effect on the shrimp). It must be noted, however, that the bioassay experiments do not mimic all potential effects of salinity changes under natural conditions. In particular, lower salinity in Mono Lake could lead to invasions by predators or competitors of the brine shrimp, which could reduce productivity of the brine shrimp population.

Dissolved Oxygen

Dissolved oxygen (DO) concentrations in Mono Lake vary with salinity, water temperature, mixing, primary production, and depth. Oxygen is less soluble in saltwater than in freshwater, and saturated oxygen concentrations in the epilimnion of Mono Lake are low to moderate. DO values are 2-6 mg/l in summer when the water is warm, and 4-7 mg/l in winter when the water is cold. Anoxic conditions develop below the thermocline or chemocline in summer due to restricted circulation between the epilimnion and the hypolimnion (NAS 1987).

Brine shrimp cannot live long in anoxic water, so they are largely restricted to the epilimnion during summer stratification. The entire water column is reoxygenated during complete mixing in winter. This reoxygenation is important for the shrimp population because the diapausing cysts, many of which settle on sediments in the hypolimnion, require dissolved oxygen for hatching (Lenz 1984). Under meromictic conditions, nearly 50% of the sediments in Mono Lake are permanently anoxic (Dana et al. 1990), so a large percentage of the cysts produced during meromictic years fail to hatch. The cysts, however, may remain viable for a number of years and may therefore hatch if sediments are reoxygenated in a later year (Jellison et al. 1989b).

The effect of DO on hatching of cysts in Mono Lake was tested *in situ* in 1985 (Dana et al. 1988). Emergence traps were set on the lake bottom at shallow (7-m depth) and deep (21-m depth) stations to capture brine shrimp nauplii hatching from cysts in the lake sediments. Mono Lake was meromictic in 1985, so the deep station was in anoxic water while the shallow water station was in oxygenated water. In April and May, the mean hatching rates from sediments at the shallow station ranged from 720 to 25,340 nauplii per square meter per day (nauplii/m^2-day) while the mean hatching rates from sediments at the deep station ranged from 3 to 138 nauplii/m^2-day. In June and July, the mean hatching rates ranged from 140 to 3,200 nauplii/m^2-day at the shallow station and from 6 to 13 nauplii/m^2-day at the deep station.

Food Supply

The Mono Lake brine shrimp feeds primarily on planktonic algae, though protozoans and bacteria also may be important food sources (NAS 1987). Each year during summer, the shrimp population becomes food limited and the abundance of algae probably affects year-to-year changes in shrimp abundance (Jellison and Melack 1992). The algae-shrimp relationship is complex because, whereas abundance of algae limits the shrimp population during summer, grazing by the shrimp also limits abundance of the algae during summer and excretion of ammonium-nitrogen by the shrimp keeps the algae from being nutrient limited during summer.

Food supply, measured as chlorophyll *a*, affects development, growth, survival, and reproductive output of the brine shrimp population. The development experiments comparing shrimp of the spring generation raised at ambient (high) food densities with those raised at low food densities showed that the shrimp grow and develop more quickly at higher food densities and begin reproducing earlier (Jellison et al. 1989a). However, the effects of food on growth are not significant for early instars (<instar 5 or 6). Survivorship also was higher for shrimp raised at the ambient food densities (Figure J-3).

Multiple regression of field data indicated that oviparous brood size (OBS) is positively related to chlorophyll *a* concentration (Chl.*a*), as milligrams per liter chlorophyll *a*, and female body length in millimeters. The regression equation is $OBS = 1.2514 + 0.0340Chl.a + 0.2235L$ concentration (Jellison et al. 1989b).

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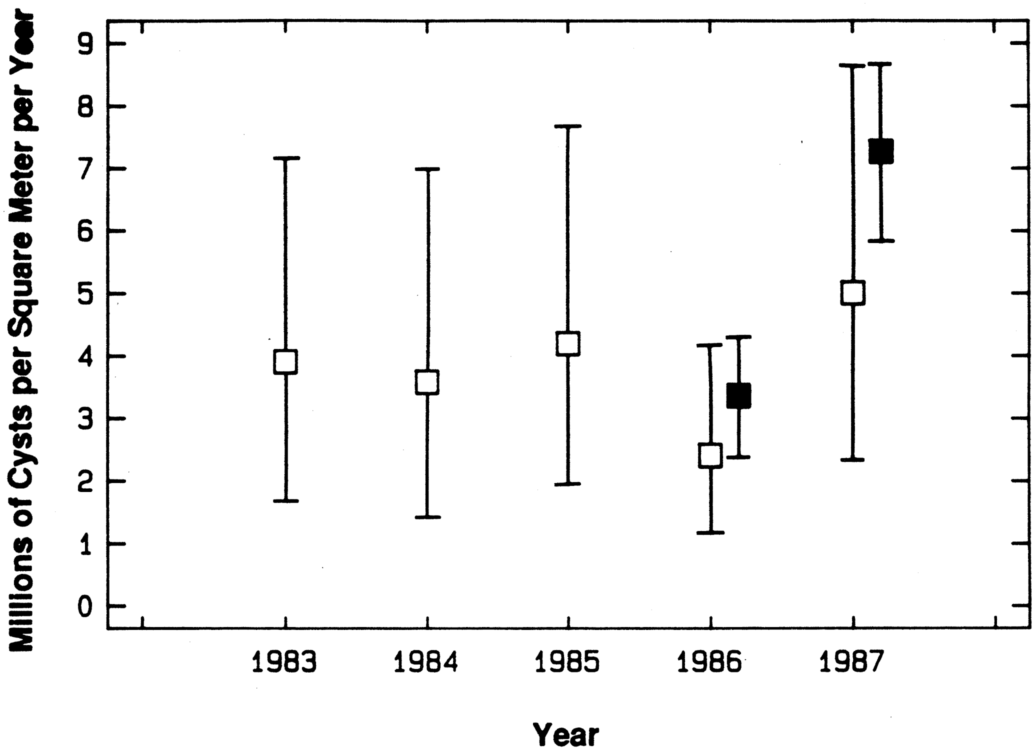
Table J-1. Regressions of *Artemia* Life History Characteristics on Salinity

Life History Character (y)	Salinity Range (g/l) (x)	Equation	Intercept (b)	Slope (m)	p Value	r^2	Number of Figure
Percent nonhatching cysts	50-159	$y = e^{(mx + b)}$	1.21	0.021	<0.001	0.68	5
Mean number of days to hatch, 10°C	50-159	$y = e^{(mx + b)}$	0.865	0.0116	<0.001	0.77	6
Percent naupliar survival	118-168	y = mx + b	186	-08.61	0.036	0.70	7
Percent adult survival	76-168	y = mx + b	99	-0.411	0.051	0.40	8
Adult length (mm)	76-168	y = mx + b	12.9	-0.034	<0.001	0.89	No figure
Juvenile length (mm)	76-168	y = mx + b	8.9	-0.024	0.004	0.66	No figure
Instar 7 length (mm)	76-168	y = mx + b	6.3	-0.018	0.008	0.61	No figure
Instar 6 length (mm)	76-168	y = mx + b	5.3	-0.015	0.033	0.45	No figure
Adult weight (mg)	76-168	y = mx + b	1.743	-0.0073	<0.001	0.91	No figure
Juvenile weight (mg)	76-168	y = mx + b	0.757	-0.0033	0.004	0.66	No figure
Instar 7 weight (mg)	76-168	y = mx + b	0.328	-0.0015	0.007	0.62	No figure
Instar 6 weight (mg)	76-168	y = mx + b	0.224	-0.001	0.025	0.48	No figure
Mean number of days to first brood production, 20°C	76-168	$y = e^{(mx + b)}$	3.2	0.006	<0.001	0.84	10
Percent ovigery	76-159	y = mx + b	135	-0.429	<0.001	0.92	11
Interbrood duration 20°C (days)	76-168	$y = e^{(mx + b)}$	1.809	0.0036	0.008	0.61	12
Brood size, #1 (eggs/brood)	76-168	y = mx + b	65.8	-0.28	<0.001	0.85	No figure
Brood size, #2-4 (eggs/brood)	76-168	y = mx + b	107	-0.446	<0.001	0.61	No figure
Percent ovoviviparity	76-168	$y = e^{(mx + b)}$	-1.32	0.031	<0.001	0.82	14

Source: Adapted from Dana, Jellison, and Melack 1992.

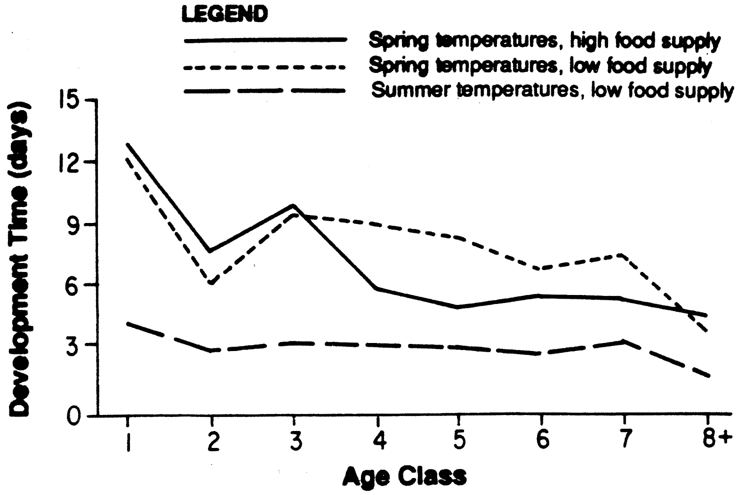


Notes: Open squares are the means for estimates based on oviparous female abundance and fecundity. Solid squares (1986 and 1987 only) are the lakewide means from sediment trap data. Vertical lines are the 95% confidence intervals.

Source: Dana, Jellison, and Melack 1990

Figure J-1.
Annual Mono Lake Brine Shrimp Cyst Production, 1983-1987

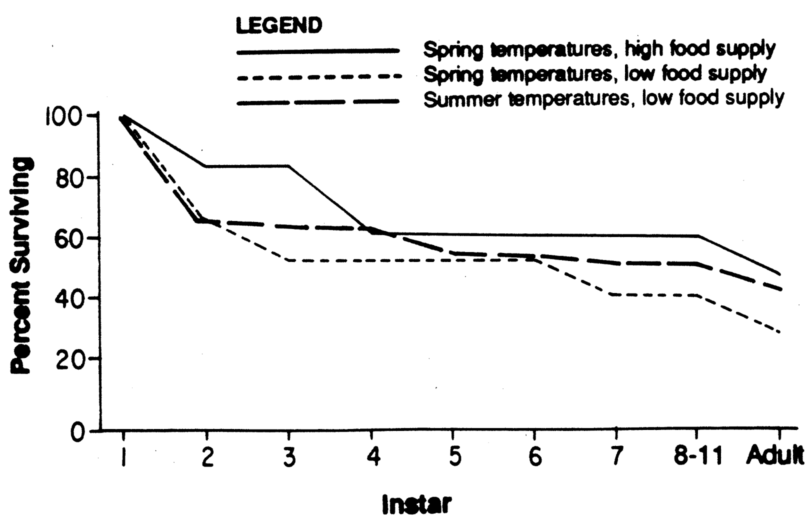
Figure J-2.
Mean Development Times of Mono Lake Brine Shrimp in Development Experiments



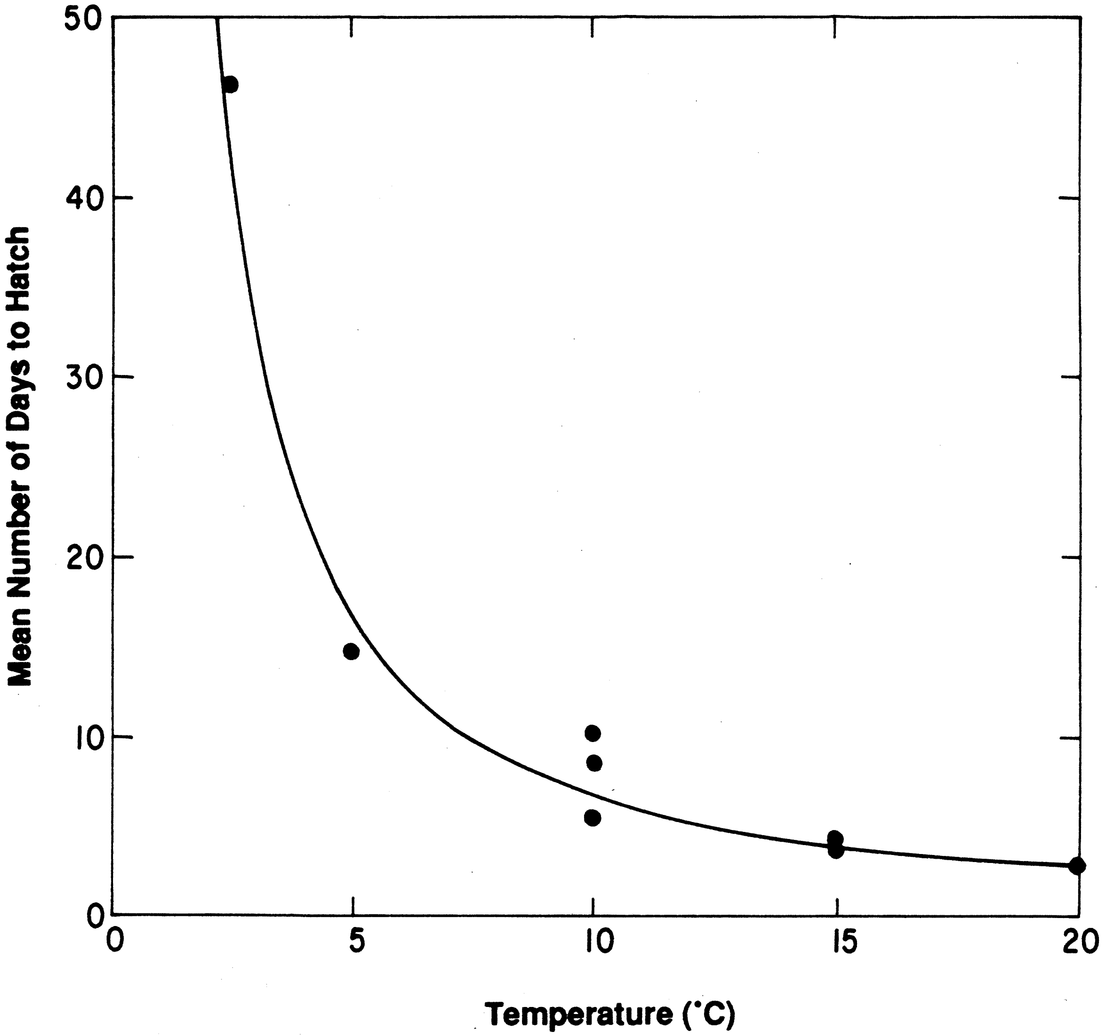
Note: Instar 8+ represents the mean development times of instars 8-11.

Source: Jellison, Dana, and Melack 1989b

Figure J-3.
Percent Surviving of Mono Lake Brine Shrimp in Development Experiments



Source: Jellison, Dana, and Melack 1989b



Source: Adapted from Dana, Jellison, and Melack 1992

Figure J-4.
Days to Hatch of Mono Lake Brine Shrimp at Different Temperatures

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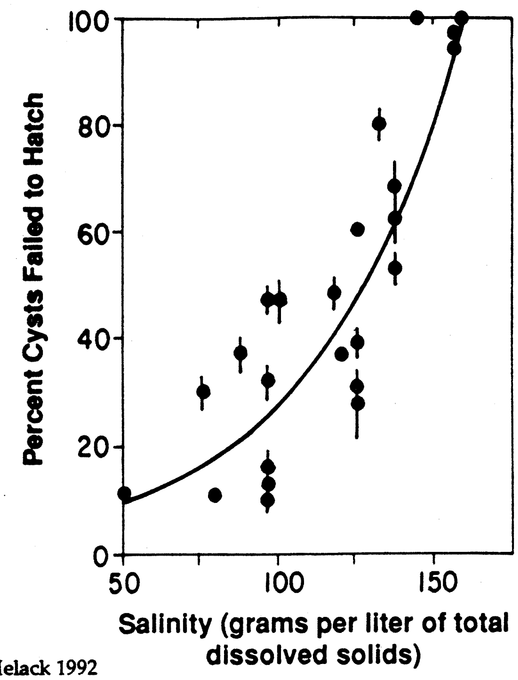
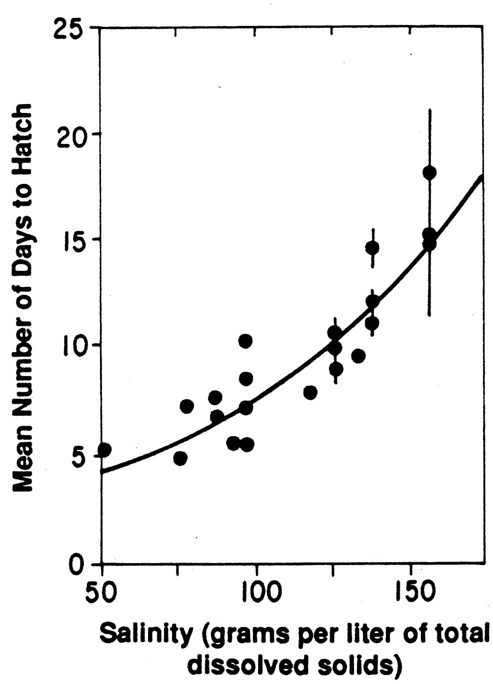
Figure J-5.
Regression of Percent of Cysts Failed to Hatch on Salinity

Note: Vertical lines represent one standard error on either side of the mean.



Source: Adapted from Dana, Jellison, and Melack 1992

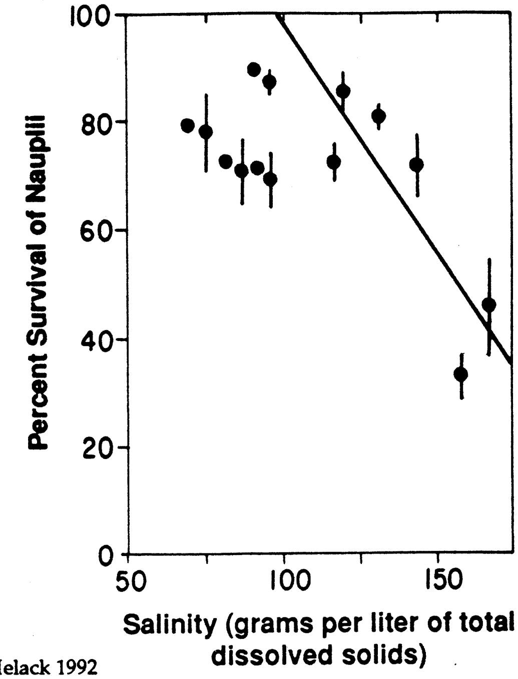
Figure J-6.
Regression of Mean Numbers of Days to Hatch on Salinity



Source: Adapted from Dana, Jellison, and Melack 1992

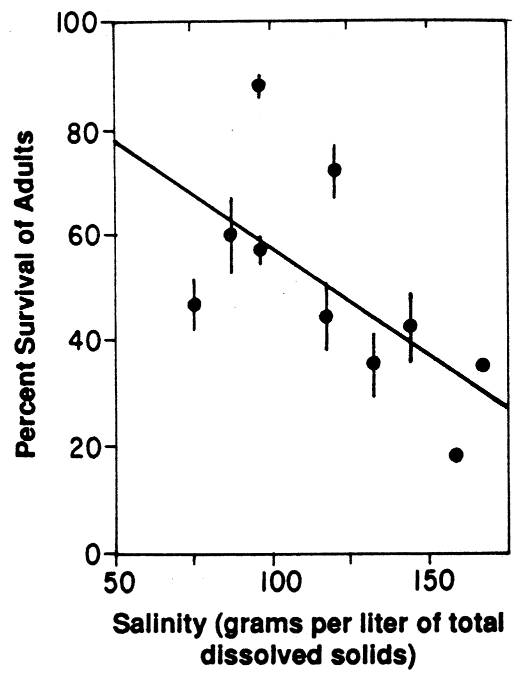
Figure J-7.
Regression of Percent Survival of Nauplii on Salinity

Note: Vertical lines represent one standard error on either side of the mean.

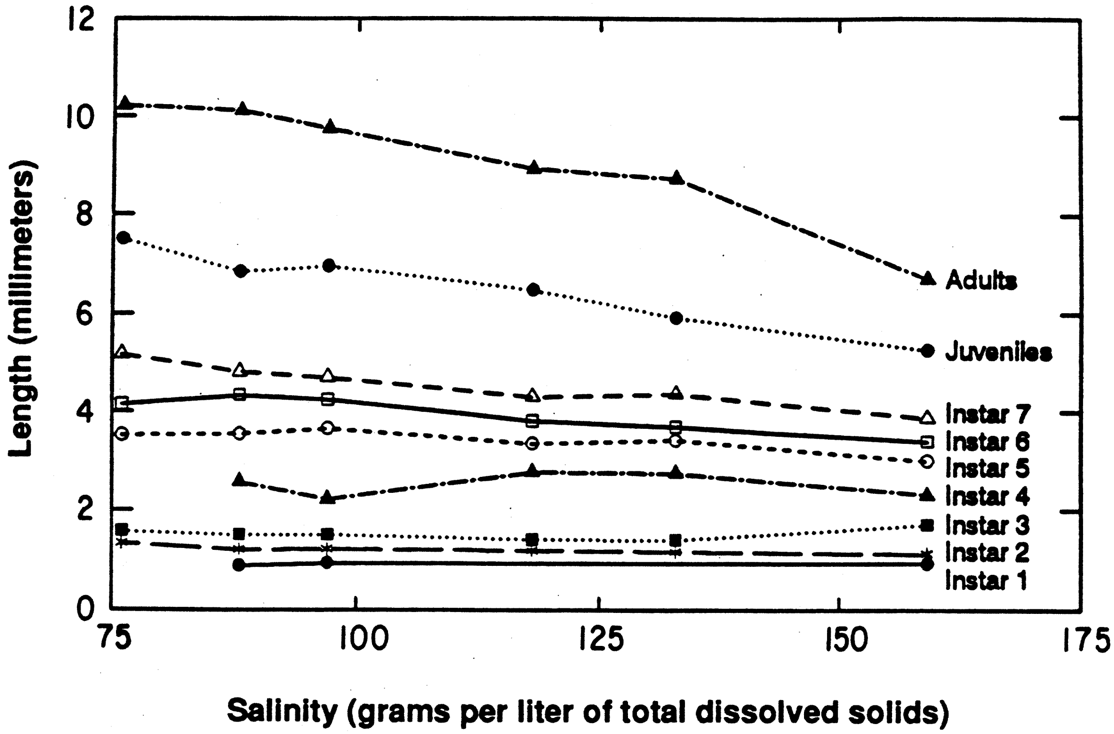


Source: Adapted from Dana, Jellison, and Melack 1992

Figure J-8.
Regression of Percent Survival of Adults on Salinity



Source: Adapted from Dana, Jellison, and Melack 1992

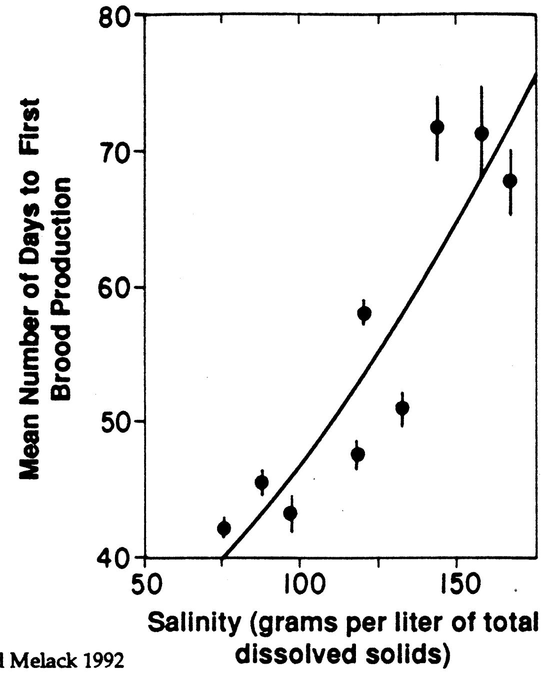


Source: Dana, Jellison, and Melack 1992

Figure J-9.
Mean Lengths of Naupliar Instars, Juveniles, and Adults of Mono Lake Brine Shrimp at Different Salinities

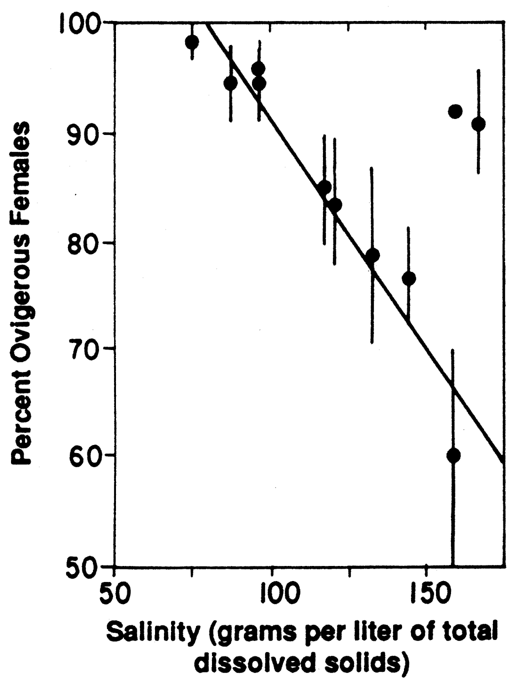
Figure J-10.
Regression of Mean Number of Days to First Brood Production on Salinity

Note: Vertical lines represent one standard error on either side of the mean.

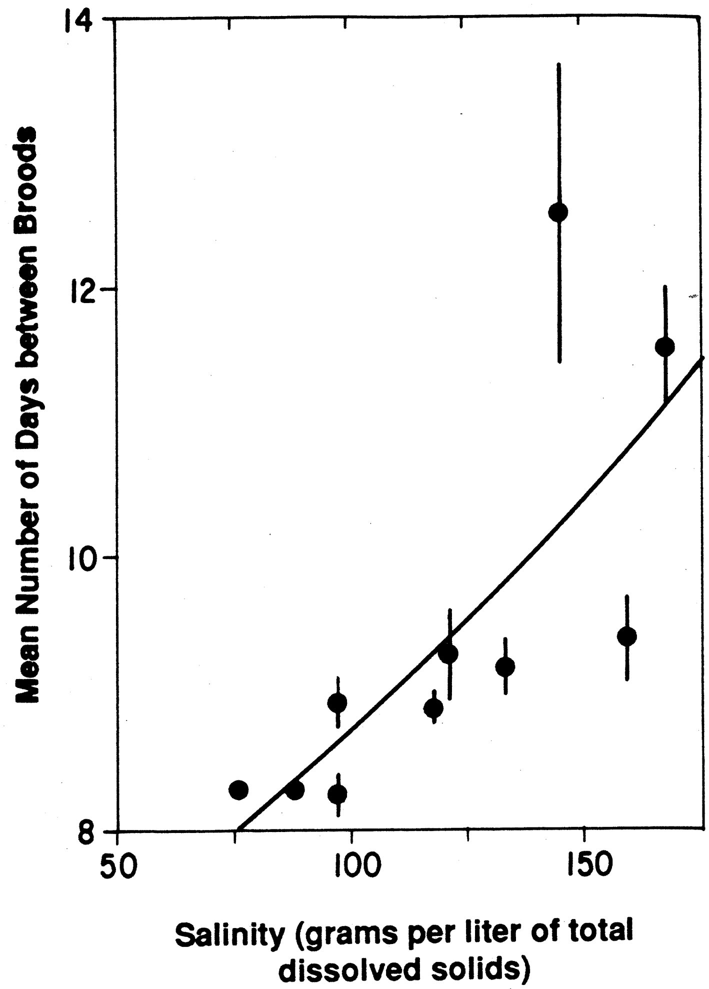


Source: Adapted from Dana, Jellison, and Melack 1992

Figure J-11.
Regression of Percent Ovigerous Females on Salinity



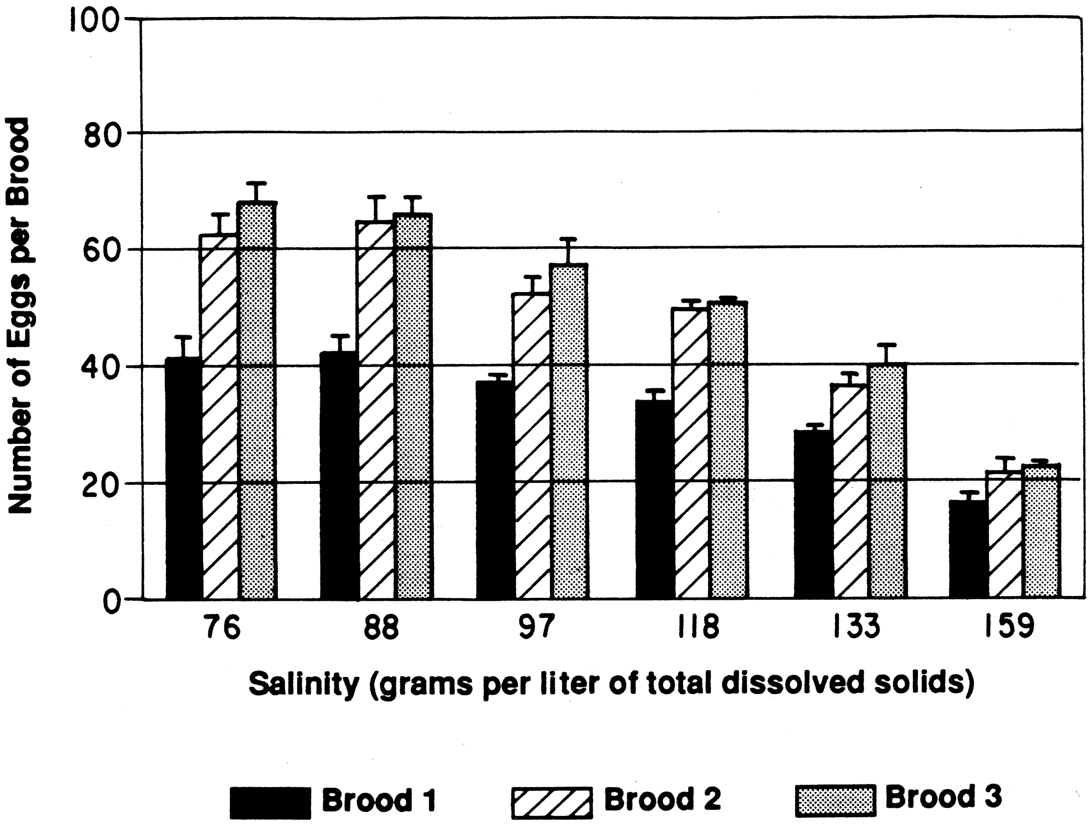
Source: Adapted from Dana, Jellison, and Melack 1992



Note: Vertical lines represent one standard error on either side of the mean.

Source: Adapted from Dana, Jellison, and Melack 1992

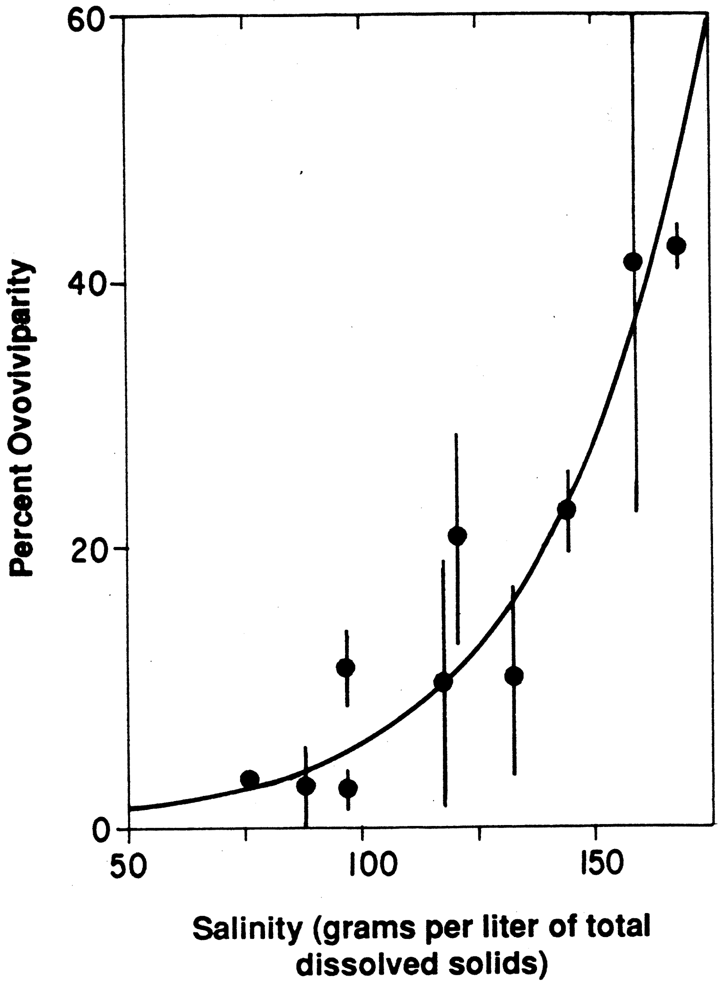
Figure J-12.
Regression of Mean Number of Days between Broods on Salinity



Notes: Height of bar indicates the mean. Height of "T" above the bar represents one standard error above the mean.

Source: Dana, Jellison, and Melack 1992

Figure J-13.
Mean Sizes of the First Three Broods of Mono Lake Brine Shrimp at Six Salinities

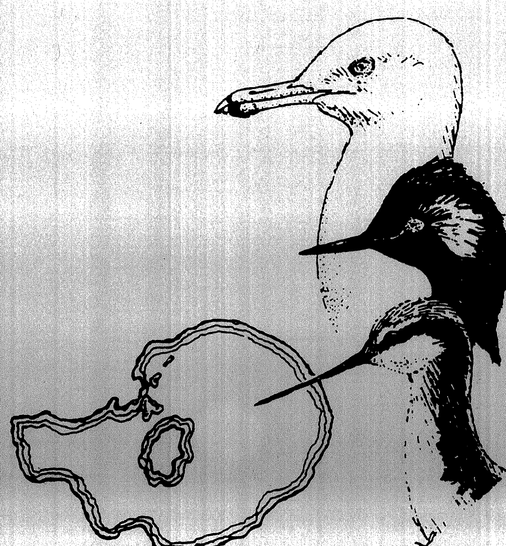


Note: Vertical lines represent one standard error on either side of the mean.

Source: Adapted from Dana, Jellison, and Melack 1992

Figure J-14.
Regression of Percent Ovoviviparity on Salinity

Appendix K. Water Quality Assessment Model



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BACKGROUND

Changes in Mono Basin export volumes will alter the dilution of high mineral content waters of Hot Creek and other geothermal sources entering Lake Crowley reservoir. These changed dilution effects will be transferred from Lake Crowley reservoir to Tinemaha Reservoir and down the Los Angeles (LA) Aqueduct system and will ultimately affect the quality of water delivered to the City of Los Angeles. The incremental effects of these changes can be estimated using a mass balance approach that includes major sources of water for each constituent of concern.

LOCATIONS FOR WATER QUALITY ESTIMATES

The LA Aqueduct Mass Balance Model estimates the water quality at three locations identified as key hydrologic points in the LA Aqueduct system: the East Portal of the Mono Craters Tunnel, Lake Crowley reservoir outflow, and the terminus of the aqueduct at the LA filtration plant. The major tributaries and water bodies affecting East Portal concentrations are Lee Vining, Walker, Parker, and Rush Creeks and Grant Lake reservoir. The major tributaries and water bodies affecting Lake Crowley reservoir outflow concentrations are the Upper Owens River at Big Springs; Mammoth-Hot Creek; Convict, McGee, Hilton, Crooked, and Rock Creeks; and Lake Crowley reservoir. Water sources affecting the LA Aqueduct filtration plant concentrations are runoff and pumped groundwater from Owens Valley and Lake Crowley reservoir outflow.

CONSTITUENTS OF CONCERN

Constituents of concern were identified based on analyses of historical water quality data. Following are the criteria for selecting constituents of concern for analysis in the model:

- the constituent was consistently measured and detected in substantial concentrations at the three locations;
- the constituent is of concern for drinking water quality;

- the constituent is of concern for aquatic habitat quality; and
- a relationship was identified between the constituent and flow, or with another selected constituent.

Conductivity was selected as the primary water quality parameter because it is a general indicator of salinity and is directly related to the concentrations of other water quality parameters. Chloride, fluoride, arsenic, and phosphate were identified as constituents of concern because their concentrations were correlated with conductivity and they are related to drinking water quality and aquatic habitat value. Examples of these relationships are presented in Figure K-1. These graphs illustrate the relationship between flow and conductivity and conductivity and arsenic at Hot Creek. Similar relationships are identified for all other sources of LA Aqueduct water.

The selected constituents of concern are indicators of water quality changes in the LA Aqueduct system resulting from different hydrologic conditions and Mono Basin export regimes. Chloride, fluoride, and arsenic are of concern in drinking waters; maximum contaminant levels (MCL) have been established by the California Department of Health Services for these constituents. Arsenic is also of concern in aquatic habitats because of its potential toxicity to aquatic organisms; a U.S. Environmental Protection Agency (EPA) water quality criterion for the protection of aquatic life has been established. Phosphates are of concern because they can cause algae growth and eutrophication, which can result in aquatic habitat degradation. EPA has suggested criteria for phosphates to prevent eutrophication in lakes and streams, but they have not been established as national criteria.

MASS BALANCE MODEL DESCRIPTION AND OPERATION

Model Concept

Incremental changes in conductivity and other constituents of concern resulting from alternative patterns of Mono Basin exports will be estimated at the three selected locations; East Portal, Lake Crowley reservoir outlet, and the LA Aqueduct filtration plant. The model uses mass balance equations to calculate total mass units of conductivity and other constituents for each water source or water body included with the selected location. The equations are of the form:

$$EC \times Q = \text{mass (load)}$$

where

Q = flow volume (acre-feet [af]/month), and
EC = electrical conductivity (microsiemens per centimeter [μS/cm])

Conductivity mass units, or loads, are the product of a flow volume multiplied by a conductivity value and are given in μS/cm multiplied by af. The term load is used to describe calculated conductivity mass units. The total calculated conductivity load of each water source is divided by the total flow volume to give the resulting conductivity at the outflow location. An example equation is given below where Q = flow volume, EC = conductivity, and Q1 through Q3 are individual streamflows with known conductivities contributing to an outflow (Q4):

$$Q1 + Q2 + Q3 = Q4$$

$$Q1 \times EC1 + Q2 \times EC2 + Q3 \times EC3 = Q4 \times EC4 \text{ (total mass load)}$$

To solve for outflow conductivity (EC4):

$$EC4 = (Q1 \times EC1 + Q2 \times EC2 + Q3 \times EC3)/Q4$$

Calculation of Other Constituent Concentrations

Analysis of historical data at each source location indicated that the concentrations of chloride, fluoride, arsenic, and phosphate are directly correlated with conductivity. This relationship is relatively linear, with the concentration of each constituent increasing with increasing conductivity. The correlations of the four constituents with conductivity at Hot Creek are illustrated in Figures K-1b and K-2. These relationships allow the concentration of each constituent to be estimated at each location using a constant ratio of the constituent concentration to conductivity. For example:

$$\text{Chloride concentration} = EC \times \text{chloride}/EC \text{ ratio}$$

Ratios between each constituent and conductivity were calculated based on historical data at each location. The constituent concentration at each location was divided by the corresponding conductivity, and the average of the ratios was used in each module. The ratios used in the mass balance model are presented in Table K-1. Ratios for chloride ranged from 0.008 to 0.11, arsenic ratios ranged from 0.0009 to 0.35, ratios for fluoride ranged from 0.0004 to 0.04, and phosphate ratios ranged from 0.00001 to 0.003.

Model Description

The model comprises three individual modules for the three hydrologic locations described above and uses 50 years of historical hydrology data from 1940 to 1989. The three modules are the Grant Lake reservoir water quality module, the Lake Crowley reservoir (Long Valley) water quality module, and the LA Aqueduct filtration plant water quality module.

Grant Lake Reservoir Module

The first module is called Grant-WQ. This module calculates the four tributary conductivity loads, Grant Lake reservoir outlet conductivity, and the resulting East Portal conductivity. A conceptual diagram of the Grant-WQ module is presented in Figure K-3.

The conductivity of Rush Creek inflow to Grant Lake reservoir is a function of dilution and mixing of Rush Creek surface runoff with a higher conductivity base flow (Figure K-3). The conductivity and flow volume values for base flow and runoff were estimated based on historical Grant Lake reservoir conductivity data. The Rush Creek conductivity load is the sum of the base flow and runoff loads divided by the Rush Creek flow. An estimated mixing volume of 10,000 af for the upper Rush Creek lakes was required to simulate the observed pattern increasing conductivity during low-flow periods.

Conductivity loads for Lee Vining, Parker, and Walker Creeks are calculated using constant flow regression equations and historical flow data. Details of the regression equations and their calibration are discussed below. The calculation of Grant Lake reservoir outlet conductivity is adjusted for storage and dilution by dividing the initial conductivity load plus the inflowing tributary conductivity load minus the outflowing load by the end of month Grant Lake reservoir storage volume.

East Portal conductivity is calculated using West Portal flows, the estimated Grant Lake reservoir outlet conductivity, and an estimated constant "tunnel make" flow and conductivity of 1,000 af/month and 425 μS/cm, respectively. Tunnel make is the groundwater inflow to the Mono Craters Tunnel. When there are no exports from Mono Basin, the East Portal flow is estimated as 1,000 af/month with an EC value of 425 μS/cm.

Long Valley Module

The second module, known as Long-WQ, incorporates all Lake Crowley reservoir inflows, including the Owens River above East Portal, five tributaries, Rock Creek diversions, and East Portal flows calculated in the Grant-WQ module. The Owens River above East Portal (Big Springs) and the five tributary conductivity loads are calculated using regression equations and historical flows. A conceptual diagram of the Long-WQ module is presented in Figure K-4.

Because gains and losses are significant between the tributary streamflow gages and Lake Crowley reservoir, the effects of gains and losses must be accounted for. The measured tributary inflows are compared with Lake Crowley reservoir inflow estimated from the outflow and storage charge. Sometimes the sum of measured tributary inflow is different than estimated inflow to the reservoir. If Lake Crowley reservoir inflow is less than tributary flows, the difference is assumed to be irrigation diversions and evapotranspiration losses. If reservoir inflow is greater than tributary flows, the difference is assumed to be local runoff. When measured Lake Crowley reservoir inflow is less than total tributary inflow, the total estimated tributary load is assumed to enter the reservoir. When measured

Lake Crowley reservoir inflow is greater than tributary inflow, the inflow conductivity load is increased by local runoff with an assumed conductivity of 950 μS/cm that was estimated by calibration.

The output from Long-WQ is the estimated Lake Crowley reservoir outlet conductivity. The outlet conductivity from the reservoir is calculated by adding the initial reservoir load to the estimated inflow load, subtracting the outflow load, and dividing by the end of month storage volume. The outlet conductivity estimates are equal to the average mixed lake concentrations.

LA Aqueduct Filter Plant Module

The third module is called LAA-WQ. This module includes the estimated Lake Crowley reservoir outlet data from Long-WQ, Owens Valley groundwater pumping above and below Tinemaha Reservoir, and Owens Valley runoff above and below Tinemaha Reservoir. These sources comprise the inflow to Haiwee Reservoir and the LA Aqueduct filtration plant. A conceptual diagram of this module is presented in Figure K-5. Tinemaha Reservoir outlet concentrations were used to calibrate the model because of the availability of an extensive data set collected by LADWP and USGS at this location.

The average conductivity for groundwater pumping was estimated from historical data. The combined average of historical conductivity for groundwater pumped from the Laws Ditch, Bishop Canal, and Big Pine Creek well fields was used for groundwater pumping from Long Valley to Tinemaha Reservoir. The historical average conductivity of groundwater pumped from Tinemaha Reservoir to Haiwee Reservoir well fields was used for groundwater pumping in this reach.

Owens Valley runoff includes flow from Long Valley to Tinemaha Reservoir and Tinemaha Reservoir to Haiwee Reservoir. Runoff above Tinemaha Reservoir includes historical flows from Round Valley (minus Rock Creek diversions), Laws Ditch, Bishop Canal, and Big Pine Creek. Runoff below Tinemaha Reservoir includes historical flow values from Tinemaha Reservoir to Haiwee Reservoir. Runoff conductivities for these locations were estimated using monthly flow regressions, which are discussed further under "Model Calibration".

The LAA-WQ module first calculates the Tinemaha Reservoir outlet conductivity using the historical Lake Crowley reservoir flow and conductivity and the runoff and groundwater flows and conductivities described above. The combined historical Tinemaha Reservoir inflow from the runoff and groundwater sources often exceeds the historical measured inflow due to diversions and evapotranspiration losses. The module accounts for this difference by assuming that a portion of the total net conductivity (salt) load in the diverted inflow enters Tinemaha Reservoir, as described above for Lake Crowley reservoir inflows. This "salt return" fraction was estimated during calibration.

The conductivity load from Tinemaha Reservoir outflow is added to the groundwater and runoff conductivity loads below Tinemaha Reservoir to give the total load in the LA Aqueduct. The estimated LA Aqueduct filtration plant conductivity is calculated by dividing the total LA Aqueduct load by the LA Aqueduct filtration plant inflow. No adjustment was made when added LA Aqueduct inflows exceeded measured LA Aqueduct inflows. The output of the LAA-WQ module reflects the cumulative change in water quality predicted for a given Mono Basin export alternative.

Model Calibration

Two steps were used to calibrate each module. The first step of model calibration estimated flow regression equations for conductivity based on historical data for individual streams. Historical conductivity and flow data were plotted for each location, regression curves were analyzed, and regression equations were calculated using the following formula:

$$\text{Conductivity} = a \times Q^{-b} = a/Q^{b}$$

where

a = conductivity at base flow of 1,000 af (TAF)/month,
Q = flow (TAF/month), and
b = regression curve exponent

Historical flows and these flow regressions were used to generate a 50-year time series of monthly conductivity values at each location. The 50-year time series of estimated monthly conductivity at each location were compared graphically and statistically to available historical data. The mean, minimum, and maximum values of modeled data were compared with historical data at individual stream locations, and adjustments were made, if necessary, by changing the appropriate regression coefficients. Calibrated flow regression equations for each location are discussed below and shown in the conceptual diagrams for each module (Figures K-3, K-4, and K-5).

The second calibration step involved estimating unknown conductivity values for specific source terms in each module to calibrate the module output calculations with historical data. The calibration results for each module are described below.

Grant-WQ Module Calibration

The calibrated regression equations used for each stream location in the Grant-WQ module are presented in Figure K-3. Water quality in Rush Creek above Grant Lake reservoir is affected by upstream storage and dilution and therefore a flow regression was not used to estimate conductivity. Calculations of direct runoff and base flow conductivity using the mass balance techniques described above were used to estimate the conductivity of Rush Creek. The Grant-WQ calibration was conducted using creek flow diversions under the point-of-reference scenario simulated with the LAAMP model. The only potential source of errors would be the estimation of diverted flows entering Grant Lake reservoir from Lee Vining, Walker, and Parker Creeks.

Estimates of constant base flow, monthly runoff, a constant mixing volume, and base flow and runoff conductivities were then used to calibrate the module output with the historical time series of Grant Lake reservoir outlet conductivity. The conductivity and flow values for base flow and runoff were estimated using a combination of 1991 Rush Creek conductivity data and historical conductivities at Grant Lake reservoir outlet. Base flow was estimated at 1,250 af/month with a conductivity of 130 μS/cm. The total mixing volume was estimated at 10,000 af. Runoff conductivity was estimated at 40 μS/cm.

Calibrated Grant Lake reservoir outlet conductivities were compared to historical values during the calibration. The minimum, mean, and maximum of the modeled values were 39, 54, and 75 μS/cm. The minimum, mean, and maximum for historical values were 40, 59, and 165 μS/cm. A graphic comparison of modeled and historical conductivity at the Grant Lake reservoir outlet is depicted in Figure K-6. Some of the scattered high EC historical data values may be inaccurate.

Long-WQ Module Calibration

The mass balance techniques described above for Grant-WQ also were used in this module to estimate conductivity at the Lake Crowley reservoir outlet. Calibrated regression equations used for each water source in the Long-WQ module are presented in Figure K-4. Equations with similar exponents indicate the same basic dilution patterns for the respective water sources.

The mass balance used in the Long-WQ module accounts for the difference between measured total tributary inflow and Lake Crowley reservoir inflow to reflect the greater net conductivity load due to local runoff. The term "gains" is used in the module to estimate this additional conductivity (salt) load entering Lake Crowley reservoir and calibrate modeled Lake Crowley reservoir outlet conductivities with historical values. The conductivity load from gains is added to the total tributary load to obtain the Lake Crowley reservoir outlet conductivity. A conductivity of 950 μS/cm was used for the gains. Gains flows were estimated as the difference between tributary flows and Lake Crowley reservoir inflows.

Calibrated Lake Crowley reservoir outlet conductivities were compared to historical values. The minimum, mean, and maximum of the modeled reservoir outlet values were 156, 316, and 540 μS/cm, respectively. The minimum, mean, and maximum for historical values were 188, 325, and 592 μS/cm, respectively. A graphic comparison of modeled and historical conductivity at Lake Crowley reservoir outlet is presented in Figure K-7.

LA Aqueduct-WQ Module Calibration

Owens Valley runoff conductivities were estimated using monthly flow regressions for runoff from Long Valley to Tinemaha Reservoir and for runoff from Tinemaha Reservoir to Haiwee Reservoir. The regression equations were adjusted to calibrate modeled Tinemaha Reservoir outflow and LA Aqueduct inflow conductivity values with the respective historical values. Calibrated regression equations used for each runoff location are presented in Figure K-5.

The average conductivity of pumped groundwater from Long Valley to Tinemaha Reservoir was calculated from historical data to be 360 $\mu S/cm$. It was estimated that 25% of the conductivity load in diverted water entered Tinemaha Reservoir as irrigation return flows. A graphic comparison of modeled and historical conductivity at Tinemaha Reservoir outlet is presented in Figure K-8.

It was assumed that the sources between Tinemaha Reservoir and Haiwee Reservoir were fully mixed and therefore no adjustment in the conductivity load was required. The average conductivity of pumped groundwater from Tinemaha Reservoir to Haiwee Reservoir was estimated to be 290 $\mu S/cm$.

Calibrated LA Aqueduct filtration plant inflow conductivities were compared to historical values for the calibration. The minimum, mean, and maximum of the modeled values were 207, 330, and 653 $\mu S/cm$, respectively. The minimum, mean, and maximum for historical values were 173, 334, and 618 $\mu S/cm$, respectively. A graphic comparison of modeled and historical conductivity at the LA Aqueduct filtration plant is presented in Figure K-9.

Calibration of EC Ratios for Other Constituents of Concern

EC ratios for the other constituents of concern were calibrated by comparing the mean, minimum, and, maximum of the estimated concentrations with historical concentrations and adjusting the ratios, if necessary. Flows under the point-of-reference scenario were simulated with the LAAMP model and were assumed to be similar to historical data for the calibration of these ratios. Historical data were compared to point-of-reference simulations at each output location to verify the accuracy of each ratio. Modeled and historical values for chlorides, arsenic, fluoride, and phosphate at the Lake Crowley reservoir outlet are presented in Figures K-10, K-11, and K-12. Lake Crowley reservoir values are compared because of the high concentrations of these constituents entering the lake. Modeled and historical values for these constituents at the LA Aqueduct filtration plant are presented in Figures K-13, K-14, and K-15.

LAAMP Simulation Data

The LA Aqueduct mass balance model will use data from the LAAMP aqueduct flow simulations developed for each Mono Basin EIR alternative. LAAMP flow simulation output data files correspond to each of the three locations in the model and use the same affected streams and water bodies. Model runs will be conducted using the simulated flows for each alternative.

The LAAMP model uses actual historical runoff data for each stream location. The major variable in the LAAMP model is the monthly volume of Mono Basin export in the East Portal outflow. Minor changes occur in storage at Grant Lake and Lake Crowley reservoirs with each flow regime. These changes are more pronounced if lower East Portal flows are simulated. The Owens Valley groundwater pumping component of the LAAMP model uses a higher volume of pumped groundwater from each of the five basins than are accounted for in historical values, but the monthly pattern of groundwater pumped is the same for each of the alternatives.

Once the LAAMP simulation data are imported into the mass balance model, a monthly conductivity estimate can be calculated at each output location for that alternative. The EC ratios are used in subsequent model runs to calculate the other constituent concentrations for a given flow regime. EC ratios for each constituent are inserted into the regression equations at the beginning of a model run. The model then recalculates monthly constituent concentrations at each location. All individual streams and water bodies are included in the recalculation. The resulting output from each model is an estimated constituent concentration at East Portal, Lake Crowley reservoir outlet, and LA Aqueduct filtration plant inflow for flow regime specified by the LAAMP model. Additional details of the LAAMP model are presented in Appendix B of the draft EIR.

Model Operational Requirements

The three modules were developed in spreadsheet format using Lotus 1-2-3 software. An IBM-compatible 386 or 486 computer with at least 2 megabytes of RAM is recommended to operate the model because of the large size of the spreadsheets.

Data Management and Analysis

Results from each alternative for all constituents of concern are combined in a single data file for evaluation and impact assessment. Data in the file will be used to evaluate the change in constituent concentrations between a given alternative and point-of-reference conditions. Tables and graphs containing data summaries and statistics will be generated as needed from each model run. A sample mass balance model output format is presented in

Table K-2. Graphic examples of the model output format for Lake Crowley reservoir outlet and LA Aqueduct filtration plant inflow conductivity and arsenic values are presented in Figures K-16, K-17, K-18, and K-19. These figures show a comparison of the model output for the No-Restriction and No-Diversion Alternatives, and the point-of-reference conditions for the two locations.

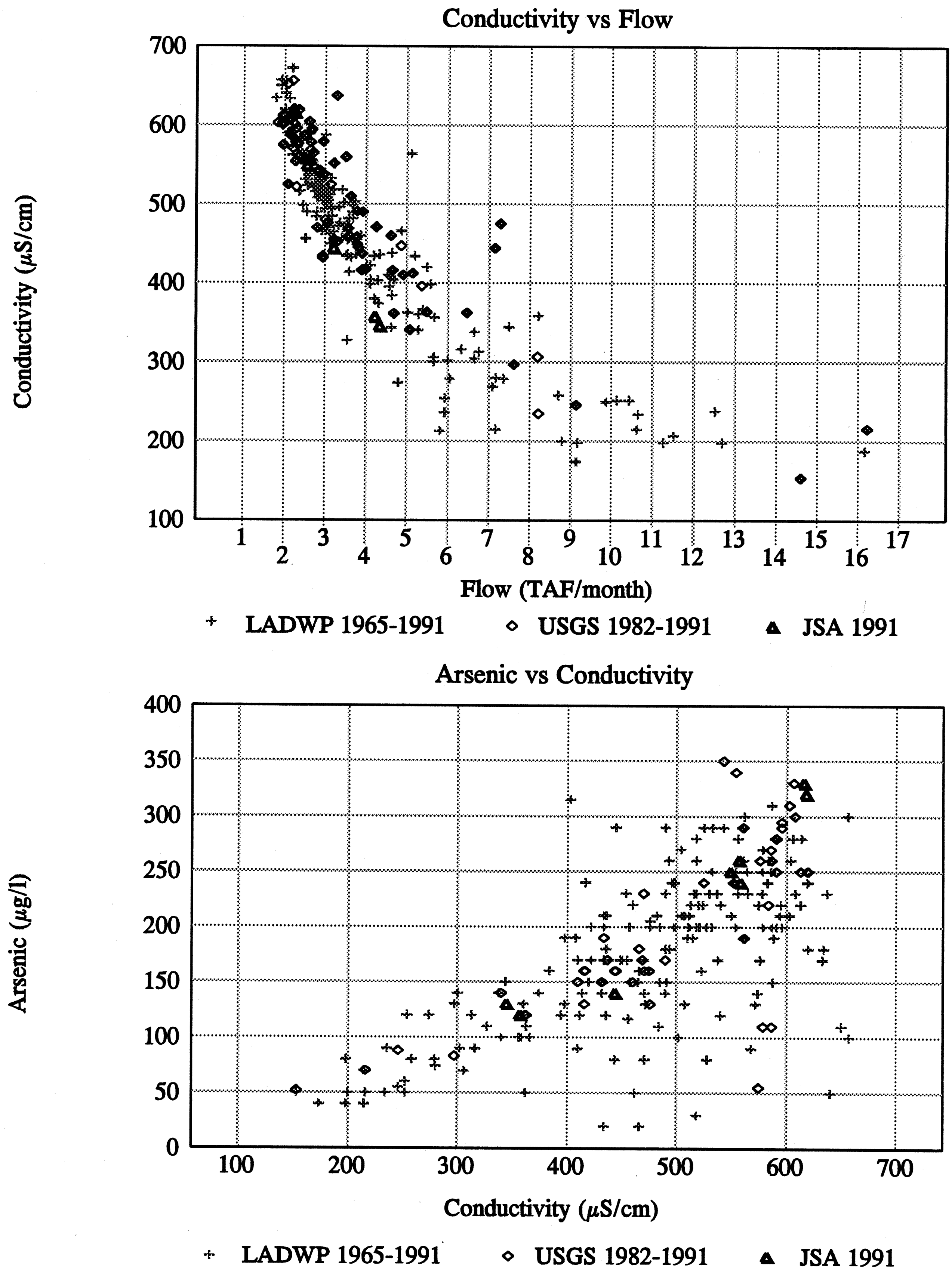
Table K-1. Ratios of Constituents of Concern to Conductivity

Module and Location	Chloride (mg/l)	Arsenic (μg/l)	Fluoride (mg/l)	Phosphate (mg/l)
	Constituent of Concern			
Grant WQ				
Lee Vining Creek	0.02	0.02	0.0004	0.001
Walker Creek	0.02	0.02	0.001	0.0005
Parker Creek	0.01	0.02	0.001	0.001
Rush Creek	0.03	0.04	0.001	0.0002
Mono tunnel make	0.04	0.06	0.0015	0.002
Long WQ				
East Portal	0.016	0.032	0.001	0.001
Big Springs	0.048	0.08	0.002	0.003
Mammoth Creek	0.01	0.12	0.0013	0.001
Hot Creek Springs	0.2	0.35	0.04	0.0004
Convict Creek	0.01	0.07	0.001	0.0001
McGee Creek	0.009	0.09	0.001	0.0001
Hilton Creek	0.024	0.26	0.0027	0.0006
Crooked Creek	0.008	0.05	0.002	0.0007
Rock Creek	0.025	0.16	0.003	0.0005
Long Gains	0.11	0.22	0.0045	0.0004
LA Aqueduct WQ				
Owens River runoff				
Above Tinemaha Reservoir	0.08	0.002	0.001	0.0004
Below Tinemaha Reservoir	0.01	0.0009	0.001	0.0001
Owens River groundwater				
Above Tinemaha Reservoir	0.10	0.12	0.003	0.0002
Below Tinemaha Reservoir	0.02	0.05	0.0015	0.00001

Table K-2. Sample Mass Balance Model Output

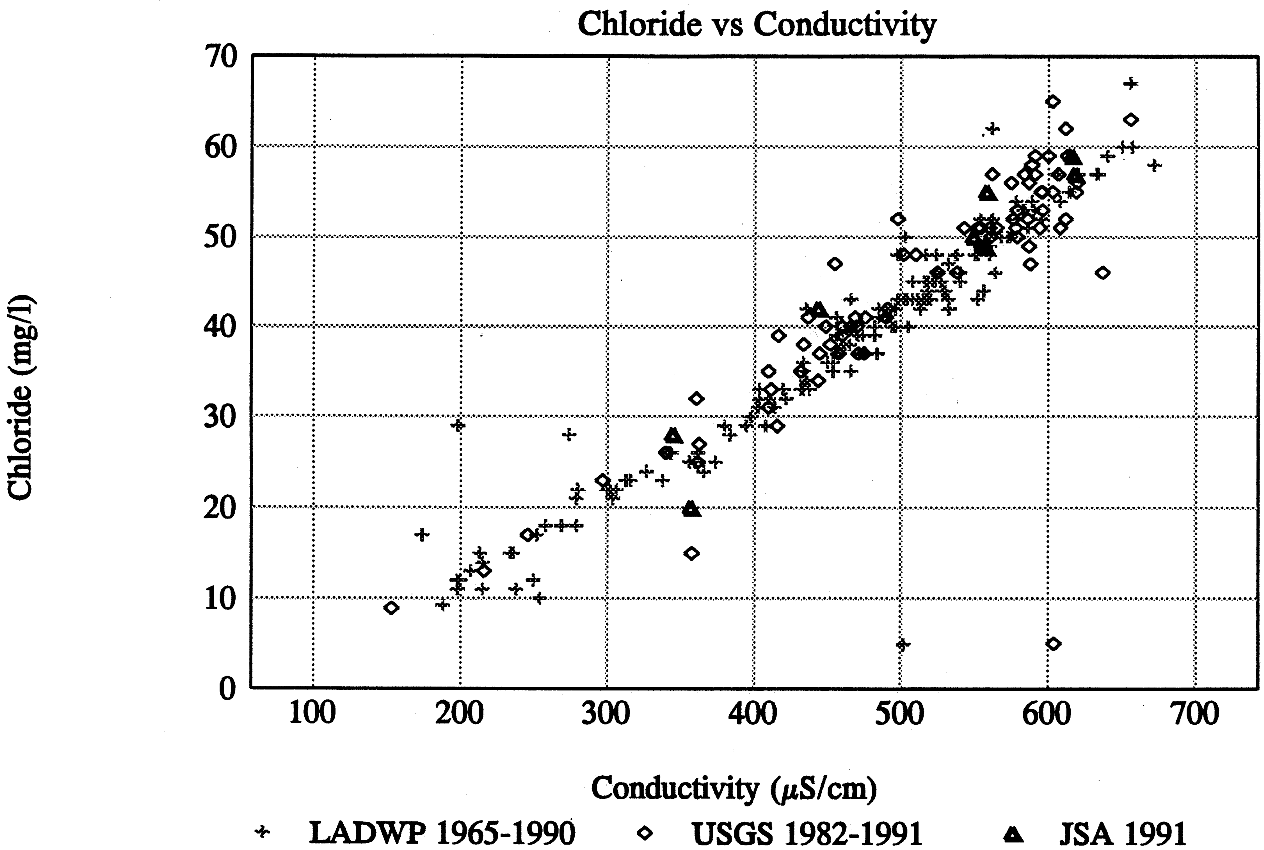
	No-Restriction Alternative					No-Diversion Alternative				
	Conductivity (µS/cm)	Chloride (mg/l)	Arsenic (µg/l)	Fluoride (mg/l)	Phosphate (mg/l)	Conductivity (µS/cm)	Chloride (mg/l)	Arsenic (µg/l)	Fluoride (mg/l)	Phosphate (mg/l)
Grant Lake reservoir outlet										
Mean	154	5.63	8.20	0.21	0.25	425	17.00	19.13	0.64	0.85
Minimum	60	1.85	2.53	0.06	0.06	425	17.00	19.13	0.64	0.85
Maximum	425	17.00	25.50	0.64	0.85	425	17.00	19.13	0.64	0.85
Lake Crowley reservoir outlet										
Mean	292	17.65	44.00	0.70	0.19	431	27.14	67.97	1.08	0.29
Minimum	225	12.30	31.87	0.49	0.12	246	13.47	36.60	0.55	0.14
Maximum	437	43.36	100.53	1.63	0.29	656	46.53	107.87	1.75	0.43
LA Aqueduct filtration plant inflow										
Mean	307	17.10	22.77	0.55	0.11	350	19.56	26.20	0.64	0.13
Minimum	212	7.77	1.20	0.24	0.04	222	7.77	1.20	0.24	0.04
Maximum	410	24.61	42.43	0.84	0.19	495	30.45	53.43	1.05	0.26

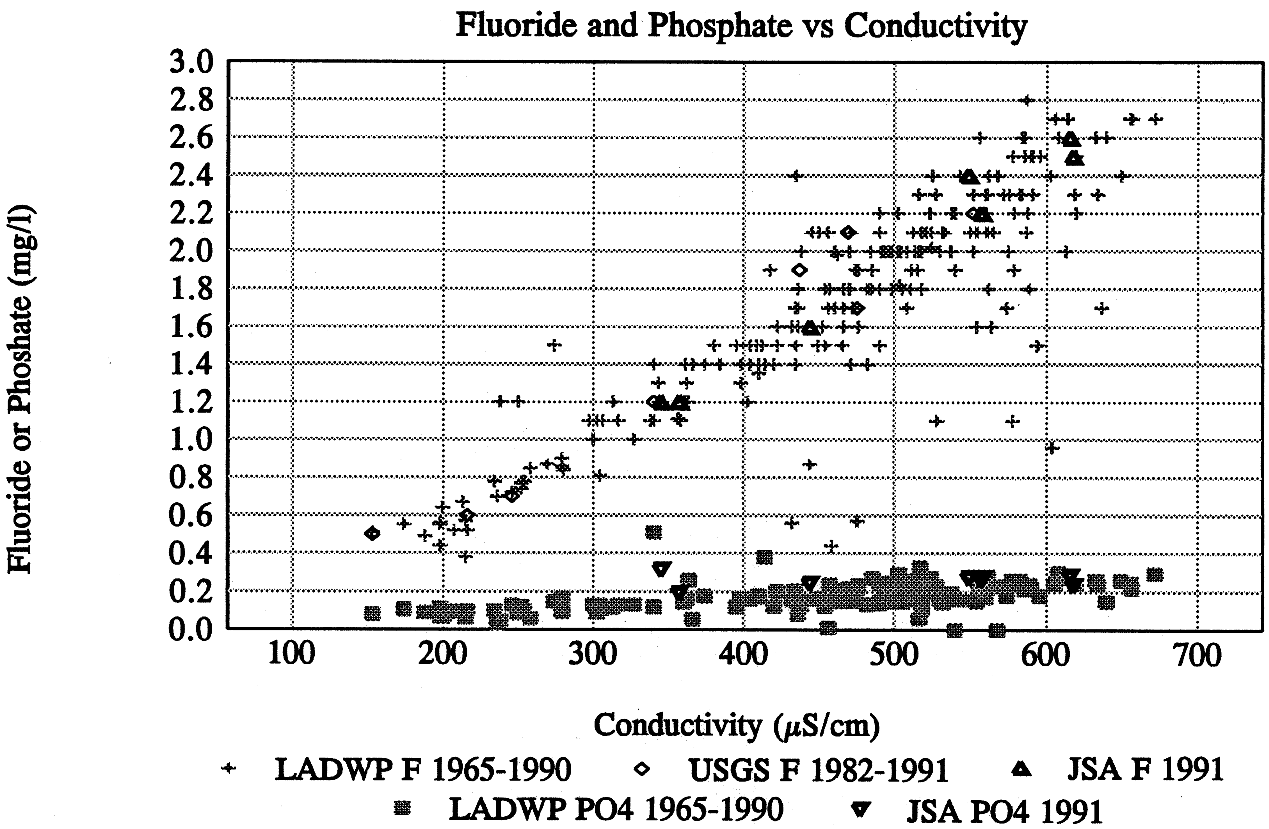
	Point-of-Reference Condition					Historical Data 1940-1990				
	Conductivity (µS/cm)	Chloride (mg/l)	Arsenic (µg/l)	Fluoride (mg/l)	Phosphate (mg/l)	Conductivity (µS/cm)	Chloride (mg/l)	Arsenic (µg/l)	Fluoride (mg/l)	Phosphate (mg/l)
Grant Lake reservoir outlet										
Mean	160	5.88	8.59	0.22	0.26	175	6.14	10.80	0.21	0.19
Minimum	60	1.85	2.53	0.06	0.06	26	0.60	2.00	0.00	0.01
Maximum	425	17.00	25.50	0.64	0.85	623	14.00	20.00	0.50	2.25
Lake Crowley reservoir outlet										
Mean	308	18.70	46.70	0.47	0.20	325	18.88	45.47	0.73	0.13
Minimum	228	12.49	32.33	0.50	0.12	188	8.50	4.00	0.31	0.00
Maximum	482	43.83	101.64	1.65	0.33	592	45.00	150.00	1.50	0.65
LA Aqueduct filtration plant inflow										
Mean	313	17.41	23.22	0.56	0.11	334	17.48	22	0.59	0.07
Minimum	214	7.77	1.20	0.24	0.04	173	6.00	5	0.16	0.00
Maximum	434	26.26	43.37	0.89	0.21	618	47.00	66	0.96	0.28



Note: Data collected from 1965 to 1991.

Figure K-1.
Relationships between Flow, Conductivity, and Arsenic at Hot Creek





Note: Data collected from 1965 to 1991.

Figure K-2.
Relationships between Chloride, Fluoride, and Conductivity at Hot Creek

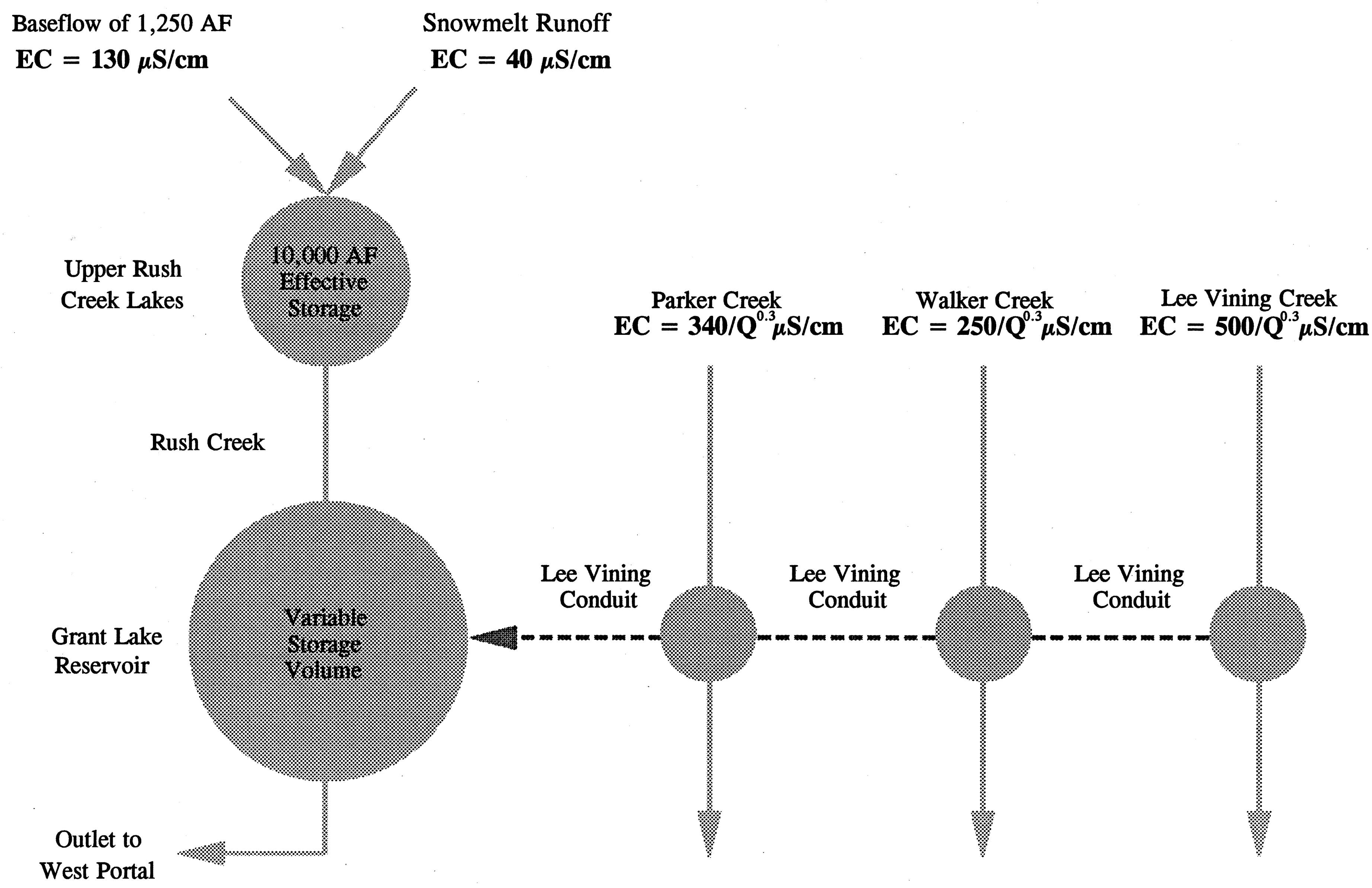


Figure K-3.
Grant Lake Module

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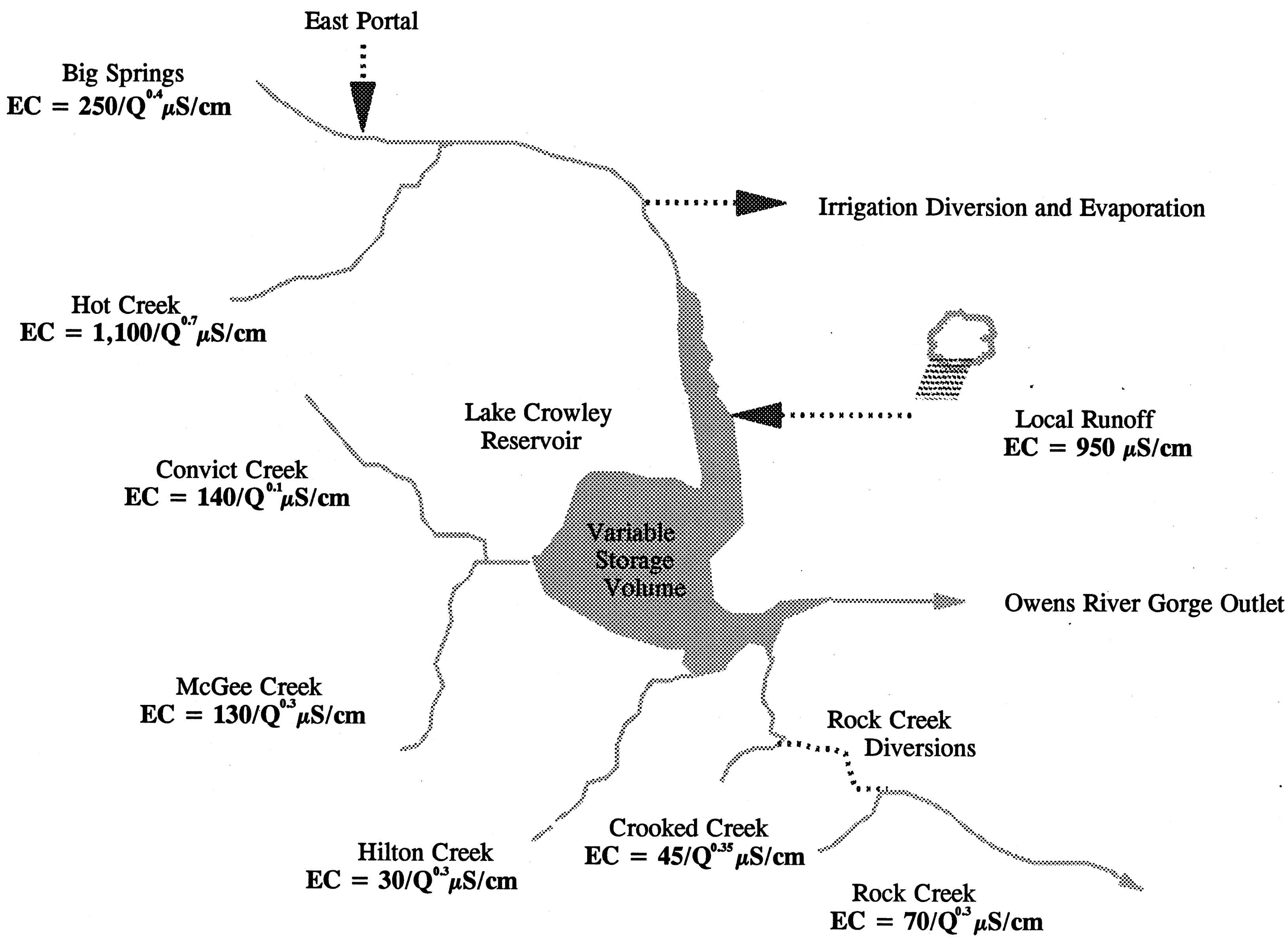


Figure K-4.
Lake Crowley Reservoir Module

MONO BASIN EIR
Prepared by Jones & Stokes Associates

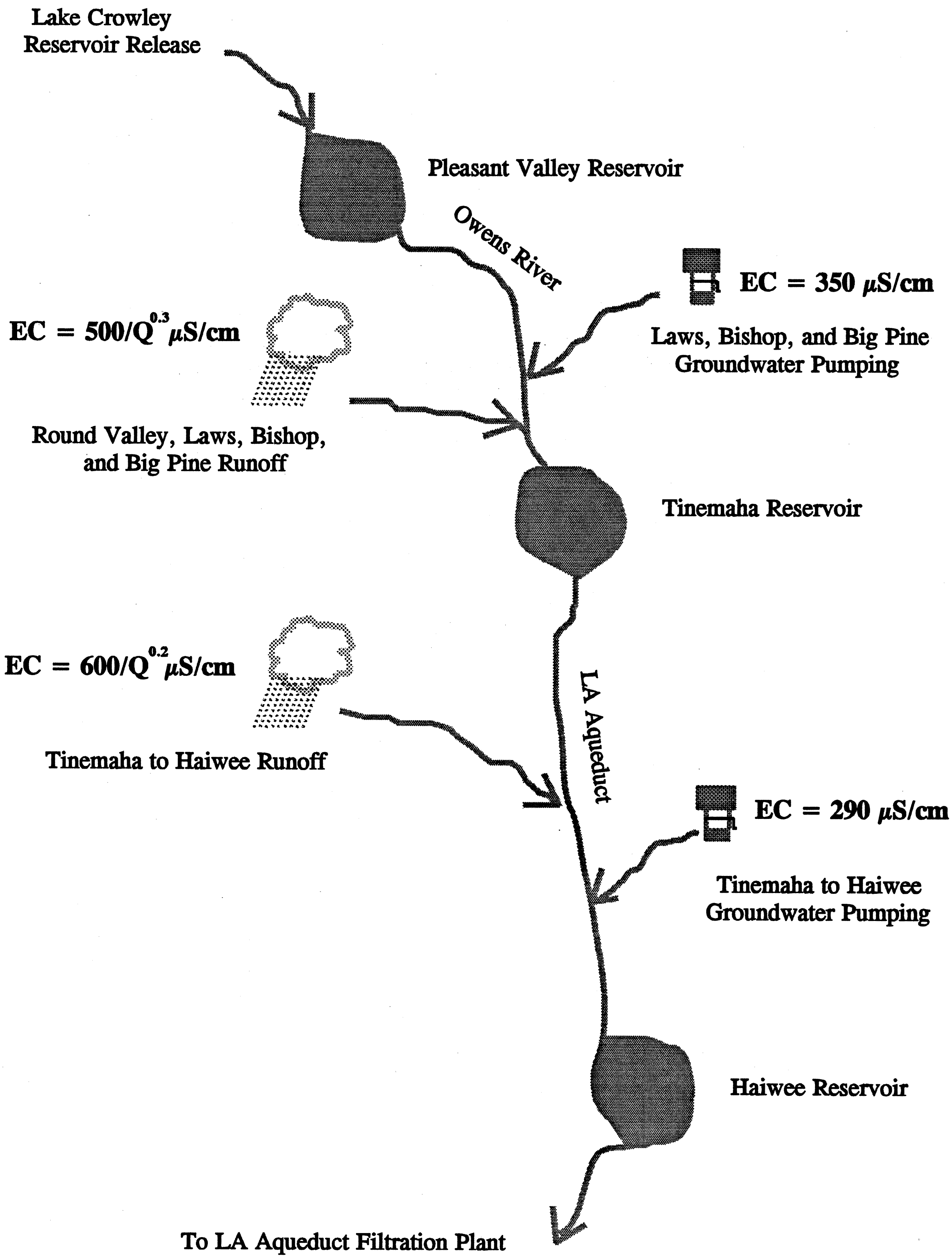


Figure K-5.
LA Aqueduct Module

Figure K-6.
Predicted Compared to Historical Conductivity
for Grant Lake Reservoir Outflow from 1940 to 1990

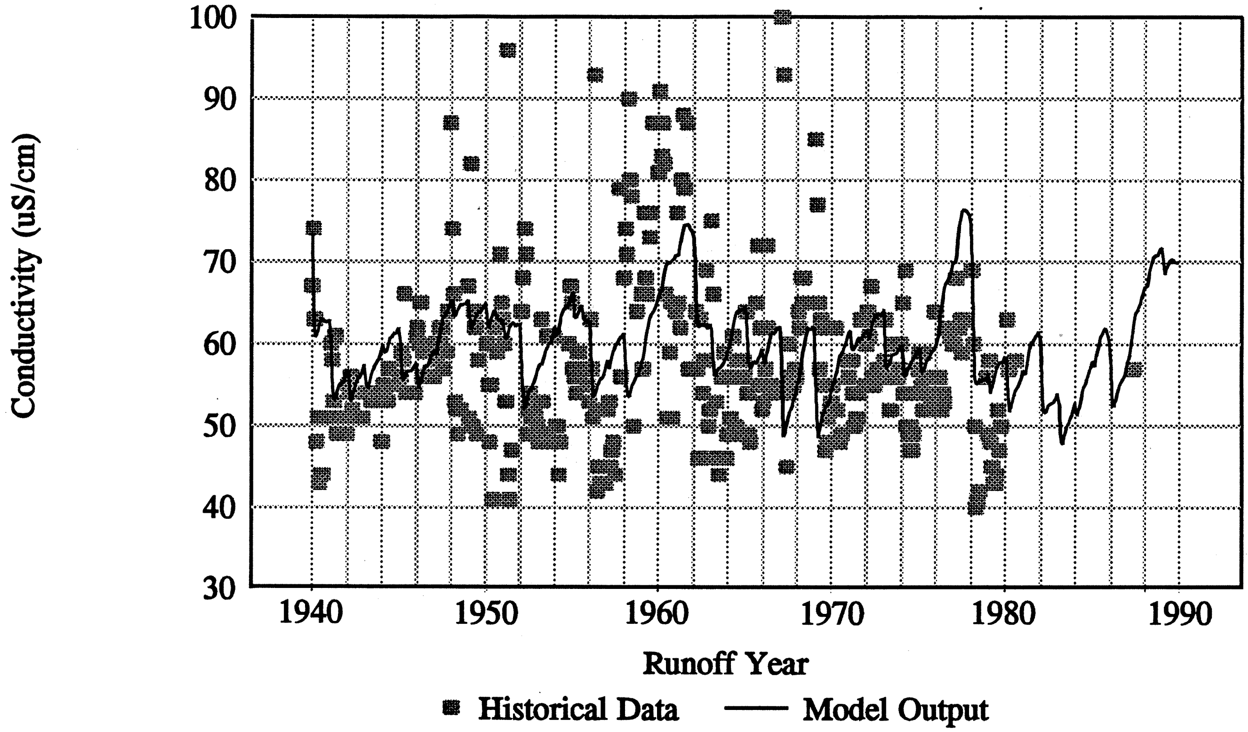


Figure K-7.
Predicted Compared to Historical Conductivity
for Lake Crowley Reservoir Outflow from 1940 to 1990

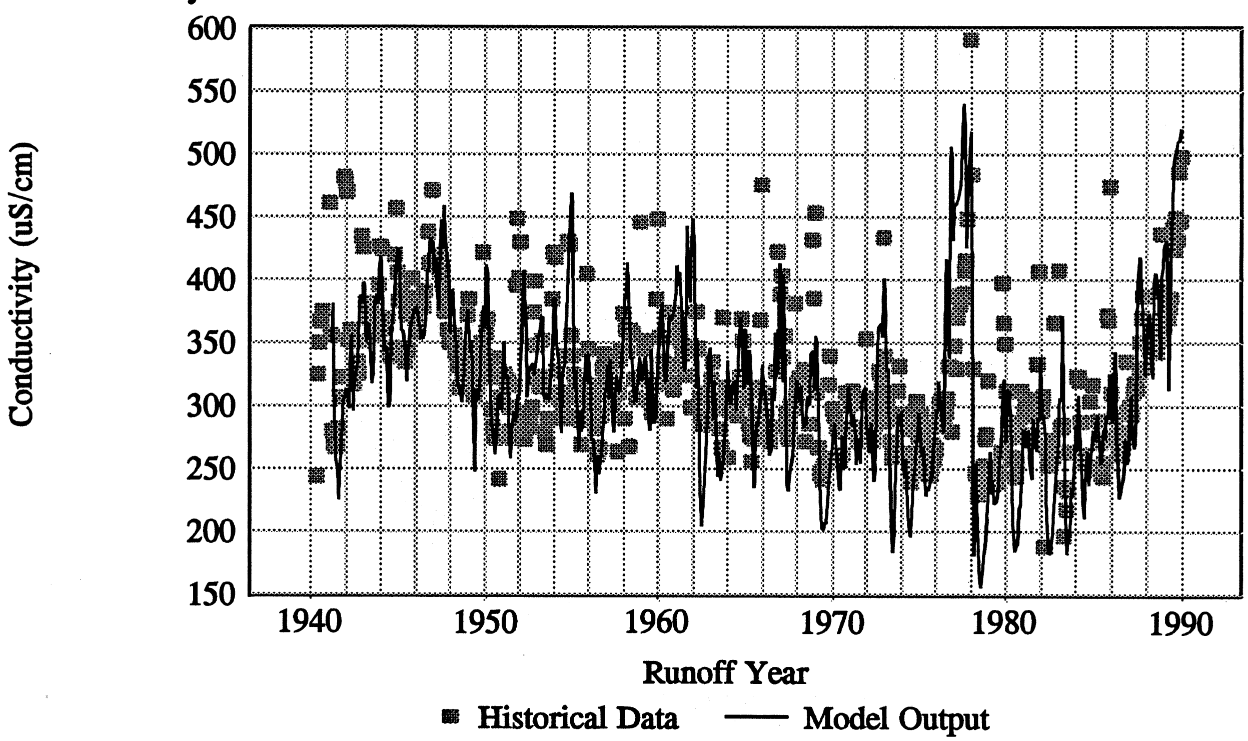


Figure K-8.
Predicted Compared to Historical Conductivity
for Tinemaha Reservoir Outflow from 1940 to 1990

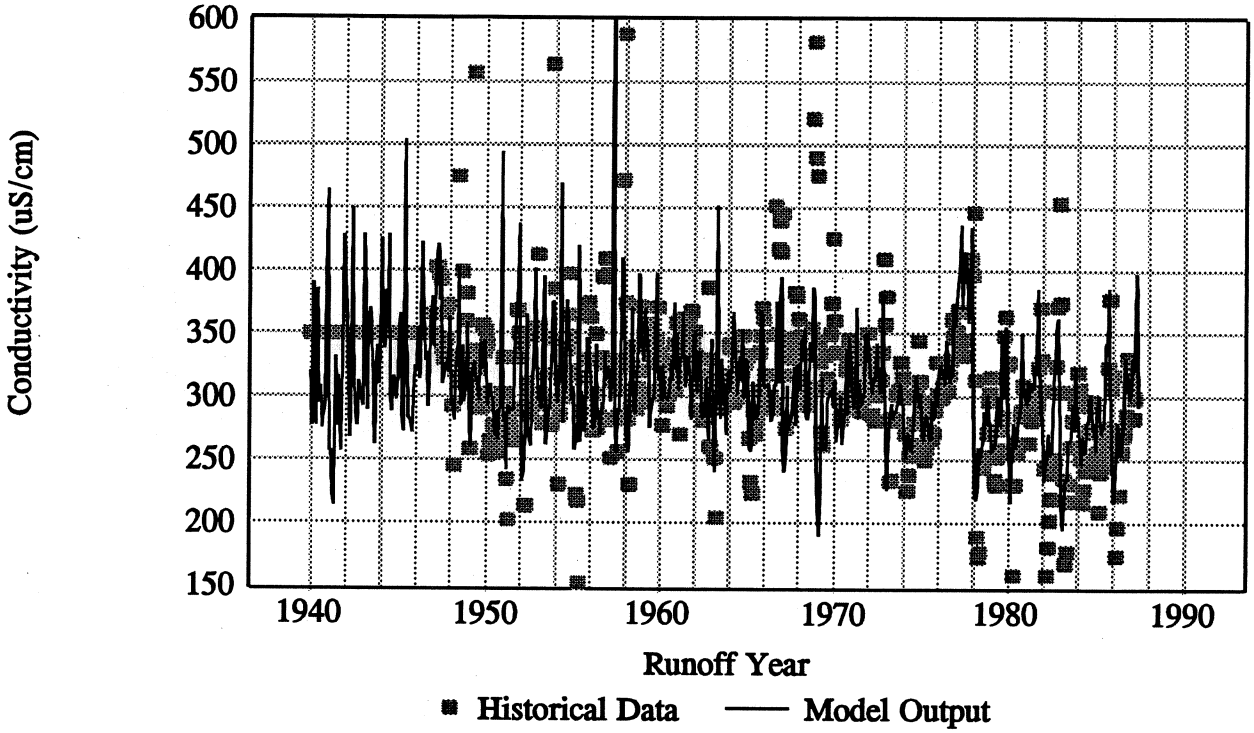


Figure K-9.
Predicted Compared to Historical Conductivity
for LA Aqueduct Filtration Plant Inflow from 1940 to 1990

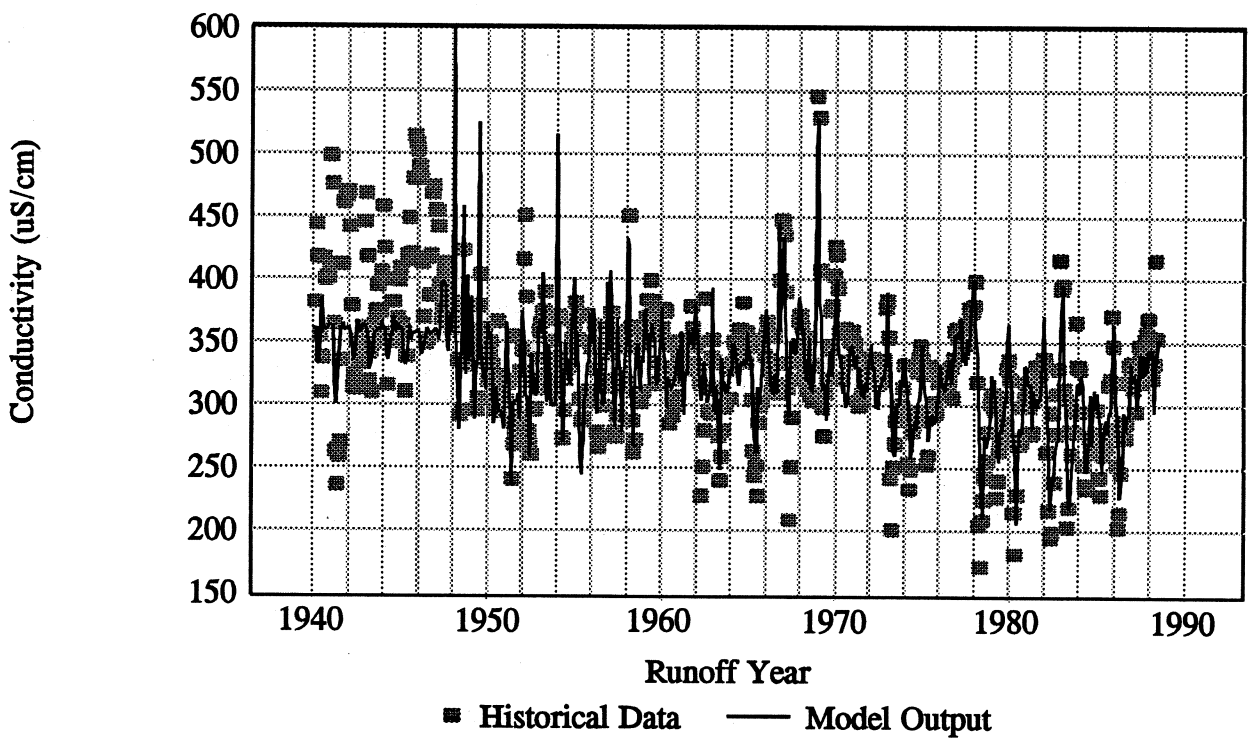


Figure K-10.
Predicted Compared to Historical Chloride Concentrations for Lake Crowley Reservoir Outflow from 1940 to 1990

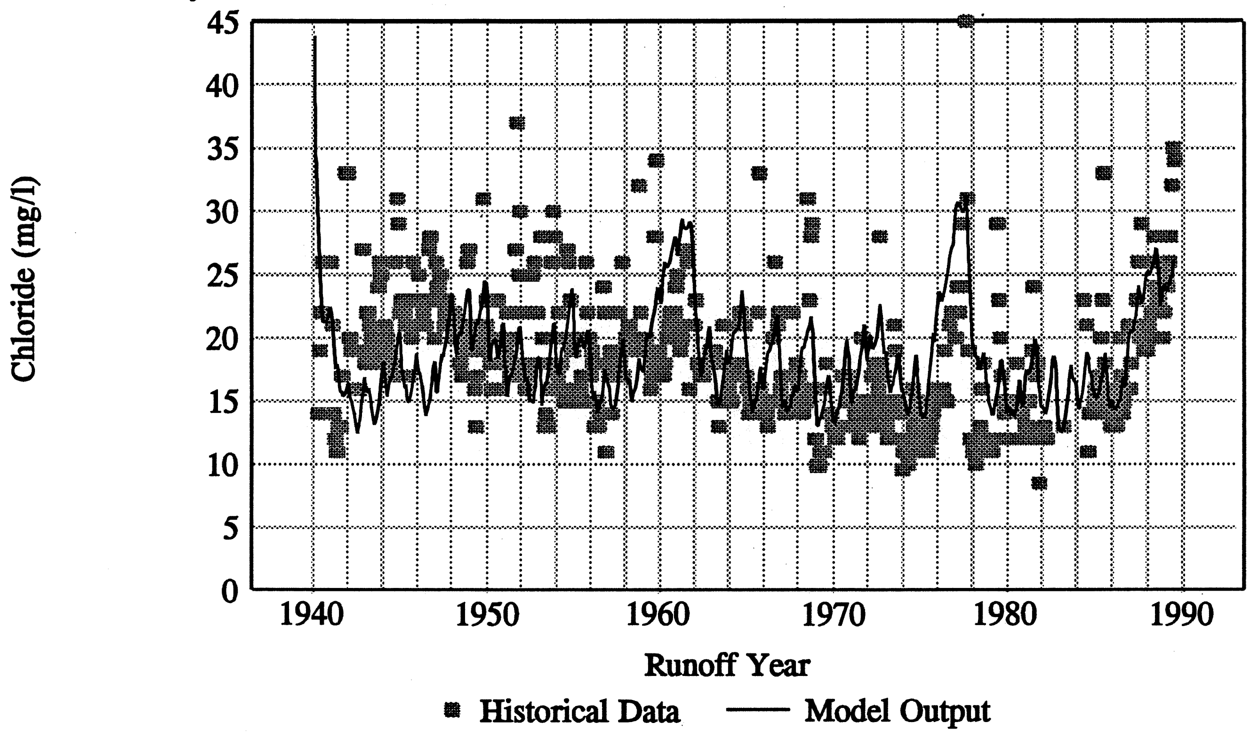


Figure K-11.
Predicted Compared to Historical Arsenic Concentrations for Lake Crowley Reservoir Outflow from 1940 to 1990

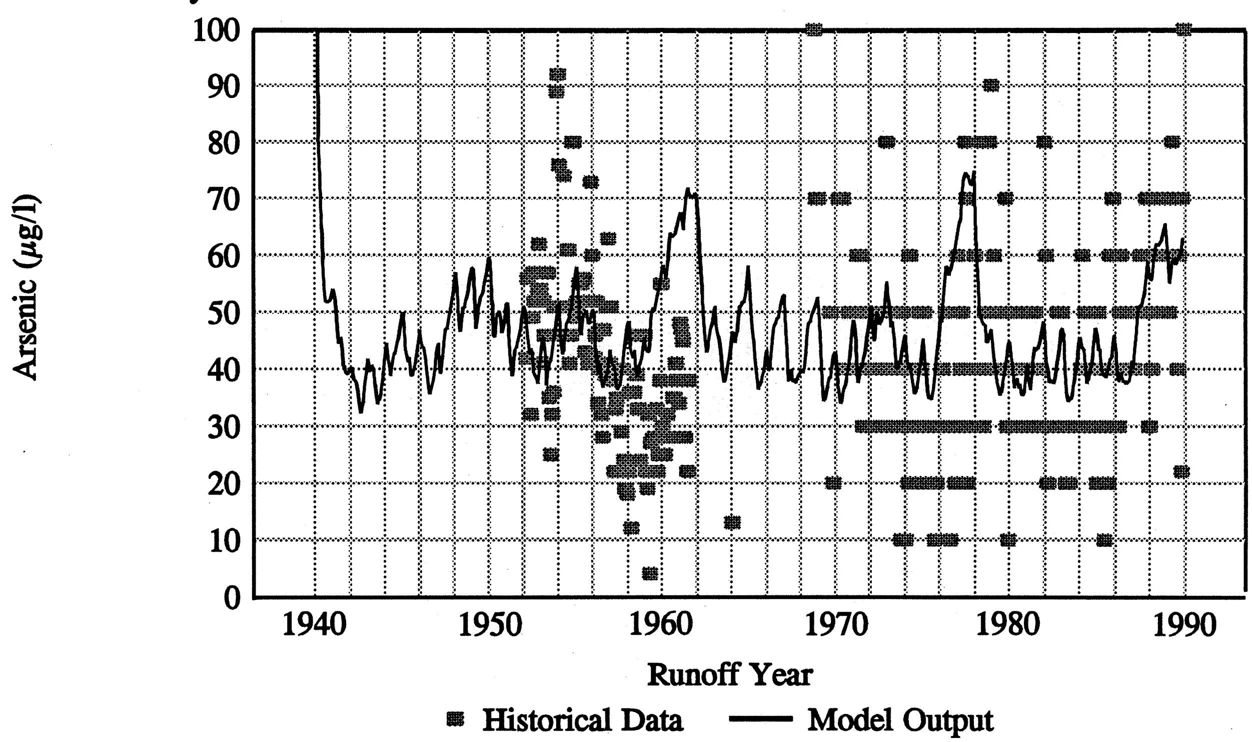


Figure K-12.
Predicted Compared to Historical Fluoride and Phosphate Concentrations for Lake Crowley Reservoir Outflow from 1940 to 1990

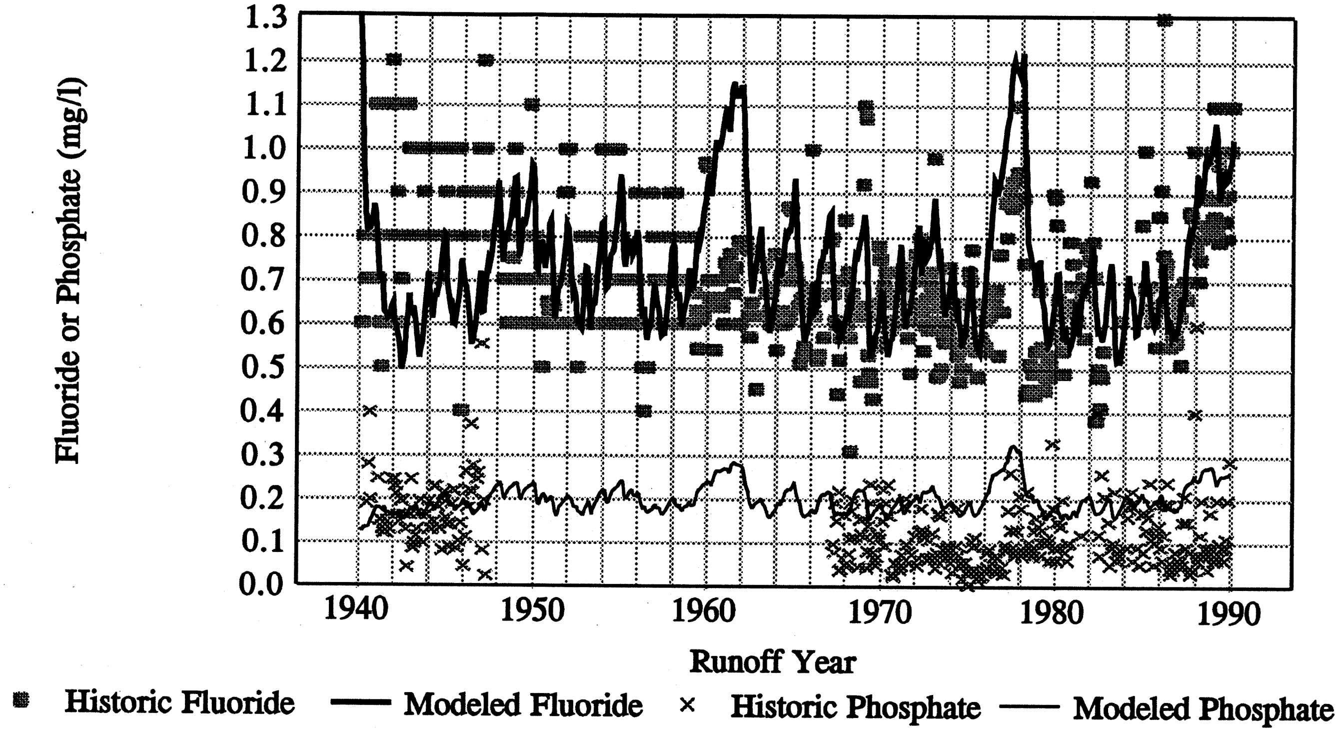


Figure K-13.
Predicted Compared to Historical Chloride Concentrations for LA Aqueduct Filtration Plant Inflow from 1940 to 1990

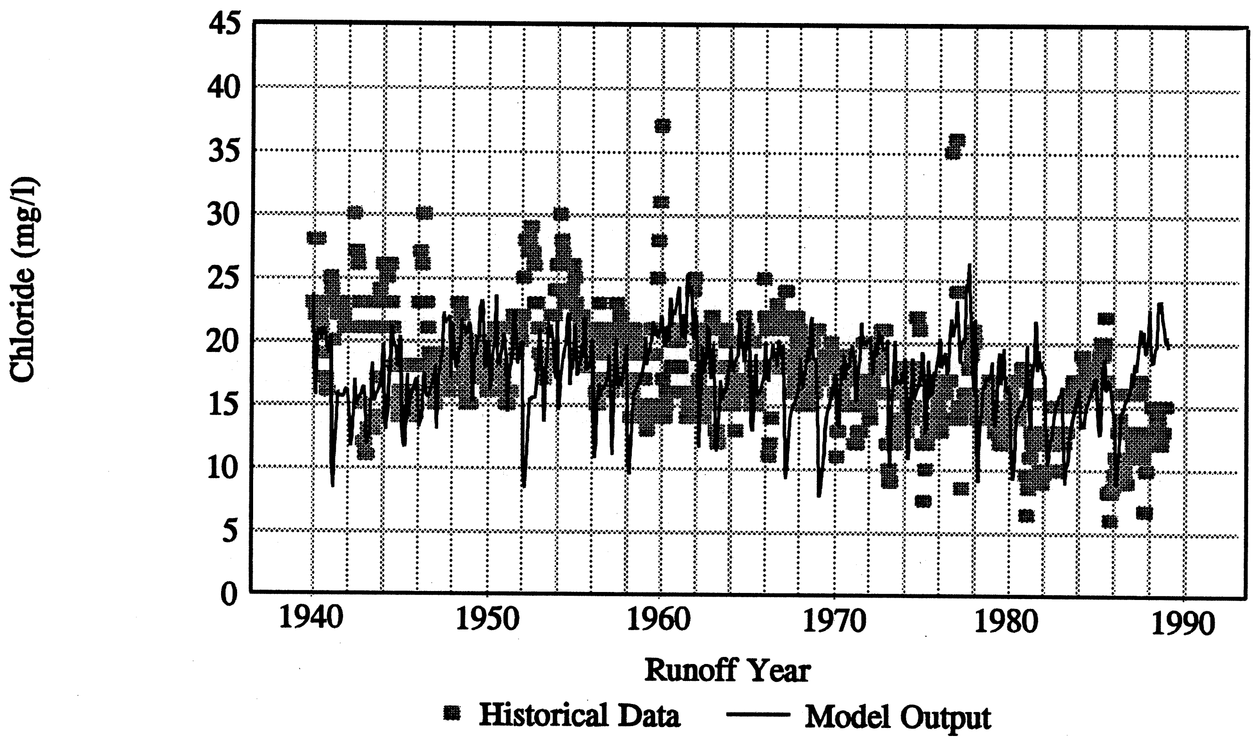


Figure K-14.
Predicted Compared to Historical Arsenic Concentrations for LA Aqueduct Filtration Plant Inflow from 1940 to 1990

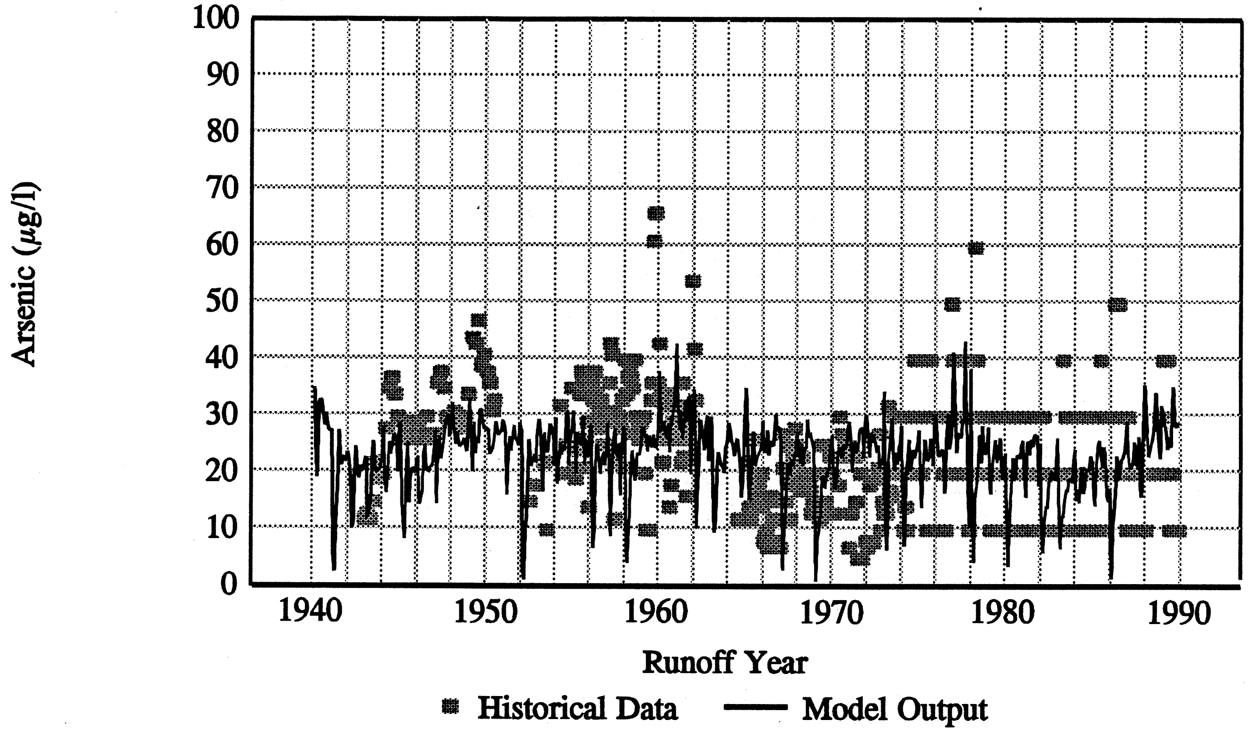


Figure K-15.
Predicted Compared to Historical Fluoride and Phosphate Concentrations for LA Aqueduct Filtration Plant Inflow from 1940 to 1990

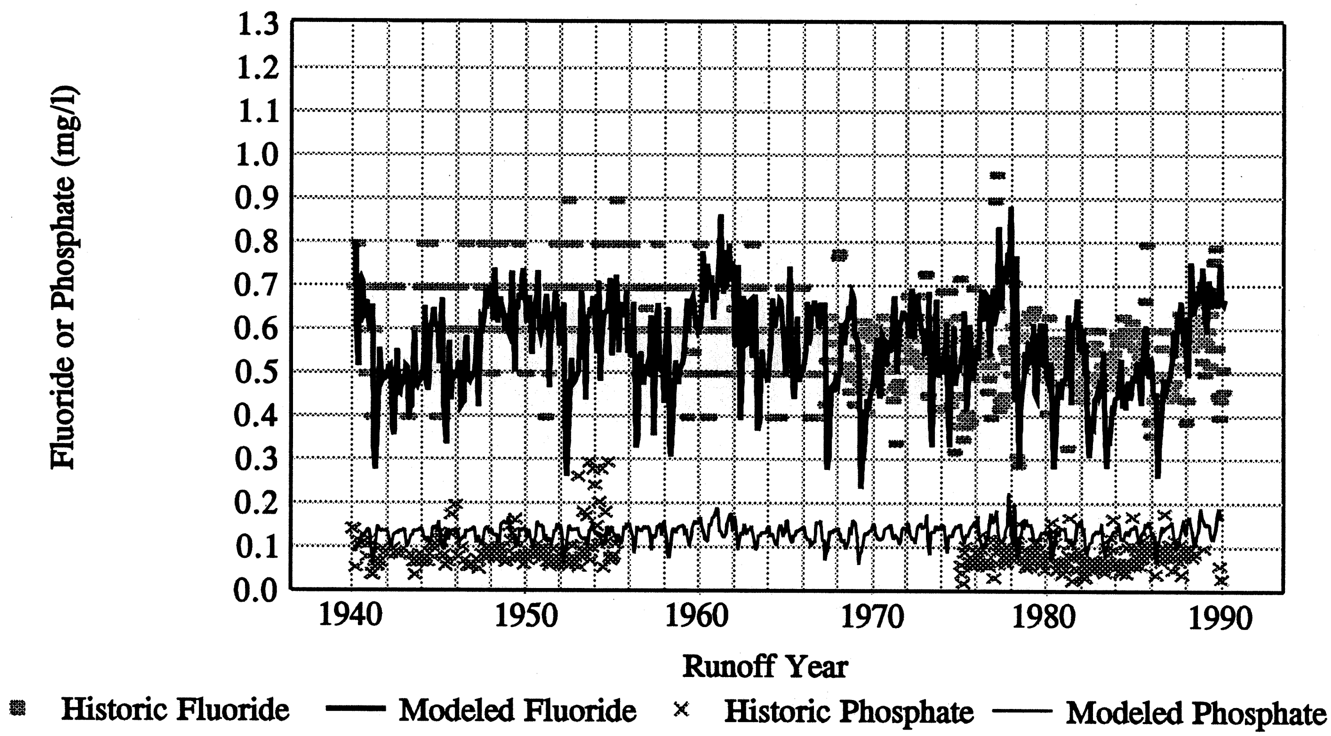


Figure K-16.
Predicted Conductivity under the No-Restriction and No-Diversion Alternatives for Lake Crowley Reservoir Outflow from 1940 to 1990

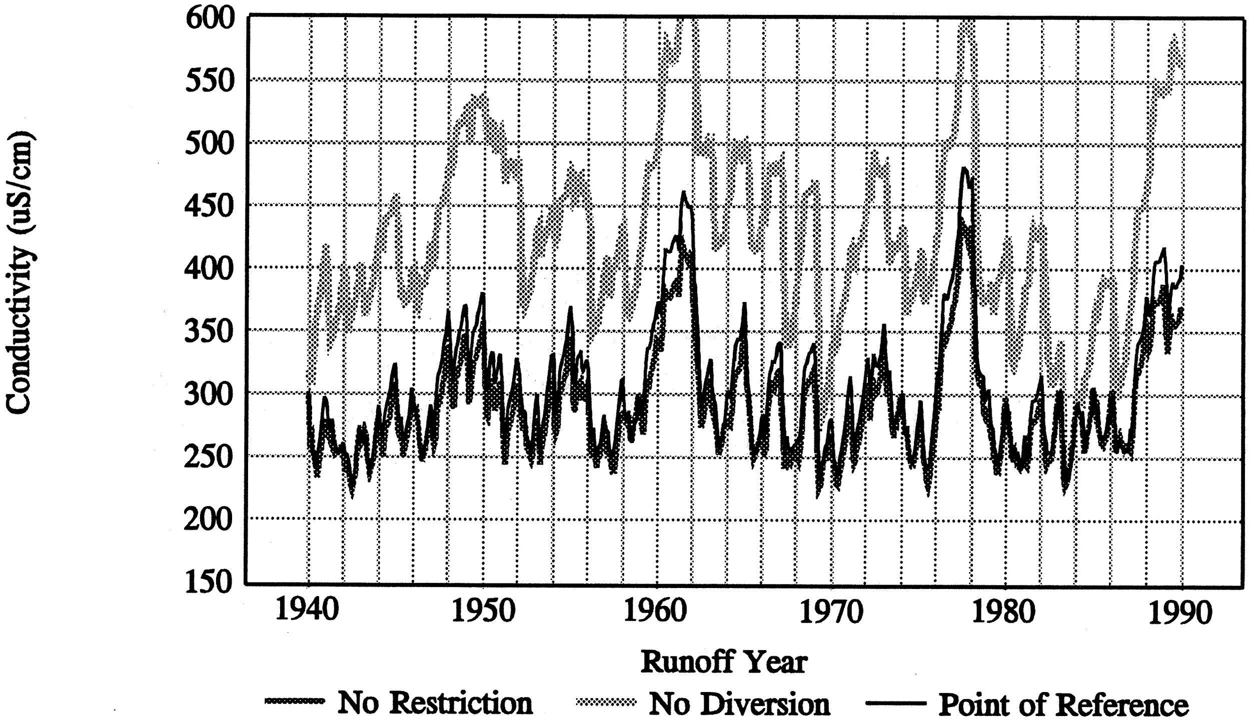


Figure K-17.
Predicted Arsenic Concentrations under the No-Restriction and No-Diversion Alternatives for Lake Crowley Reservoir Outflow from 1940 to 1990

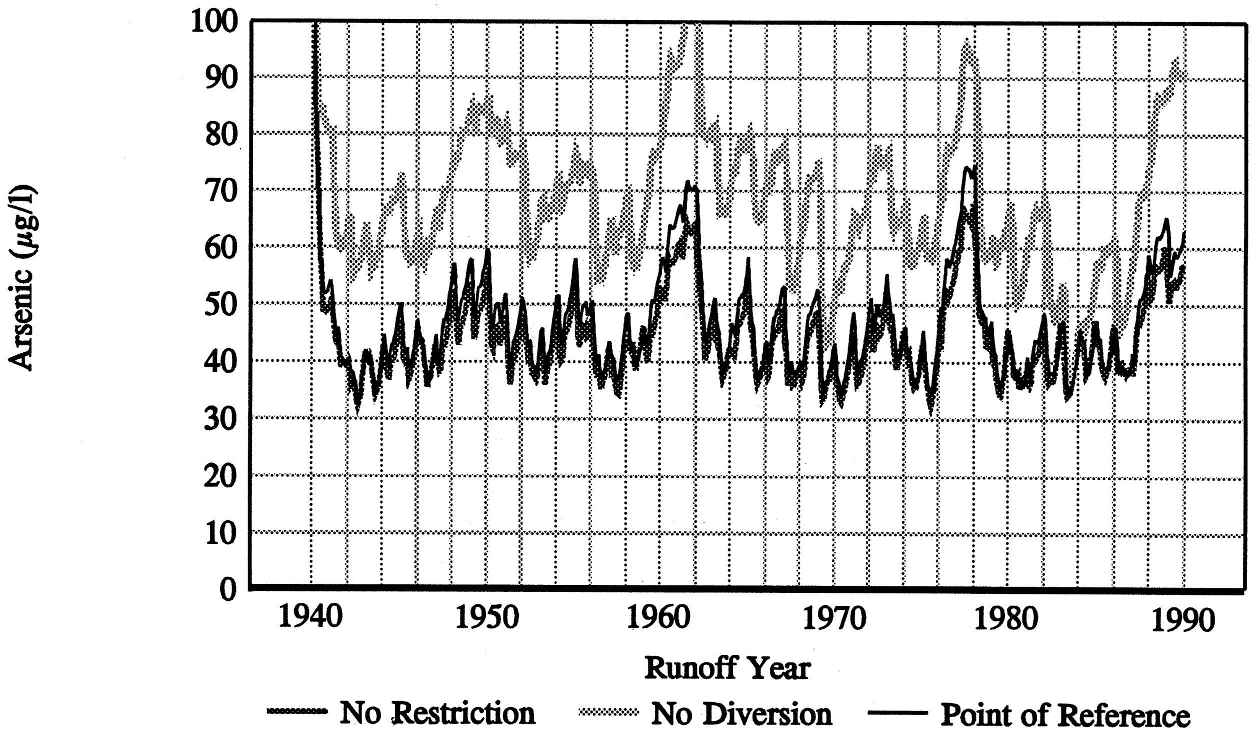


Figure K-18.
Predicted Conductivity under the No-Restriction and No-Diversion Alternatives for LA Aqueduct Filtration Plant Inflow from 1940 to 1990

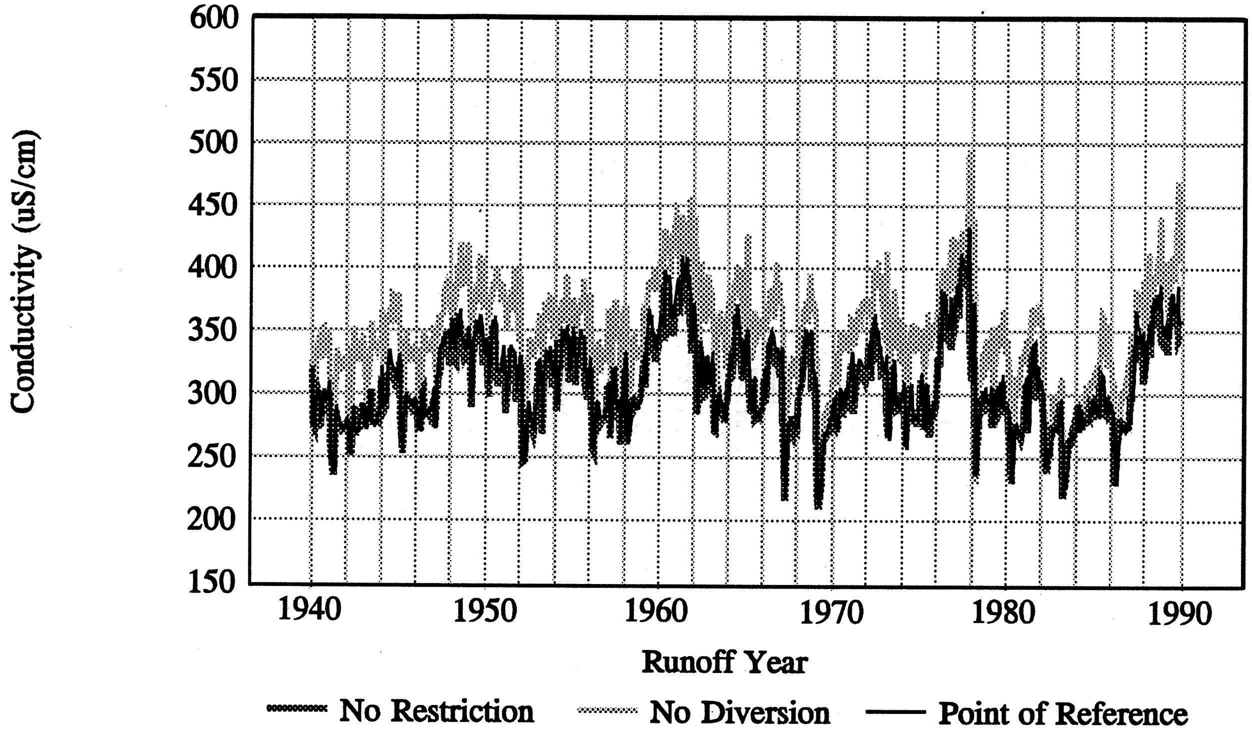
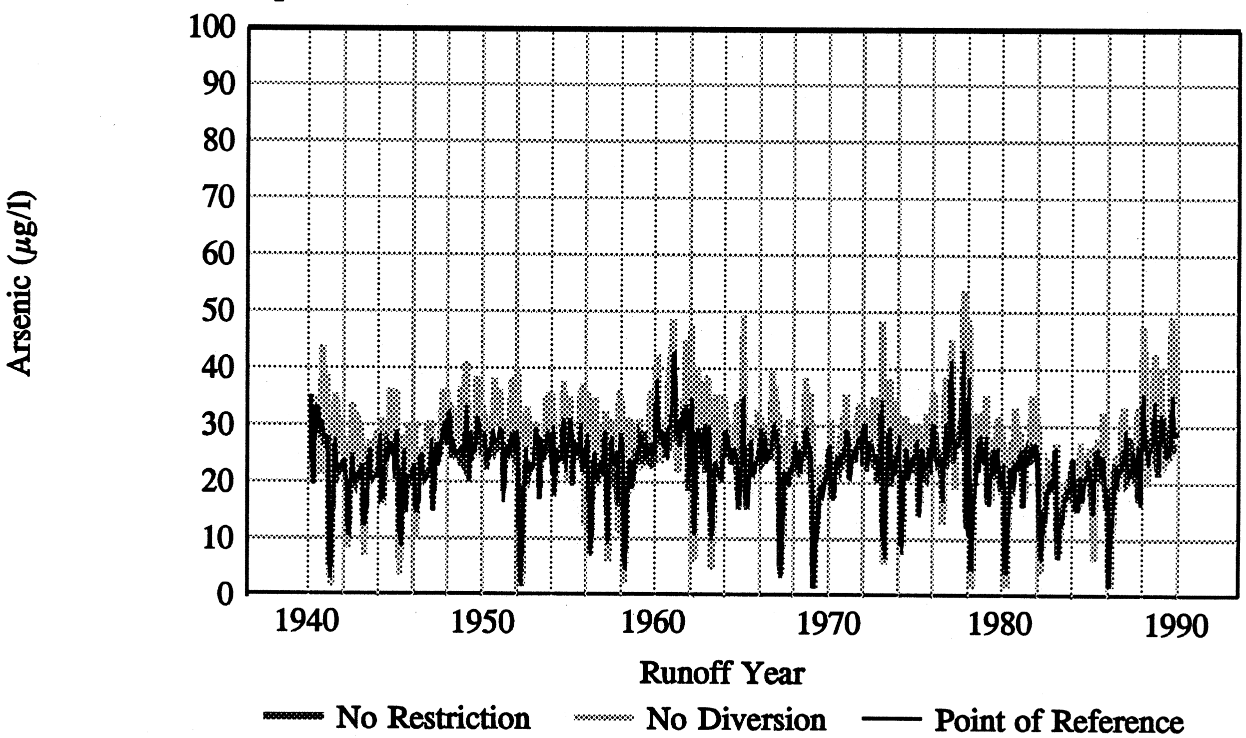
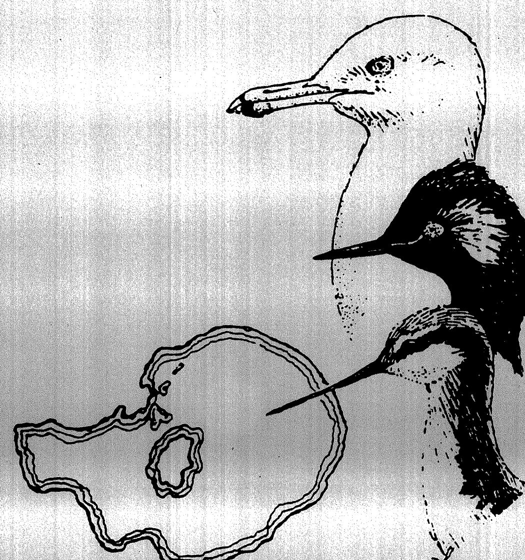


Figure K-19.
Predicted Arsenic Concentrations under the No-Restriction and No-Diversion Alternatives for LA Aqueduct Filtration Plant Inflow from 1940 to 1990



Appendix L. Alkali Fly Productivity Model



MONO BASIN EIR

Prepared by Jones & Stokes Associates

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Appendix L. Alkali Fly Productivity Model

The alkali fly productivity model (Figure L-1) provides an essential tool for predicting the effects on the alkali fly population of various Mono Lake elevations resulting from alternative management scenarios. Using available lake bathymetry and alkali fly data for model input and calibration, this population model compares the relative seasonal abundance of aquatic lifestages at different projected lake levels. The spreadsheet model estimates monthly alkali fly average biomass and cumulative production at environmental conditions corresponding to lake elevations from 6,350 to 6,420 feet. Summary results are graphically displayed to allow comparison between EIR alternatives.

MODEL ORGANIZATION AND USE

The alkali fly production model, POPFLY.WK1, was created in LOTUS 1-2-3, Release 2.3, for use on most personal computers. The spreadsheet is organized as a series of interconnected tables with progressive calculations as shown in Figure L-2. The first table is an input area, where input parameters are specified and adjustment factors calculated. The second table consists of alkali fly lifestage development times, sizes, and mortalities as functions of salinity and temperature. Temperature coefficients for each lifestage development time also are found in this table. The third table contains two-dimensional (2D) geometric means of alkali fly lifestage density data collected by Dr. David Herbst from six locations at Mono Lake in 1991. These data provide initial values of population densities for input into the model's daily calculation table and are used for calibrating the daily estimates of population densities. The fourth table calculates daily lifestage densities, biomass, and production per square meter for a specified lake elevation. Monthly and seasonal integrated production of total third instars and dislodged pupae, and monthly and seasonal average biomass of all lifestages for the entire lake, are computed and output to a fifth table, the lake summary table. Input conditions, temperature and salinity effects, daily estimates at a particular elevation, and monthly summary values for the range of elevations can be displayed with various graphs.

Instructions for using the model are found at the top of the spreadsheet. The model is run by pressing the "ALT" and "A" keys simultaneously, which activates an user-interactive macro. The macro allows the user a choice between daily or summary outputs and enables the user to alter various model inputs before running the model. Experienced users can change input parameters within the input tables without stepping through the macro.

MODEL DEVELOPMENT

The alkali fly productivity model was developed using several types of data for input and calibration: Mono Lake bathymetry and hard substrate data, alkali fly density data, and relationships between fly growth and mortality for each aquatic lifestage with environmental factors such as temperature, salinity, food availability, and substrate. The above data are contained within the data file spreadsheets BATHY.WK1 and FLYDATA.WK1. Summarized data necessary for model input and calibration were copied to the assessment model spreadsheet.

Bathymetry and Hard Substrate Data

BATHY.WK1 provides data on lake elevation, area, volume, salinity, and available fly habitat. It combines data from the PELAGOS Corporation (PELAGOS), Dr. Scott Stine, Dr. David Herbst, and Jones & Stokes Associates.

PELAGOS provided a bathymetry map of Mono Lake and a computer-generated table of lake area and volume corresponding to each lake elevation. A surface and subsurface topographical survey of Mono Lake was conducted by PELAGOS in August 1986 for LADWP employing a Mini-Ranger III navigation system. The lake was mapped below 6,370 feet at 5-foot contour intervals. Because the water level at the time of the survey was 6,380.7 feet elevation and the survey vessels had to maintain a certain distance from the shore, survey data near the lake perimeter (between 6,370 and 6,380 feet elevation) had the lowest accuracy. Contours from 6,375 to 6,330 feet elevation were mapped at 5-foot intervals using photogrammetric mapping compiled by Pacific Western Aerial Surveys (1982). Contours above 6,430 feet elevation were interpolated from preliminary U.S. Geological Survey (USGS) 7.5-minute quadrangle mapping (1982) for visual presentation only and were represented at 20-ft contours. Lake area (acres) and volume (acre-feet) were computer-generated for each foot of lake elevation based on the topographical data.

Jones & Stokes Associates compiled a map using a geographic information system (GIS) (ARC-INFO) system by combining contours from the PELAGOS map with data from additional aerial and ground surveys. The GIS map, which was verified by ground surveys, ranges from 6,320 feet elevation to 6,440 feet elevation and is more accurate than the PELAGOS map at contours above 6,365 feet elevation. However, the comparison with PELAGOS results is generally close for total and incremental lake area; the location of the elevation contours is the major difference. The Mono Lake bathymetry map is shown in Figure L-3. Jones & Stokes Associates smoothed the PELAGOS areas and volumes to eliminate variability in the 1-foot incremental areas. Salinity (grams per liter [g/l] of total dissolved solids [TDS]) as a function of lake volume was calculated assuming a total lake salt content of 285 million tons.

Stine approximated locations and densities of various types of soft and hard substrate on a map (1:24,000) provided by Jones & Stokes Associates, based on his extensive knowledge of Mono Basin geology and numerous surveys of the area. Incremental hard substrate areas of tufa, pumice bedrock, and beachrocks were planimetered by Jones & Stokes Associates from 6,300 feet elevation to 6,440 feet elevation. Areas between 6,300-6350 feet elevation were planimetered in 10-foot contour increments and areas between 6,350-6375 feet elevation were planimetered in 5-foot contour increments using the PELAGOS base map. Areas between 6,375-6,420 feet elevation were planimetered in 5-foot contour increments and areas between 6,420-6,440 feet elevation were planimetered in 10-foot contour increments using the Jones & Stokes Associates base map. In some steep areas, 10- to 20-foot contour increments were the highest resolution that could be achieved.

The 2D incremental substrate areas were then calculated by Jones & Stokes Associates with no consideration of slope. Bedrock and beachrocks are flat substrates covering almost 100% of their respective areas, and their planimetered areas were considered to be their 2D areas. Pumice areas consist of irregular-sized blocks scattered over areas otherwise covered by mud or sand. Stine provided a rough estimate of the densities of these blocks and their 2D and 3D areas. Jones & Stokes Associates computed the 2D flat pumice areas based on these estimates. Although tufa towers are highly variable in height, width, and coverage, their planimetered areas were considered to be identical with their 2D areas. The distribution of hard substrate could be determined only at a moderately low level of accuracy (±20%). The location and extent of planimetered hard substrate types are shown in Figure L-3.

The 2D incremental hard substrate areas were further divided into 1-foot contour incremental areas assuming equal area increments. Incremental soft substrate areas were calculated as incremental hard substrate area subtracted from the incremental total lake area at each elevation. A relationship showing declining alkali fly densities with increasing depth (Herbst and Bradley 1990) was used to determine suitable fly habitat to a depth of 32 feet for each foot of elevation. Hard substrate is considered to provide the maximum alkali fly densities and relates to depth exponentially as follows:

$$EHA = \sum_{d=0}^{32} (IHA \times e^{(-0.075\,d)})$$

where

EHA is the effective hard substrate area in acres,
d is the depth of the water column in feet, and
IHA is the incremental hard substrate area in acres at a depth of **d** feet.

Soft substrate is considered to provide an assumed fraction (5%) of maximum alkali fly densities and relates to depth linearly as follows:

$$ESA = \sum_{d=1}^{32} (ISA \times (1 - d/32)$$

where

ESA is the effective soft substrate area in acres,
d is the depth of the water column in feet, and
ISA is the incremental soft substrate area in acres at a depth of **d** feet.

The total effective habitat area at a given lake elevation is the depth-weighted hard substrate area increased by a perimeter of high-quality soft substrate area (assumed to be 10% of the depth-weighted hard substrate area) and an assumed fraction (5%) of the depth-weighted soft substrate area. Figure L-4 shows the pattern of effective habitat area for elevations between 6,350-6,420 feet.

USGS lake elevation; smoothed PELAGOS volume, area, and incremental area; and Jones & Stokes Associates salinity, incremental hard substrate area, depth-weighted hard, soft, and total substrate area, and the percentage of depth-weighted hard to total substrate area was copied into the POPFLY.WK1 spreadsheet. These data are part of the summary lake elevation table and provide input to the model to locate salinity and suitable habitat area for a given elevation. These values are given in Table L-1.

Alkali Fly Data

Alkali fly data are contained within the FLYDATA.WK1 spreadsheet, which provides the results of three interrelated projects completed by Herbst in 1991 (Herbst 1992): collection of field density data on alkali fly lifestage during the growing season, microcosm experiments to study the effects of salinity on the fly population, and collection of field drift data to determine the timing and extent of drift.

Field Density Data

Methods. Mono Lake field abundance data were gathered by Herbst from April 30 to October 15, 1991, in 11 sampling excursions to six selected sites around Mono Lake: North Land Bridge, Black Point Tufa Shoals, Old Marina, Lee Vining Tufa Grove, South Tufa Grove, and Willow Spring (Figure L-3). These are generally hard substrate areas that normally contain high densities of alkali flies. Multiple samples (usually eight) were collected from various types of soft and hard substrates on each sampling trip. A total of 1,052 samples were collected and analyzed. Hard substrate consisted of tufa, pumice, gaylussite, mudshale, alluvium, and sandstone beach pavement and was sampled by retrieving a piece of the substrate. Longest length and perimeter of the hard substrate were noted to calculate the 2D projected surface area. 3D exposed surface areas were found by wrapping the exposed rock area with aluminum foil and calculating the area by weighing the foil. Soft substrate consisted of sand and mud in vicinity of hard substrate (considered high-quality soft substrate because the density of larvae is higher on soft substrate close to hard substrate) and was sampled with a 4-centimeter (cm)-diameter corer. The number of animals for aquatic lifestages (i.e., eggs, first instars, second instars, third instars, full pupae, and empty pupae) in each sample was recorded.

Jones & Stokes Associates further analyzed Herbst's data to estimate 2D densities of the various lifestages per square meter (individuals per square meter [ind/m^2]) by dividing the individuals per sample by the 2D surface area of the sample. The geometric and arithmetic means of 2D lifestage densities per site were found by averaging the densities calculated from multiple samples taken on the same date at that site.

Results. Both arithmetic and geometric means of 2D lifestage densities over time are presented by site and substrate type (Figures L-5 through L-10). Figures L-5A and L-5B show geometric mean density of each lifestage on hard and soft substrates at site 1 (North Land Bridge). The peak density of pupae occurred on September 24 (day 267) with 97,000 ind/m^2 on hard substrate, the highest pupae density measured on any site and more than twice the average pupae density of 40,000 ind/m^2 on hard substrate. Almost no pupae were observed on soft substrate at site 1 or any other site. The peak density of third instars occurred during September 4 (day 247) with about 33,000 ind/m^2 on hard substrate. Third instar density on the soft substrate was considerably lower but peaked at the same time as the hard substrate with about 6,000 ind/m^2. These third instar densities and peak periods were typical for most sites. Densities of second instars on hard substrate climbed steadily and peaked at 10,000 ind/m^2 at the end of the season, whereas second instars on soft substrate peaked at 6,000 ind/m^2 on September 4 (day 247). Site 1 had the lowest second instar densities on either soft or hard substrate of any site. Densities of first instars on hard and soft substrate peaked earlier (day 220) at 10,000 and 1,500 ind/m^2, respectively, which is low compared to other sites. Egg densities on hard substrate reached a maximum of 30,000 ind/m^2 on August 7 (day 220). On soft substrate, egg densities at site 1 were lower than at any other site (less than 1,000 ind/m^2) throughout the season.

Figures L-6A and L-6B show geometric mean density of each lifestage on hard and soft substrates at site 2 (Black Point). Pupae were observed at densities of 20,000-50,000 ind/m^2 on hard substrate, which is fairly representative of most sites. Third instars were less abundant than pupae with densities of 10,000-20,000 ind/m^2 throughout the season. The most abundant lifestage on soft substrate was second instars at about 10,000-20,000 ind/m^2, the highest densities seen on soft substrate. Site 2 also had the highest densities of first instars on soft substrate at 15,000 ind/m^2. Soft substrate third instar densities were only 5,000-10,000 ind/m^2, a typical value. Egg densities were slightly above average, peaking at 23,000 ind/m^2 for hard substrate and 9,000 ind/m^2 for soft substrate.

Figures L-7A and L-7B show geometric mean density of each lifestage on hard and soft substrates at site 3 (Old Marina). Densities of all lifestages on both soft and hard substrate were consistently among the highest measured. Pupae on hard substrate peaked in the end of September (on day 267) at about 93,000 ind/m^2, with a smaller peak in the end of July (on day 205) of 40,000 ind/m^2. Double peaks of pupae were seen at several sites. Third instars on hard substrate slowly increased to 33,000 ind/m^2 by September 4 (day 247). Third instars on soft substrate reached 25,000 ind/m^2 on August 7 (day 220), by far the highest value measured.

Figures L-8A and L-8B show geometric mean density of each lifestage on hard and soft substrates at site 4 (Lee Vining Tufa Grove). Lifestage density patterns at site 4 were typical. Pupae peaked at 65,000 ind/m^2, while third instars slowly increased from 20,000 to 35,000 in September on hard substrate. On soft substrate, third instars peaked in the beginning of August (day 220) at 7,000 ind/m^2.

Geometric mean density of each lifestage on hard and soft substrates at site 5 (South Tufa Grove) are shown in Figures L-9A and L-9B. Values are similar to those from other sites. On hard substrate, pupae slowly increased to 55,000 ind/m^2 in September. Third instars peaked slightly earlier in the beginning of September at 33,000 ind/m^2. On soft substrate, third instars peaked in July at 8,000 ind/m^2.

Figures L-10A and L-10B show geometric mean density of each lifestage on hard and soft substrates at site 6 (Willow Spring). With the exception of egg densities measured at 170,000 ind/m^2 on hard substrate in the end of July (day 205), this site exhibited low to average density values. Pupae and third instars on hard substrate remained at 5,000-15,000 ind/m^2 throughout the season. Third instars on soft substrate peaked in the end of July (day 205) at 5,000 ind/m^2.

Both arithmetic and geometric 2D overall average densities from the six sites were calculated and graphed for each lifestage and substrate type. Figures L-11a and L-11b show overall geometric mean density of each lifestage on hard and soft substrates. Pupal densities on hard substrate peaked in the end of September at 40,000 ind/m^2, while no pupae were found on soft substrate. Third instar densities reached a maximum of 25,000 ind/m^2 on hard substrate and 7,000 ind/m^2 on soft substrate. Third instar densities on soft substrate peaked at the end of August (day 234), approximately 2 weeks earlier than third instar densities on hard substrate, which peaked in early September (day 247). Second instar densities on soft substrate reached a maximum of 4,500 ind/m^2 and persisted at that level for the remainder of the season. On hard substrate, second instar densities increased throughout the season to a peak in October of approximately 27,000 ind/m^2.

Data Application. The 2D geometric means of the hard and soft substrate densities of the various aquatic lifestages for each of the six stations, as well as for the means of all stations, were copied into the POPFLY.WK1 spreadsheet. These data provide initial densities of the individual lifestages and allow calibration of simulated densities with actual observed densities.

Microcosm Experiments on Salinity Effects

FLYDATA.WK1 also contains the results of Herbst's microcosm experiment in which the effects of varying salinity on alkali fly abundance and mortality was researched. Microcosms are large aquariums where the ecological effect of changing environmental variables such as salinity can be studied. Twenty 500-liter tanks were filled with Mono Lake water adjusted to 50, 75, 100, and 175 g/l salinity (four tanks for each salinity level) and inoculated with a known population of alkali flies. The tanks were covered with sand (soft substrate) on which concrete blocks (10 x 7 x 4 cm) were placed. The concrete blocks constituted artificial hard substrate. All tanks were sampled twice; 10 samples of soft and hard substrate from each tank were collected on day 30 (September 6) and on day 60 (October 6) after the inoculation. The density per lifestage per sample and the number of dead third instars were recorded.

Jones & Stokes Associates calculated 2D densities and arithmetic and geometric mean densities for tanks with identical salinities per date using the procedure described above for the field data. The microcosm data were indirectly used in the assessment model to verify modeled salinity effects corresponding to various lake elevations.

Field Drift Data

Alkali fly drift estimates were collected during 1991 by Herbst. Littoral drift, consisting of floating larvae, pupae, and adults, was sampled using a boat-towed floating net with a sampling width of 65 cm and a sampling depth of 55 cm. Distance and volume sampled were measured with a current meter. Tows were typically 3 minutes in duration and covered a distance of 50-100 meters at UC Santa Barbara brine shrimp sampling stations (Figure L-3). One surface tow at each of 10 stations was conducted biweekly from May through October. Near-shore phalarope feeding areas at the northeast edge of the lake (Figure L-3) also were transected from August 28 to 30 (days 241-243), when phalaropes were most numerous.

Open water drift data were analyzed by Jones & Stokes Associates in FLYDATA.WK1, with summary results included in POPFLY.WK1. The distribution of third instars, pupae, and adults in the drift is shown in Figure L-12. Drift consists mainly of third instars until the end of July through the beginning of September when pupae become the dominant lifestage. Adult flies represent a small fraction of the drift through most of the season, except August. Drift was present in patches because of wind and circulation patterns. Highest drift densities observed were 5-10 ind/m^2 in foam lines and 30-50 ind/m^2 at near-shore circulation convergence areas where phalaropes feed. Phalarope feeding areas had average drift densities of 5-8 ind/m^2. Open water drift densities were much lower. Figure L-13 shows the 2D densities of third instars and pupae per square meter (ind/m^2) in open water drift. Typical averages were 0-0.5 ind/m^2 throughout the season, except in August when a peak average of 1-2 ind/m^2 was found. Adult flies were not included in Jones & Stokes Associates' analysis of Herbst data because the assessment model does not calculate adult fly densities. The open water drift data were used in the assessment model to estimate reasonable values for drift throughout the growing season.

Other Data

Daily temperatures used in the model were measured at site 3 (Old Marina) by Jones & Stokes Associates at a depth of 0.5 meter. Herbst provided mean fully developed lifestage dry weights (milligrams per liter [mg/l]) and mean development times of each lifestage at 50, 100, and 150 g/l salinity from 1991 laboratory data (Herbst 1992). Herbst also furnished mean development times as a function of temperature (Herbst 1990, Court Testimony). Mean fully developed weights of each lifestage were used to calculate fly biomass and production per square meter of soft and hard substrates. For first, second, and third instars, mean fully developed weights were multiplied by 0.5 to approximate a middle-of-stage weight. Production of third instars and pupae were calculated from fully developed weights. A table of mean weights, development time, and mortality for selected salinities was created using interpolation of the 1991 laboratory data (Table L-2).

MODEL ASSUMPTIONS AND CALCULATIONS

The model (POPFLY.WK1) calculates daily density, biomass, and production for each lifestage for a square meter of ideal hard substrate between May 1 and October 31. Temperatures are too cold for significant growth in other months, and 1991 field data were collected during this period.

Development Rate and Time Estimates

The model estimates the development rates for each lifestage as the inverse of the development times. The development times are estimated as functions of temperature and salinity at each lifestage. Table L-2 shows the estimated development times for a range of temperatures. Development times of each lifestage is modeled as:

$$DT\ (\text{lifestage}) = a \times e^{(-b/T)} \times SF\ (\text{lifestage})$$

where

DT (lifestage) is the development time in days,
T is the water temperature on that day,
SF (lifestage) is the salinity adjustment factor, and
a and **b** are coefficients chosen to achieve reasonable development times.

Figure L-14 shows development time as a function of temperature for each lifestage assuming a salinity of 100 g/l. These temperature functions are based on pupal development time experiments conducted by Herbst. The pupal development time increased from 10 days at 25°C to 29 days at 15°C. Development is considered not to occur at temperatures below 10°C. Development times of all other lifestages increase proportionally to pupal development times. The development times at 20°C are assumed to be 3 days for eggs, 4 days for first instars, 7 days for second instars, 15 days for third instars, and 15 days for pupae. Daily temperatures are used to estimate development times for each lifestage.

Development times for larval instars are considered salinity dependent, whereas eggs and pupae are assumed to be insulated from salinity effects. Figure L-15 shows development times of the various aquatic lifestages as a linear function of salinity assuming an ambient temperature of 20°C. For first instars, development times increase linearly from 3.6 days at 50 g/l salinity to 4.7 days at 150 g/l salinity. Development times for second instars are 6.3 days at 50 g/l salinity and 8.2 days at 150 g/l salinity. For third instars, development times increase from 10 days at 50 g/l to 20 days at 150 g/l. Figure L-16 shows 1991 field temperatures measured at Old Marina and the corresponding lifestage development times at salinity 92 g/l (elevation 6,375 feet). Very little development occurs at any lifestage at temperatures below 15°C.

Egg Density Estimates

Daily egg density is estimated with an empirical function of temperature to match the observed average hard substrate egg density pattern during 1991. The equation for egg density is given below:

$$N\ (eggs) = 0.3 \times (T - 7)^{\wedge 4}$$

where

N (eggs) is the density of eggs in ind/m^2 and
T is the water temperature on that day.

Daily estimated egg, first, second, third, and pupal densities at elevation 6,375 feet (92 g/l salinity) are shown in Figure L-17. Eggs were most abundant in July and August when temperatures were approximately 20°C. The number of eggs hatching each day to become first instars is simply the egg density divided by the development time multiplied by percent hatching success:

$$H\ (eggs) = N\ (eggs)/DT\ (eggs) \times (1 - MF\ (eggs))$$

where

> **H (eggs)** is the number of eggs hatching each day,
> **MF (eggs)** is the mortality fraction, and
> **(1 - MF (eggs))** is the hatching success.

Egg Hatching Success Estimates

The assessment model version at elevation 6,375 feet (92 g/l salinity) indicates that a total of approximately 320,000 eggs/m^2 were hatched during the year assuming 100% hatching success. Egg hatching success is assumed to decrease linearly with salinity from 80% per day at 50 g/l salinity to 60% per day at 150 g/l salinity. At the lowest simulated lake elevation of 6,350 feet (147 g/l salinity), approximately 190,000 eggs/m^2 hatched (59% hatching success). At the highest lake elevation of 6,420 feet (46.5 g/l salinity), approximately 256,000 eggs/m^2 hatched (80% hatching success). The model assumes that adult densities and fecundity are not affected by salinity, so the same empirical egg pattern is used for all lake levels.

Instar Mortality Rate Estimates

Daily first instar density is calculated as the previous day's density plus the hatching eggs minus the first instars that develop into second instars and minus the first instars lost to salinity controlled mortality:

$$\text{N (first instars)}_{i+1} = \text{N (first instars)}_i \times (1 - 1/\text{DT (first instars)}_{i+1} - \text{MF (first instars)}) + \text{H (eggs)}$$

An initial first instar density is obtained from selected field data on April 31. Second, third, and pupal densities are calculated similarly:

$$\text{N (second instars)}_{i+1} = \text{N (second instars)}_i \times (1 - 1/\text{DT (2nd instars)}_{i+1} - \text{MF (second instars)}) + \text{N (first instars)}_i \times (1/\text{DT (first instars)}_{i+1} - \text{MF (first instars)})$$

Mortality data are not available. Mortality was assumed to increase from 1% per day at 50 g/l salinity to 10% per day at 150 g/l salinity for the larval lifestages. Pupal mortality is not affected by salinity and is set at 0% for all salinities. Temperature does not affect mortality rates in the model.

Biomass Estimates

Biomass represents the total weight of the population standing stock at a single point in time. Units are in dry weight of the population per area (milligrams per square meter [mg/m^2]). Daily biomass for each lifestage is estimated as follows:

$$B = N \times MW$$

where

B is the daily biomass of the lifestage,
N is the population density (ind/m^2) of the lifestage, and
MW is the mean weight of the lifestage.

The mean weight was assumed to be 50% of the weight of a fully developed larval lifestage. Pupal weight is assumed constant throughout this lifestage.

No direct measurements of biomass from the 1991 field data exist for calibration of daily modeled biomass. Daily biomass estimates of first, second, third, and pupal lifestages at elevation 6,375 feet (92 g/l salinity) are shown in Figure L-18. The biomasses of first and second instars were negligible compared to the biomasses of third instars and pupae. Third instars peaked in August at 25 mg/m^2, while pupae peaked later in early September at 35 mg/m^2. Monthly and seasonal average biomass of third instars and pupae are calculated for each lake elevation in the range from 6,350 to 6,420 feet elevation and are shown in Figures L-19A and L-19B. At 6,420 feet elevation (46.5 g/l salinity), the total biomass peaked in early September at about 100 grams per square meter (g/m^2) (monthly average of 110 metric tons [MT]/Lake) for third instars and 65 g/m^2 (monthly average of 80 MT/Lake) for pupae. At 6,350 feet elevation (147 g/l salinity), the total biomass peaked in August at about 8 g/m^2 (monthly average of 12 MT/Lake) for third instars and 17 g/m^2 (monthly average of 25 MT/Lake) for pupae. Biomass of both third instars and pupae reached a maximum at elevations between 6,380 and 6,390 feet of about 40 g/m^2 (monthly average of 170 MT/Lake) at the end of August.

Production Estimates

Production is a measure of how much biomass is produced over a given interval. Units are in dry weight of the population per area per interval (mg/m^2 per day [$mg/m^2/day$]). Production at each lifestage is estimated as the product of the mean weight of the fully developed lifestage and the development rate of that lifestage. The useable production is estimated from third instar production. Daily production of fully developed third instars is calculated using the following equation:

$$P\ (\text{third instars}) = N\ (\text{third instars})/DT\ (\text{third instars}) \times MFW\ (\text{third instars})$$

where

MFW is the mean full weight.

Daily third instar productivity estimates at a lake level of 6,375 (92 g/l salinity) are graphed in Figure L-20 and show daily productivity peaking at 4 $mg/m_2/day$ at the end of August. At 6,350 feet elevation, peak daily productivity is less than 2 $mg/m_2/day$, while at 6,420 feet elevation, peak daily productivity reaches 9 $mg/m_2/day$.

The assessment model further calculates the seasonal total production for each lake level by summarizing daily production values (units are in mg/m^2). Lakewide monthly and seasonal production of third instars (MT/lake/month) are estimated by multiplying the hard substrate production per square meter by the effective habitat area for the range of lake elevations from 6,350 to 6,420 feet (Figure L-21). At low elevations, both high salinity and reduced habitat area cause a minimum seasonal production. At the highest simulated salinity (6,350 feet elevation) the seasonal production was only 150 MT/Lake (47.5 mg/m^2 dry weight) with 49% occurring in August and 19% in September. At intermediate lake elevations of 6,380 to 6,390 feet, the lakewide simulated seasonal production is maximum at approximately 1,350 MT/lake. At higher lake elevations, salinity impacts are reduced, but the effective habitat area is decreased. The total seasonal production at the lowest simulated salinity of 46.5 g/l (6,420 feet elevation) was approximately 710 MT/Lake (227 $mg/m^{2)}$. Most production occurred in August (41%) and September (29%). The majority of production occurs in August for all lake elevations.

The model estimates the proportion of third instar population that remains attached to the substrate as pupae and the fraction that is lost from the substrate to become open water drift or is windrowed ashore. The model specifies separate loss fractions for hard substrate (10%) and soft substrate (90%). The loss fraction increases as the fraction of hard substrate to total substrate decreases. The estimated loss fraction is 60% at 6,350 and 6,420 feet elevation, where the hard substrate constitutes 40% of the total habitat. The estimated loss is 44% at elevation 6,380 feet, where the hard substrate is 58% of the total effective substrate area. Figure L-20 shows the daily production (MT/lake/day) of pupae lost to drift or windrows at elevation 6,375 feet (92 g/l salinity), and Figure L-22 shows the cumulative seasonal production (MT/lake). Cumulative seasonal drift production reaches a maximum of 630 MT/lake at elevations between 6,380 and 6,390 feet. By far, most of these dislodged third instars and pupae are blown ashore as windrows. Some unknown fraction of the generated drift becomes available to the water birds. The open water drift data collected in 1991 by Herbst was used for confirmation of model results.

Primary Productivity Estimates

The benthic algae primary production required for the predicted alkali fly secondary production has not yet been investigated. However, the grazing pressure exerted on benthic algae by alkali fly larvae was estimated by the following equation:

$$GP = P\,(\text{third})/GF$$

where

GP is the daily algal grazing by third instars in $g/m^2/day$ and

GF is the grazing efficiency factor, which for the assessment model is set at 0.2, but which for many ecological systems are as low as 0.1

Although food availability probably influences alkali fly development rates and mean weights, no attempt was made in the model to correlate these. The estimated grazing rate approaches 45 $g/m^2/day$ (dry weight) in the end of August at an elevation of 6,420 feet, a value that is near the upper range of possible aquatic primary production rates.

MODEL CALIBRATION

The 1991 Herbst field data (Herbst 1992) (6,375 feet elevation, 92 g/l salinity) were used to calibrate the daily density patterns for each lifestage. The user can select geometric mean densities from six different sites or an average of all sites and may further choose between soft or hard substrate. The assessment model uses the mean geometric density of all sites on hard substrate. The selected density data were graphed and compared to daily simulated density patterns and minimum and maximum densities of all sites.

The empirical egg density pattern is shown with the observed egg densities in Figure L-23. Figure L-24 shows the simulated first instar density at the 6,375 feet elevation (95 g/l salinity) that occurred in 1991 when the Herbst field data were collected. Both simulated and observed density peaked at 13,000 ind/m^2 during August. Figure L-25 shows the simulated second instar density. Simulated and observed densities reached 15,000 ind/m^2 in August. However, the simulated second instar densities decreased in September and October while the observed second instar density continued to increase dramatically to 35,000 ind/m^2 by October. The reason for these persistent second instars is unknown, and the assessment model cannot simulate this feature of the alkali fly population dynamics.

Figure L-26 shows the simulated and observed third instar densities. Both peaked at approximately 24,000 ind/m^2 in early September. Figure L-27 shows the simulated and observed pupal densities, both of which reached a maximum of 17,000 ind/m^2. The model assumes that all pupae remain attached, so the model densities should be higher than the observed densities. The estimated development time for pupae was increased to equal the third instar development time (30 days at 20°C) to match the observed densities. However, the higher-than-predicted pupal densities might have been due to third instars immigrating from the surrounding soft substrate onto the hard substrate. These discrepancies cannot be resolved with existing information.

The open water drift data (third instars and pupae) collected in 1991 by Herbst were used to obtain reasonable estimates of daily generated drift. Jones & Stokes Associates drift estimates were converted from drift produced per square meter of effective habitat to drift produced per square meter of lake area by multiplying the values with the effective habitat area and dividing with the lake area. Figure L-28 shows modeled drift densities at elevation 6,375 feet (1991 lake level) compared to the arithmetic mean of the drift data. Units are in ind/m^2 and are calculated based on the entire lake. The simulated drift values are approximately tenfold greater than the mean observed drift densities but follow the same seasonal pattern, peaking at about 15 ind/m^2 in the end of August. The observed pattern of drift data generally confirms the seasonal pattern of third instar production.

Assuming that dislodged larvae and pupae endure in the open water for several days would increase the calculated drift values by several fold. However, most of the generated drift is washed ashore rather than swept into the open lake, and some fraction sinks and decays. These unknown daily losses are not incorporated into the model and would greatly reduce the simulated values. The assessment model appears to give a reasonable estimate of drift generation rates if drift persistence and losses are considered and the calibration is considered adequate for alkali fly impact assessment purposes.

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Table L-1. Mono Lake Bathymetry and Effective Alkali Fly Habitat

USGS Mono Lake Elevation (ft)	Smoothed Pelagos Volume (af)	Salinity Assuming 285 MT Total (g/l)	Smoothed Pelagos Area (acres)	Smoothed Pelagos Increment Area (acres)	Jones & Stokes Associates Hard Substrate Area (acres)	Depth-Weighted Hard Area (acres)	Depth-Weighted Soft Area (acres)	Total Weighted Habitat Area (acres)	Hard/Total Substrate Area (%)
6,350	1,429,659	146.6	29,650	259	16.57	173	4,395	410	42
6,351	1,459,436	143.6	29,904	254	17.46	177	4,364	413	43
6,352	1,489,467	140.7	30,158	253	17.46	182	4,334	417	44
6,353	1,519,750	137.9	30,409	251	17.46	186	4,304	419	44
6,354	1,550,286	135.2	30,662	253	17.46	189	4,277	422	45
6,355	1,581,077	132.6	30,920	258	17.46	192	4,257	424	45
6,356	1,612,128	130.0	31,182	262	20.56	198	4,238	430	46
6,357	1,643,443	127.5	31,449	267	20.56	204	4,224	435	47
6,358	1,675,028	125.1	31,720	271	20.56	209	4,216	441	47
6,359	1,706,886	122.8	31,998	279	20.56	214	4,215	446	48
6,360	1,739,027	120.5	32,283	285	20.56	218	4,221	451	48
6,361	1,771,456	118.3	32,575	292	20.28	222	4,233	456	49
6,362	1,804,180	116.2	32,873	298	20.28	226	4,251	461	49
6,363	1,837,207	114.1	33,182	309	20.28	229	4,279	466	49
6,364	1,870,557	112.0	33,517	336	20.28	232	4,333	472	49
6,365	1,904,250	110.1	33,869	352	20.28	235	4,400	478	49
6,366	1,938,297	108.1	34,224	355	25.96	243	4,464	490	50
6,367	1,972,705	106.2	34,593	369	25.96	250	4,539	502	50
6,368	2,007,537	104.4	35,070	477	25.96	257	4,719	519	50
6,369	2,042,882	102.6	35,619	549	25.96	264	4,966	538	49
6,370	2,078,825	100.8	36,266	647	25.96	269	5,302	562	48
6,371	2,115,443	99.1	36,970	704	78.56	328	5,633	642	51
6,372	2,152,772	97.4	37,688	717	78.56	382	5,966	718	53
6,373	2,190,820	95.7	38,409	721	78.56	432	6,291	789	55
6,374	2,229,588	94.0	39,127	718	78.56	478	6,603	856	56
6,375	2,269,109	92.4	39,915	789	78.56	520	6,974	921	56
6,376	2,309,428	90.8	40,724	809	76.52	558	7,353	981	57
6,377	2,350,556	89.2	41,531	807	76.52	593	7,716	1038	57
6,378	2,392,484	87.6	42,325	794	76.52	625	8,052	1090	57
6,379	2,435,153	86.1	43,012	687	76.52	655	8,267	1134	58
6,380	2,478,494	84.6	43,670	658	76.52	683	8,443	1173	58
6,381	2,522,457	83.1	44,256	585	45.94	678	8,566	1174	58
6,382	2,566,976	81.6	44,783	527	45.94	673	8,623	1172	57
6,383	2,612,015	80.2	45,295	512	45.94	669	8,656	1169	57
6,384	2,657,562	78.9	45,799	505	45.94	665	8,675	1166	57
6,385	2,703,617	77.5	46,310	511	45.94	662	8,693	1163	57
6,386	2,750,139	76.2	46,734	424	18.78	631	8,644	1127	56
6,387	2,797,062	74.9	47,112	378	18.78	603	8,544	1091	55
6,388	2,844,364	73.7	47,492	380	18.78	577	8,442	1057	55
6,389	2,892,042	72.5	47,865	373	18.78	552	8,330	1024	54
6,390	2,940,097	71.3	48,245	379	18.78	529	8,220	993	53
6,391	2,988,512	70.1	48,584	339	10.60	500	8,076	954	52
6,392	3,037,250	69.0	48,893	309	10.60	473	7,898	915	52
6,393	3,086,294	67.9	49,194	301	10.60	447	7,712	878	51
6,394	3,135,637	66.8	49,491	297	10.60	424	7,521	842	50
6,395	3,185,280	65.8	49,796	304	10.60	402	7,337	809	50
6,396	3,235,225	64.8	50,093	297	12.88	384	7,144	780	49
6,397	3,285,459	63.8	50,375	282	12.88	368	6,936	751	49
6,398	3,335,976	62.8	50,660	284	12.88	352	6,733	724	49
6,399	3,386,771	61.9	50,930	270	12.88	338	6,517	697	48
6,400	3,437,838	61.0	51,204	274	12.88	324	6,308	672	48
6,401	3,489,175	60.1	51,469	265	11.84	310	6,096	646	48
6,402	3,540,769	59.2	51,720	252	11.84	297	5,880	621	48
6,403	3,592,613	58.3	51,967	246	11.84	286	5,670	598	48
6,404	3,644,700	57.5	52,208	241	11.84	270	5,468	571	47
6,405	3,697,030	56.7	52,451	243	11.84	256	5,279	545	47
6,406	3,749,598	55.9	52,685	235	9.10	240	5,098	519	46
6,407	3,802,392	55.1	52,904	218	9.10	225	4,914	493	46
6,408	3,855,403	54.4	53,117	214	9.10	211	4,741	469	45
6,409	3,908,624	53.6	53,326	208	9.10	199	4,579	447	44
6,410	3,962,054	52.9	53,534	209	9.10	187	4,434	427	44
6,411	4,015,692	52.2	53,741	207	9.06	176	4,304	409	43
6,412	4,069,532	51.5	53,939	197	9.06	166	4,176	391	42
6,413	4,123,568	50.8	54,134	196	9.06	157	4,059	375	42
6,414	4,177,799	50.2	54,327	193	9.06	150	3,951	363	41
6,415	4,232,226	49.5	54,527	200	9.06	145	3,859	352	41
6,416	4,286,854	48.9	54,730	203	7.22	138	3,780	340	40
6,417	4,341,681	48.3	54,924	194	7.22	131	3,701	329	40
6,418	4,396,703	47.7	55,120	196	7.22	125	3,632	319	39
6,419	4,451,922	47.1	55,318	199	7.22	122	3,573	312	39
6,420	4,507,348	46.5	55,534	215	7.22	118	3,535	307	39

Table L-2. Salinity- and Temperature-Dependent Lifestage Parameters

Lifestage Parameter	Development Time					Mean Dry Weight of Fully Developed Lifestages				Mortality Rate				
	Eggs (days)	First Instars (days)	Second Instars (days)	Third Instars (days)	Pupae (days)	First Instars (mg)	Second Instars (mg)	Third Instars (mg)	Pupae (mg)	Eggs (%)	First Instars (%)	Second Instars (%)	Third Instars (%)	Pupae (%)
Salinity (g/l)[a]														
40	3.0	3.5	6.2	9.0	13.1	0.027	0.27	3.45	2.00	19	0	0	0	0
50	3.0	3.6	6.3	10.0	13.1	0.026	0.26	3.29	2.00	20	1	1	1	0
60	3.0	3.7	6.4	11.0	13.1	0.025	0.25	3.13	2.00	21	2	2	2	0
70	3.0	3.8	6.6	12.0	13.1	0.024	0.24	2.97	2.00	22	3	3	3	0
80	3.0	3.8	6.7	13.0	13.1	0.022	0.22	2.82	2.00	24	3	3	3	0
90	3.0	3.9	6.9	14.0	13.1	0.021	0.21	2.66	2.00	25	4	4	4	0
100	3.0	4.0	7.0	15.0	13.1	0.020	0.20	2.50	2.00	26	5	5	5	0
110	3.0	4.1	7.2	16.0	13.1	0.019	0.19	2.43	2.00	29	6	6	6	0
120	3.0	4.3	7.5	17.0	13.1	0.019	0.19	2.36	2.00	32	7	7	7	0
130	3.0	4.4	7.7	18.0	13.1	0.018	0.18	2.30	2.00	36	8	8	8	0
140	3.0	4.6	8.0	19.0	13.1	0.018	0.18	2.23	2.00	39	9	9	9	0
150	3.0	4.7	8.2	20.0	13.1	0.017	0.17	2.16	2.00	42	10	10	10	0
Lookup1	3.0	3.8	6.6	12.0	13.1	0.024	0.24	2.97	2.00	22	3	3	3	0
Lookup2	3.0	3.8	6.7	13.0	13.1	0.022	0.22	2.82	2.00	24	3	3	3	0
77.5	3.0	3.8	6.7	12.8	13.1	0.023	0.23	2.86	2.00	23	3	3	3	0
Correction factor	1.00	1.06	1.06	1.25	1.00	0.85	0.85	0.84	1.00	1.17	1.92	1.92	1.92	1.00
Temperature (°C)[b]														
10	21.8	30.0	51.9	109.2	109.2									
15	5.8	7.9	13.7	28.8	28.8									
20	3.0	4.1	7.0	14.8	14.8									
25	2.0	2.7	4.7	9.9	9.9									
C1	0.4	0.55	0.95	2	2									
C2	40	40	40	40	40									

[a] Assumes a constant temperature of 20°C.

[b] Assumes a constant salinity of 100 g/l.

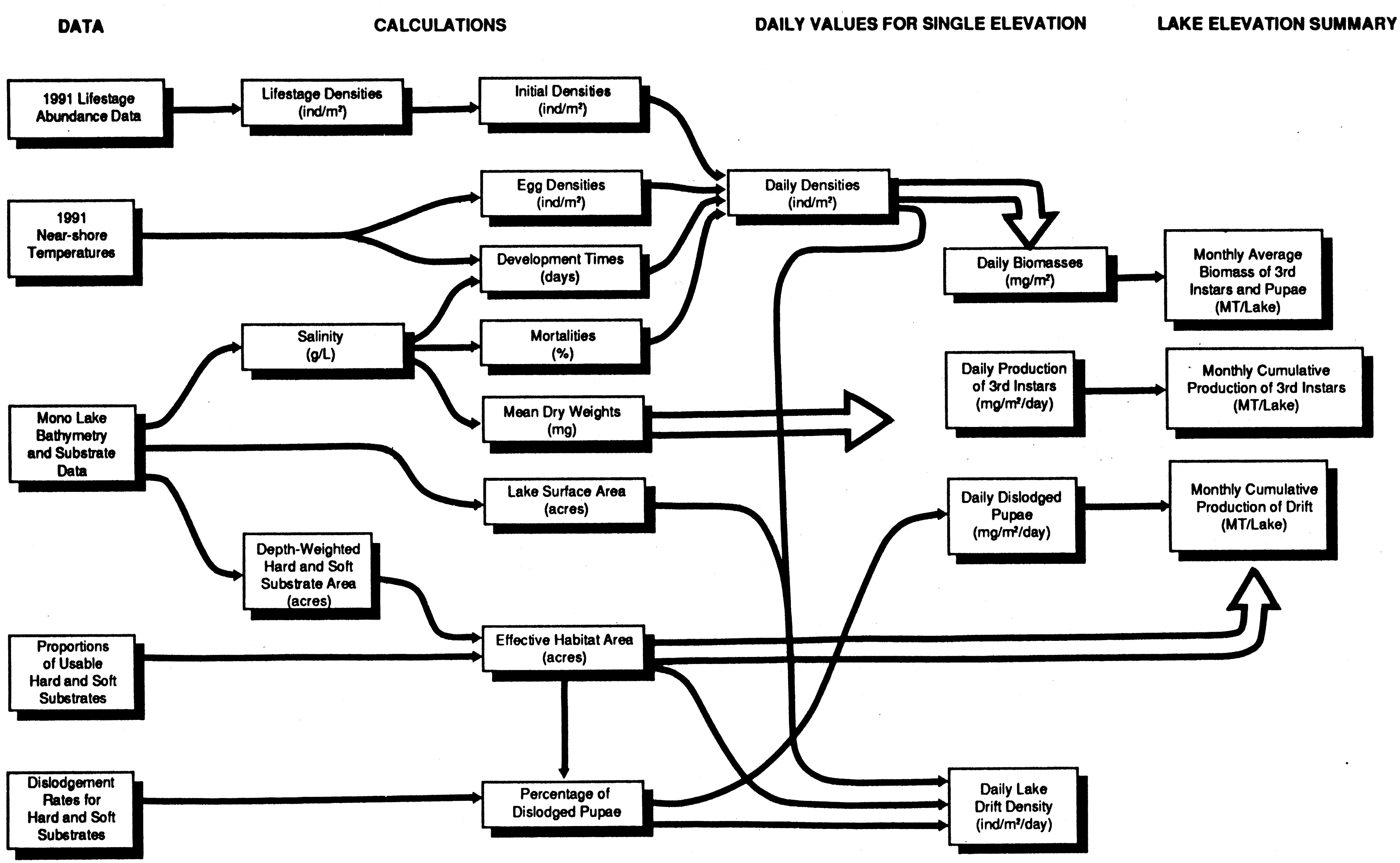


Figure L-1.
Schematic of Alkali Fly Productivity Model

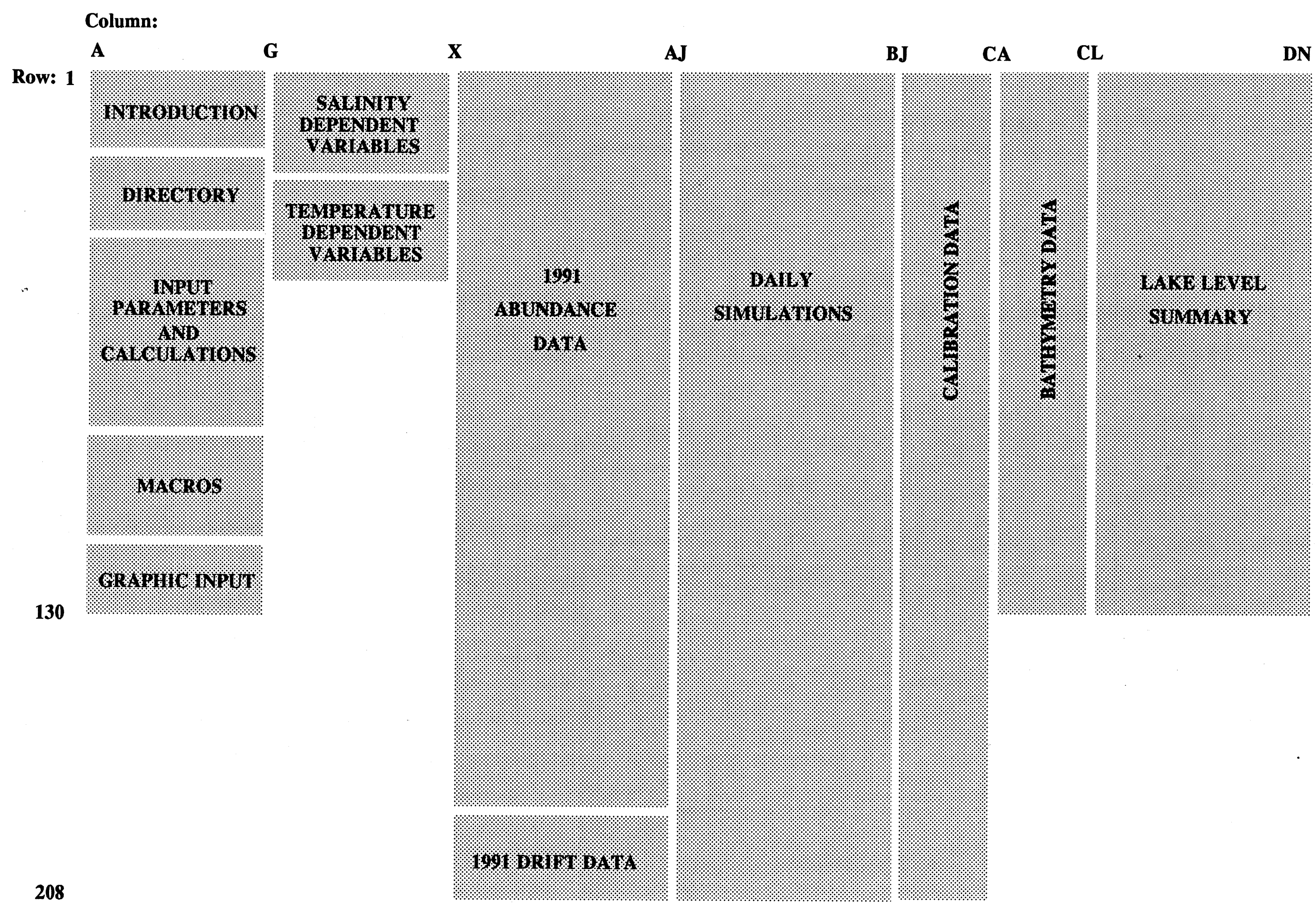
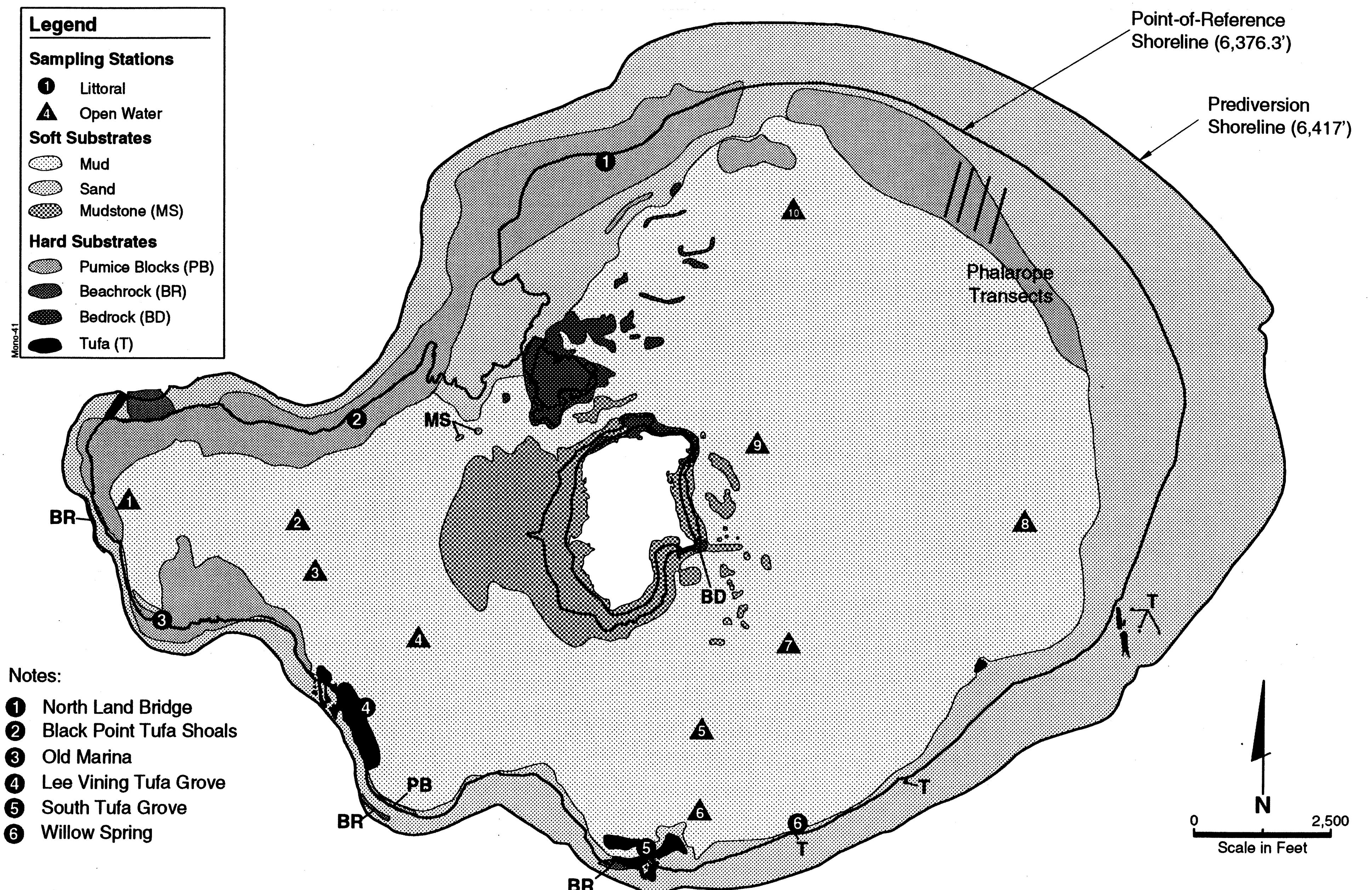


Figure L-2.
Organization of the Alkali Fly Productivity Model



Source of Substrates: Stine 1990

Figure L-3.
Substrates at Mono Lake and 1991 Littoral and Open Water Sampling Locations

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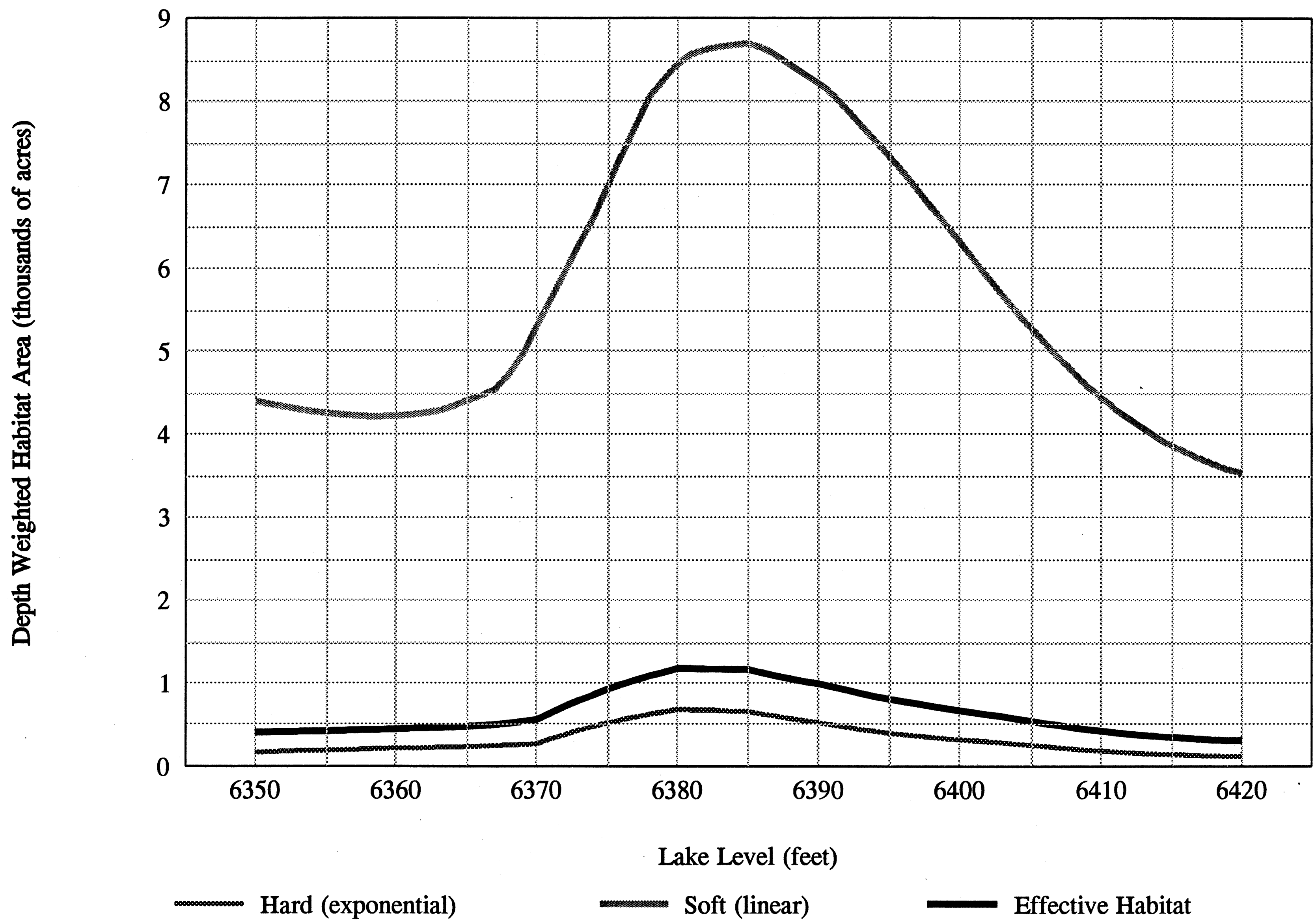


Figure L-4.
Effective Alkali Fly Habitat Area as a Function of Lake Level
Effective Habitat is 110% of Hard Substrate plus 5% of Soft Substrate

MONO BASIN EIR
Prepared by Jones & Stokes Associates

Figure L-5a.
Seasonal 1991 Mean Densities of Alkali Fly Lifestages on Hard Substrate
Site 1 (North Land Bridge)

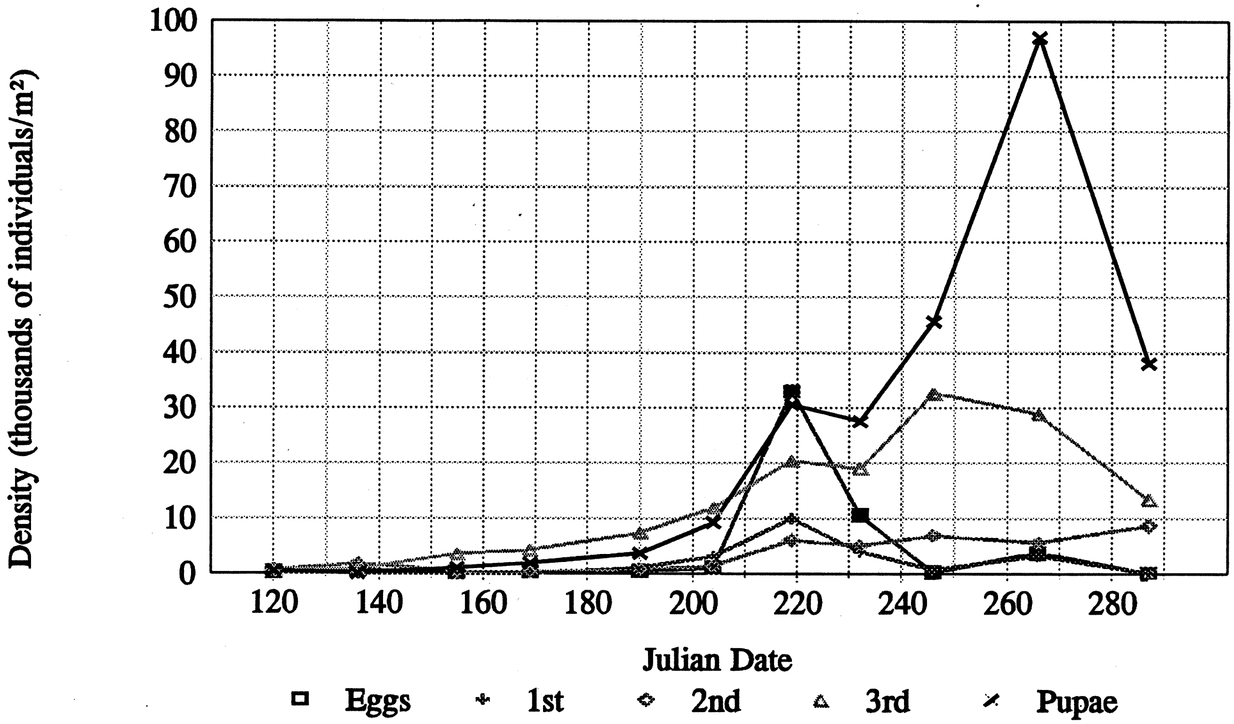


Figure L-5b.
Seasonal 1991 Mean Densities of Alkali Fly Lifestages on Soft Substrate
Site 1 (North Land Bridge)

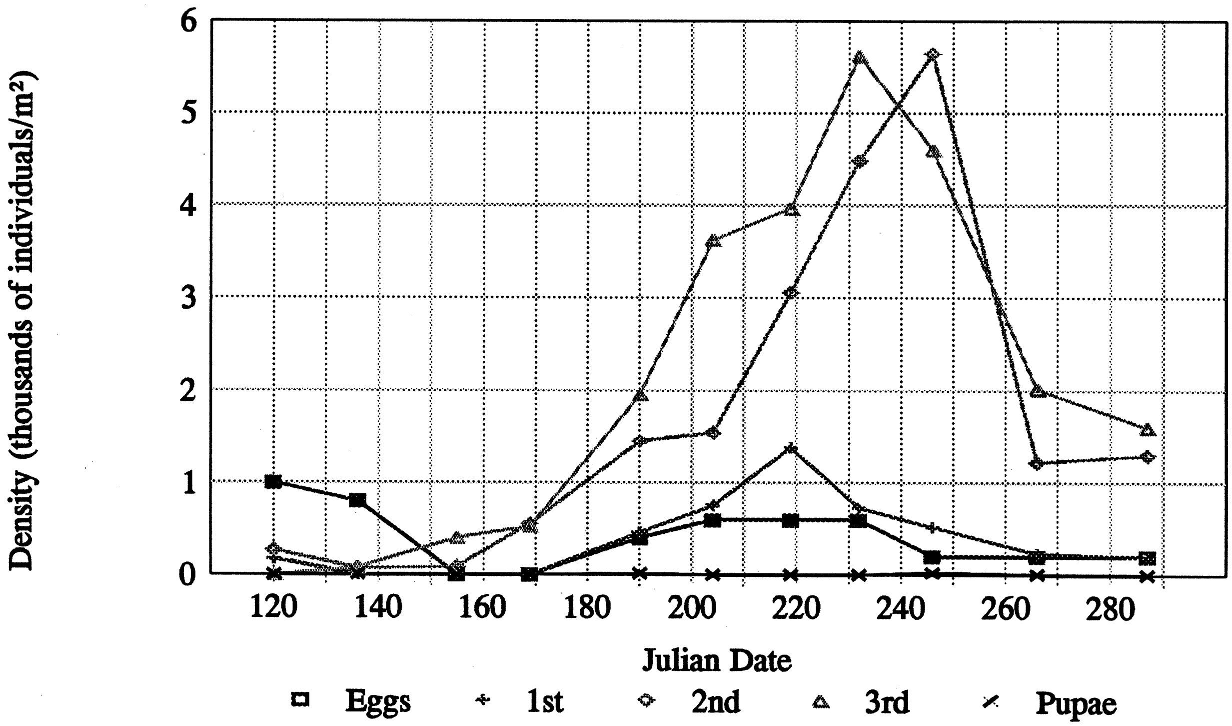


Figure L-6a.
Seasonal 1991 Mean Densities of Alkali Fly Lifestages on Hard Substrate
Site 2 (Black Point)

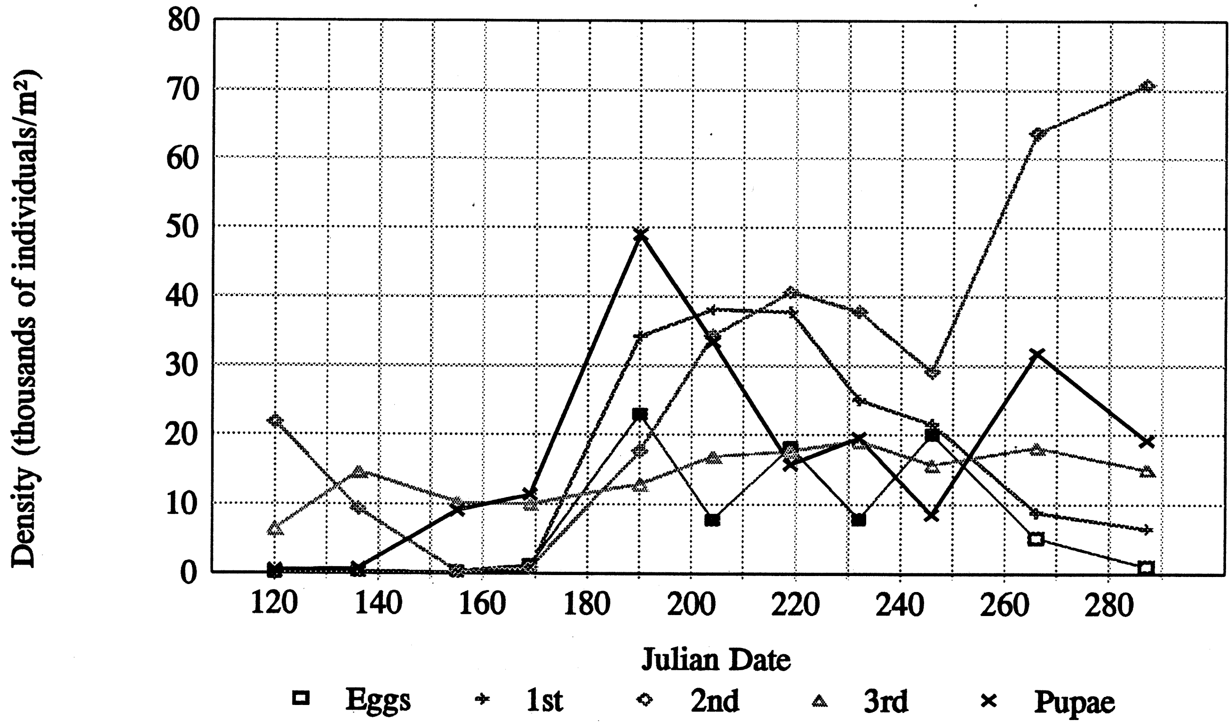


Figure L-6b.
Seasonal 1991 Mean Densities of Alkali Fly Lifestages on Soft Substrate
Site 2 (Black Point)

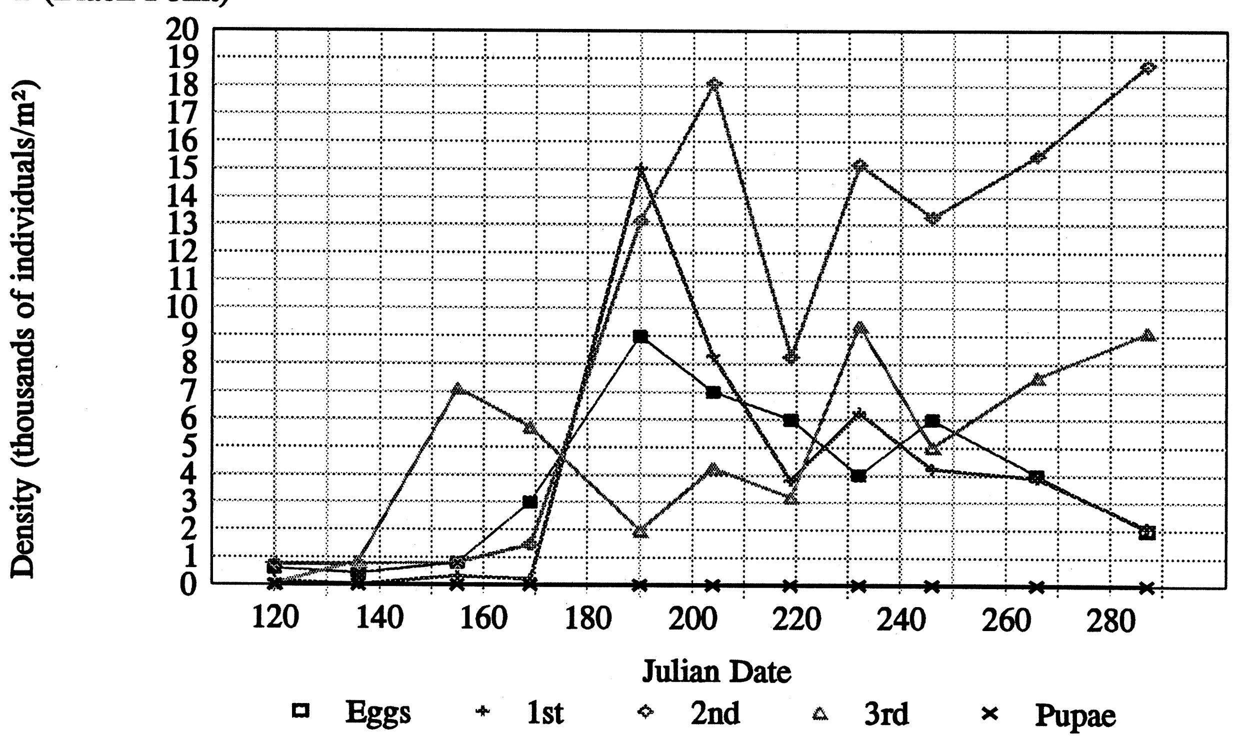


Figure L-7a.
Seasonal 1991 Mean Densities of Alkali Fly Lifestages on Hard Substrate
Site 3 (Old Marina)

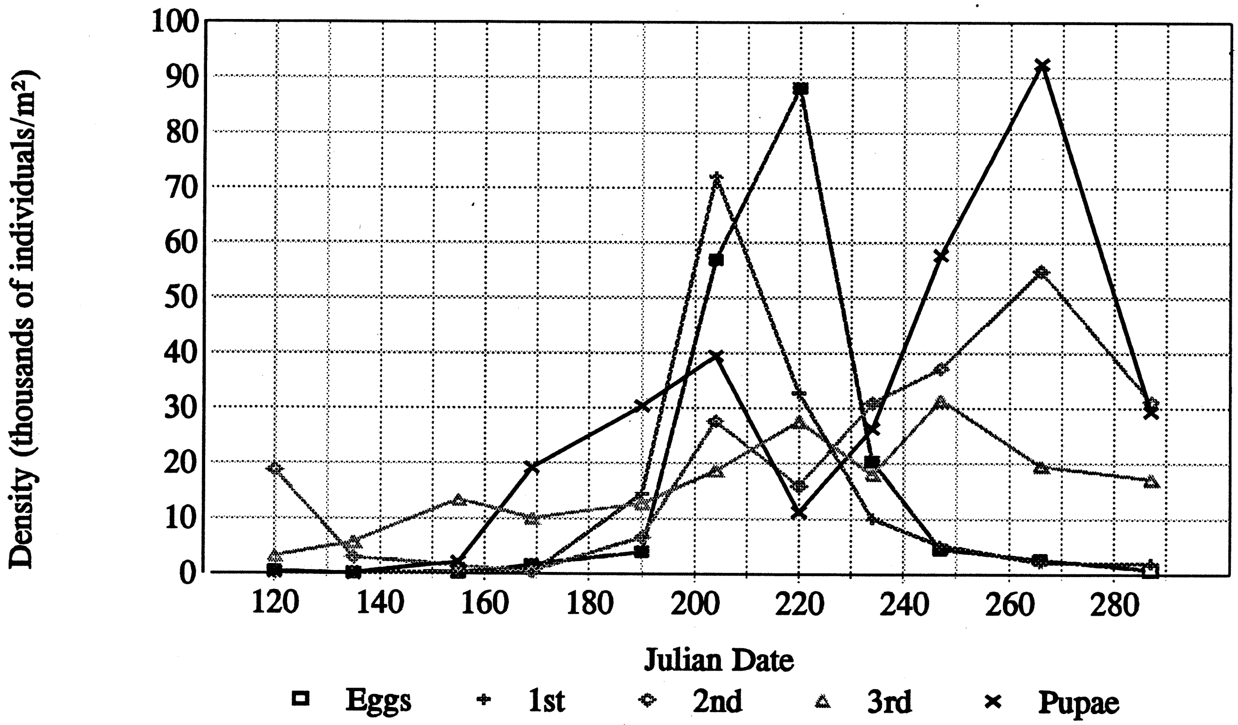


Figure L-7b.
Seasonal 1991 Mean Densities of Alkali Fly Lifestages on Soft Substrate
Site 3 (Old Marina)

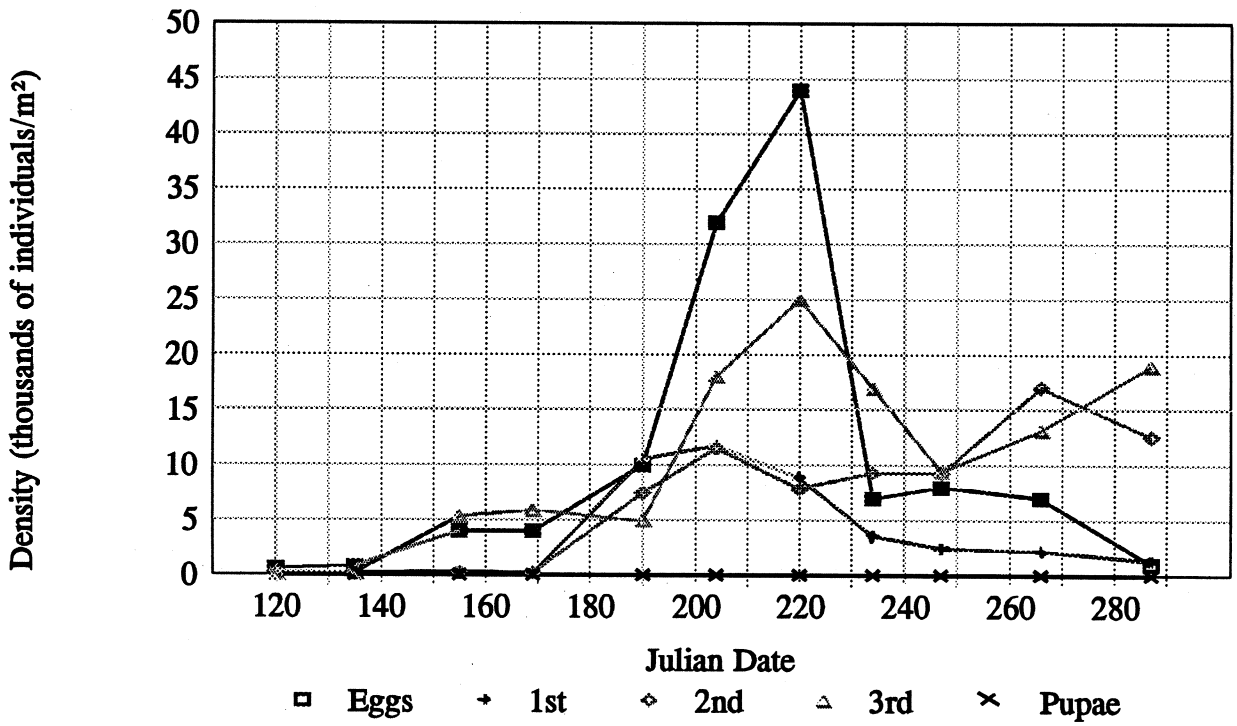


Figure L-8a.
Seasonal 1991 Mean Densities of Alkali Fly Lifestages on Hard Substrate
Site 4 (Lee Vining Tufa Grove)

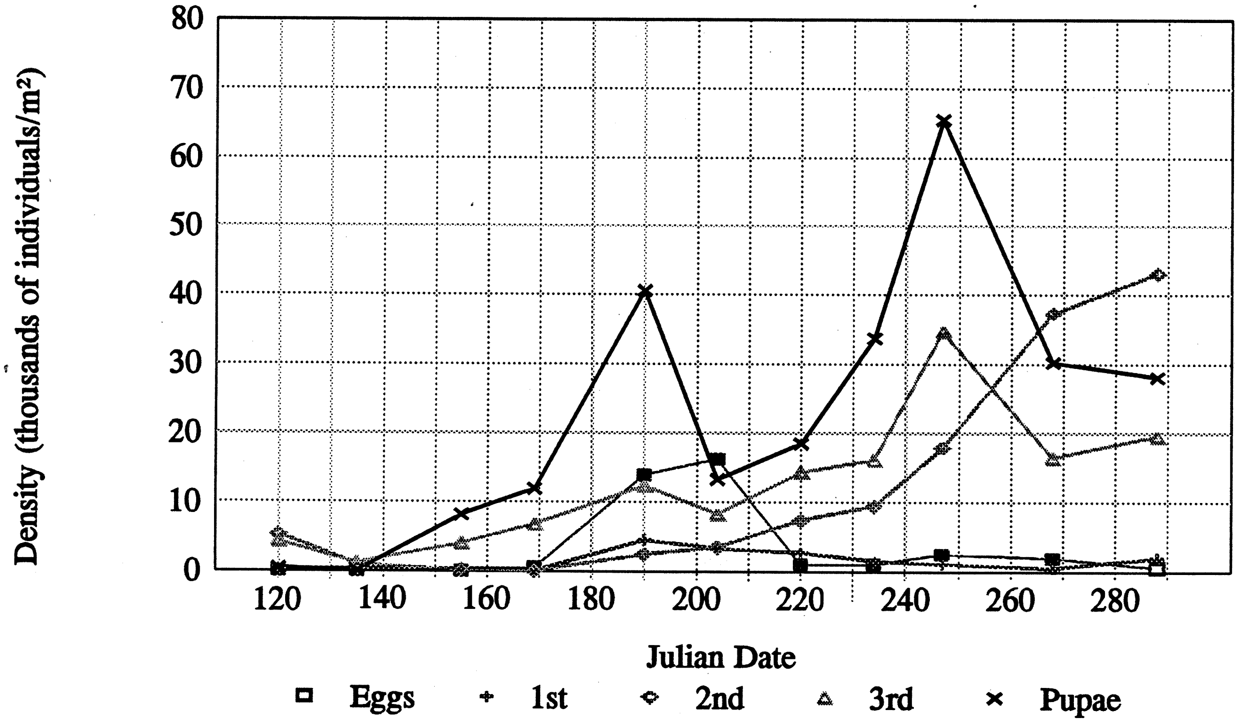


Figure L-8b.
Seasonal 1991 Mean Densities of Alkali Fly Lifestages on Soft Substrate
Site 4 (Lee Vining Tufa Grove)

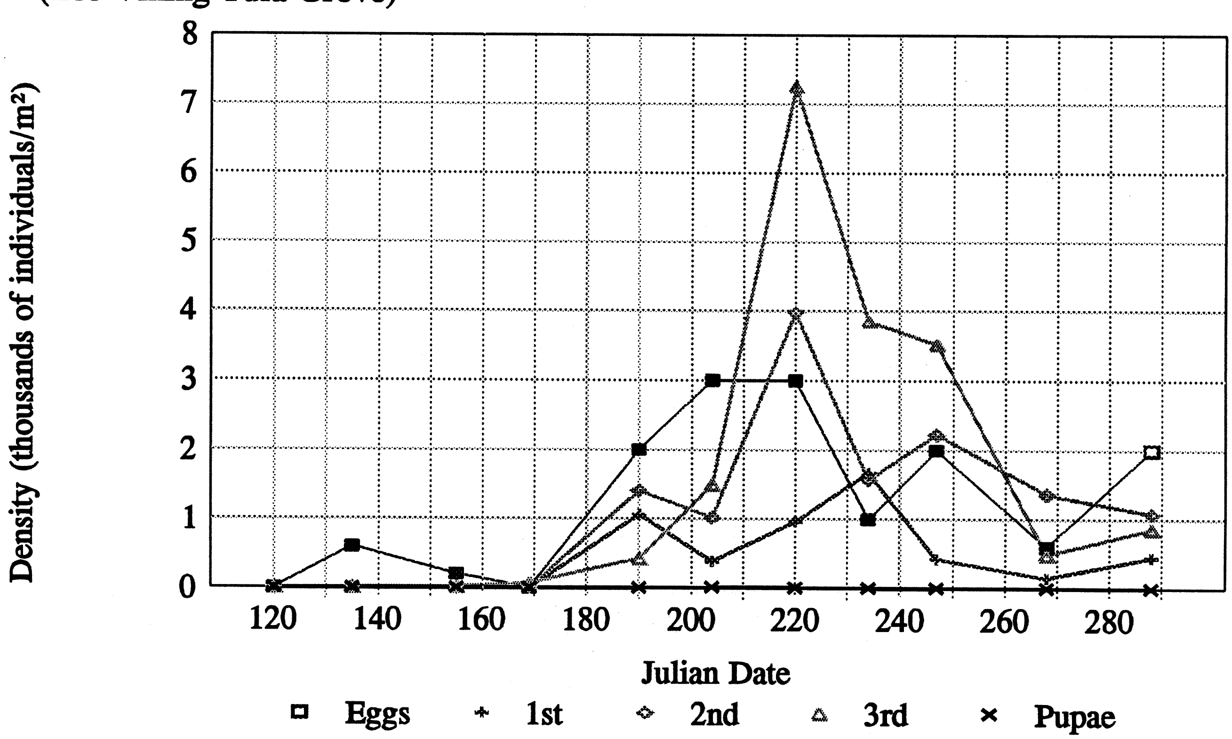


Figure L-9a.
Seasonal 1991 Mean Densities of Alkali Fly Lifestages on Hard Substrate
Site 5 (South Tufa Grove)

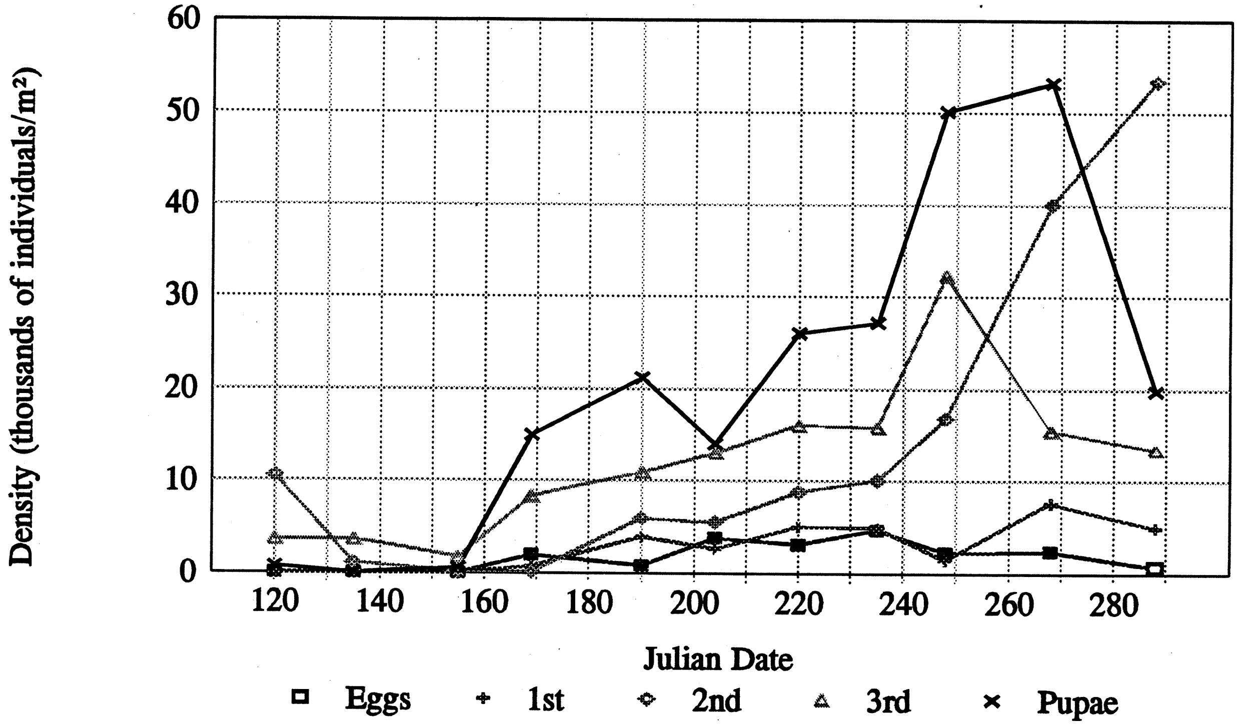


Figure L-9b.
Seasonal 1991 Mean Densities of Alkali Fly Lifestages on Soft Substrate
Site 5 (South Tufa Grove)

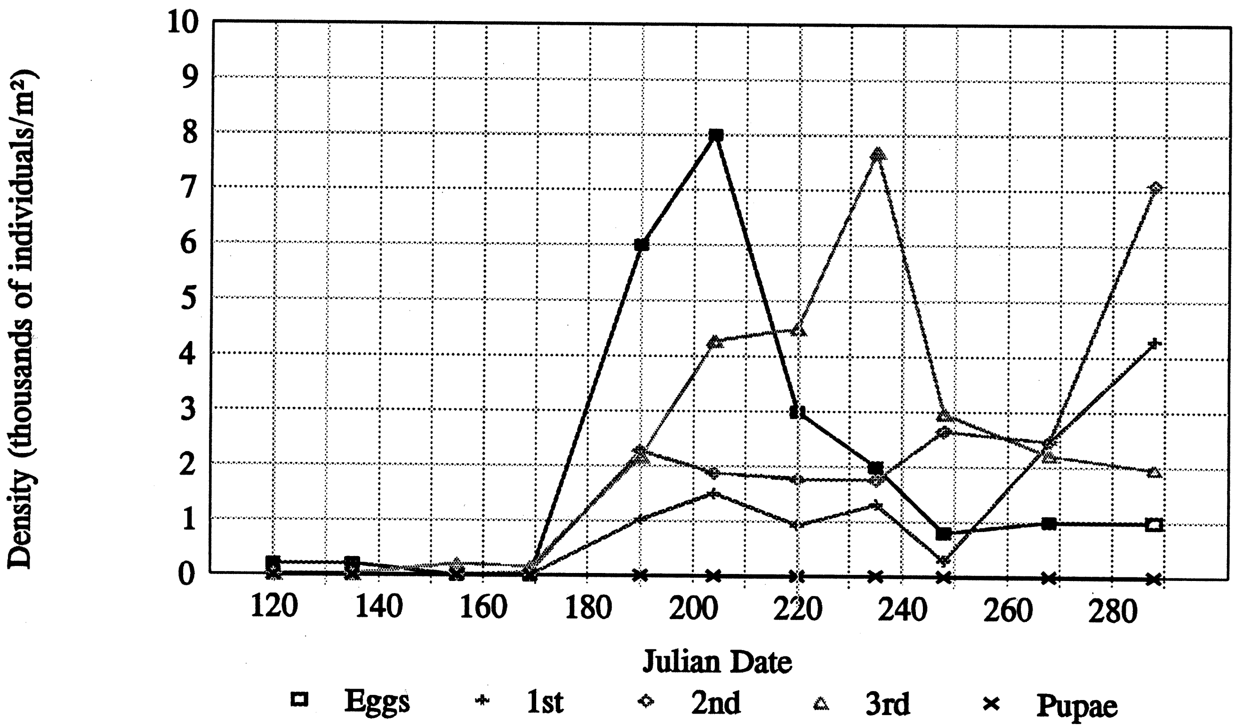


Figure L-10a.
Seasonal 1991 Mean Densities of Alkali Fly Lifestages on Hard Substrate
Site 6 (Willow Spring)

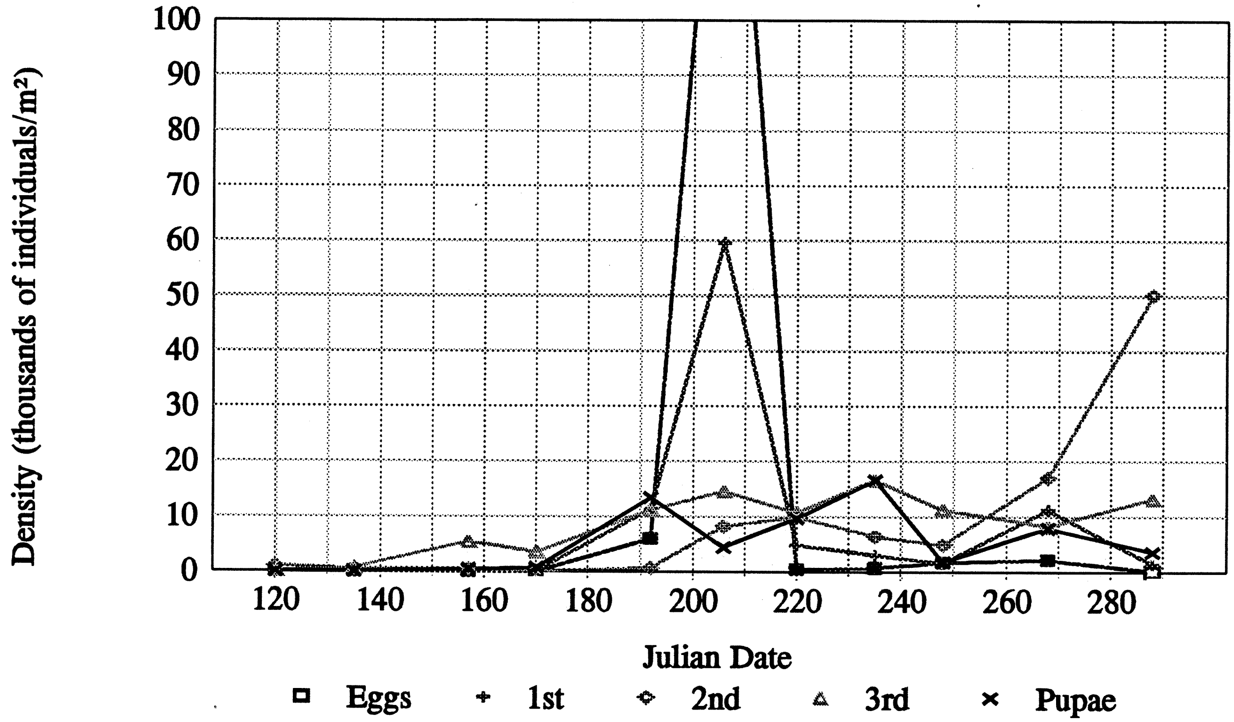


Figure L-10b.
Seasonal 1991 Mean Densities of Alkali Fly Lifestages on Soft Substrate
Site 6 (Willow Spring)

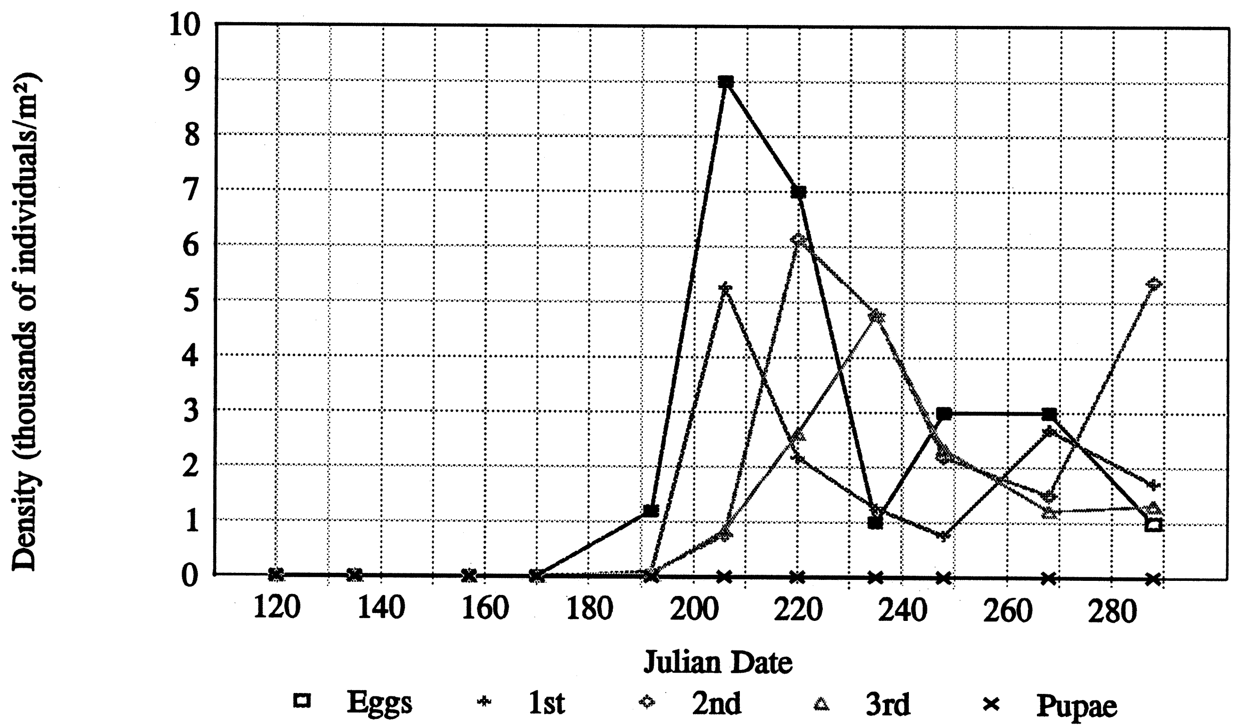


Figure L-11a.
Seasonal 1991 Mean Densities of Alkali Fly Lifestages on Hard Substrate
Average of All Sites

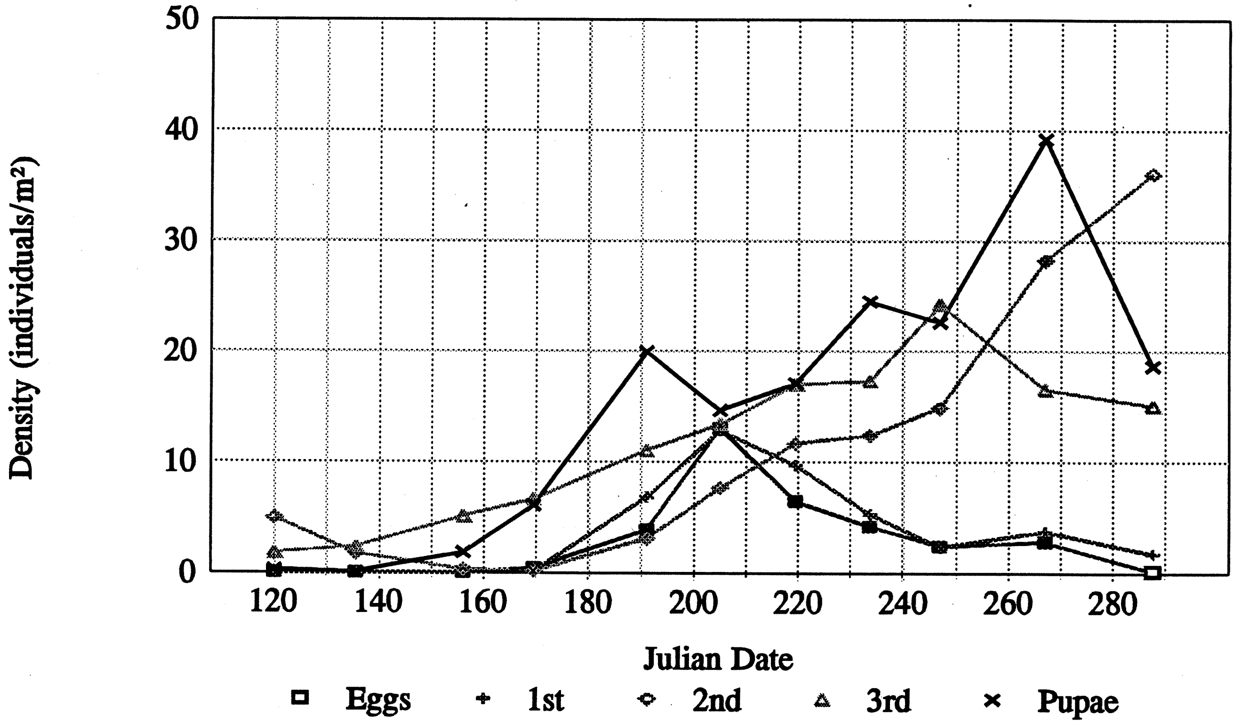


Figure L-11b.
Seasonal 1991 Mean Densities of Alkali Fly Lifestages on Soft Substrate
Average of All Sites

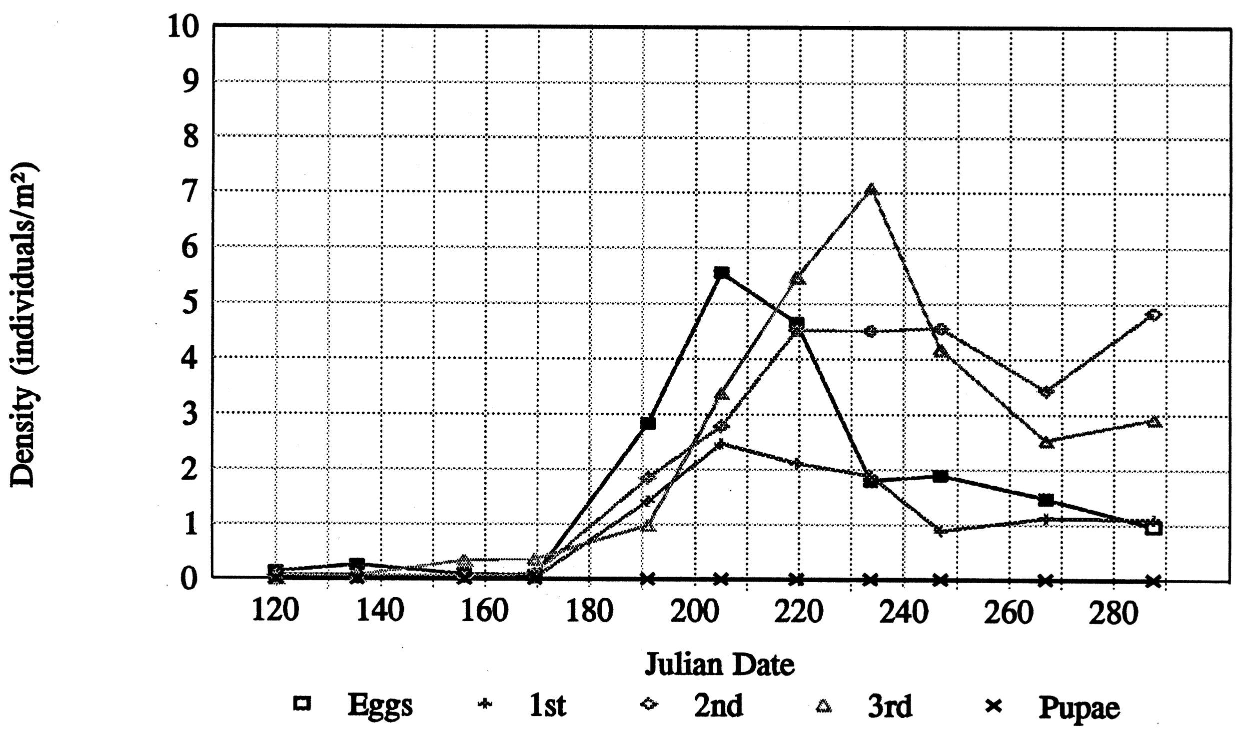


Figure L-12.
Seasonal 1991 Distribution of Alkali Fly Lifestages in Open Water Drift

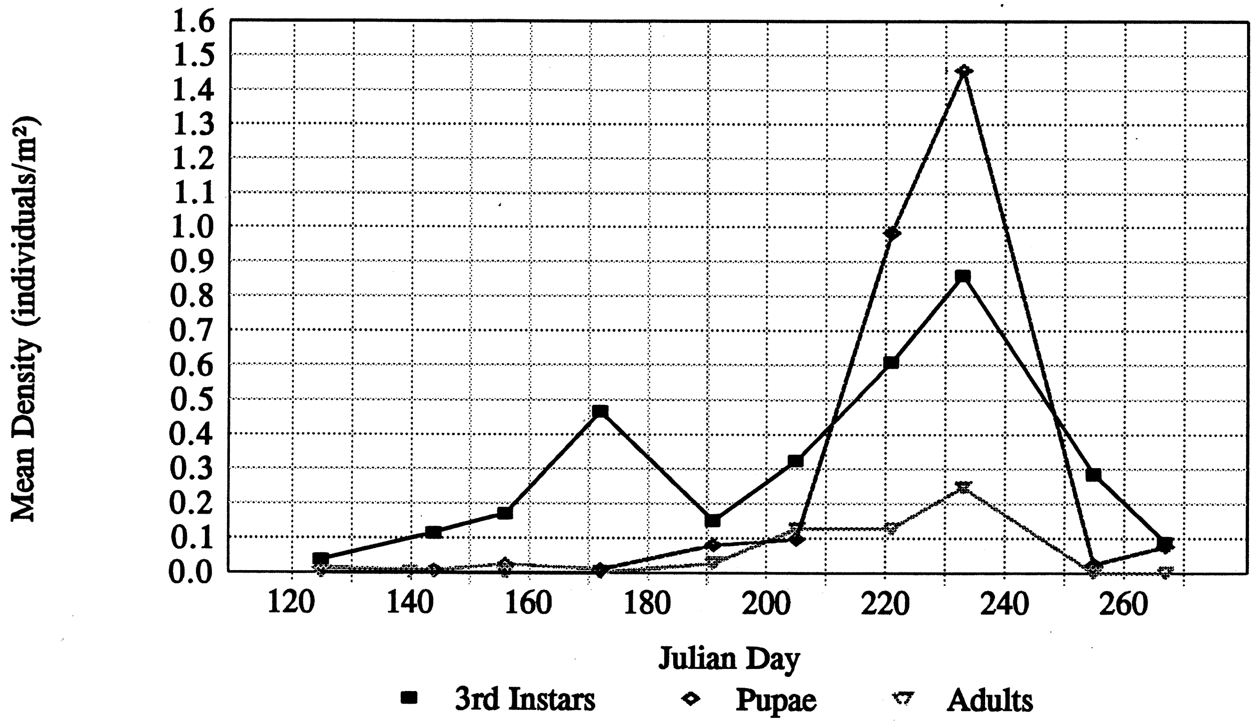


Figure L-13.
Seasonal 1991 Densities of Alkali Fly Larvae and Pupae in Open Water Drift

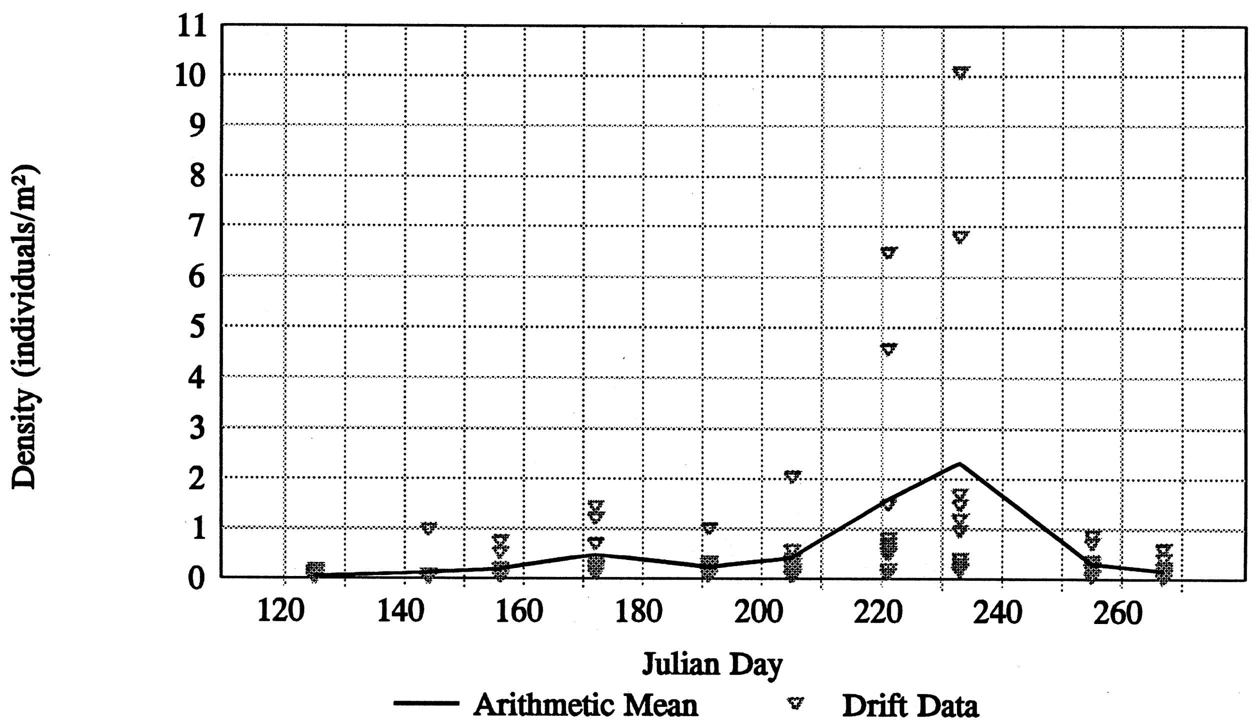


Figure L-14.
Development Time of Aquatic Alkali Fly Lifestages Modeled as a Function of Temperature
Salinity Held Constant at 100 g/L

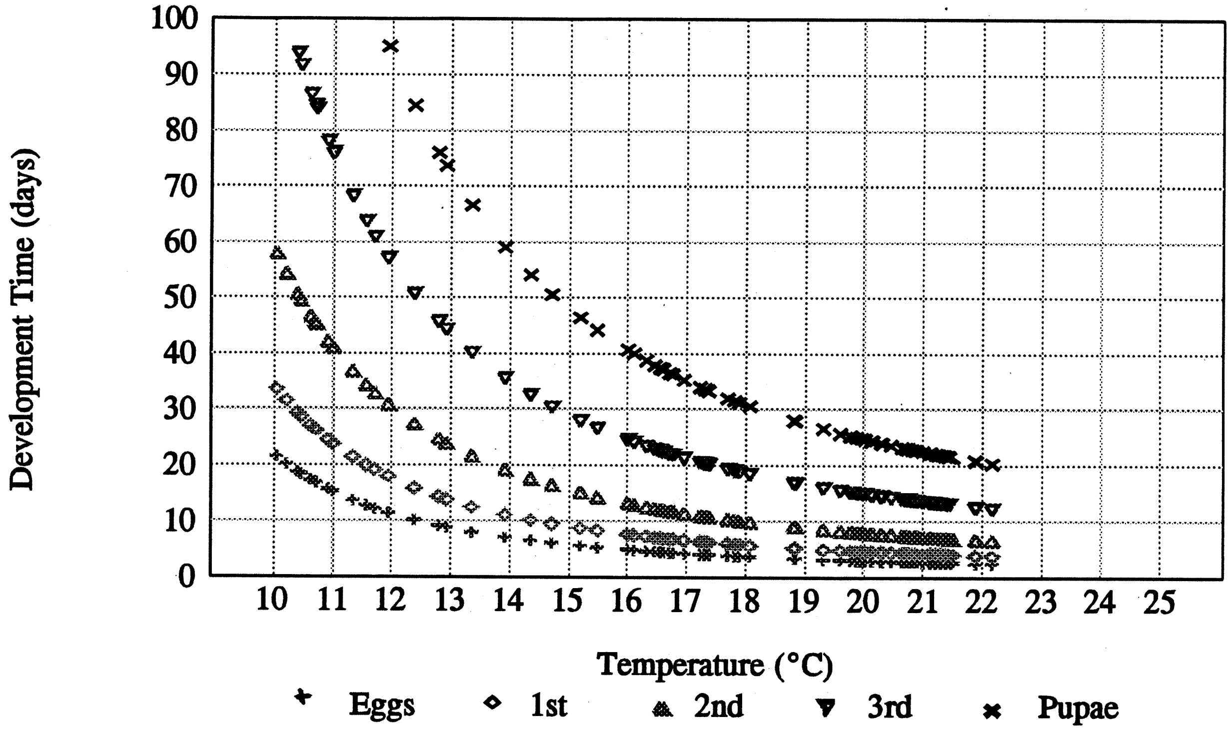
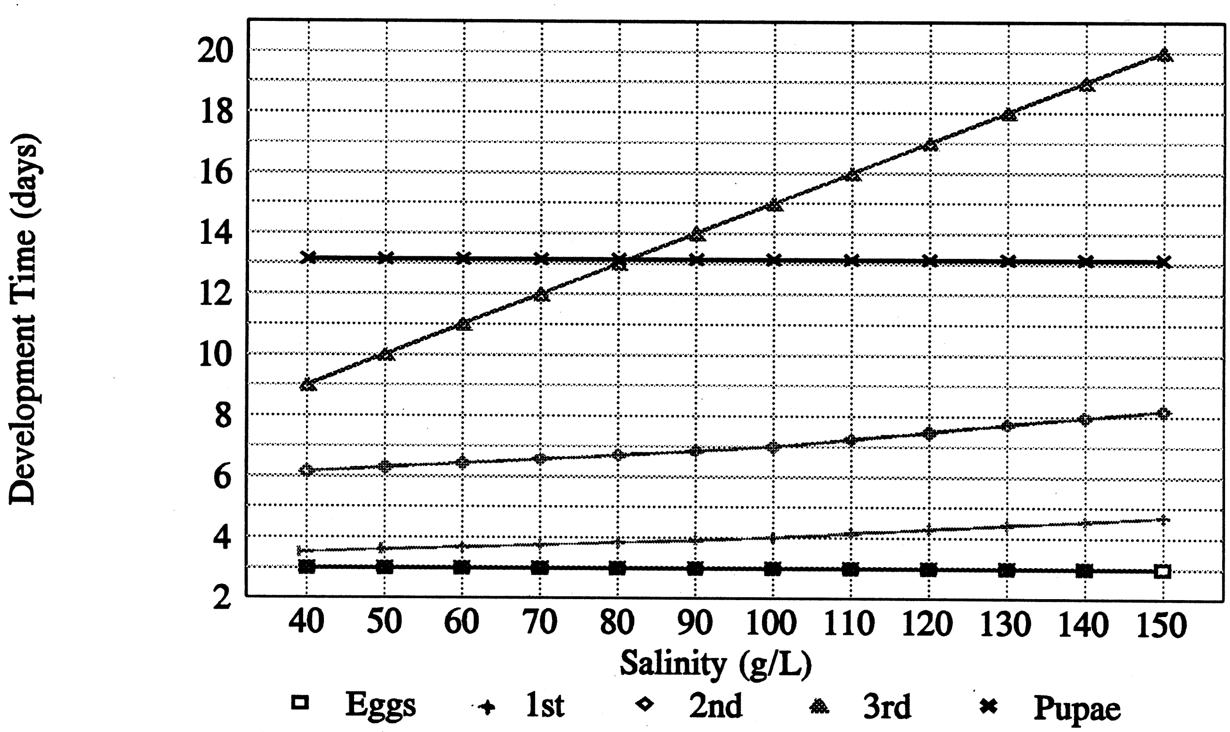


Figure L-15.
Development Time of Aquatic Alkali Fly Lifestages Modeled as a Function of Salinity
Temperature Held Constant at 20°C



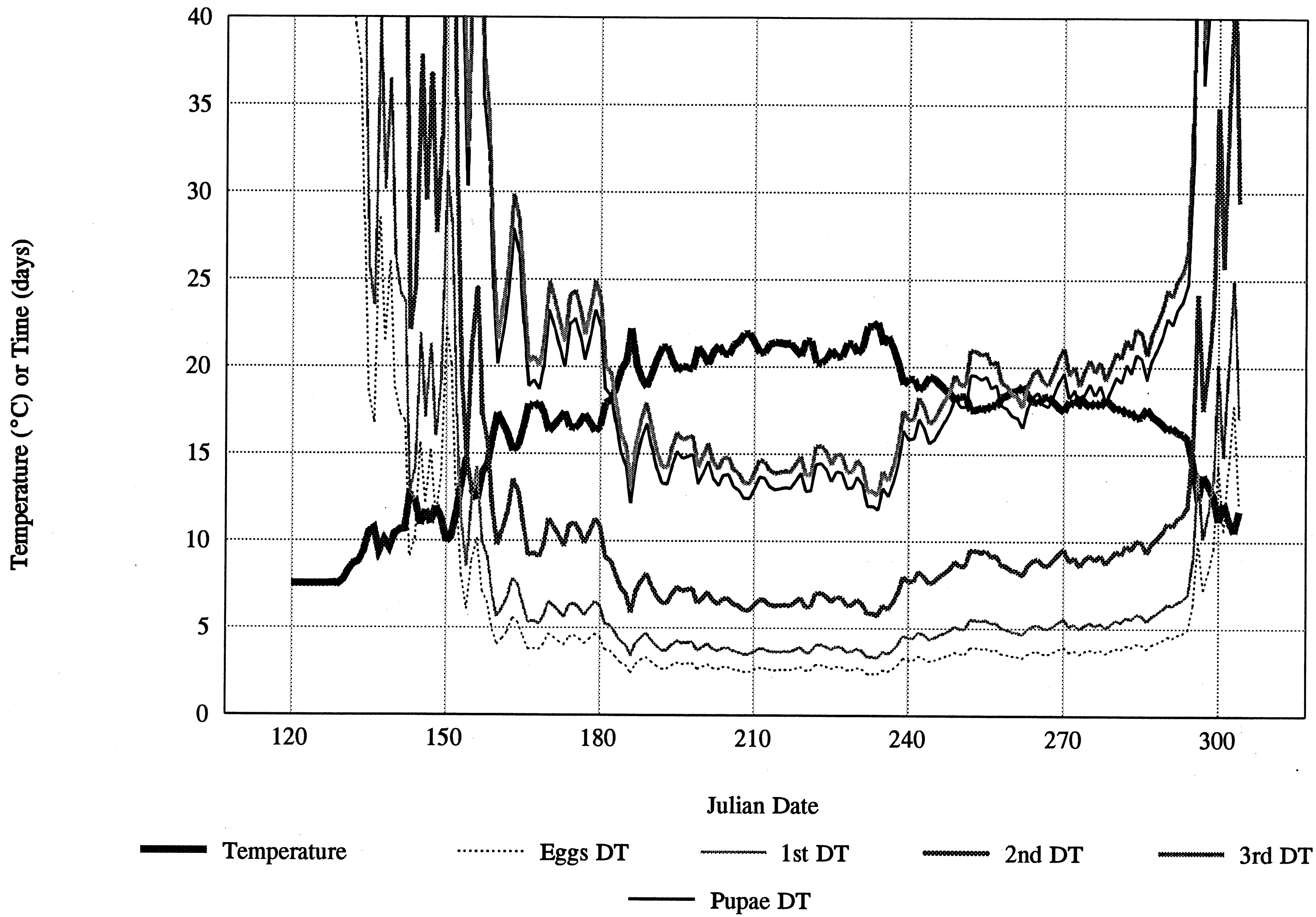


Figure L-16.
Seasonal Temperature and Development Time of Aquatic Alkali Fly Lifestages
Modeled at a Salinity of 92 g/L Corresponding to a Lake Level of 6,375 Feet

Figure L-17.
Predicted Daily Densities of Aquatic Alkali Fly Lifestages
Modeled at a Salinity of 92 g/l Corresponding to a 6,375- Ft Lake Level

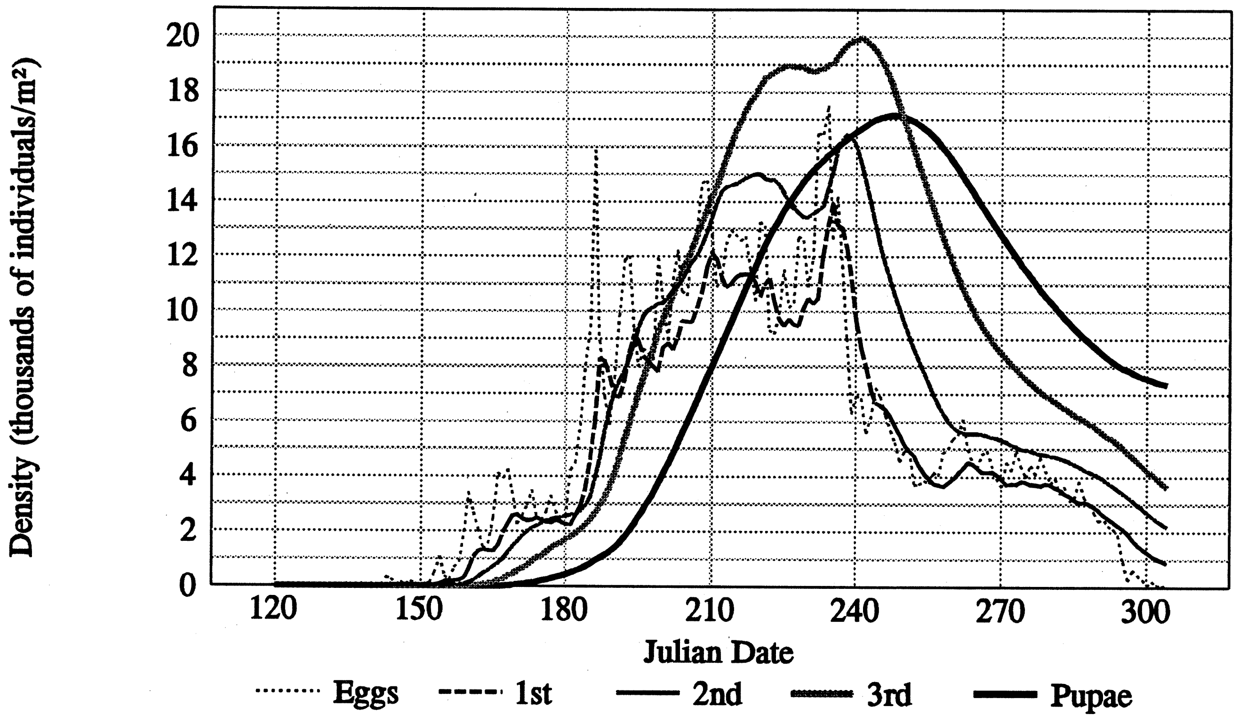


Figure L-18.
Predicted Daily Biomasses of Aquatic Alkali Fly Lifestages
Modeled at a Salinity of 92 g/l Corresponding to a 6,375- Ft Lake Level

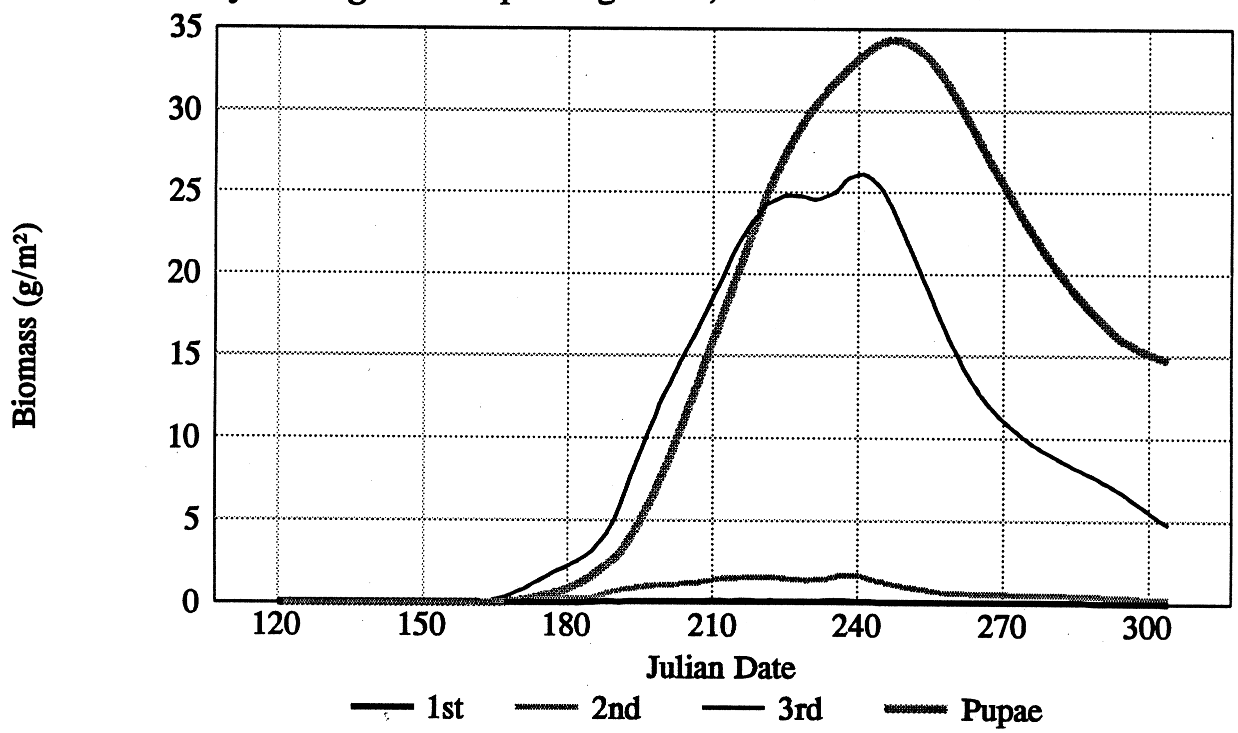


Figure L-19a.
Predicted Lakewide Average Monthly Biomass of Third Instar Alkali Fly Larvae

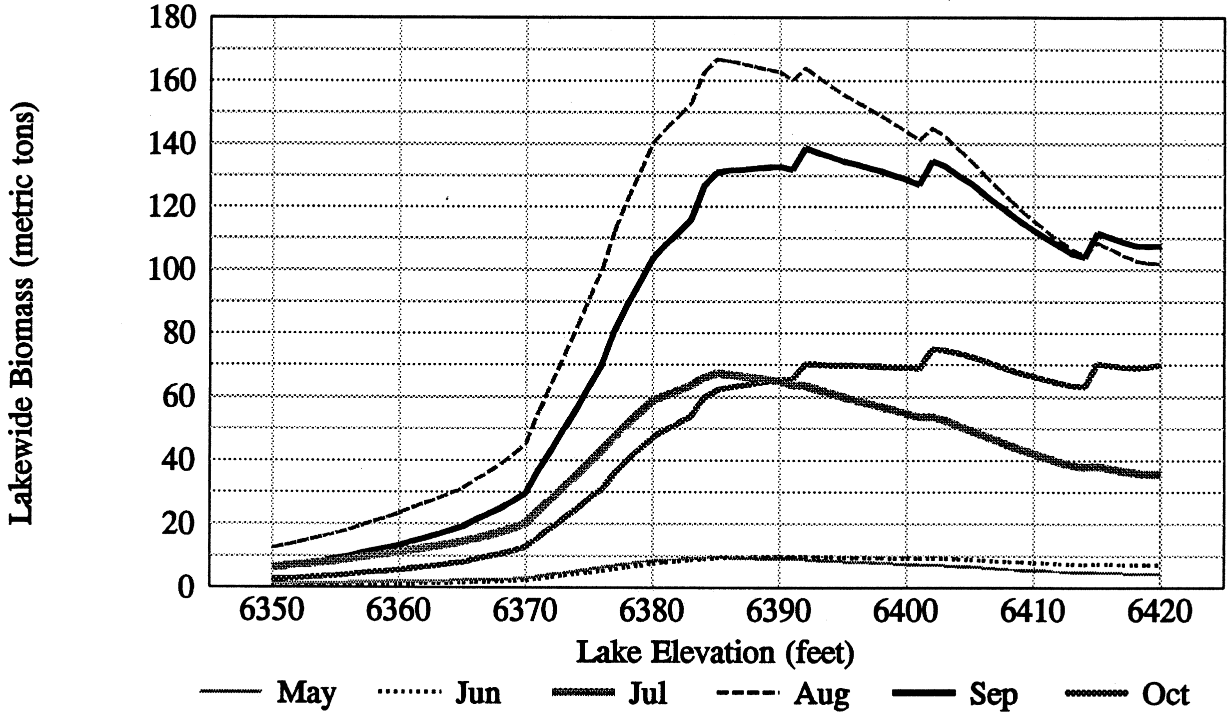
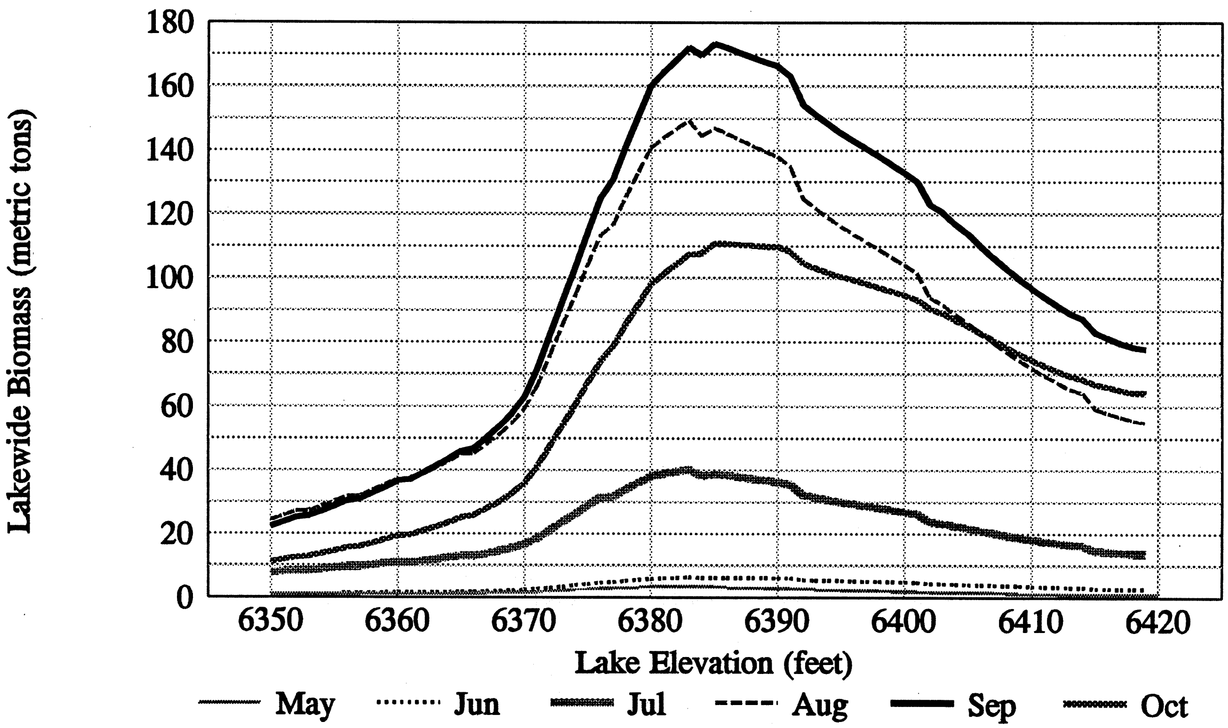


Figure L-19b.
Predicted Lakewide Average Monthly Biomass of Alkali Fly Pupae



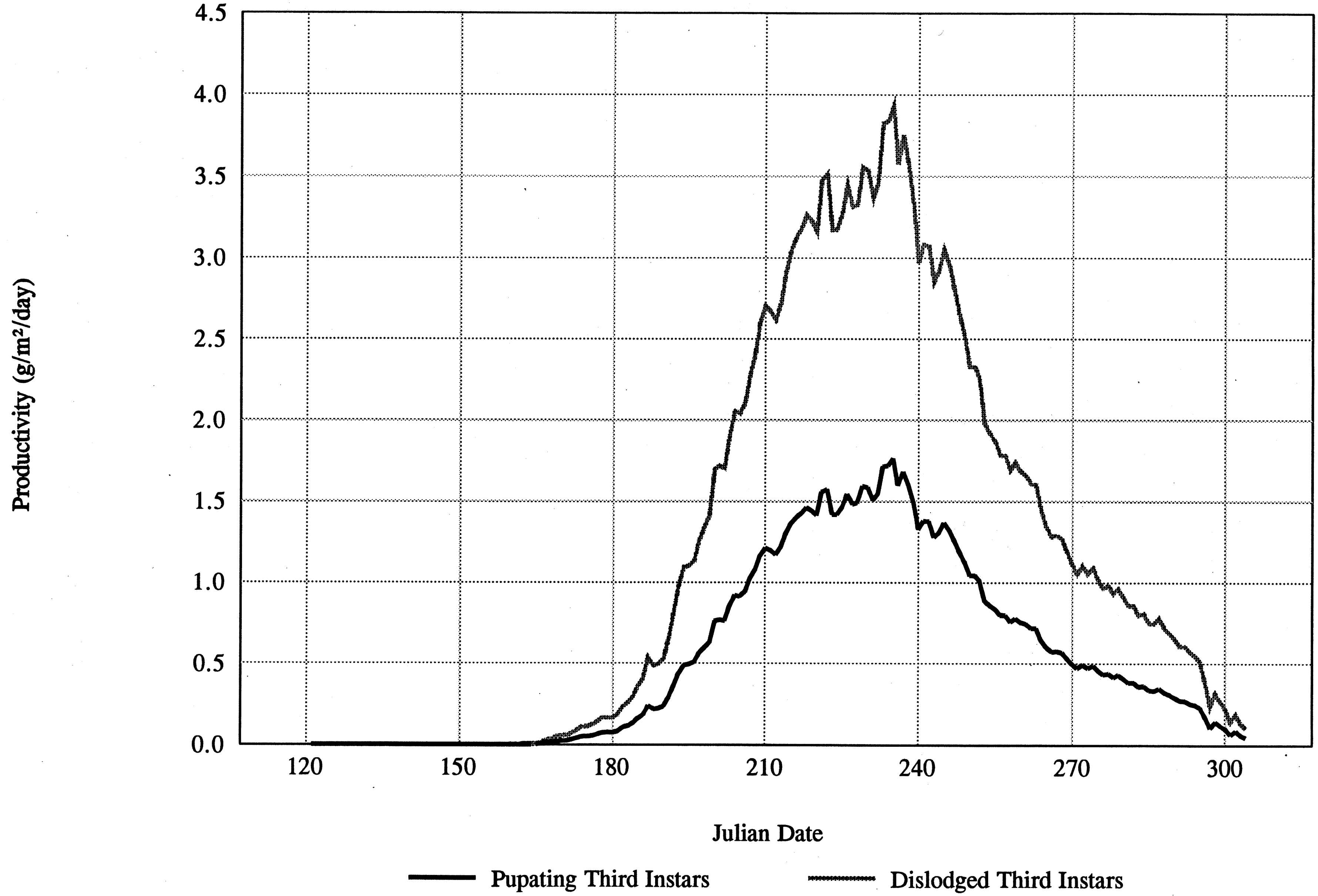
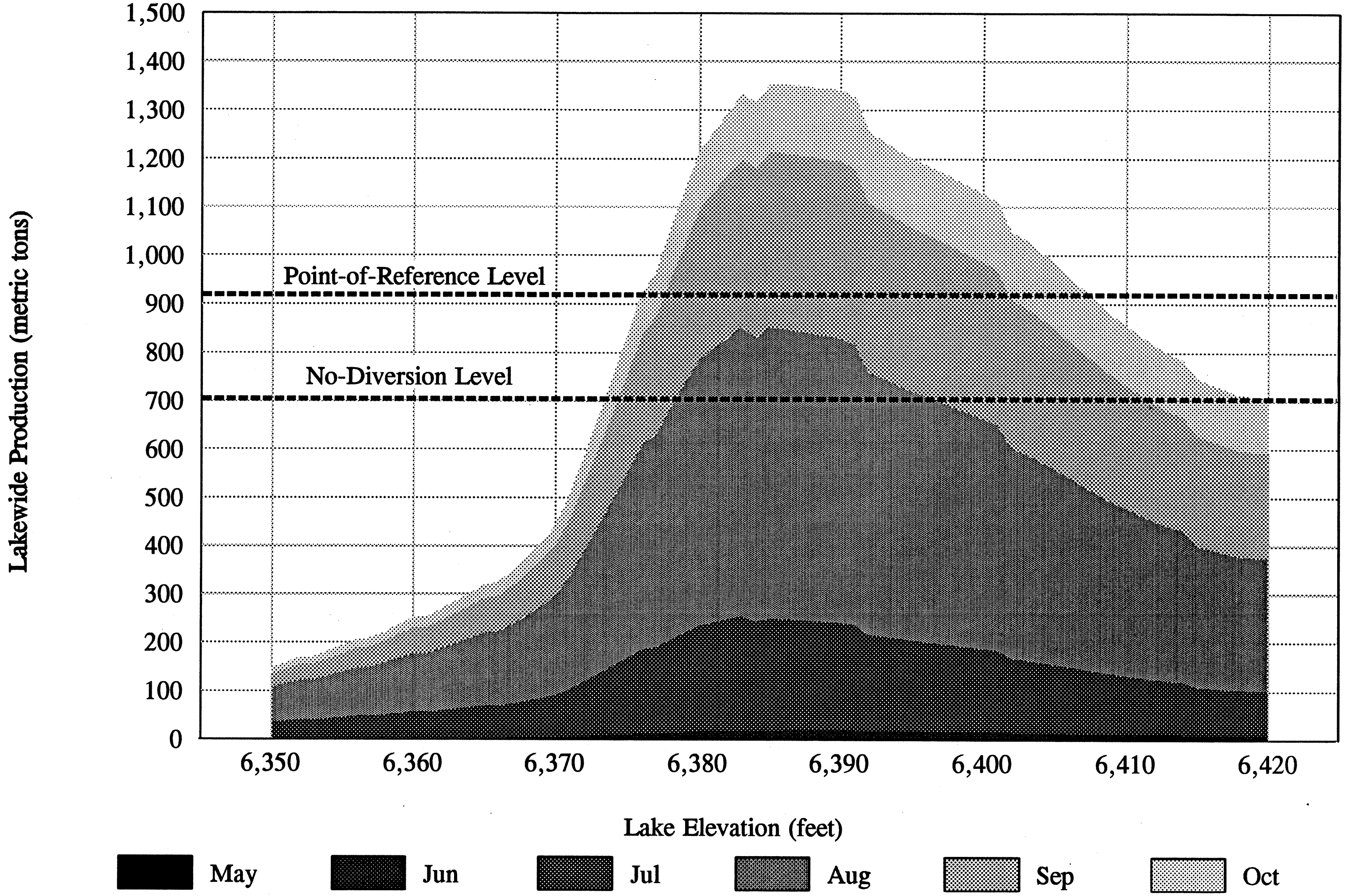


Figure L-20.
Predicted Daily Productivity of Pupating and Dislodged Third Instar Alkali Fly Larvae Modeled at a Salinity of 92 g/l Corresponding to a 6,375-Ft Lake Level



Notes: Predictions do not include potential effects of submerged vegetation.
Little production occurs in May and June due to low temperatures.

Figure L-21.
Predicted Lakewide Production of Pupating Third Instar Alkali Fly Larvae

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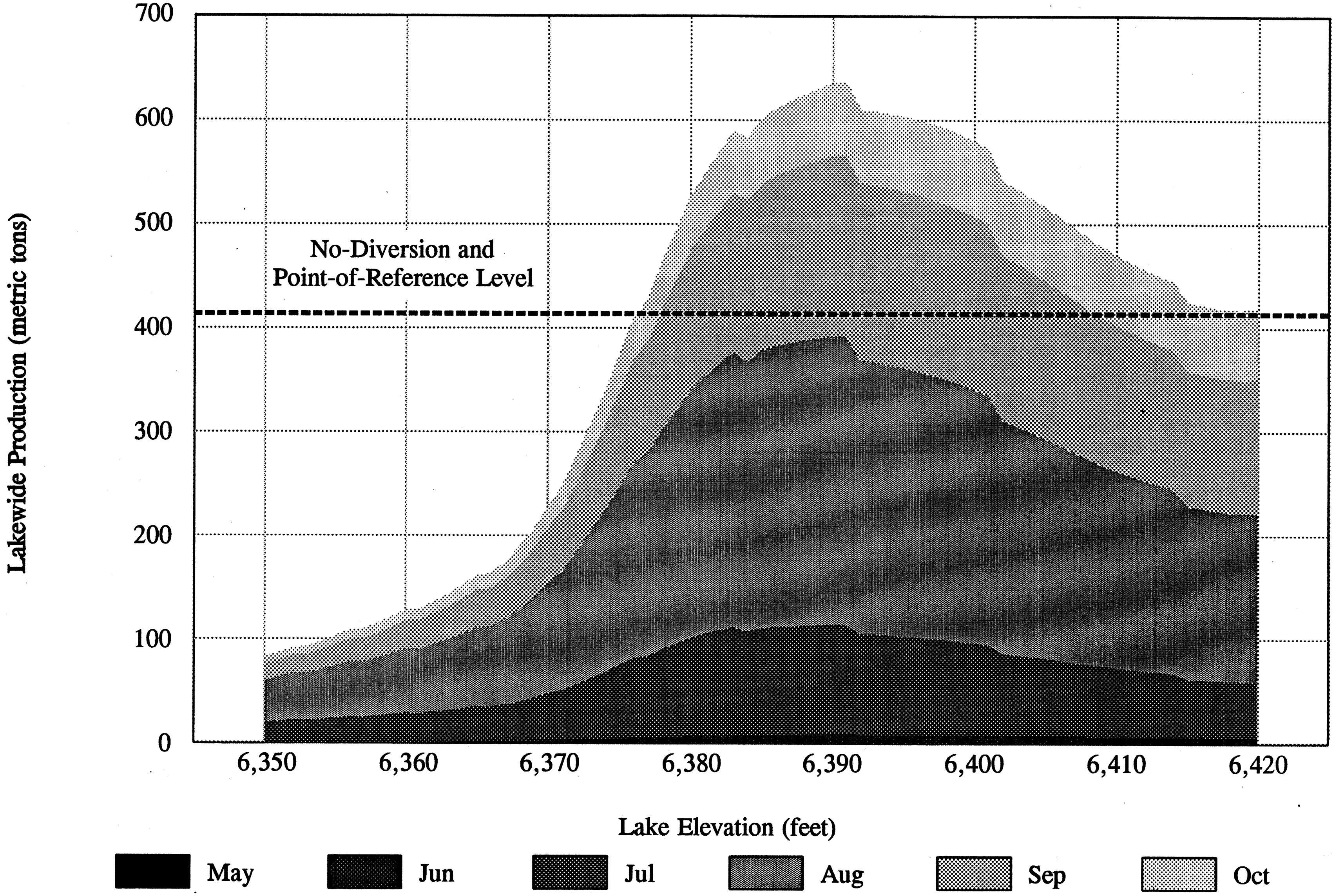


Notes: Predictions do not include potential effects of submerged vegetation.
Little production occurs in May and June due to low temperatures.

Figure 3L-22.
Predicted Lakewide Production of Alkali Fly Drift

Figure L-23.
Daily Simulated Egg Densities Compared to Observed 1991 Densities
Modeled at a Salinity of 92 g/l Corresponding to a 6,375-Ft Lake Level

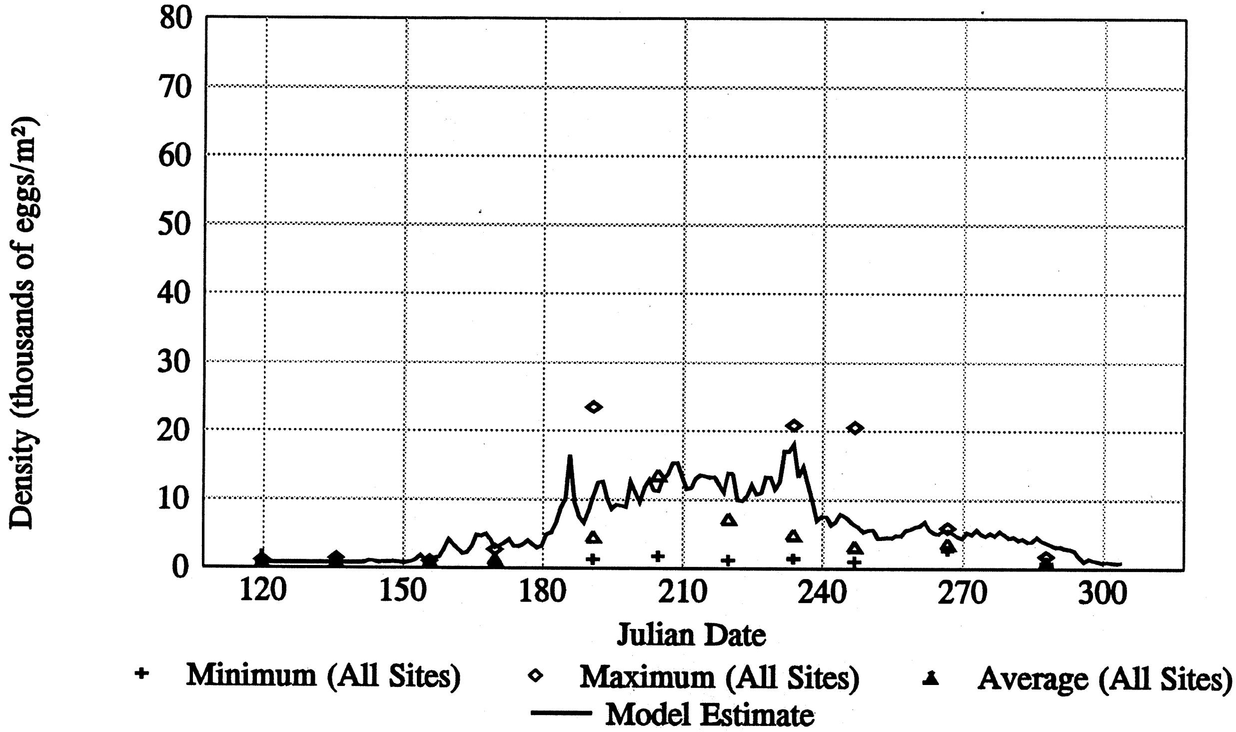


Figure L-24.
Daily Simulated First Instar Densities Compared to Observed 1991 Densities
Modeled at a Salinity of 92 g/l corresponding to a 6,375-Ft Lake Level

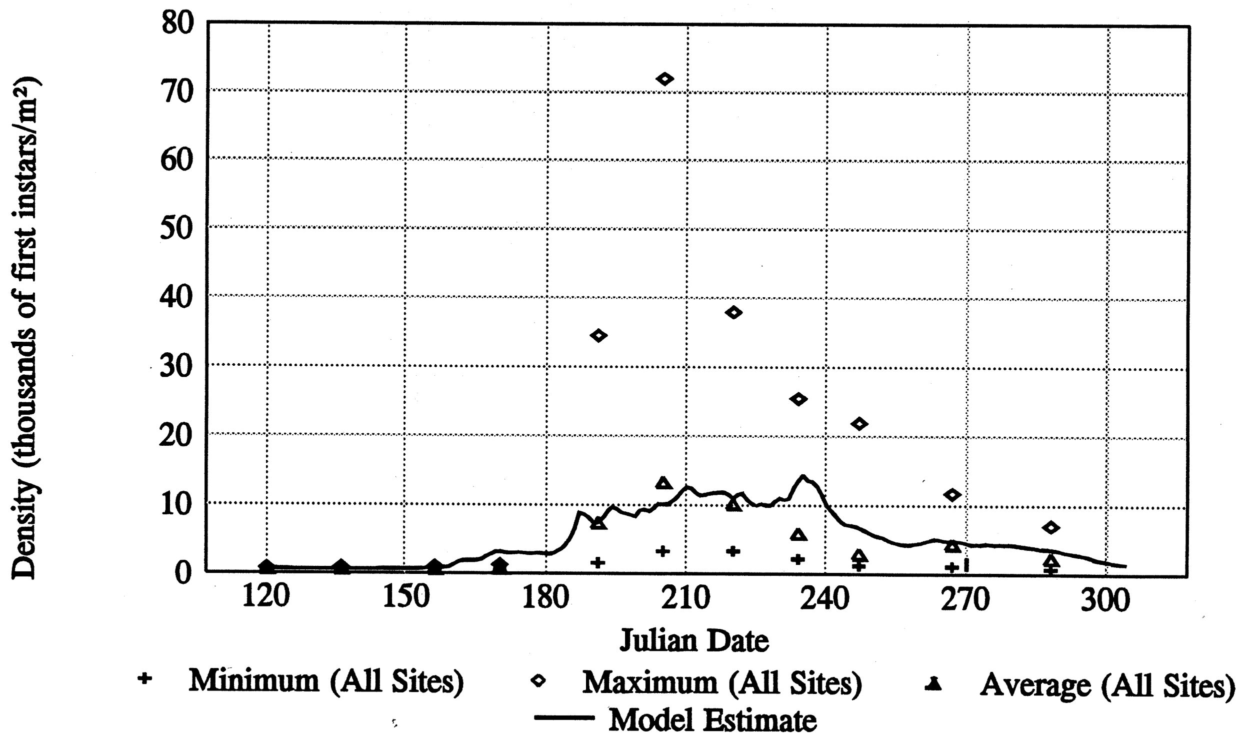


Figure L-25.
Daily Simulated Second Instar Densities Compared to Observed 1991 Densities
Modeled at a Salinity of 92 g/l Corresponding to a 6,375-Ft Lake Level

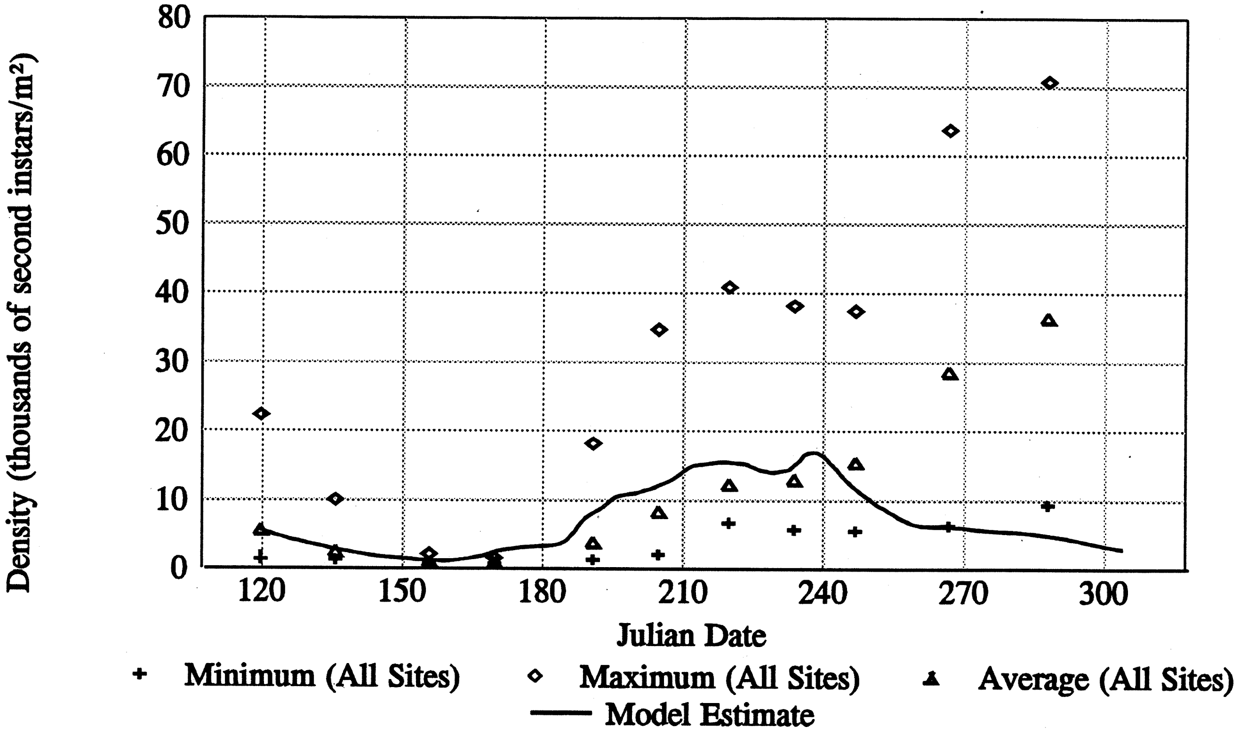


Figure L-26.
Daily Simulated Third Instar Densities Compared to Observed 1991 Densities
Modeled at a Salinity of 92 g/l corresponding to a 6,375-Ft Lake Level

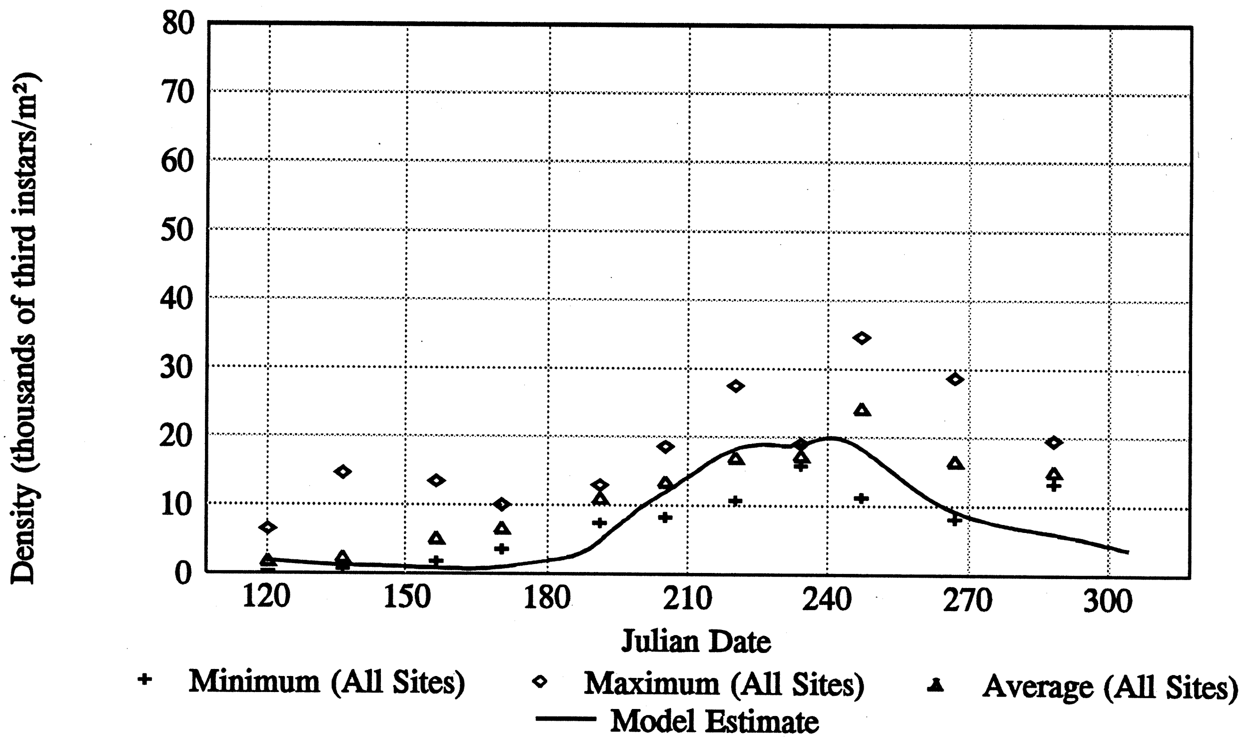


Figure L-27.
Daily Simulated Pupal Densities Compared to Observed 1991 Densities
Modeled at a Salinity of 92 g/l Corresponding to a 6,375-Ft Lake Level

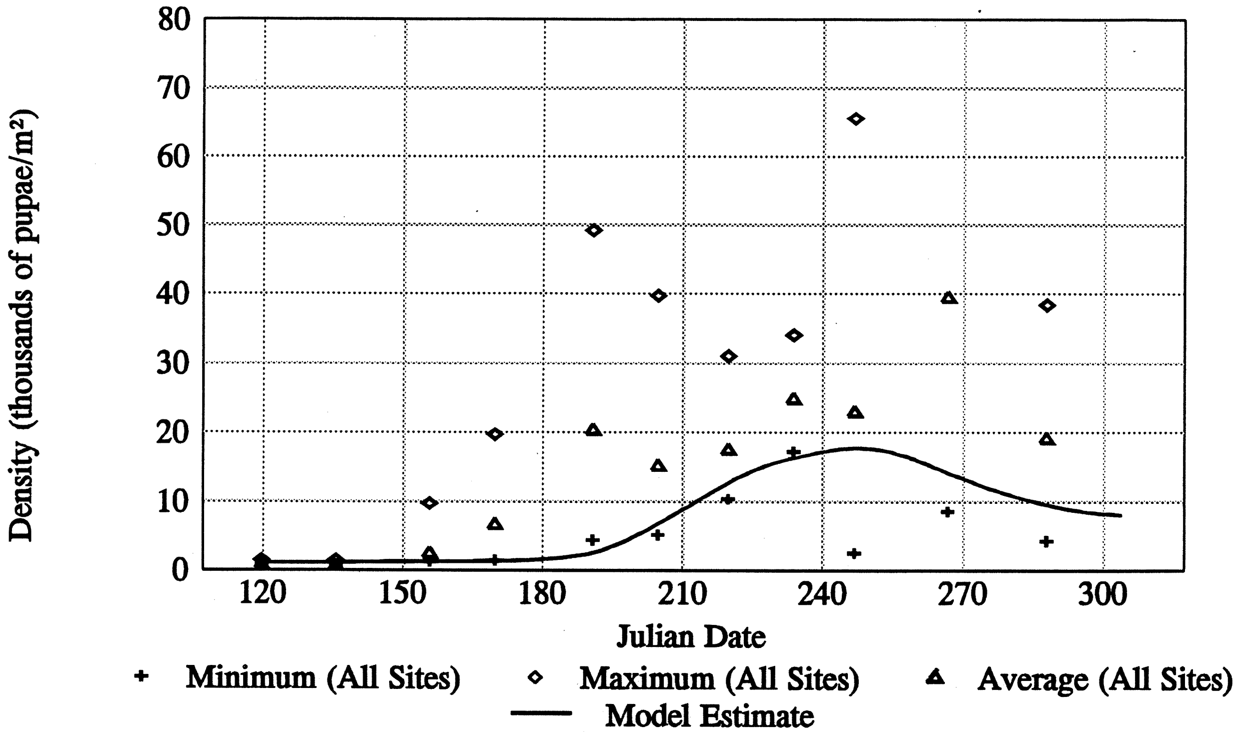
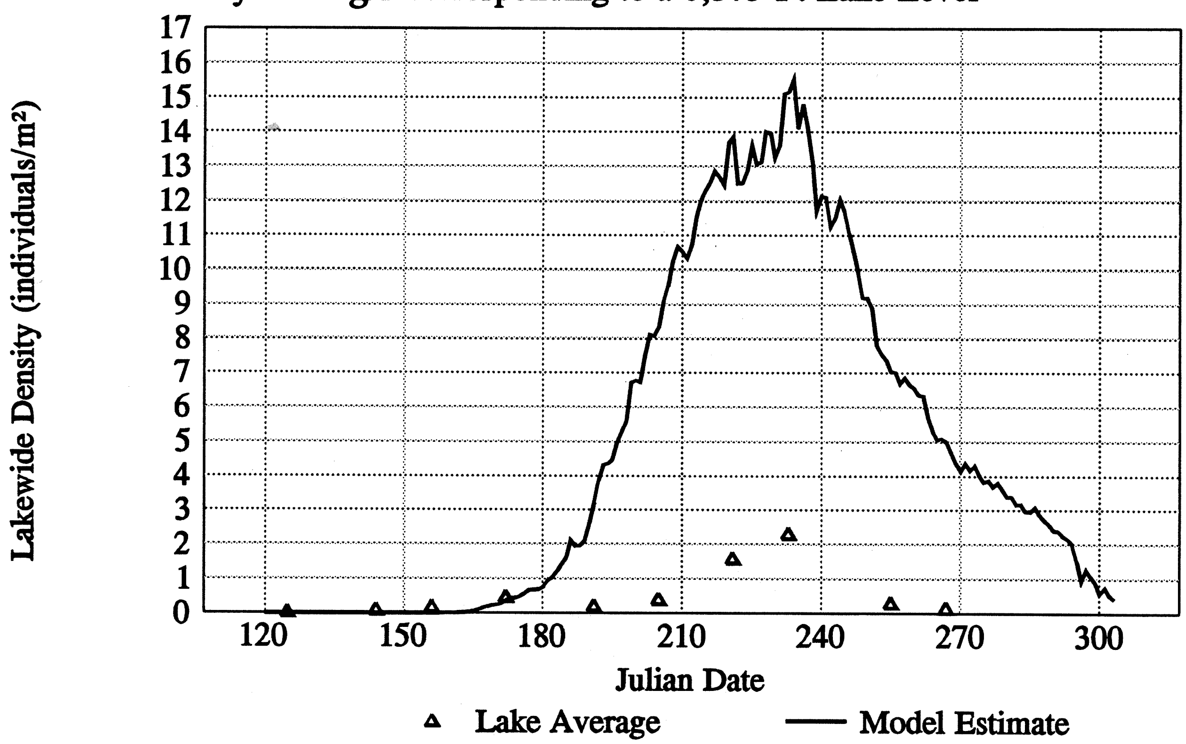
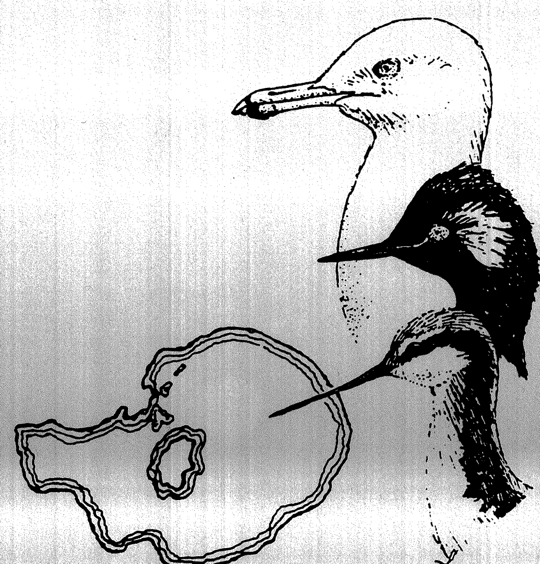


Figure L-28.
Daily Simulated Drift Densities Compared to Observed 1991 Densities
Modeled at a Salinity of 92 g/l corresponding to a 6,375-Ft Lake Level



Appendix M. Brine Shrimp Productivity Model



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Appendix M. Brine Shrimp Productivity Model

The brine shrimp productivity model was used to predict effects on brine shrimp productivity of various Mono Lake elevations resulting from alternative management scenarios. The model includes separate physical and biological limnology models to simulate temperature, light level, vertical mixing, and salinity changes and their effects on algae and brine shrimp production.

PHYSICAL LIMNOLOGY MODEL

Mono Lake brine shrimp are generally restricted to the upper mixed layer of Mono Lake because low dissolved oxygen concentrations and cold temperatures limit growth in deeper layers. Algal production and salinity in the upper mixed layer are both strongly affected by vertical mixing between the surface and bottom layers. Vertical mixing is controlled by the temperature and salinity gradient between layers. Therefore, effects of alternative lake levels on the vertical mixing regime must be understood to estimate brine shrimp production patterns.

Vertical temperature, salinity, and mixing patterns in Mono Lake were simulated with a computer model, Dynamic Reservoir Simulation Model (DYRESM) (Jellison et al. 1991). DYRESM models the lake as a vertical stack of horizontal layers of uniform temperature and salinity (as conductivity). Conductivity is the measure of salinity used in University of California, Santa Barbara (UC Santa Barbara) monitoring of Mono Lake limnology. The surface mixed layer, in which temperature and conductivity are relatively uniform, is modeled as thick slabs, whereas the thermocline and chemocline, in which temperature and conductivity change rapidly with depth, are modeled as a number of thin sections. These layers fluctuate vertically with changes in volume caused by inflows, rainfall, and evaporation.

DYRESM simulations for each lake level alternative were run for a 50-year period beginning with the point-of-reference elevation of 6,376.3 feet. Inflows and lake level fluctuations simulated with the Los Angeles Aqueduct Model (LAAMP) (Appendix B) were used as input for the DYRESM model. Daily meteorological data for 1990 were used for all 50 years of simulation.

The inputs that are required to run the DYRESM model, a brief account of how the model operates, and a description of the model outputs are given below.

DYRESM Model Description

The DYRESM model simulates the vertical patterns of temperature, salinity, and mixing within Mono Lake. The model uses mass balance equations to calculate a water budget, a salt budget, and a heat budget for each of the vertical water layers. Each water layer has a storage term (i.e., volume, heat, or salt mass) and may have inflow, outflow, and vertical mixing exchange terms.

All the modeled inflows and outflows occur near the surface of Mono Lake, so these surface exchange processes are quite important for accurate model results. Water inflows from runoff and rainfall enter the surface mixed layer. Groundwater inflows rise rapidly to the surface because of the large density difference between fresh water and Mono Lake water.

Wind and thermal energy inputs produce a surface mixed layer that is usually several meters deep in Mono Lake. Surface heat exchange governs the heating and cooling of Mono Lake. Evaporation removes water and heat from the surface mixed layer. Because of the effects of salinity on density, ice usually does not form on Mono Lake, and the lake surface is exposed to wind energy throughout the year.

No inflow or outflow of salt from Mono Lake is assumed to exist, but salt is moved between modeled layers by vertical mixing exchange processes. Surface evaporation increases the salinity concentration in the surface mixed layer, while freshwater inflow dilutes the salinity concentration in the surface mixed layer.

The water budget, heat budget, and salt budget are directly linked in several important ways. The density of Mono Lake water is directly dependent on the temperature and salinity, so the volume of a modeled layer changes slightly as the temperature or salinity changes. These relationships are described by the "equations of state" for Mono Lake water (Jellison et al. 1991).

Vertical mixing is strongly dependent on the density differences between layers, so that heating or reduced salinity from freshwater inflows greatly restrict vertical mixing. Cooling and evaporation will increase the density of the surface mixed layer and allow greater mixing with underlying layers. Mixing exchanges of water, heat, and salinity are directly related.

The DYRESM model algorithms are more fully described in the model documentation (Imberger and Patterson 1981) and the UC Santa Barbara application to Mono Lake (Jellison et al. 1991, Dana, Jellison, Romero, and Melak 1992).

DYRESM Water Budget

The bathymetry of Mono Lake describes the surface area and volume at any elevation. DYRESM uses the metric equivalent of the Pelagos Corporation bathymetry described in Appendix L. The deepest portion of Mono Lake is at elevation 6,230 feet (1,899 meters), so the total depth of Mono Lake is 44.5 meters at the August 1989 point-of-reference elevation of 6,376.3 ft (1,943.5 meters). The model layer volumes and exchange areas between layers are estimated from the bathymetric tables.

The DYRESM model uses variable layer depths, but the resulting temperature and salinity patterns are output at 1-meter increments, using linear interpolation of the modeled layer values. The surface mixed layer is modeled with several layers that are completely mixed with each other and so have the same temperature, salinity, and density.

The model calculations are made several times within each day, although the boundary conditions of inflow and meteorology are daily average values. Rainfall and surface runoff were simulated to enter the surface layer because of the large density difference between fresh water and Mono Lake water, regardless of the temperature of these inflows. Groundwater inflows were modeled to enter the lake with an assumed vertical distribution that provided some inflow to all layers (Dana, Jellison, Romero, and Melak 1992). Daily evaporation from the surface was calculated using daily average meteorology and daily mixed layer temperatures. The annual total evaporation for the 1990 meteorology was estimated to be about 48 inches.

Mono Lake volume changes directly with the addition and removal of water. Slight volumetric changes are caused by thermal expansion and salinity effects. The water budget for Mono Lake was internally adjusted to match the historical or LAAMP model simulated lake elevation fluctuations. Because evaporation is internally calculated, the daily modeled inflows are reduced or increased to provide this matching surface elevation. The LAAMP model assumes an unmeasured inflow of about 34,000 acre-feet per year (af/yr) plus 5% of the diverted tributary runoff (Appendix A). Because DYRESM uses the measured or simulated tributary streamflows, DYRESM assumes all the "adjusted" inflow is groundwater.

DYRESM Salt Budget

Salinity is defined as the mass of total dissolved solids per unit of water volume, usually reported as grams per liter (g/l) for Mono Lake. Based on available field measurements, the total mass of dissolved solids in Mono Lake is estimated to be 285 million tons (258.5 metric tons). For the August 1989 point-of-reference elevation, the volume of Mono Lake was approximately 2.33 million af, and the salinity was about 90 g/l.

UC Santa Barbara field data for salinity are vertical profiles of electrical conductivity (EC) measurements, adjusted to a standard temperature of 25°C. Because EC exhibits a linear relationship with salinity in the 65-95 g/l range tested, EC was modeled as salinity in DYRESM. Because EC is a strong function of temperature, the EC values are all adjusted to 25°C, regardless of the modeled layer temperature. The assumed relationship (Jellison 1992) between EC and salinity is:

Salinity (g/l) = 1.4205 x EC (microsiemens/centimeter [mS/cm]) - 35.64

Salinity will increase as evaporation removes water from the surface layer and will be reduced as inflows add water to the surface layer. All other changes in salinity within Mono Lake will be caused by mixing from the surface layer. During periods of complete mixing, the entire lake will have the same average salinity. Salt is redistributed by mixing processes, but none is added or removed from Mono Lake.

As salinity increases, part of the salt will increase the water density without changing the volume, while the remainder will expand the volume of water, much as heat will cause the water volume to expand and the density to decrease. Figure M-1 shows the experimental determination of the density of Mono Lake water that was diluted and concentrated to a wide range of salinities (LADWP 1987). The experiment indicates a linear response of density to salinity increases, with approximately 80% of the dissolved solids increasing the density and 20% increasing the volume. For example, the density of 125 g/l salinity (12.5% by weight) has increased 10% to a density of 1,100 g/l (specific gravity of 1.10). If the salt is removed from a liter of water, the remaining water will weigh 975 grams and occupy 0.975 liter, indicating that the volume increased 2.5% as the salt was dissolved. The DYRESM model properly simulates these effects of salinity on density and volume.

DYRESM Heat Budget

The heat content of each modeled layer is calculated from the temperature multiplied by the density multiplied by the heat capacity. Because of Mono Lake's high salt content, the density and heat capacity of its waters are higher than that of fresh water. The relative effects of temperature on thermal expansion (density) are similar to fresh water, except that the maximum density does not occur at 4°C, as it does for fresh water (Mason 1967).

Heat is exchanged at the surface only, except for photosynthetically available radiation (PAR) attenuation that is generally confined to the surface mixed layer. DYRESM considers turbulent bulk aerodynamic exchange of sensible (dry) and latent (moisture) heat that depend directly on wind speed and the difference between air and water temperature or vapor pressure. The unmeasured bulk transfer coefficient is often adjusted during calibration to include the effects of the differences between average wind speed for the entire lake and wind speed at the measurement location.

The largest heat exchange terms are long-wave radiation between the water surface and the atmosphere. The long-wave radiation processes are proportional to the emissivity multiplied by absolute temperature raised to the fourth power. While the temperature can be measured, the emissivity of the water and the atmosphere must be estimated. Water emissivity is estimated at 0.97, while the atmospheric emissivity is estimated as a function of temperature and cloud cover.

The overall accuracy of the heat budget is determined by calibration with the available temperature profiles. Temperature profiles are governed by both surface exchange and mixing processes, however, and the absolute accuracy of these approximate heat exchange formulations cannot be certain. Nevertheless, the ability of the DYRESM model to simulate the surface temperatures of Mono Lake during 1990 is indicated in Figure M-2. Observed surface temperatures were best matched with a 20% reduction in the bulk exchange evaporation coefficient, approximating 48 inches of evaporation.

DYRESM Vertical Mixing

Vertical mixing is simulated as mass exchanges (entrainment) caused by energy inputs and momentum transfers. For Mono Lake, the dominant energy inputs are kinetic energy from wind and convective overturn energy caused by surface cooling. The wind energy input is assumed to be proportional to the wind speed squared, while the convective overturn energy is simulated by the heat budget. Both of these processes cause a slight deepening of the surface mixed layer and a small transfer of turbulent energy into underlying layers. Turbulent mixing is simulated with an effective diffusivity coefficient that depends on the overall energy input. Density gradients at the thermocline or chemocline greatly reduce the transfer of mixing energy to deeper layers.

DYRESM Model Inputs

Daily flows and temperatures of streams and other inflows to Mono Lake are required inputs of DYRESM (Dana, Jellison, Romero, and Melack 1992). Fifty-year projections of monthly inflows associated with each lake level alternative were obtained from the LAAMP model (Appendix B). LAAMP provided estimates of tributary inflow and unmeasured inflow (ungaged runoff and groundwater) into Mono Lake. Average daily stream temperatures of Convict Creek in 1990 were used as estimates of Mono Lake tributary temperatures. The Convict Creek temperatures were measured at the Sierra Nevada Aquatic Research Laboratory (SNARL), 25 miles southwest of Mono Lake at an elevation of 7,087 feet, which is about 700 feet higher than Mono Lake (Jellison et al. 1991). The 1990 stream temperature data were used for all years of simulation. Because of the large difference in density, tributary inflows enter the surface layer regardless of temperature. Daily rainfall was obtained from monthly Cain Ranch values used in LAAMP.

DYRESM also requires inputs of daily average air temperature, vapor pressure, wind speed, short wave (solar) radiation, and cloud cover. These meteorological inputs were computed with data collected from November 17, 1989, to November 16, 1990, at weather stations at SNARL (relative humidity), Cain Ranch (solar insolation), and Paoha Island (wind speed and air temperature). Cain Ranch is 4 miles southwest of Mono Lake and about 500 feet higher in elevation. Paoha Island is in the middle of Mono Lake. Further details about meteorological data used in the DYRESM simulations are given in Dana, Jellison, Romero et al. (1992).

The vertical attenuation with depth of incident PAR (400-700 nanometers of wavelength light) affects near-surface temperatures. PAR profiles were measured monthly and attenuation coefficients were calculated. Attenuation of PAR in Mono Lake is controlled primarily by the algal biomass. Daily attenuation coefficients were estimated by linearly interpolating between measured dates. The daily attenuation coefficients for 1990 were input to the model for each of the 50 years. This implies that similar algal biomass patterns would develop each year. Because the surface mixed layer is usually between 5-15 meters deep, the majority of PAR is absorbed within the surface mixed layer for any reasonable algal biomass.

DYRESM Model Outputs

The DYRESM model outputs 1-meter-increment depth profiles of temperature, conductivity, and water density of Mono Lake on a daily basis. Daily outputs include surface elevation, evaporation estimate, depth of the surface mixed layer (determined by a specified temperature gradient) and average surface mixed layer temperature, salinity (as conductivity), and density. Temperature, salinity, and density at the 35-meter depth also were output for determining meromictic conditions. For comparing alternatives, however, monthly average values for the 50-year simulations were used to characterize the simulations.

DYRESM Calibration and Validation

The accuracy of the overall simulation of heat exchange and vertical mixing is indicated by Figure M-3 showing the measured and simulated temperature profiles in Mono Lake for 1990. Simulated surface mixed layer depths and temperatures are well matched with field measurements. The only major discrepancy is the bottom temperatures; field data indicate that bottom temperatures increased during 1990 from about 2.5°C on day 99 (April 9) to about 4°C on day 250 (September 7), while the simulated temperatures remained nearly constant at 2°C without warming. The simulated temperature gradient in the thermocline also may be too strong compared to the field data. This gradient may indicate slightly too little mixing in the hypolimnion but does not significantly affect the seasonal development of the surface mixed layer nor the chemocline that is caused by large freshwater inflows.

The 1982-1990 period of UC Santa Barbara monitoring of Mono Lake temperature and salinity profiles was used to validate the DYRESM model results. The simulated and measured surface mixed layer depth is shown in Figure M-4. The seasonal deepening from about 5 meters in spring to 15-20 meters in fall was well simulated. In addition, the development of the strong chemocline in 1983, its reinforcement in 1986, and its erosion and overturn in subsequent years was generally well simulated. The simulated overturn was not quite complete in fall 1988, when it was observed to occur, but the simulated surface mixed layer depth had increased to about 25 meters. A slightly greater mixing during the meromictic period might have given an even better match with the observed conditions. Nevertheless, this multiple-year DYRESM simulation provides a strong test of the model and indicates that DYRESM is certainly sufficiently accurate for comparative simulations of the alternative lake levels.

BIOLOGICAL LIMNOLOGY MODEL

The dynamics of the brine shrimp population in Mono Lake are governed by strong interactions between trophic levels; nitrogen, light, and brine shrimp grazing may limit algae production, but excretion by brine shrimp is an important source of nitrogen for algae, and brine shrimp grazing clears the water and increases light penetration. Vertical mixing affects nitrogen availability, and the surface mixed layer depth affects average mixed-layer light levels.

A computer model was developed to simulate the major limnological features that determine algal and brine shrimp production (Figure M-5). The model contains two linked submodels: a nitrogen submodel that simulates the nitrogen balance in Mono Lake and a brine shrimp submodel that simulates brine shrimp population dynamics. Although the submodels are described separately, they operate in tandem during simulations.

The biological effects of alternative lake levels were assessed by simulating the nitrogen balance and brine shrimp population dynamics at a daily time scale for a period of 1 year at each of the alternative lake levels. Different model parameter values were used to reflect salinity effects on the nitrogen balance and brine shrimp dynamics.

Nitrogen Balance Submodel

Submodel Description

Nitrogen is the limiting nutrient in the pelagic food chain of Mono Lake (Jellison, Dana, Romero, and Melack 1991). The nitrogen balance submodel simulates nitrogen movement among pools representing the sediments, the hypolimnion, the epilimnion, the planktonic algae, and the brine shrimp population (Figure M-5). Nitrogen in the hypolimnetic and epilimnetic pools is present almost entirely as ammonium (NH_4^+), while that in the algae and brine shrimp is bound up in tissues, feces, or other particulate forms. Only the ammonium nitrogen, which is dissolved, is immediately available to algae. Both dissolved and particulate nitrogen are present in the sediments. Dissolved ammonium is released from the sediments into the epilimnion and hypolimnion.

Hypolimnetic and Epilimnetic Ammonia. The nitrogen submodel assumes a constant rate of ammonium release from the sediments (56 milligrams of ammonium nitrogen per square meter per day) (Jellison, Dana, Romero, and Melack 1992). When Mono Lake is holomictic (not stratified), the released ammonium moves directly into the combined epilimnetic and hypolimnetic pool. When the lake is stratified, the ammonium is added to the hypolimnetic and epilimnetic pools separately, based on the area of sediments within each layer. Vertical movement of ammonium between the hypolimnion and epilimnion is modeled by moving slabs of water with the ammonium they contain back and forth between the water layers as the epilimnetic depth changes. When the lake is stratified and the epilimnion is deepening, the slabs are moved from the hypolimnion to the epilimnion, whereas when the epilimnion is thinning (i.e., when the thermocline is rising), the water slabs are moved in the reverse direction. The model calculates daily average areal concentrations of hypolimnetic and epilimnetic ammonia as the products of the daily mean volumetric concentrations and the daily hypolimnetic and epilimnetic depths.

Excretion by brine shrimp also adds ammonium to the epilimnion, while ammonium uptake by algae decreases ammonium. Modeling of these biological processes is described in the following section and the section on the brine shrimp pool. The model assumes that no ammonium is lost by volatization (Dana et al. 1992).

Algal Nitrogen Pool. Movement of nitrogen from ammonium to the algae (nitrogen assimilation) is modeled as a photosynthetic growth process. The model assumes algal growth rate is regulated by temperature, light, ammonium concentration, and salinity in the epilimnion. A standard growth rate of 1.25 per day, the maximum (specific) growth rate when temperature is 20°C and salinity is 92 g/l, is input into the model. The maximum growth rate is the growth rate for a given combination of temperature and salinity when light and nutrient conditions are optimal. The equation for the maximum growth rate is as follows (Dana, Jellison, Romero, and Melak 1992):

$$G_m = A \times 1.25 \times 1.08^{T-20} \times e^{-Ps}$$

where

G_m = maximum growth of algae (milligrams of nitrogen/cubic meter/day [mg $N/m^3/d$]),

A = standing crop of algae nitrogen (mgN/m3),

T = average mixing layer temperature (°C), and

P_s = proportional increase (or negative decrease) in salinity from the point of reference (92 g/l).

The maximum growth rate decreases exponentially with decreasing temperature and with increasing salinity. For example, the maximum growth rate at 10°C is about half of that at 20°C and maximum growth rate at 120 g/l (corresponding to lake level of 6,360 feet is about three quarters that at 92 g/l (corresponding to lake level 6,375 ft asl).

When light levels or ammonium concentrations in the epilimnion are below optimal values, algal growth rates are reduced below the maximum rates. The effects of light and ammonium on algal growth are modeled as Monod-type rectangular hyperbolic functions, which describe an asymptotic increase in growth rate as light levels or ammonium concentrations approach their optimal values. If both light and ammonium are below optimal levels, then the growth rate is determined by whichever is more limiting (i.e., predicted growth rate is the lower of the growth rates computed from the equations for light level effects and ammonium concentration effects).

Ambient light conditions of the algae are estimated as the average light level for the epilimnion. The average light level is determined by surface insolation of PAR, the depth of the epilimnion, and an attenuation factor (i.e., rate of light reduction with depth) derived from *in situ* determinations of average attenuation of Mono Lake water. Algal biomass increases attenuation. The depth of the epilimnion affects light level because it determines the depth to which the algae are mixed. The model assumes that no algal growth occurs below the epilimnion. In reality, algal growth does occur below the epilimnion, but this growth is usually insubstantial (Jellison, Dana, Romero, and Melack 1991). When algal growth rate is limited by light level, the realized growth rate (G) is computed with the following equations:

$$G = G_m \times \frac{L}{L + 6}$$

and

$$L = I \times \frac{1 - e^{(KxD)}}{KxD}$$

where

L = average light level in the mixing layer (einsteins per meter squared per day [$E/m^2/d$]),

I = insolation at lake surface ($E/m^2/d$),

D = depth of the mixing layer (m),

K = light attenuation = 0.3873+(0.000632 x A), and

A = standing crop of algae nitrogen (mgN/m^3).

When the growth rate is limited by nitrogen concentration, the realized growth rate is computed as follows:

$$G = G^m \times \frac{(E - 7)}{14}$$

where

E = ammonium concentration in the mixed layer ($mg/N/m^3$).

If E is less than 7, then G is set to 0 to avoid negative values for growth.

Nitrogen leaves the algal pool by two paths: sedimentation and brine shrimp grazing. Sedimentation is the rate of settling of algae out of the epilimnion. The model uses a constant sinking rate of 0.1 meter per day, so the settling loss rate ($mg\ N/m^2/d$) is computed as 0.1 multiplied by the algal standing crop ($mg\ N/m^3$) divided by the mean epilimnetic depth. Grazing is discussed below.

Brine Shrimp Pool. Although the brine shrimp population is an integral and important constituent in the nitrogen cycle of Mono Lake, population dynamics of the brine shrimp require a separate submodel for their description. In this section, only those processes that directly affect movement of nitrogen in and out of the brine shrimp pool are covered. Other properties of the brine shrimp population are described in the section on the brine shrimp submodel.

Transfer of nitrogen from the algal pool to the brine shrimp pool occurs entirely by brine shrimp grazing on the algae. The grazing is modeled as a filtration process bounded by an upper limit. The upper limit is the maximum grazing rate that occurs when algal biomass is not limiting. The maximum grazing rate is dependent on the individual weight of the brine shrimp and temperature as follows:

$$C_m = 0.03 \times (1 - e^{-239 \times W_i}) \times e^{-.008 \times (T-30)2}$$

where

C_m = maximum grazing rate (mg N/d),

W_i = weight of individuals of the ith brine shrimp weight class (mg N), and

T = temperature (°C).

The weight classes, which are artificial groupings created to improve model performance, were produced by dividing growth of the brine shrimp lifestages (instars) in thirds (Table M-1). The class weights were derived from measured weights of the instars (Jellison et al. 1989b) by linear interpolation.

When the grazing rate is below maximum (because algal biomass is below the upper limit), grazing rate (C) is computed by the following equation:

$$C = (W_i/.5) \times e^{-.008x(T-30)2} \times (A-7.5)/124$$

where

A = algal biomass (mg N/m^3).

The temperature factor produces a normal distribution in the response of grazing to temperature with a peak grazing rate of 30°C, well above Mono Lake temperatures. The temperature optimum was adopted from experiments with another brine shrimp species (Jellison, Dana, Romero, and Melack 1992).

Total daily transfer of nitrogen from the algal pool to the brine shrimp pool is the sum over all subclasses of the subclass grazing rate multiplied by the number of brine shrimp in the subclass.

Nitrogen leaves the brine shrimp pool by several pathways. Most importantly, brine shrimp excrete nitrogen as ammonium into the epilimnion where it is immediately available for reuse by the algae. The other exports of nitrogen occur via defecation, cyst production, and mortality. These processes result in particulate nitrogen that settles to the lake bottom. The model assumes no direct release of nitrogen to the epilimnion or hypolimnion during settling of the particulates.

Nitrogen excretion and defecation rates are assumed equal to that portion of nitrogen from ingested algae not used for growth or production of cysts or nauplii (i.e., grazing minus production). The assumed model parameters allocate 56% of ingested nitrogen to the waste products, 75% of which is assumed to be excretion and 25% of which is assumed to be feces.

Cyst production and mortality are discussed in the section on brine shrimp submodel.

Submodel Inputs

Daily surface insolation, initial nitrogen pool concentrations, and epilimnetic estimates of depth, surface and bottom areas, volume, and temperature are required inputs of the nitrogen submodel. Values for these variables were obtained from field data; 1984 field data were used to simulate meromictic conditions, and 1990 field data were used to simulate monomictic conditions. Other model parameters are derived from these inputs or are input as constants. The constants were approximated from field and laboratory data or were adopted from other studies (Jellison, Dana, Romero, and Melack 1992).

Submodel Outputs

The nitrogen submodel outputs daily nitrogen concentrations of the hypolimnetic, epilimnetic and algal pools. The submodel also provides estimates of algal production of nitrogen. All model outputs are given in volumetric or areal units of nitrogen; Table M-2 gives the formulas used for converting the model outputs to the measurement units of the field data.

Submodel Validation

The nitrogen balance submodel was validated by comparing simulation results with field data. A meromictic year, 1984, and a monomictic year, 1990, were used for most validations. Values of the input variables were derived from the field data for these years.

The model predicted the partitioning of nitrogen among the epilimnetic, algal, and brine shrimp pools fairly accurately for 1990, but results for 1984 were less satisfactory (Figure M-6). The simulation for meromictic conditions was only partially successful because, as noted earlier, the model simulates two layers, whereas the actual vertical structure of Mono Lake, after the thermocline forms in the spring, is three-layered (epilimnion, hypolimnion, and monimolimnion). The model successfully simulates meromictic conditions during the spring and fall mixing periods when the lake has only two layers, the mixed layer and the monimolimnion. During the summer stratification period, however, the model treats the hypolimnion and monimolimnion as a single combined layer. Deepening of the thermocline during summer transfers water to the epilimnion from this combined layer. Under actual meromictic conditions during summer, mixing transfers water from the hypolimnion only. The monimolimnion has much higher ammonium concentrations than the hypolimnion, so the model overestimates the amount of ammonium transferred to the epilimnion. A three-layer model might be able to isolate monimolimnetic ammonium properly, but such a model has not yet been developed.

In the 1984 simulation, epilimnetic ammonium that was overestimated by the model in spring was converted to algal biomass, producing an algal bloom that was much greater than the observed bloom (Figure M-6). The model also overestimated epilimnetic ammonium concentration for summer 1984 (Figure M-6). In this case, the lower observed values may have been caused by the presence of a subthermocline layer of algae that absorbed ammonium before it could reached the epilimnion (Jellison, Dana, Romero, and Melack 1992). The two-layer model is unable to simulate any such complex layering.

A second validation of the nitrogen submodel was carried out by simulating nitrogen partitioning from 1983 through 1990, a period that included both meromictic (1983-1988) and monomictic (1989-1990) years (Figure M-7). Surface elevations, temperatures, epilimnetic depth, and insolation were input using observed values. Observed initial 1983 shrimp abundances and available cysts also were input. The model successfully duplicated several general features of the observed data. These include reduced algal biomass in late winter and early spring during meromixis, increased epilimnetic ammonium and brine shrimp biomass during summer in the latter part of the meromictic period (because of mixed layer deepening), and a large algal bloom following the breakdown of meromixis in late 1988. Because the model simulates two layers only and thus combines the hypolimnion and monimolimnion, it overestimates ammonium concentration in the hypolimnion during meromixis and underestimates ammonium concentration in the monimolimnion.

The model estimates of annual primary production for 1983-1990 ranged from 15 to 40 g N/m^2, which is equivalent to 90-240 grams of carbon per meter squared per year (g $C/m^2/yr$) (Jellison, Dana, Romero, and Melack 1992). These estimates are well below measured rates reported by Jellison and Melack (in press). However, the measured rates are for the upper 18 meters of the water column, while the model estimates are for the mixed layer only, which was often substantially less than 18 meters. Brine shrimp production estimates for same period ranged from 1.6 to 4.8 g $N/m^2/yr$ or, equivalently, 9.6 to 28.8 g $C/m^2/yr$ (Jellison, Dana, Romero, and Melack 1992). These values agree well with independent estimates of 16-23 g $C/m^2/yr$ for the period.

Brine Shrimp Submodel

Model Description

The brine shrimp submodel simulates hatching of cysts, grazing, growth, development, naupliar production, cyst production, excretion, defecation, and mortality of a population of brine shrimp (Jellison, Dana, Romero, and Melack 1992). As noted earlier, the brine shrimp and nitrogen submodels are linked in the assessment model to reflect the strong feedbacks between algal biomass, brine shrimp grazing, and brine shrimp excretion.

Brine Shrimp Growth and Development. Brine shrimp growth is modeled by incrementing their weight by a fixed proportion (44%) of the weight of the grazed algae. Grazing and growth are computed in terms of nitrogen content (i.e., weight of nitrogen consumed and nitrogen weight added to body tissue). Linking growth directly to grazing was necessary to capture the tight coupling of the algae and the brine shrimp population. Because grazing rate is influenced by algal biomass and temperature, growth rate also is linked to these variables.

Development of the brine shrimp is modeled as movement of individuals through lifestages. As noted earlier, each of the 12 stages (instars) of the brine shrimp is divided into three weight classes (Table M-1). Movement of the brine shrimp from one weight class to the next depends on their growth. The fraction of the brine shrimp that move to the next weight class each day is computed as the weight gain per individual in the weight class divided by the difference in weights of the two weight classes. If, for example, the weight gain in the first weight class is 0.0211 μg N per individual, the difference between the weights of the first and second weight classes is 0.0422 μg N (Table M-1]), so 0.0211/0.0422 = 1/2 of the shrimp in the first weight class move to the second weight class.

Brine Shrimp Reproduction. The model assumes no growth takes place during the adult stage. For ovigerous females, all retained nitrogen (i.e., that grazed but not lost to feces and excretion) is devoted to production of nauplii (ovoviviparity) or cysts (oviparity). The reproductive efficiency, or proportion of grazed algae used by ovigerous females for production of nauplii and cysts, is 0.3. The model assumes that adult males and nonovigerous females retain no nitrogen (i.e., they immediately recycle all ingested nitrogen through excretion, defecation, or mortality). To compute naupliar and cyst production, the model first computes total grazing by ovigerous females as the product of total weight (as nitrogen) of algae grazed by the adults multiplied by the proportion of adults that are female and the proportion of females that are ovigerous. Both proportions are assumed constant (proportion female = 0.41; proportion ovigerous = 0.84). The product is multiplied by 0.3, the reproductive efficiency. The total number of nauplii and cysts produced is determined by dividing the total naupliar and cyst production by the individual weight of a nauplius or cyst (0.2636 μg N).

Division of the total number of nauplii and cysts produced depends on the time of year, water temperature, algal biomass, and the number of broods previously produced. However, the relative importance of these factors is not well understood. For most of the year, a regression equation is used to determine the proportion of nauplii (P_n) on the basis of algal biomass (A) and temperature (T) (Jellison, Dana, Romero, and Melack 1992):

$$P_n = 1.432 - 0.936xT + 0.00054xA$$

This equation poorly predicts the proportion of nauplii during September-December when only a small fraction of the females (usually less than 2%) are producing nauplii. Therefore, the model assumes a constant 2% naupliar production for this period. The model also assumes that naupliar production is limited to the first two broods of a female and that the proportion of second broods consisting of nauplii is half that of first broods.

The initial size of the brine shrimp population each year depends on the number of cysts produced in the previous year and their hatching success. However, for simulations comparing alternative lake levels, number of cysts produced was held constant at 1.6 million cysts per square meter (the estimated number produced in 1984) to simplify comparisons. The percentage of cysts that hatch was set at 1%. The mean day of cyst hatching in the model is March 15. A normal distribution with a standard deviation of 15 days was used to model the variability in the day of hatching. Thus, 95% of the cysts are assumed to hatch between mid-February and mid-April.

Brine Shrimp Mortality. Mortality of brine shrimp was modeled by removing from the population each day a proportion (mortality rate) of the individuals in each age class. Separate mortality rates were estimated for nauplii, juveniles, and adults. The model uses a constant mortality rate (0.025 per day) for juveniles, but the mortality rate for nauplii (M_n) increases as algal biomass (A) and temperature (T) decrease, in accordance with the following equation:

$$M_n = 0.007 \text{ x } (A+45.5)/A \text{ x } (T+2.2)/T$$

The mortality rate for adults is set at 0.01 per day initially and is increased 30% for each brood produced. The constant increase in mortality rate of adults was required to simulate the observed population decline in fall.

Salinity Effects. The effects of salinity on brine shrimp population dynamics were estimated from results of the salinity bioassays (Jellison, Dana, Romero, and Melack 1992). Effects on algal growth were taken from Melack (1985). The model probably underestimates the effects of salinity on the brine shrimp because food was abundant in all the salinity bioassays. Jellison, Dana, Romero, and Melack (1992b) argue that salinity effects are probably greater under low food conditions than under high food conditions because the requirement to maintain osmotic balance takes precedence over other energy needs.

The effect of salinity on brine shrimp growth is incorporated into the model by computing growth efficiency (GE) with the following equation:

$$GE = 17.67 \times \frac{1.743-(0.0073 \times TDS)}{e^{3.21+(0.006 \times TDS)}}$$

where TDS is salinity as g/l TDS. Growth efficiency is increased by about 30%, from 0.44 to 0.57, as salinity is reduced from 92 g/l to 71 g/l (corresponding to an increase in lake surface elevation from 6,375 feet to 6,390 feet) (Jellison, Dana, Romero, and Melack 1992). Conversely, growth efficiency is reduced by about 32%, from 0.44 to 0.30, if salinity is raised to 120 g/l (corresponding to a lake level of 6,360 feet).

Reproductive efficiency (RE), percent ovigerity (i.e., percent ovigerous females) (PO), cyst hatching success (HS), and maximum rate of algal growth (AG) also increase in the model as salinity declines, whereas base mortality rates of juveniles (MJ) and adults (MA), the peak day of cysts hatching (HD), and percent ovoviviparity (i.e., percent of broods containing nauplii rather than cysts) (PV) decrease. The equations used to calculate all these effects are as follows:

$$RE = 0.064 \times \frac{65.8-(0.28 \times TDS)}{e^{1.809+(0.0036) \times TDS}}$$

$$PO = 0.0088 \times 135-(0.429 \times TDS)$$

$$HS = 0.00013 \times 100-e^{1.21+(0.021 \times TDS)}$$

$$AG = 1.25 \times e^{((TDS-92)/92)}$$

$$MA = 0.00026 \times 1+(0.411 \times TDS)$$

$$MJ = 0.00064 \times 1+(0.411 \times TDS)$$

$$HD = 75 - (6.90-e^{(0.0116 \times TDS)+0.865}$$

$$PV = P_n/64.85 \times e^{(0.031xTDS)+1.32}$$

where P_n is computed using the regression equation given earlier. All changes in model parameters cause higher brine shrimp production at lower salinities (i.e., higher lake levels) except for the change in percent ovoviviparity, which has the opposite effect. However, the ovoviviparity results are suspect because percent ovoviviparity in the bioassays was consistently much lower than that observed in the first generation of brine shrimp in the field (Jellison, Dana, Romero, and Melack 1992).

Because of trophic interactions, productivity of the brine shrimp population would probably be much less affected by increases in salinity than are suggested by the direct effects of salinity on the brine shrimp. For instance, because brine shrimp food is limited much of the year, reductions in brine shrimp growth efficiency because of higher salinity would result in more ammonium excretion and algal growth, thereby allowing higher brine shrimp grazing and growth rates. The effects of salinity cannot be properly understood in isolation from the other factors that affect brine shrimp production.

Submodel Inputs

Daily mean epilimnetic depth, temperature, and algal biomass are required inputs for the brine shrimp submodel. Algal biomass is estimated in the nitrogen submodel, while values for the other variables are estimated from 1984 (for meromictic conditions) or 1990 (for monomictic conditions) field data. Adjustment factors are input for several model parameters to account for effects of the different salinities at the alternative lake levels.

Submodel Outputs

The brine shrimp submodel outputs daily biomass (as nitrogen) and numerical density estimates for each brine shrimp instar. These estimates can be used to plot trajectories of instar abundance over time. The submodel also provides daily and annual estimates of secondary production and cyst production. Daily rates of excretion and grazing are output and used as inputs to the nitrogen submodel.

Submodel Validation

The brine shrimp submodel was validated by comparing simulation results of brine shrimp abundance in 1984 and 1990 with field data. The model fairly accurately described the timing and abundance of adults, but naupliar and juvenile abundances were less well simulated (Figure M-8). Naupliar and juvenile abundances in the model are strongly affected by the timing and distribution of the spring hatch (Jellison, Dana, Romero, and Melack 1992). In reality, the spring hatch is likely to be highly variable, but the factors affecting it are poorly understood. In any case, naupliar and juvenile abundance patterns seem to have little effect on overall brine shrimp and cyst production (Jellison, Dana, Romero, and Melack 1992). Annual brine shrimp production for 1983-1990, as noted earlier, was simulated quite accurately.

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Table M-1. Least Squared Mean Weights (as nitrogen [N]) of Brine Shrimp Life Stages (Instars) and Nominal Weights (as nitrogen [N]) of Submodel Weight Classes

Instar	Mean Weight (mg N)	Weight Class	Weight (mg N)
		1	0.0002636
1	0.0003058	2	0.0003058
		3	0.0003547
		4	0.0004115
2	0.0004774	5	0.0004774
		6	0.0005539
		7	0.0006426
3	0.0007455	8	0.0007455
		9	0.0008649
		10	0.001003
4	0.001164	11	0.001164
		12	0.001350
		13	0.001567
5	0.001818	14	0.001818
		15	0.002109
		16	0.002446
6	0.002838	17	0.002838
		18	0.003292
		19	0.003820
7	0.004431	20	0.004431
		21	0.005141
		22	0.005964
8	0.006919	23	0.006919
		24	0.008027
		25	0.009313
9	0.01080	26	0.01080
		27	0.01253
		28	0.01454
10	0.01687	29	0.01687
		30	0.01957
		31	0.02270
11	0.02634	32	0.02634
		33	0.03056
		34	0.03545
12	0.35454	35	0.03545
		36	0.03545

Table M-2. Nitrogen Equivalents

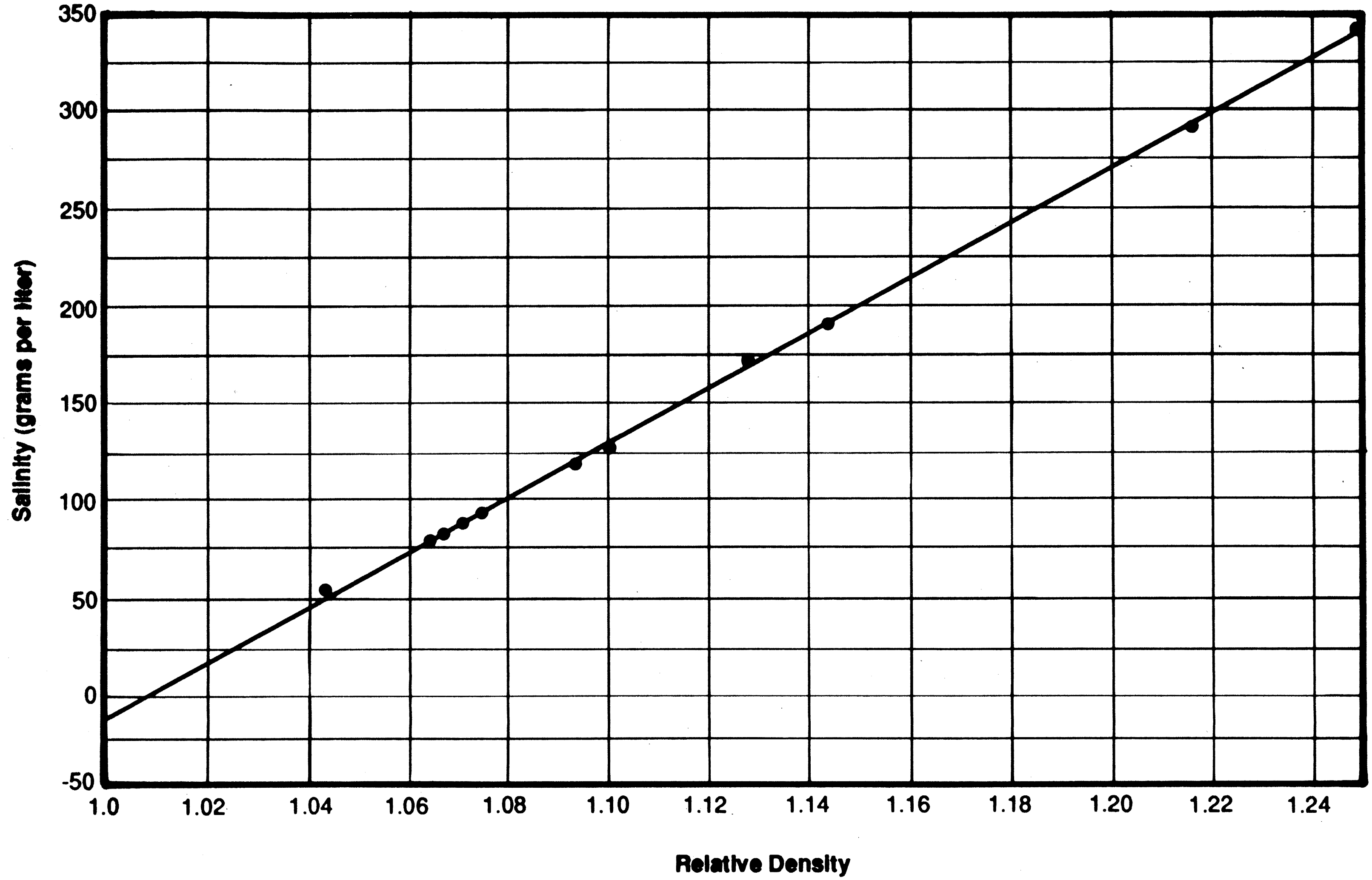
Variable	Nitrogen (N) Equivalents
Ammonium (1 micromole)	14 mg/m^3
Algae	
Biomass[a]	0.05 gram
Production[b]	0.167 gram
Brine shrimp	
Biomass or production[c]	0.07 gram
Production[d]	0.167 gram

[a] Measured as chlorophyll *a*.

[b] Measured as 1 gram of carbon.

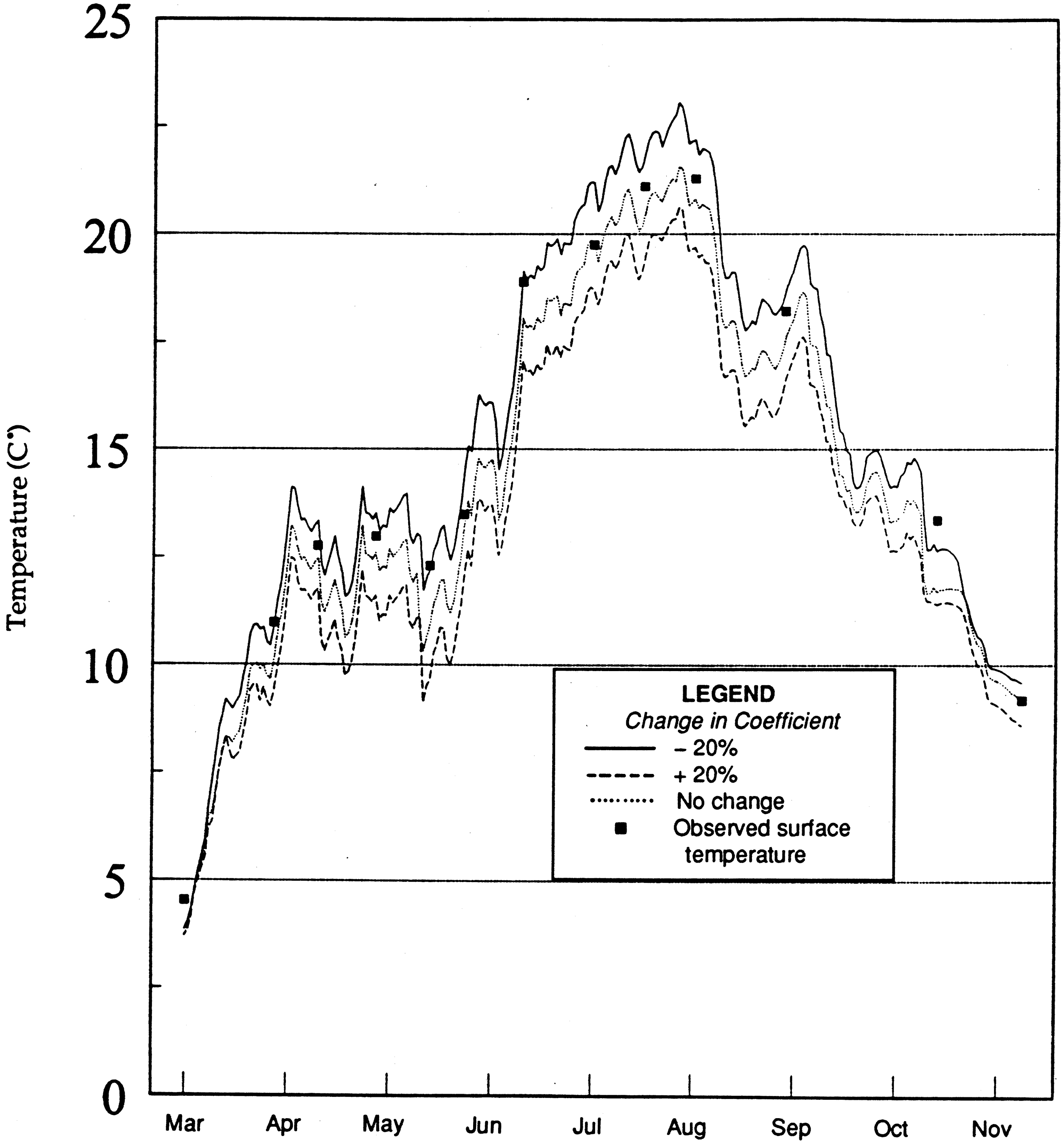
[c] Measured as 1 gram of dry mass.

[d] Measured as 1 gram of carbon.



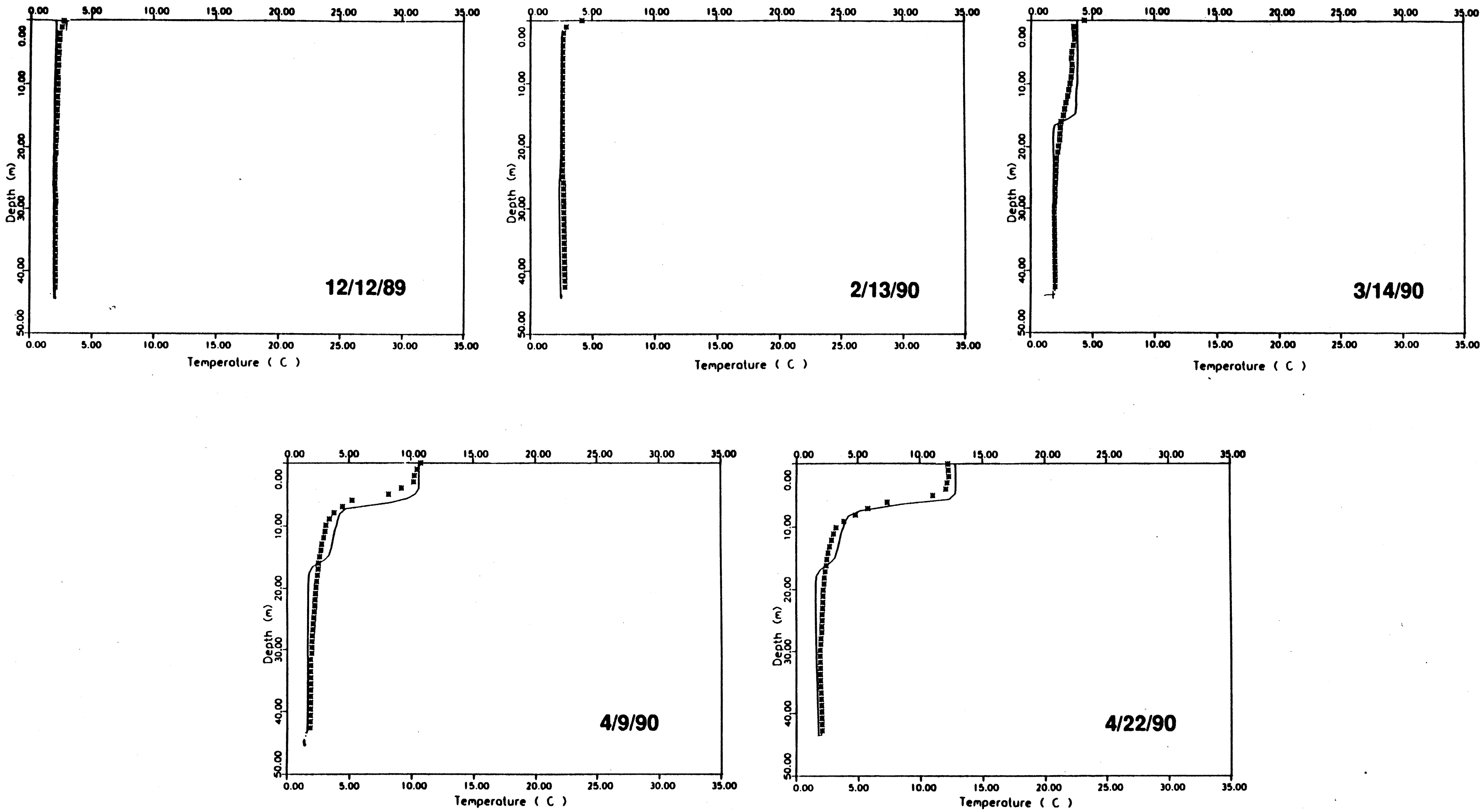
Source: Adapted from Dana, Jellison, Romero, and Melack 1992

Figure M-1.
Relationship of Salinity and Relative Density of Mono Lake Water



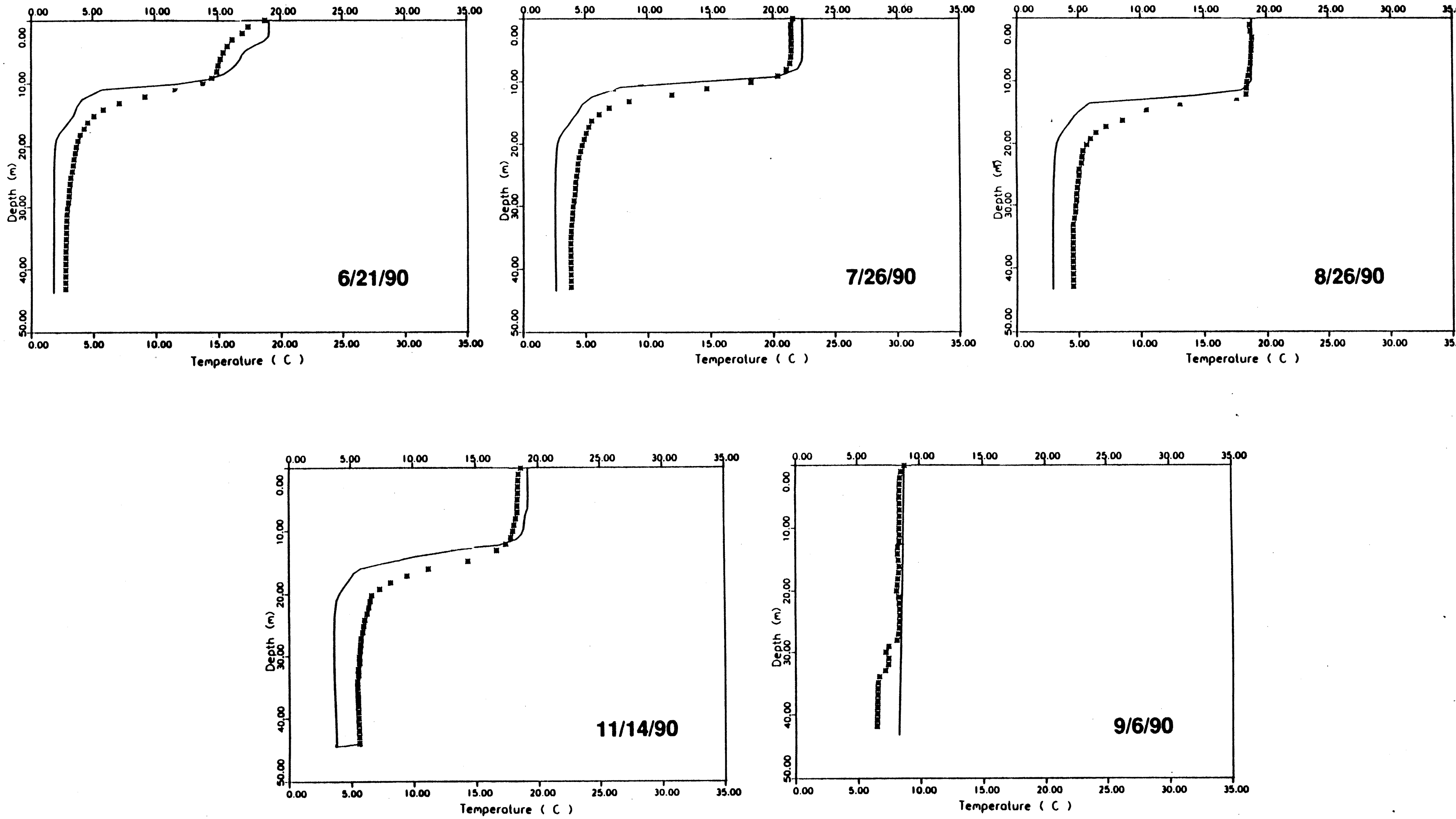
Source: Adapted from Dana, Jellison, Romero and Melack 1992

Figure M-2.
Effect of Changes in Bulk Exchange Evaporation Coefficient on Predicted Surface Water Temperatures



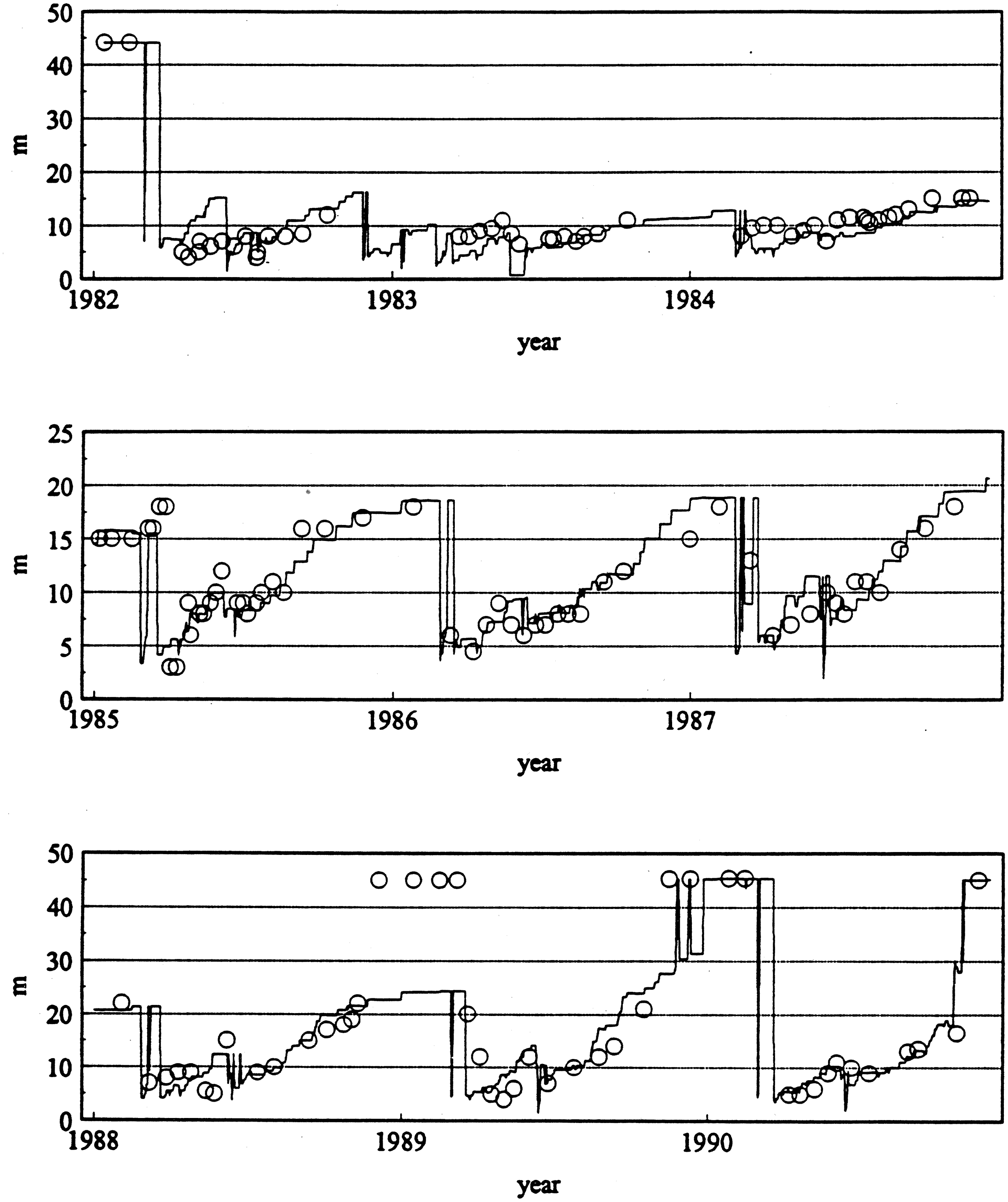
Source: Adapted from Dana, Jellison, Romero, and Melack 1992

Figure M-3.
Observed and Predicted Temperature Profiles in Mono Lake



Source: Adapted from Dana, Jellison, Romero, and Melack 1992

Figure M-3.
Continued

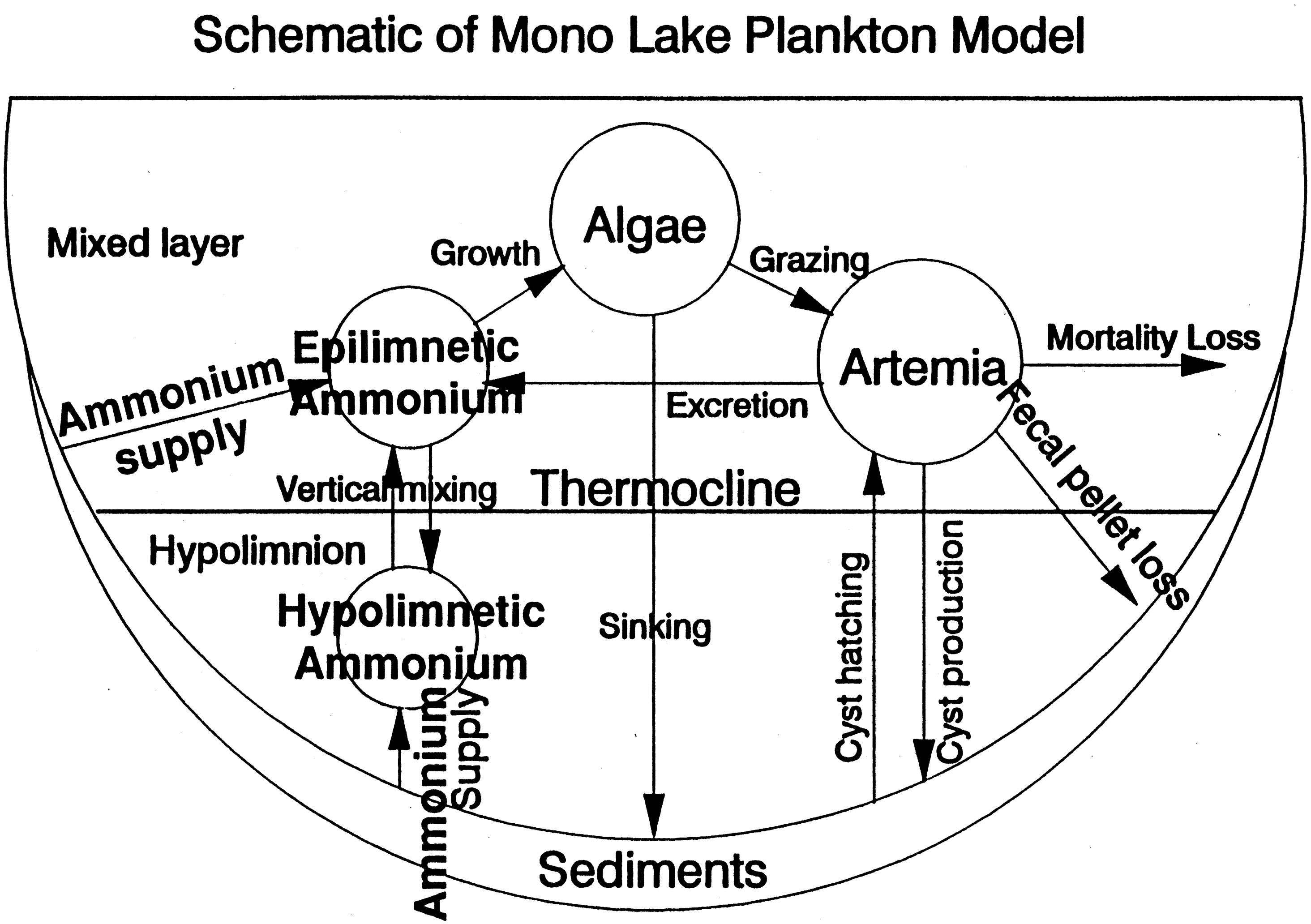


Source: Dana, Jellison, Romero, and Melack 1992

Figure M-4.
Observed and Predicted Depth of the Mixed Layer
in Mono Lake, 1982-1990

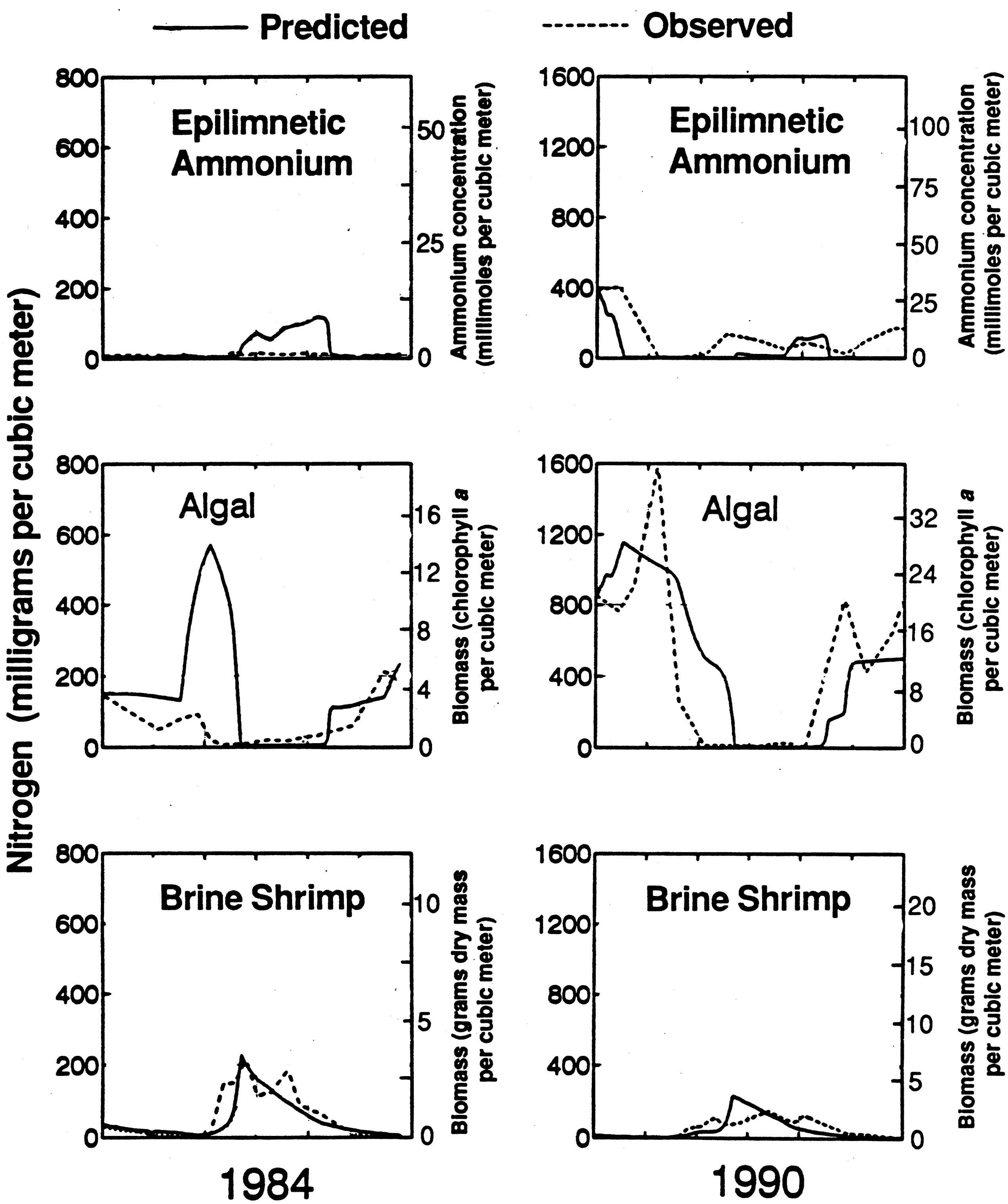
MONO BASIN EIR

Prepared by Jones & Stokes Associates



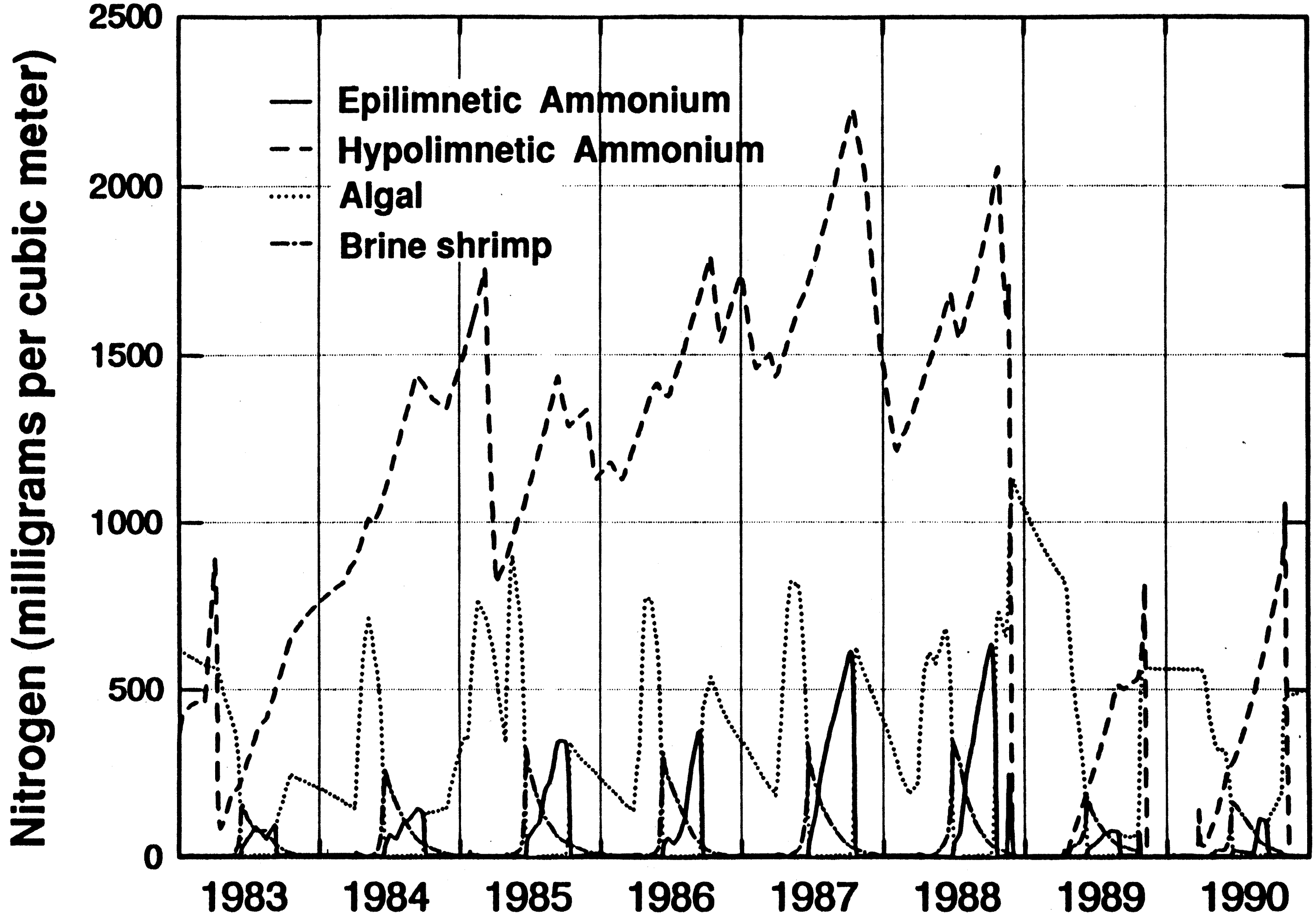
Source: Dana, Jellison, Romero, and Melack 1992

Figure M-5.
Schematic of Brine Shrimp Nitrogen Submodel



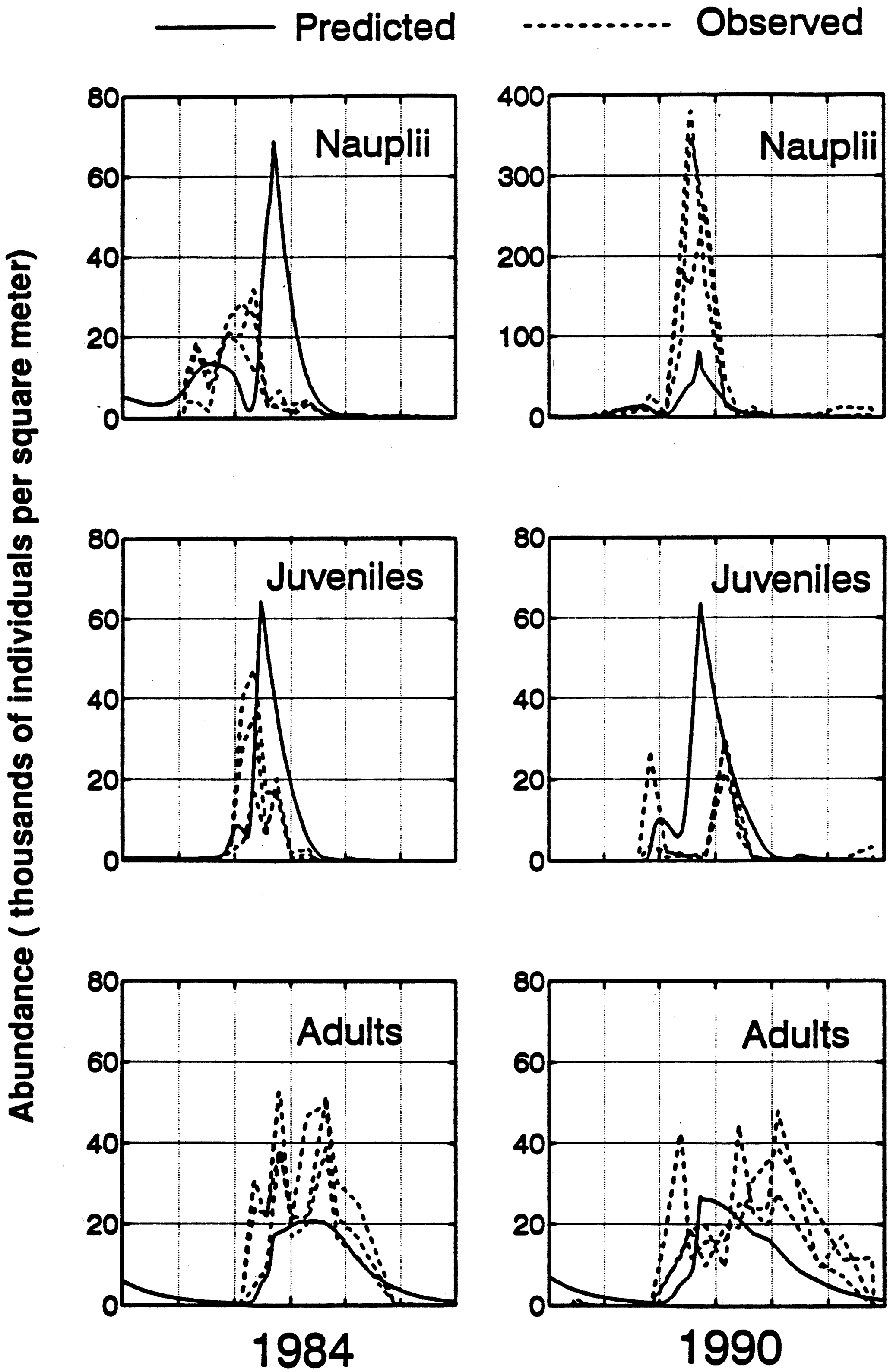
Source: Adapted from Dana, Jellison, Romero, and Melack 1992

Figure M-6.
Predicted and Observed Partitioning of Nitrogen in Mono Lake in 1984, a Meromictic Year, and 1990, a Monomictic Year



Source: Dana, Jellison, Romero, and Melack 1992

Figure M-7.
Eight-Year Simulation of Nitrogen Concentration in Mono Lake

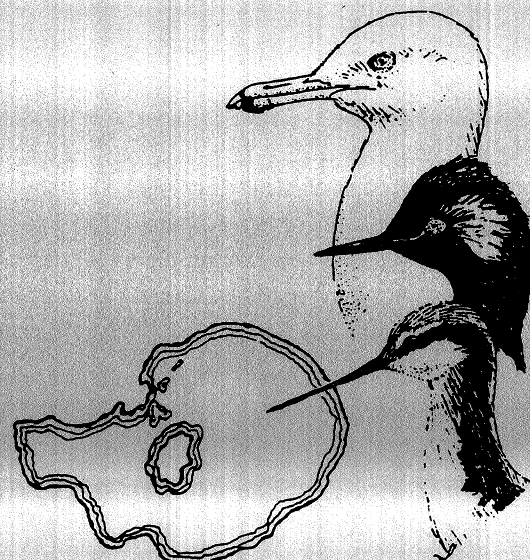


Note: Observed data are from three different stations.

Source: Dana, Jellison, Romero, and Melack 1992

Figure M-8.
Predicted and Observed Abundances of Brine Shrimp Nauplii, Juveniles, and Adults in Mono Lake in 1984, a Meromictic Year, and 1990, a Monomictic Year

Appendix N. Air Quality Background Information



Mono Basin EIR

Prepared by Jones & Stokes Associates

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AIR QUALITY BACKGROUND INFORMATION

Particle Size Terminology

Physical particle size is important to many industrial process operations. Pollution control and medical considerations, however, are more easily addressed by considering particle behavior rather than particle size. Two considerations of special importance to pollution control and medical evaluations are the rate at which particles settle in still air and the extent to which particles in a moving air stream will be removed by inertial impaction if the air stream follows a bent or curved path. Large, dense particles settle rapidly and are easily removed from an air stream by inertial impaction; small, low density particles settle very slowly and tend to follow a bent or curved air stream pathway.

Several particle diameter terms are used to describe particle size and aerodynamic behavior. Allen (1990) provides a partial list of 13 particle diameter definitions, only four of which reflect the actual physical dimensions of a particle. The other nine definitions refer to the diameters of circles or spheres with the same perimeter, surface area, volume, or surface-to-volume ratio as the actual particle or its image in a microscope. Unfortunately, most air pollution discussions refer only to particle size ranges without clarifying which technical definition has been used.

The definitions used or implied most frequently in ambient air quality discussions are presented below. A sieve diameter is usually implied when large particles have been mechanically sorted into size categories. Particle size determinations based on microscopic examination may reflect any of several definitions, with the projected area diameter being a common definition. Particle size information provided by ambient air quality sampling instruments usually refers to the aerodynamic equivalent diameter.

Sieve Diameter

The sieve diameter of a particle is the width of the minimum square aperture through which the particle will pass. Because many particles have complex physical shapes, the sieve diameter will often be larger than the minimum physical dimension and smaller than the maximum physical dimension of the particle.

Projected Area Diameter

The projected area diameter of a particle is the diameter of a circle having the same enclosed area as the outline of the particle (generally viewed or photographed through a microscope). Two different projected area diameter definitions are widely used. One definition is based on particles in a random orientation. The other is based on particles resting in a stable orientation.

Equivalent (Volume) Diameter

Because most suspended particulate matter has an irregular shape, the equivalent spherical diameter (generally referred to as the equivalent diameter) is used as a standardized description of physical particle size. The equivalent diameter is calculated by measuring the volume of a particle and computing the diameter of a sphere having the same volume. Some references use the term "volume diameter" instead of equivalent diameter.

Sedimentation (Stokes) Diameter

The sedimentation (or Stokes) diameter of a particle is based on the terminal settling velocity of a particle in still air. The sedimentation diameter is the diameter of a sphere having the same terminal settling velocity and density as the particle. Some references use the term "free-falling diameter" for evaluations based on the terminal settling velocity in fluids other than air.

Aerodynamic Equivalent Diameter

The aerodynamic equivalent diameter of a particle also is based on the terminal settling velocity of a particle in still air. The aerodynamic equivalent diameter is the diameter of a sphere with a density of 1 gram per cubic centimeter that has the same terminal settling velocity as the particle. Thus, the aerodynamic equivalent diameter differs from the sedimentation diameter of a particle whenever the real particle has a density other than 1 gram per cubic centimeter. For convenience, the term "aerodynamic equivalent diameter" is often shortened to aerodynamic diameter.

Quartz Grain Equivalent Diameter

Soil scientists occasionally use the term "equivalent diameter" when discussing particle sizes associated with wind erosion, but define the term differently than do atmospheric scientists. The term used by soil scientists is less ambiguous if phrased as "quartz grain equivalent diameter". Soil scientists calculate the quartz grain equivalent diameter by multiplying the sieve diameter of a particle by the density of the suspended particle or particle aggregate and dividing that product by the particle density of quartz (2.65 grams per cubic centimeter). If particle aggregates are being considered, the density of the aggregate is treated as a bulk density (including pore spaces within the particle aggregate).

Particle Size Ranges for TSP and PM_{10}

Until the mid-1980s, federal and state particulate matter standards applied to a broad range of particle sizes and were referred to as total suspended particulate matter (TSP) standards. The high-volume samplers used at TSP monitoring stations are most effective in collecting particles with aerodynamic diameters smaller than 30-50 microns, although larger particles also are collected (U.S. Environmental Protection Agency 1982, Lodge 1989).

Health concerns associated with suspended particles focus on those particles small enough to reach the lower respiratory tract (tracheobronchial passages and alveoli in the lungs) when inhaled. When breathing occurs through the nose, few particles with an aerodynamic diameter larger than 10 microns reach the lower respiratory tract. When breathing occurs through the mouth, particles with aerodynamic diameters as large as 20 microns may reach the lower respiratory tract (U.S. Environmental Protection Agency 1982). Not all particles with small aerodynamic diameters reach the lower respiratory tract; some are removed in the nasal passages, mouth, or upper throat regions.

Both the federal and state air quality standards for particulate matter have been revised to apply only to "inhalable" particles (generally designated PM_{10}) with a size distribution weighted toward particles having aerodynamic diameters of 10 microns or less. The particle size distribution implied by the PM_{10} definition is intended to approximate the size distribution of particles that reach the lower respiratory tract. The State of California converted from a TSP standard to a PM_{10} standard in 1983; the federal government converted from a TSP standard to a PM_{10} standard in 1987.

It is difficult to relate the former TSP and current PM_{10} standards to a precise range of physical particle sizes. Although the TSP designation does not have any obvious particle size connotations, the use of the word "total" in total suspended particulate matter implies 100% collection efficiency over a large range of particle sizes. As explained below, very few particle sizes are sampled with 100% efficiency by a TSP sampler.

The PM_{10} designation seems to imply a rather precise size limit. The most widely quoted definition of PM_{10} is "particulate matter smaller than 10 microns in (aerodynamic) diameter." Unfortunately, that simple definition is incorrect. The only absolute size limit that can be established for PM_{10} is substantially larger than 10 microns.

The true definitions of TSP and PM_{10} are derived by considering the equipment used to collect samples of suspended particulate matter.

Sampling Criteria for TSP and PM_{10} Collectors

Both the former TSP standards and the current PM_{10} standards have been defined primarily by the type of equipment used to collect suspended particulate matter samples. The sampling equipment incorporates inlet designs intended to exclude particles with large aerodynamic diameters. Because aerodynamic diameters are not an actual physical dimension, perfect screening of particle sizes is impossible. Some particles outside the target size range will be collected and some within the target size range will be excluded.

The performance of TSP and PM_{10} sampling equipment is characterized by the "aerodynamic cutpoint diameter" of the collector inlet. The aerodynamic cutpoint diameter is the aerodynamic diameter at which the device excludes 50% of the mass of the corresponding ambient particles.

Design criteria for TSP samplers do not include tight tolerances on the size distribution of collected particles. Most TSP collectors have rectangular or square inlets with a peaked-roof precipitation shield. The design of standard TSP sampler inlets causes the cutpoint diameter of a TSP collector to vary with relative wind direction and wind speed.

No specific aerodynamic cutpoint diameter criteria were specified in the former federal TSP standards. Most references (e.g., U.S. Environmental Protection Agency 1982, Lodge 1989) indicate that TSP collectors have an aerodynamic cutpoint diameter of 30-50 microns under common wind speed conditions. The limited published literature on TSP collector sampling efficiency (Wedding et al. 1977, McFarland et al. 1979) implies a much broader range of aerodynamic cutpoint diameters (13-67 microns) depending on wind speed and relative wind direction. According to McFarland et al. (1979), the aerodynamic cutpoint diameter of TSP collectors decreases at high wind speeds and increases at low wind speeds.

The high-volume samplers used to monitor compliance with the current PM_{10} standards have a narrow aerodynamic cutpoint diameter range of 9.5-10.5 microns. PM_{10} samplers also incorporate round inlet designs that are not sensitive to relative wind direction. In addition, PM_{10} samplers are much less sensitive to wind speed than are TSP samplers.

The 10-micron component of the PM_{10} definition refers to a 50% collection efficiency measure, not an absolute size limit. When operated during wind speeds of 1-15 mph, an acceptable PM_{10} sampler must collect 45-55% of the mass of particles with aerodynamic equivalent diameters of 9.5- 10.5 microns. In addition, the size-based collection efficiency curve derived for the sampler must pass a test for total particle mass collection. When the collection efficiency curve is applied to a standardized particle mass distribution, the calculated total mass of collected particles must be within 10% of the total mass calculated for the "ideal" PM_{10} sampler collection efficiency curve. The standardized particle mass distribution used for the mass collection test includes particle sizes ranging from less than 1 micron to 45 microns in aerodynamic diameter.

Sampling Efficiency Curves for TSP and PM_{10} Collectors

Although the aerodynamic cutpoint diameter is useful as a single number for characterizing collector performance, proper understanding of the particle sizes collected by TSP and PM_{10} samplers requires a more complete description of collection efficiencies at various particle sizes.

Few studies have been performed to characterize the effectiveness of TSP samplers in collecting particles of various size ranges. Some of the studies that have been performed examined only a limited range of particle sizes. Figure N-1 illustrates the range of measured and extrapolated collection efficiencies for TSP samplers under variable wind speed and direction conditions.

The EPA definition of an ideal PM_{10} sampler is illustrated in Figure N-2. An ideal PM_{10} sampler would collect 50% of the particle mass present in the 10- to 10.5-micron aerodynamic diameter size range and would not collect any particles with aerodynamic diameters larger than 16 microns. In practice, most actual PM_{10} samplers will collect some particles with aerodynamic diameters of 25-30 microns (Purdue 1988, Lippmann 1989). The formal specifications for PM_{10} samplers imply an absolute aerodynamic diameter limit of 45-50 microns (40 CFR 53.43).

Figure N-2 includes representative upper and lower size distribution limits for PM_{10} sampler performance. Absolute upper and lower size distribution limits cannot be defined precisely because many different distribution curves can be drawn that meet both the cutpoint diameter and the 10% mass variation criteria. A sampler that collects 100% of all particles with aerodynamic diameters smaller than 10 microns and 0% of all particles with aerodynamic diameters larger than 10 microns would meet certification requirements but would not represent an ideal PM_{10} sampler.

Figure N-3 provides a comparison of collection efficiency curves for typical TSP and PM_{10} collectors. The collection efficiency curve for a typical TSP collector reflects varying wind directions and wind speeds predominantly in the 5-10 mph range.

HISTORICAL DESCRIPTIONS OF MONO BASIN CONDITIONS

I. C. Russell's Geological Study

Russell (1984) described the floor of the Mono Valley as a sloping plain with sage brush vegetation, scattered sand dunes, and a series of ancient beaches. Russell's reference to "dunes of drifting sand" implies that at least some of the sand dunes were not stabilized. The eastern shore of Mono Lake near Warm Springs was described as windrows of sand, gravel, and larval cases of the brine fly. The sand and gravel were characterized as volcanic in origin, with fragments of pumice.

Russell noted that on windy days Mono Lake was streaked with an alkaline froth. He described this froth as collecting on the leeward shore in a band "many rods wide and sometimes several feet thick" (a rod is 16.5 feet). He described "sheets of this tenacious froth" blowing inland through the desert shrubs "in fluffy masses that look like balls of cotton". When viewed from the surrounding mountains on a windy day, the fringe of white foam made the outline of the lake "unusually distinct".

Russell recognized tufa deposits as being a calcium carbonate precipitate formed under water. However, he failed to identify the factors that produced different physical forms of tufa deposits. He characterized tufa crags as being composed of three physical forms of tufa (lithoid tufa, thinolite crystals, and dendritic tufa), all of which are a calcium carbonate deposit. He noted that sands and pumice fragments along the lake shore were often cemented with an amorphous calcium carbonate deposit he called "stony" tufa. He also observed tufa-cemented sands and gravels in the terraces and beaches of former shore-lines.

Russell mentions that efflorescent salts were found in two situations: in the exposed cavities of partially submerged tufa crags and in cave-like recesses in cliffs at water's edge, especially on Paoha Island. He characterized the efflorescent salts as being primarily sodium carbonate and sodium sulfate, in contrast to the calcium carbonate of tufa deposits. He also recognized that efflorescent salt deposits form only on porous substrates exposed to the air as capillary action draws salty water to the surface.

Other Written Accounts

Some other early accounts of Mono Lake make passing references to "alkali" deposits. A careful reading of these accounts reveals that the writers were usually describing tufa formations and amorphous tufa deposits, not alkaline salt deposits. Three examples of such accounts are presented below.

Browne (1961) described Mono Lake as it appeared in the mid-1860s, making several references to alkaline incrustations of calcareous deposits. Browne described former lakeshore strand lines as follows: "On the eastern shore low plains or alluvial bottoms, incrusted with alkali, show in distinct curvicular rims, composed of calcareous deposits, the gradual retrocession of the lake to its present level." (Browne 1961, page 49.)

Browne's drawings of the lake shore clearly show tufa towers. Browne described these lakeshore deposits as follows:

> The shores of Lake Mono, in the vicinity of the water, have a whitish color, arising from the prevalence of calcareous deposits [Browne 1961, page 48] . . . . The beach is strewn with beautiful specimens of boracic or alkaline incrustations. Weeds, twigs, stones, and even dead birds and animals, are covered by this peculiar coating, and present the appearance of coral

> formations. Some specimens that I picked up are photographic in the minuteness and delicacy of their details. . . . It is commonly supposed that these are formations of white coral; but there is no doubt that they are produced by the chemical action of the water, which at frequent intervals is forced up through the fissures of the earth by subterranean heat. These springs are numerous, and probably form around them a base of calcareous matter, which by constant accretions rises above the surrounding level [Browne 1961, pages 49-51].

A brief but similar description of deposits on one of Mono Lake's islands (presumably Paoha Island) dates from 1865: "There are to be found, all over these islands, some of the most beautiful calcareous and alkaline incrustations, which form on the surface of everything that the water of either the lake or that emitted from the hot springs happens to come in contact with." (The Mining and Scientific Press, October 7, 1865, page 210.)

Chase (1911) provided a brief and rather cryptic description of the shore of Mono Lake: "The shores are whitened with alkaline incrustations, and the branches and twigs of dead trees that rise above the surface are petrified to the semblance of bone." (Chase 1911, pages 308-309.)

A map that accompanies Chase's book indicates that he reached the shore of Mono Lake by following a wagon road along Rush Creek. Thus, Chase's description is probably a reference to tufa deposits in the South Tufa or Lee Vining tufa areas.

While all the writers quoted above use the term alkali or alkaline, none of them make any specific mention of salts or salt deposits. The clear implication from these accounts is that many early observers used the term alkali as a synonym for any white mineral deposit.

SUPPLEMENTAL METEOROLOGICAL AND AIR QUALITY DATA

Lee Vining and Simis Ranch Wind Patterns

Table N-1 summarizes seasonal and annual wind patterns for Lee Vining according to time of day. Table N-2 summarizes seasonal and annual wind patterns for Simis Ranch according to time of day.

Low Concentration PM_{10} Events

Figure N-4 shows the monthly pattern of very low PM_{10} measurements from the Simis Ranch monitoring station. Figure N-5 shows the monthly pattern of very low PM_{10} concentrations from the Lee Vining monitoring station.

Observed Relationship between TSP and PM_{10} Concentrations at Mono Lake

Table N-3 presents a detailed summary of the relationship between TSP and PM_{10} concentrations at Simis Ranch. PM_{10} concentrations have generally been 25%-75% of the concurrent TSP concentration. The average relationship between PM_{10} and TSP concentrations does not vary significantly from low to high PM_{10} concentrations. The range of PM_{10}-to-TSP ratios is greater at low PM_{10} concentrations than at high PM_{10} concentrations. There have been several instances when measured PM_{10} concentrations exceeded measured TSP concentrations.

The wide range of PM_{10}-to-TSP ratios may result in part from artifacts of sample handling and analysis. The wide range of ratios may also reflect inherent differences in sampling effectiveness between PM_{10} and TSP samplers. At very low particulate matter concentrations (especially those composed of small particle sizes), PM_{10} samplers may be more efficient than TSP samplers; this would produce some PM_{10} concentrations higher than the concurrent TSP concentrations.

Physical and Chemical Analyses of Particulate Matter Samples

No comprehensive studies of the physical, chemical, or mineralogical characteristics of erodible substrates or suspended particulate matter in Mono Basin have been performed. Limited analyses have been performed on some particulate matter samples (Kusko et al. 1981, Kusko and Cahill 1984, NEA 1990) and a few soil samples (Kusko et al. 1981, Truesdail Laboratories 1981). A few soil samples have been analyzed for particle size distributions (Truesdail Laboratories 1981). One study of particle size distributions by the RJ Lee Group was available only as a summary document in court proceeding exhibits (Superior Court of the State of California for the County of El Dorado 1990). None of the chemical or particle size analyses have distinguished the mineralogical components of the material being evaluated.

None of the studies have analyzed particle densities (specific gravities) or have clearly described the procedures used to measure particle size; consequently, the available data are a mixture of sieve diameters, unexplained physical dimension measurements, and aerodynamic equivalent diameter.

Physical Characteristics

Truesdail Laboratories (1981) analyzed ten soil samples collected from various locations around Mono Lake. The general locations at which the samples were collected are indicated. No descriptions of the soil or sediment conditions at the sampling sites are included in the report. Table N-4 summarizes the particle size analysis results reported.

Actual suspended particulate matter samples collected by the GBUAPCD have been examined microscopically by the RJ Lee Group using manual and computer-controlled scanning electron microscope techniques. Most of the filter samples analyzed by the RJ Lee Group were PM_{10} samples; one filter sample from Simis Ranch and 11 filter samples from the Binderup site were TSP samples. The summary of the RJ Lee Group results does not describe the procedure used for measuring particle sizes, thus making the data difficult to interpret.

Chemical Composition

Several studies have included chemical analyses of soil samples or suspended particulate matter samples. All these chemical analyses, however, have been limited to elemental analyses and determinations of a few major ion groups (e.g., sulfates, nitrates, or chlorides). None of the studies have attempted to determine specific chemical compounds or mineralogical components.

Summary of Air Quality Monitoring Data Collected by the University of California, Davis

Data from air quality monitoring studies conducted in Mono County by researchers from the UC Davis are summarized in Table N-5. The sampling inlet for monitoring equipment used for this study had a nominal aerodynamic cutpoint diameter of 15 microns. Stacked filters were used to separate particles into two size categories. An upper filter allowed fine particles to pass through to a bottom filter. The upper filter provided an aerodynamic cutpoint diameter of 2.5 microns (Cahill et al. 1990). As discussed previously, aerodynamic diameters are not physical dimensions and aerodynamic cutpoint diameters represent a 50% collection efficiency, not an absolute size discrimination. For convenience, however, results from the two filters have been described as representing aerodynamic diameters smaller than 2.5 microns or between 2.5 and 15 microns. Combined results from the two filters provide a nominal PM_{15} measurement.

The nominal aerodynamic cutpoint diameter of the sampler inlet introduces a minor complication for comparing data to the current PM_{10} standards. The inlet for the stacked filter unit samplers used in the UC Davis studies have an aerodynamic cutpoint diameter of 15 microns in still air, decreasing to 11 microns at an ambient wind speed of 13.7 mph (Cahill et al. 1990). As a practical matter, the PM_{15} values reported by Kusko et al. (1981) are probably 25% higher than PM_{10} values. A more important complication affecting interpretation of the UC Davis data involves the duration of sampling.

As indicated in Table N-5, monitoring instruments operated continuously for 1-week periods during most of the study. PM_{15} data for multiday periods cannot be directly compared with the current 24-hour PM_{10} standards. Nevertheless, weekly average PM_{15} values above 40 $\mu g/m^3$ suggest the occurrence of at least one 24-hour episode of PM_{10} values above 50 $\mu g/m^3$. Multiday PM_{15} data for Lee Vining exceeded 40 $\mu g/m^3$ four times during the UC Davis study and were between 35 and 40 $\mu g/m^3$ two other times.

WIND EROSION PROCESSES

Dust Storms and Sand Storms

Meteorologists use the terms "dust storm" and "sand storm" to describe episodes of windblown particulate matter that significantly restrict visibility. Visibility limits of 0.5-7 miles are used by different agencies and authors in defining dust storm and sand storm events; a visibility limit of 1 kilometer (0.62 mile) is used more often than other visibility limits (Orgill and Sehmel 1976, Goudie 1978, World Meteorological Organization 1983). Dust storms and sand storms are generally differentiated by the size range of the suspended particles. Dust storms are dominated by particles with sieve diameters smaller than 100 microns; sand storms are dominated by particles with sieve diameters larger than 100 microns (World Meteorological Organization 1983).

Particulate matter concentrations associated with dust and sand storms vary substantially depending on proximity to the source area and the averaging time associated with the concentration measurement. Chepil and Woodruff (1957) report visibility estimates and measured dust concentrations for 24 dust storm events monitored in Kansas and Colorado during 1954 and 1955. The dust concentration measurements approximate a total suspended material estimate rather than a TSP or PM_{10} measurement. Dust storm events with visibilities of 1.3-4.8 miles had dust concentrations of 3,180-9,180 $\mu g/m^3$; events with visibilities of 0.5-1.25 miles had dust concentrations of 25,070-95,350 $\mu g/m^3$. Most dust storm events with visibilities of 0.25-0.5 mile had dust concentrations of 100,000-300,000 $\mu g/m^3$.

Chepil and Woodruff (1957) report particulate matter concentrations of 1,000,000 $\mu g/m^3$ and 1,327,000 $\mu g/m^3$ for the two largest dust storms monitored in Kansas during 1954; visibilities during these dust storms were 265-370 feet. Chepil and Woodruff

(1957) also report particulate matter concentrations of 353,000-583,000 $\mu g/m^3$ for the three largest dust storms monitored in Colorado during 1955; visibilities during these dust storms were about 650-1,050 feet.

Chepil and Woodruff (1957) suggest that visibilities of about 1 kilometer are associated with dust concentrations of about 56,000 $\mu g/m^3$. Orgill and Sehmel (1976) suggest that visibility reductions to about 7 miles are associated with dust concentrations of 3,000-5,000 $\mu g/m^3$.

Meteorological conditions producing strong winds or significant vertical turbulence have the potential for producing dust storms of various sizes and durations. Weather conditions that typically have relatively short durations include various convective systems, such as squall lines and decaying thunderstorm cells. Windy conditions associated with the passage of warm and cold fronts have a somewhat variable duration. Strong mountain katabatic (downslope) wind conditions (e.g., Chinook and Santa Ana winds) also have somewhat variable durations. Windy conditions associated with strong regional pressure gradients sometimes persist for a few days.

General Mechanism of Wind Erosion

At a general level, wind erosion represents a transfer of energy from moving air to sediment and soil particles at the ground surface. At the scale of individual particles, wind erosion is the result of several interacting forces, some of which induce particle movement and others that resist particle movement. Lift, shear, and ballistic impact forces induce particle movement, and gravity, friction, and cohesion among particles resist movement. (The term "shear" as used in discussions of wind erosion processes is different from the term "wind shear" used to describe rapid changes in wind direction and velocity over short horizontal distances.)

Lift represents a difference in pressure between the top and bottom of a particle; shear represents a difference in pressure between the upwind and downwind sides of a particle. Lift represents forces producing vertical movement; shear represents forces producing horizontal movement. Together, lift and shear forces extract a particle from the ground surface and transport it downwind. Gravity and cohesion among particles resist lift forces while friction and cohesion among particles resist shear forces.

The pressure differences that generate lift forces are caused by vertical differences in wind velocity and by vertical turbulence in wind flow conditions. Friction at the ground surface causes wind speeds to be lower near the ground than at greater heights above the ground. The vertical changes in wind speed are associated with vertical changes in air pressure. Air moving at a higher velocity exerts a lower pressure than air moving at a low velocity. Small-scale vertical turbulence also produces temporary fluctuations in pressure that generate lift forces.

A very thin nonturbulent layer of air always exists immediately next to the ground surface. This layer, often called the laminar layer, is essentially a zone of calm air; its thickness depends on the roughness of the ground surface. Horizontal shear forces only affect objects that extend above or are lifted above this laminar layer. Rough surfaces and minor irregularities in smooth surfaces often result in some surface particles being perched partially or completely above the laminar layer. Sand-sized particles are often large enough to project into the turbulent wind flow zone above the laminar layer.

Three types of particle movement occur during wind erosion: surface creep, saltation, and suspension. Initial particle movement is generally by saltation. Saltation is a bouncing movement in which particles of moderate size are lofted slightly into the air and carried a short distance downwind before falling back to the ground. The impact of saltating particles helps initiate the saltation, surface creep (a rolling or sliding movement along the ground surface), or suspension movement of other particles. Surface creep and saltation are the dominant movement processes for large particles. Suspension is important for small particles. Wind erosion of most soils is dominated by saltation and surface creep.

Factors Affecting Erodibility of Sediments and Soils

Actual wind erosion rates are determined by a combination of wind conditions and the physical condition of the soil or sediment surface. The vertical profile of wind speeds and the extent of vertical turbulence are key wind components. The directional persistence of strong winds is also a factor, especially for surface creep and saltation processes. The most important aspects related to the soil or sediment surface include:

- surface moisture conditions,
- the extent of nonerodible surface material,
- the extent of particle aggregation in the erodible material, and
- the size of the exposed area.

Wet or frozen surfaces are essentially immune to wind erosion. Chepil and Woodruff (1963) determined that surface moisture levels above the permanent wilting point (15 atmospheres suction) effectively protect soil surfaces from wind erosion. Shikula (1981) examined the effect of atmospheric moisture levels on the threshold wind speed associated with dust storm events in Ukraine. Atmospheric moisture levels were characterized as a moisture deficit (the difference between actual water vapor pressure and the saturation vapor pressure level). A strong correlation was found between threshold wind speeds for initiating dust storms and moisture deficit levels. The threshold wind speed averaged 12.1 mph at a moisture deficit of 35 millibars, 19.9 mph at a moisture deficit of 25 millibars, 27.7 mph at a moisture deficit of 15 millibars, and 35.6 mph at a moisture deficit of 5 millibars.

The presence of nonerodible surface material (e.g., rocks, vegetation, or chemically cemented sediments) normally reduces the potential for wind erosion by reducing wind speeds near the ground and blocking surface creep and saltation movements. However, very sparse coverage by nonerodible material may sometimes induce small-scale air turbulence that enhances the erosion of fine surface sediments by suspension.

Particle aggregation in erodible material can have complicated effects. The aggregates may result in surface characteristics that raise portions of the soil or sediment above the laminar layer. The size and density of the aggregates will also affect the minimum wind velocity necessary to initiate particle movement. Saltation, ballistic impact, and airborne collisions among aggregates often break the aggregates apart into particles small enough to be carried in suspension as opposed to saltation or surface creep.

The size and dimensions of areas susceptible to wind erosion also have some effect on wind erosion rates. These size factors are most important for surface creep and saltation processes and are less important for particle removal by suspension transport.

SALT DEPOSIT MINERALOGY

The mineralogy of salt deposit formations has been studied at several locations used for commercial extraction of various salts. Study results at one location can be extrapolated to other locations only if enough similarities exist among key salt chemistry factors. It is important to distinguish between salt deposits dominated by chlorides and those dominated by carbonates, bicarbonates, and sulfates. If chemical similarities are sufficient in this respect, more refined chemical similarities and differences must be considered. It is generally necessary to distinguish between calcium and sodium salts; differences in the relative amounts of potassium and lithium salts may also be important.

Differences between Owens Lake and Mono Lake Salt Deposits

Studies conducted at Owens Lake (Alderman 1985, Saint-Amand et al. 1986, Smith and Friedman 1986, Smith et al. 1987) have been especially useful in identifying processes that probably operate at Mono Lake. Mono Lake and Owens Lake are exposed to the same general climatic conditions, and both lakes were sodium-dominated with high carbonate and sulfate concentrations when salt deposits began to form. Evaluation of studies from Owens Lake, however, must recognize some important differences between these locations.

One difference is that the salt deposits at Owens Lake have been formed on a playa while those at Mono Lake have formed on sediments above a permanent lake. A playa is most accurately defined as the flat, generally dry, mostly barren, largely gravel-free floor of an interiorly drained topographic basin; portions of a playa may be subject to alternating periods of inundation and evaporative drying (Motts 1970, 1972; see also Academic Press Dictionary of Science and Technology 1992, Levin 1986, Bates and Jackson 1984). Surface substrates of playas are generally clays, silts, sands, or salt deposits.

The topographic distinction between a playa and a lakeshore helps explain an important difference between salt deposits at Owens Lake and those in Mono Basin. Salt deposits at these two locations formed in different hydrologic settings. The salt deposits at Owens Lake were formed primarily as underwater precipitates. The salt deposits at Mono Lake have formed as surface evaporative deposits in contact with air.

An underwater environment for salt formation will differ in several respects from a ground surface environment. Four considerations are especially relevant to comparisons between Owens Lake and Mono Basin:

- the range of temperatures to which the deposited salt minerals are exposed and the rate at which the temperature changes after initial salt formation;
- the amount of carbon dioxide available during and after initial salt formation;
- the amount of water available for mineral transformations after initial salt formation; and
- the potential for spatial separation of sequentially precipitated salts.

The precise mineralogy of carbonate and sulfate salts is highly sensitive to temperature conditions; chloride salts, however, show little temperature sensitivity. Many carbonate and sulfate salts also undergo temperature-dependent transformations after the initial salts precipitate. Salts precipitated in an underwater environment will experience a more narrow range of temperatures and a slower rate of temperature change than will salts precipitated at the ground surface.

The mineralogy of carbonate and bicarbonate salts is sensitive to the amount of dissolved carbon dioxide present in the water from which the salts precipitate. Many carbonate and bicarbonate salts also exhibit carbon dioxide-dependent mineral transformations. Dissolved carbon dioxide concentrations may be more variable and can reach higher concentrations in an underwater environment than water in the pore spaces of a surface soil or sediment.

Many carbonate and sulfate salts undergo hydration and dehydration reactions. Some hydration reactions involve amounts of water available only in an underwater environment. Hydration of burkeite, for example, can require 10-20 molecules of water for each molecule of salt.

Underwater precipitation of salt beds typically results in horizontal and vertical zonation of different salt minerals, as the different salts precipitate in sequence as they reach saturation concentrations in the lake water. The slow rate of temperature change in a large body of water enhances this effect. The physical dimensions of the capillary film of water producing surface evaporative salt deposits preclude such spatial zonation patterns in surface evaporite deposits. Spatial zonation of different minerals in a surface evaporative salt deposit would indicate a moving zone of evaporation, probably accompanied by changes in salinities and dissolved mineral content of the evaporating water.

The pressure to which the salt minerals are exposed is a fifth potential factor differentiating underwater and surface salt formation. Pressure is probably relevant only for deep saline lakes or marine conditions. The literature reviewed by SWRCB consultants does not suggest that air and water pressure considerations are important for comparisons of Owens Lake and Mono Basin.

Salt Minerals Identified at Owens Lake

Smith and Friedman (1986), Saint-Amand et al. (1986), and Smith et al. (1987) have noted that many of the carbonate and sulfate salts present in the Owens Lake salt deposits undergo rapid transformations and phase changes in response to changes in temperature, humidity, and carbon dioxide concentrations. As a result, the mineral composition of salt samples (particularly those collected during cool periods) will change significantly before the samples can be analyzed in a laboratory. Laboratory analyses often detect only the products of mineral transformations and not the minerals that were present in the field. The researchers noted above have used a variety of techniques to estimate the mineralogy of salt deposits presently found at Owens Lake. Many of the salt minerals believed to be present at Owens Lake also can be expected to occur in the evaporative salt deposits found at Mono Lake.

The major salt minerals expected to be present in the surface layer of the Owens Lake salt deposit during different seasons can be categorized into four chemical groups as follows:

- Sodium carbonates:
  - natron (a decahydrate),
  - thermonatrite (a monohydrate),
  - sodium carbonate heptahydrate,
  - sodium carbonate dihydrate, and
  - anhydrous sodium carbonate (a noncrystalline salt).

- Sodium carbonate-bicarbonate double salts:
  - trona (a dihydrate).

- Sodium sulfates:
  - mirabilite (a decahydrate),
  - thenardite (a crystalline anhydrous salt),
  - sodium sulfate heptahydrate, and
  - anhydrous sodium sulfate (a noncrystalline salt).

- Halides:
  - halite (rock salt).

All these salts are probably present in the salt deposits at Mono Lake during some seasons.

Several additional salt minerals are known to occur in the Owens Lake salt deposits but may occur only in the deeper consolidated layers of the deposits. It is uncertain whether the following salts occur in the surface layers of the Owens Lake salt deposits or in the Mono Lake salt deposits:

- Sodium bicarbonates:
  - nahcolite (a crystalline anhydrous salt).

- Sodium carbonate-sodium sulfate double salts:
  - burkeite (a crystalline anhydrous salt).

- Sodium carbonate-calcium carbonate double salts:
  - pirssonite (a dihydrate),
  - gaylussite (a pentahydrate), and
  - shortite (a crystalline anhydrous salt).

According to Saint-Amand et al. (1986), nahcolite formation may be prevented in a surface evaporative salt deposit by low carbon dioxide concentrations. Burkeite is a temperature-sensitive salt that forms only at temperatures above 57°F; trona and mirabilite or thenardite formation may be more likely in surface evaporative deposits.

As indicated above, most of the major salts expected in surface evaporative deposits are hydrated. Hydrated salts include water molecules chemically bound to the salt molecule. A monohydrate has one water molecule bound to each salt molecule, a dihydrate has two water molecules bound to each salt molecule, a pentahydrate has five water molecules bound to each salt molecule, a heptahydrate has seven water molecules bound to each salt molecule, and a decahydrate has ten water molecules bound to each salt molecule. Anhydrous salts do not contain any chemically bound water molecules.

The amount of water contained in hydrated salts can be substantial. Natron is almost 63% water by weight; mirabilite is almost 56% water by weight. The hydration and dehydration reactions of carbonate and sulfate salts are largely responsible for variations in the susceptibility of salt deposits to wind erosion.

Salt Deposit Formation Processes

The mineralogy of a salt deposit is determined by the interaction of several factors: salt formation temperature, effects of moisture addition, dehydration reactions, and phase changes induced by salt deposit temperature changes. Although the salt deposits at Owens Lake and Mono Lake have formed in different ways, ongoing salt formation processes at the surface of the Owens Lake salt deposit provide insight into the evaporative salt deposits at Mono Lake. The following discussion is based largely on the process described by Saint-Amand et al. (1986) for Owens Lake but seems to be a reasonable estimate of the process occurring at Mono Lake.

Initial Salt Precipitation

The salts formed when saline water evaporates at the soil surface depend primarily on the temperature of the saline groundwater when saturation concentrations are reached for different salts. The saturation concentrations for sodium carbonate and sodium sulfate salts depend strongly on temperature; the saturation concentration for sodium chloride changes only slowly with temperature. Thus, sodium chloride can precipitate as halite at any temperature while the mineralogy of carbonate and sulfate salts varies at different temperatures.

At temperatures below 50°F, carbonate salts crystallize as natron and sulfate salts crystallize as mirabilite. At temperatures of 50-65°F, carbonates precipitate as trona and sulfates continue to precipitate as mirabilite. At temperatures above 65°F, carbonates continue to precipitate as trona and sulfates precipitate as thenardite. As noted above, halite can precipitate at any temperature if the salt solution reaches saturation conditions.

Natron and mirabilite are heavily hydrated salts that can precipitate at cool temperatures from relatively dilute salt solutions. Because these salts are heavily hydrated, their formation rapidly removes water from the solution, increasing its salinity and causing precipitation of more salts. The amount of water removed from the salt solution by formation of hydrated salts may exceed the amount of water lost through surface evaporation.

Moisture Addition Effects

If sufficient water becomes available from precipitation or surface flooding, the salt deposit will dissolve and a new cycle of salt deposition will begin. A slight rainfall will result in formation of hydrated salts at any season if the temperature falls below the dehydration temperature of the salts. Similarly, moisture available from dehydrating salts (see below) may dissolve some salts or allow others to become hydrated. Moisture and temperature effects can be linked as a result of evaporative cooling.

Dehydration Effects

As long as natron and mirabilite remain cool and damp, they remain stable. Once permitted to dry, natron and mirabilite quickly dehydrate to amorphous, noncrystalline powders. Natron dehydrates to anhydrous sodium carbonate and mirabilite dehydrates to anhydrous sodium sulfate. The process can be hastened by osmotic transfer of water of hydration to halite.

During cool weather, crystals of mirabilite or natron can form on a wet substrate following a rain and then dehydrate in cool dry air to an amorphous powder. Mirabilite (a sulfate salt) is especially prone to this process, as mirabilite crystallization occurs at temperatures that are too warm to allow natrite (a carbonate salt) to form.

The dehydration of natron and mirabilite have important effects on the physical condition of the salt deposit. Dehydration converts crystalline salts to noncrystalline powders. Equally important are the significant volume changes that occur with dehydration (or rehydration) reactions.

Dehydration of natron to anhydrous sodium carbonate is accompanied by a volume reduction of 79%. Dehydration of mirabilite to anhydrous sodium sulfate is accompanied by a volume reduction of 76%. Rehydration of sodium carbonate to natron results in a volume increase of 375%. Rehydration of sodium sulfate to mirabilite results in a volume increase of 315%. These volume changes can disrupt the cohesion of a cemented salt crust even when natron and mirabilite are only modest components of the crust.

Temperature Change Effects

In addition to the dehydration reactions discussed above, carbonate and sulfate salts undergo other temperature-dependent transformations. The precise transformations depend on a combination of temperature, moisture availability, and carbon dioxide availability.

The simplest transformations seem to involve the sulfate salts. As temperatures increase, mirabilite dehydrates to anhydrous sodium sulfate if exposed to dry air. Any mirabilite present in deeper portions of a salt deposit releases its water of hydration and redissolves. The redissolved sulfate salt can precipitate later as either thenardite or mirabilite, depending on temperature. Although the literature reviewed is unclear, it seems to suggest that other polyhydrate sodium sulfate salts undergo comparable reactions.

As temperatures increase, natron dehydrates to anhydrous sodium carbonate if exposed to dry air. Natron present in deeper portions of a salt deposit will generally transform into trona. If salt deposit temperatures rise to extremely high levels, trona decomposes to thermonatrite. On cooling, thermonatrite can transform back into trona if some moisture is available. At cool temperatures and with adequate moisture available, trona can convert back into natron.

Factors Affecting the Erodibility of Salt Deposits

The erodibility of salt deposits is affected by conditions and factors common to other substrates: surface moisture conditions, wind speeds above the threshold wind velocity for various salt deposit conditions, the size of the exposed area, and the presence of saltating particles that can abrade any salt crust. A factor of special relevance to salt deposits is the physical structure of the deposit. Unlike most sediment types, the physical structure of a salt deposit can change on daily and seasonal cycles.

The physical structure of a salt deposit is determined largely by the mineralogy of the salts forming the deposit. As discussed above, the mineralogy of a salt deposit is determined by the interaction of several factors: salt formation temperature, effects of moisture addition, dehydration reactions, and mineral transformations induced by temperature changes.

Salt deposits dominated by halite have a hard, crystalline, cemented texture highly resistant to wind erosion. Dust storms are rare from salt crusts formed primarily from halite (Saint-Amand et al. 1986).

Salt deposits dominated by carbonate or sulfate salts can have a variety of textures, most of which are more subject to wind erosion than deposits dominated by halite. Deposits dominated by crystalline salts with low degrees of hydration (e.g., trona, thermonatite, and thenardite) present a hard, cemented crust that resists wind erosion. Deposits dominated by salts with a higher degree of hydration (e.g., trona and mirabilite) will have a weaker crust more susceptible to wind erosion. Deposits dominated by natron and mirabilite will be protected from significant wind erosion by their high moisture content rather than by a well-cemented crust but can easily transform into a powdery deposit of noncrystalline anhydrous salts. Deposits of anhydrous sodium carbonate and sodium sulfate have little resistance to wind erosion.

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Table N-1. Seasonal Time-of-Day Wind Patterns at the Lee Vining Monitoring Site, 1986-1991

	Winter (December, January, February)						Spring (March, April, May)					
Time of Day	Average Wind Direction (degrees)	Average Wind Speed (mph)	Maximum Hourly Average Wind Speed (mph)	Minimum Hourly Average Wind Speed (mph)	Mean of Daily Maximum Wind Speed (mph)	Mean of Daily Minimum Wind Speed (mph)	Average Wind Direction (degrees)	Average Wind Speed (mph)	Maximum Hourly Average Wind Speed (mph)	Minimum Hourly Average Wind Speed (mph)	Mean of Daily Maximum Wind Speed (mph)	Mean of Daily Minimum Wind Speed (mph)
M - 1 a.m.	218	3.4	36.1	0.0	15.7	0.5	207	4.9	35.0	0.0	16.2	0.8
1 - 2 a.m.	215	3.8	33.8	0.0	17.0	0.8	206	5.6	34.0	0.0	18.9	0.9
2 - 3 a.m.	215	3.9	42.3	0.0	19.3	0.7	206	5.2	30.0	0.0	19.1	1.0
3 - 4 a.m.	216	3.9	37.5	0.0	18.5	0.8	209	5.0	31.2	0.0	19.2	0.7
4 - 5 a.m.	219	3.9	35.4	0.0	19.2	0.8	208	4.9	40.8	0.0	21.5	0.8
5 - 6 a.m.	219	3.9	31.1	0.0	18.0	0.5	210	4.8	33.9	0.0	20.3	0.5
6 - 7 a.m.	218	3.8	34.9	0.0	17.5	0.5	278	4.7	36.6	0.0	19.2	0.5
7 - 8 a.m.	231	3.7	45.7	0.0	18.2	0.3	347	5.1	41.9	0.0	21.3	0.7
8 - 9 a.m.	306	3.8	46.4	0.0	20.9	0.3	5	5.9	38.0	0.0	21.0	1.5
9 - 10 a.m.	346	4.1	44.2	0.0	22.2	0.7	13	7.0	37.9	0.0	22.4	2.3
10 - 11 a.m.	354	4.4	43.9	0.0	22.0	1.0	8	7.9	37.6	1.0	24.4	2.9
11 a.m. - N	354	4.8	44.5	0.0	23.0	1.1	357	8.8	39.7	2.0	24.3	3.9
N - 1 p.m.	350	5.2	47.9	0.0	25.0	1.4	342	9.7	39.2	1.5	25.3	4.2
1 - 2 p.m.	343	5.5	44.6	0.0	26.2	1.4	319	10.4	36.0	0.0	25.6	3.8
2 - 3 p.m.	327	5.4	41.2	0.0	25.8	1.2	294	11.0	34.0	1.6	26.3	4.1
3 - 4 p.m.	288	4.9	43.5	0.0	24.0	0.6	283	11.1	37.2	2.0	26.4	3.8
4 - 5 p.m.	232	5.0	38.6	0.0	23.0	0.6	274	11.0	41.9	1.0	25.2	3.2
5 - 6 p.m.	216	5.6	37.9	0.0	21.4	0.9	259	10.4	42.9	0.0	24.8	2.2
6 - 7 p.m.	210	5.7	40.1	0.0	21.3	1.2	247	9.7	45.4	0.0	25.3	1.5
7 - 8 p.m.	213	5.2	41.5	0.0	20.1	1.4	234	8.4	31.8	0.0	23.3	1.3
8 - 9 p.m.	214	5.0	41.7	0.0	20.5	0.9	222	7.2	29.8	0.0	20.7	1.2
9 - 10 p.m.	212	4.6	38.9	0.0	19.8	1.0	211	6.8	31.0	0.0	19.4	1.3
10 - 11 p.m.	216	4.3	39.2	0.0	20.3	1.0	207	6.6	34.0	0.0	19.5	1.3
11 a.m. - M	218	4.1	41.6	0.0	20.7	0.8	205	6.2	34.0	0.0	18.3	1.1

Table N-1. Continued

Time of Day	Summer (June, July, August)						Fall (September, October, November)					
	Average Wind Direction (degrees)	Average Wind Speed (mph)	Maximum Hourly Average Wind Speed (mph)	Minimum Hourly Average Wind Speed (mph)	Mean of Daily Maximum Wind Speed (mph)	Mean of Daily Minimum Wind Speed (mph)	Average Wind Direction (degrees)	Average Wind Speed (mph)	Maximum Hourly Average Wind Speed (mph)	Minimum Hourly Average Wind Speed (mph)	Mean of Daily Maximum Wind Speed (mph)	Mean of Daily Minimum Wind Speed (mph)
M - 1 a.m.	200	4.8	21.7	0.0	13.2	1.2	202	4.8	31.1	0.0	15.7	1.1
1 - 2 a.m.	199	4.4	21.8	0.0	13.0	1.2	202	4.5	44.7	0.0	16.1	0.8
2 - 3 a.m.	198	4.2	22.1	0.0	11.5	0.9	204	4.2	45.9	0.0	16.3	0.9
3 - 4 a.m.	198	3.9	19.8	0.0	11.0	1.0	205	4.0	44.9	0.0	16.5	0.8
4 - 5 a.m.	198	3.6	18.7	0.0	10.9	1.0	207	3.7	40.9	0.0	13.8	0.4
5 - 6 a.m.	203	2.9	19.1	0.0	9.6	0.5	207	3.6	36.3	0.0	15.9	0.4
6 - 7 a.m.	327	2.5	22.6	0.0	11.0	0.4	214	3.1	40.0	0.0	14.1	0.4
7 - 8 a.m.	357	3.3	21.8	0.0	10.9	1.0	294	3.1	31.4	0.0	13.5	0.4
8 - 9 a.m.	359	4.5	26.4	0.0	13.9	1.9	347	3.7	25.5	0.0	14.7	0.6
9 - 10 a.m.	2	5.6	29.9	0.7	15.4	2.8	360	4.6	27.5	0.0	16.9	1.5
10 - 11 a.m.	9	7.1	29.8	1.0	20.7	3.9	3	5.4	28.9	0.0	17.8	2.0
11 a.m. - N	8	8.5	31.0	2.0	23.7	4.3	4	6.1	37.8	0.0	19.7	2.2
N - 1 p.m.	4	9.7	35.7	0.0	23.2	4.3	2	6.7	41.2	1.0	21.6	2.6
1 - 2 p.m.	346	10.4	29.6	2.0	22.8	4.5	358	7.3	30.5	1.5	22.0	2.8
2 - 3 p.m.	285	11.0	32.3	1.8	22.6	4.6	332	7.4	37.6	0.8	22.3	2.7
3 - 4 p.m.	269	11.5	42.5	1.0	23.8	4.4	288	7.3	35.0	0.0	21.6	2.1
4 - 5 p.m.	263	11.6	30.9	1.2	22.6	4.2	250	7.4	35.0	0.9	20.6	1.8
5 - 6 p.m.	263	11.6	29.5	0.0	22.2	3.6	231	7.7	46.8	0.0	22.2	1.6
6 - 7 p.m.	259	11.2	30.3	0.0	23.0	2.7	229	7.3	28.6	0.0	21.5	1.6
7 - 8 p.m.	246	9.6	27.0	0.0	21.9	1.9	217	6.3	33.0	0.0	19.0	1.3
8 - 9 p.m.	225	7.4	29.4	0.0	19.4	1.6	205	5.9	25.6	0.0	16.7	1.5
9 - 10 p.m.	215	6.1	23.0	0.0	16.7	1.1	201	5.8	32.0	0.0	17.9	1.5
10 - 11 p.m.	205	5.5	22.0	0.0	13.9	1.6	199	5.3	25.3	0.0	14.9	1.1
11 a.m. - M	203	5.1	26.4	0.0	14.7	1.3	200	5.0	24.4	0.0	14.9	1.0

Table N-1. Continued

Time of Day	Maximum Hourly Average Wind Direction (degrees)	Minimum Hourly Average Wind Speed (mph)	Mean of Daily Average Wind Speed (mph)	Mean of Daily Average Wind Speed (mph)	Maximum Wind Speed (mph)	Minimum Wind Speed (mph)
	Annual Average, 1986-1991					
M - 1 a.m.	206	4.9	36.1	0.0	15.2	0.9
1 - 2 a.m.	205	4.6	44.7	0.0	16.2	0.9
2 - 3 a.m.	205	4.4	45.9	0.0	16.6	0.9
3 - 4 a.m.	206	4.2	44.9	0.0	16.3	0.8
4 - 5 a.m.	208	4.0	40.9	0.0	16.3	0.7
5 - 6 a.m.	210	3.7	36.3	0.0	16.0	0.5
6 - 7 a.m.	251	3.5	40.0	0.0	15.4	0.4
7 - 8 a.m.	314	3.7	45.7	0.0	15.9	0.6
8 - 9 a.m.	348	4.4	46.4	0.0	17.6	1.1
9 - 10 a.m.	1	5.3	44.2	0.0	19.2	1.8
10 - 11 a.m.	4	6.2	43.9	0.0	21.3	2.4
11 a.m. - N	1	7.1	44.5	0.0	22.7	2.8
N - 1 p.m.	354	7.9	47.9	0.0	23.7	3.1
1 - 2 p.m.	341	8.5	44.6	0.0	24.2	3.1
2 - 3 p.m.	310	8.8	41.2	0.0	24.2	3.2
3 - 4 p.m.	282	8.8	43.5	0.0	24.0	2.8
4 - 5 p.m.	256	8.9	41.9	0.0	22.8	2.4
5 - 6 p.m.	244	9.0	46.8	0.0	22.7	2.1
6 - 7 p.m.	237	8.6	45.4	0.0	22.8	1.7
7 - 8 p.m.	228	7.5	41.5	0.0	21.1	1.5
8 - 9 p.m.	216	6.4	41.7	0.0	19.3	1.3
9 - 10 p.m.	210	5.9	38.9	0.0	18.4	1.2
10 - 11 p.m.	206	5.5	39.2	0.0	17.2	1.2
11 p.m. - M	208	5.2	41.6	0.0	17.1	1.0

Source: GBUAPCD files.

Table N-2. Seasonal Time-of-Day Wind Patterns at the Simis Ranch Monitoring Site, 1986-1991

Time of Day	Winter (December, January, February)						Spring (March, April, May)					
	Average Wind Direction (degrees)	Average Wind Speed (mph)	Maximum Hourly Average Wind Speed (mph)	Minimum Hourly Average Wind Speed (mph)	Mean of Daily Maximum Wind Speed (mph)	Mean of Daily Minimum Wind Speed (mph)	Average Wind Direction (degrees)	Average Wind Speed (mph)	Maximum Hourly Average Wind Speed (mph)	Minimum Hourly Average Wind Speed (mph)	Mean of Daily Maximum Wind Speed (mph)	Mean of Daily Minimum Wind Speed (mph)
M - 1 a.m.	4	3.7	23.5	0.0	12.1	0.5	3	5.0	25.3	0.0	14.4	1.2
1 - 2 a.m.	5	3.7	20.3	0.0	14.8	0.9	3	4.7	26.8	0.0	16.4	1.3
2 - 3 a.m.	359	3.4	21.3	0.0	13.4	0.8	7	4.6	23.2	0.0	15.9	1.0
3 - 4 a.m.	6	3.3	19.0	0.0	13.9	0.5	6	4.6	24.0	0.0	16.3	1.1
4 - 5 a.m.	6	3.3	26.0	0.0	15.0	0.7	6	4.5	22.6	0.0	16.1	1.4
5 - 6 a.m.	7	3.4	26.0	0.0	15.0	0.7	8	4.3	23.4	0.0	17.7	1.2
6 - 7 a.m.	7	3.3	25.0	0.0	14.7	1.0	39	3.9	24.8	0.0	17.9	1.0
7 - 8 a.m.	9	3.1	26.0	0.0	14.5	0.7	137	4.2	27.5	0.0	19.4	0.9
8 - 9 a.m.	75	3.0	26.0	0.0	16.9	0.7	180	5.2	25.1	0.0	20.4	1.5
9 - 10 a.m.	181	3.5	27.0	0.0	18.2	0.7	181	6.3	31.0	0.0	22.2	2.3
10 - 11 a.m.	187	4.2	32.0	0.0	19.4	1.1	187	7.5	34.0	0.0	23.3	2.9
11 a.m. - N	194	4.6	28.0	0.0	18.7	1.0	191	8.7	31.0	0.0	23.1	3.7
N - 1 p.m.	196	4.9	26.0	0.0	20.0	1.4	201	9.7	29.3	0.0	23.9	4.0
1 - 2 p.m.	200	5.1	26.3	0.0	19.2	1.7	207	10.5	31.7	0.0	24.2	3.9
2 - 3 p.m.	206	5.4	23.0	0.0	19.1	1.5	222	11.2	28.1	0.0	24.0	3.7
3 - 4 p.m.	212	5.0	27.9	0.0	19.1	1.2	238	11.4	27.0	0.0	22.4	3.4
4 - 5 p.m.	257	4.6	27.4	0.0	17.7	0.8	261	11.4	26.5	0.0	21.7	4.2
5 - 6 p.m.	347	4.9	27.2	0.0	17.3	1.1	286	10.6	25.4	0.7	19.7	3.7
6 - 7 p.m.	6	4.8	22.3	0.0	15.7	1.3	318	9.1	28.3	0.6	18.8	3.3
7 - 8 p.m.	6	4.3	23.2	0.0	14.3	1.2	335	7.5	22.0	0.0	17.9	2.2
8 - 9 p.m.	359	4.1	25.2	0.0	13.7	1.2	344	6.1	21.8	0.6	167	2.1
9 - 10 p.m.	10	3.9	22.5	0.0	12.3	0.9	351	5.7	24.8	0.0	17.3	1.6
10 - 11 p.m.	8	3.8	22.0	0.0	14.2	1.2	356	5.3	25.1	0.0	16.7	1.4
11 a.m. - M	20	3.7	22.1	0.0	13.8	0.8	349	5.1	30.0	0.0	18.4	1.5

Table N-2. Continued

Time of Day	Summer (June, July, August)						Fall (September, October, November)					
	Average Wind Direction (degrees)	Average Wind Speed (mph)	Maximum Hourly Average Wind Speed (mph)	Minimum Hourly Average Wind Speed (mph)	Mean of Daily Maximum Wind Speed (mph)	Mean of Daily Minimum Wind Speed (mph)	Average Wind Direction (degrees)	Average Wind Speed (mph)	Maximum Hourly Average Wind Speed (mph)	Minimum Hourly Average Wind Speed (mph)	Mean of Daily Maximum Wind Speed (mph)	Mean of Daily Minimum Wind Speed (mph)
M - 1 a.m.	6	4.0	31.0	0.09	10.2	1.3	10	4.0	30.0	0.0	13.3	1.2
1 - 2 a.m.	8	3.7	23.0	0.0	9.6	1.3	8	3.9	31.0	0.4	13.6	1.3
2 - 3 a.m.	11	3.6	17.8	0.0	9.7	1.0	10	3.8	30.8	0.0	14.3	1.2
3 - 4 a.m.	9	3.5	22.0	0.0	9.8	1.1	7	3.7	28.3	0.0	12.9	1.0
4 - 5 a.m.	10	3.3	24.0	0.0	9.9	1.0	8	3.6	22.4	0.0	11.7	1.1
5 - 6 a.m.	11	2.8	22.0	0.0	9.6	0.6	7	3.6	23.0	0.0	11.9	1.1
6 - 7 a.m.	76	2.2	23.0	0.0	11.1	0.3	11	3.3	23.2	0.0	11.4	0.7
7 - 8 a.m.	139	2.3	24.0	0.0	12.6	0.6	66	2.9	27.9	0.0	12.7	0.6
8 - 9 a.m.	179	3.2	25.0	0.0	12.1	1.4	135	3.2	27.1	0.0	14.5	0.8
9 - 10 a.m.	189	4.2	27.0	0.0	14.4	1.9	175	4.0	28.9	0.0	16.6	1.4
10 - 11 a.m.	188	5.5	28.7	0.0	15.9	2.7	187	5.0	29.1	0.0	17.3	1.8
11 a.m. - N	194	6.8	31.7	0.0	19.5	3.5	188	5.8	31.3	0.0	19.4	2.2
N - 1 p.m.	199	8.0	28.0	0.0	21.0	4.0	192	6.3	30.4	0.0	20.8	2.6
1 - 2 p.m.	202	9.1	28.0	0.0	21.4	3.9	195	7.1	28.0	0.0	22.1	2.8
2 - 3 p.m.	209	9.7	29.0	0.0	21.8	4.1	199	7.7	27.1	0.8	21.4	2.7
3 - 4 p.m.	223	10.4	28.0	0.0	21.9	4.0	207	7.8	31.8	0.0	21.6	2.4
4 - 5 p.m.	243	10.7	29.0	0.0	21.3	4.2	238	7.8	31.8	0.0	20.7	2.6
5 - 6 p.m.	266	10.7	26.2	0.0	20.8	3.4	355	7.4	28.4	0.0	19.5	2.2
6 - 7 p.m.	287	9.5	22.3	0.0	17.5	3.3	3	6.5	23.6	1.0	16.4	2.7
7 - 8 p.m.	314	7.5	21.0	0.2	16.2	2.9	1	5.5	25.0	0.7	16.5	1.9
8 - 9 p.m.	339	6.0	21.0	0.0	15.1	2.2	7	5.0	20.3	0.4	14.5	1.9
9 - 10 p.m.	1	5.1	22.4	0.0	13.4	2.3	10	4.6	25.0	0.5	14.6	1.5
10 - 11 p.m.	5	4.6	23.4	0.0	13.1	1.7	8	4.3	24.0	0.3	14.2	1.5
11 a.m. - M	8	4.3	27.0	0.0	12.7	1.2	13	4.3	28.0	0.0	13.8	1.5

Table N-2. Continued

Time of Day	Maximum Hourly Average Wind Direction (degrees)	Minimum Hourly Average Wind Speed (mph)	Mean of Daily Average Wind Speed (mph)	Mean of Daily Average Wind Speed (mph)	Maximum Wind Speed (mph)	Minimum Wind Speed (mph)
	Annual Average, 1986-1991					
M - 1 a.m.	7	4.3	31.0	0.0	12.5	1.0
1 - 2 a.m.	7	4.1	31.0	0.0	13.6	1.0
2 - 3 a.m.	9	3.9	30.8	0.0	13.3	1.0
3 - 4 a.m.	8	3.9	28.3	0.0	13.2	0.9
4 - 5 a.m.	9	3.8	26.0	0.0	13.2	1.1
5 - 6 a.m.	9	3.6	26.0	0.0	13.5	0.9
6 - 7 a.m.	29	3.3	25.0	0.0	13.8	0.8
7 - 8 a.m.	92	3.2	27.9	0.0	14.8	0.7
8 - 9 a.m.	146	3.7	27.1	0.0	16.0	1.1
9 - 10 a.m.	179	4.6	31.0	0.0	17.8	1.6
10 - 11 a.m.	186	5.7	34.0	0.0	19.0	2.1
11 a.m. - N	191	6.6	31.7	0.0	20.2	2.6
N - 1 p.m.	197	7.4	30.4	0.0	21.4	3.0
1 - 2 p.m.	200	8.2	31.7	0.0	21.7	3.1
2 - 3 p.m.	209	8.7	29.0	0.0	21.6	3.0
3 - 4 p.m.	221	8.9	31.8	0.0	21.2	2.8
4 - 5 p.m.	251	8.9	31.8	0.0	20.3	3.0
5 - 6 p.m.	307	8.6	28.4	0.0	19.3	2.6
6 - 7 p.m.	337	7.7	28.3	0.0	17.1	2.7
7 - 8 p.m.	346	6.4	25.0	0.0	16.2	2.0
8 - 9 p.m.	354	5.5	25.2	0.0	15.0	1.8
9 - 10 p.m.	6	4.9	25.0	0.0	14.4	1.6
10 - 11 p.m.	6	4.6	25.1	0.0	14.5	1.4
11 p.m. - M	8	4.4	30.0	0.0	14.7	1.3

Source: GBUAPCD files.

Table N-3. Simis Ranch PM_{10}:TSP Ratios, Data Clustered by PM_{10} Range

Year	PM_{10} Range ($\mu g/m^3$)	Number of Paired Samples	PM_{10}: TSP Ratio Statistics Low Ratio (%)	High Ratio (%)	Mean Ratio (%)	Ratio of Data Sums (%)
1990	1-5	12	5.0	55.6	29.7	26.1
1991	1-5	22	14.3	500.0	98.1	50.6
1992	1-5	7	71.4	300.0	162.6	133.3
Combined	1-5	41	5.0	500.0	89.1	44.7
1990	6-10	27	33.3	71.4	47.7	45.5
1991	6-10	27	20.9	200.0	59.0	42.3
1992	6-10	9	19.5	350.0	105.0	43.4
Combined	6-10	63	19.5	350.0	60.7	43.7
1990	11-20	25	24.1	73.1	46.0	43.7
1991	11-20	28	29.7	75.0	50.3	47.7
1992	11-20	9	47.1	80.0	64.9	61.7
Combined	11-20	62	24.1	80.0	50.7	47.5
1990	21-49	4	38.5	67.5	52.7	49.8
1991	21-49	4	33.9	53.5	41.2	40.0
1992	21-49	5	43.1	104.2	62.3	56.1
Combined	21-49	13	33.9	104.2	52.8	48.5
1990	50+	4	38.2	72.5	52.2	46.4
1991	50+	4	32.6	57.4	46.3	44.1
1992	50+	2	51.4	55.9	53.6	52.0
Combined	50+	10	32.6	72.5	50.1	48.2
1990	10+	36	24.1	73.1	47.9	45.6
1991	10+	48	23.8	75.0	47.5	44.1
1992	10+	16	43.1	104.2	62.7	53.9
Combined	10+	100	23.8	104.2	60.1	47.4
1990	All data	72	5.0	73.1	44.6	44.4
1991	All data	85	14.3	500.0	64.8	44.9
1992	All data	32	19.5	350.0	96.4	53.9
Combined	All data	189	5.0	100.0	62.5	47.1

Notes: All data are from the Simis Ranch monitoring site, May 199-June 1992.
Mean Ratio = mean value of ratios for individual pairs of PM_{10} and TSP values.
Ratio of Data Sums = sum of PM_{10} values divided by sum of TSP values; this provides a weighted average PM_{10}:TSP ratio.

Source: California Air Quality Data, Volumes XXII-XXIV.

Table N-4. Particle-Size Distribution for Erodible Fractions of Soil Samples Collected near Mono Lake

Sieved Sample Number	Mass (grams)	Location	Percentage Size Class Distribution of Sieved Samples (Aerodynamic Equivalent Diameters)					
			< 1.1 microns	1.1-2.1 microns	2.1-3.3 microns	3.3-4.7 microns	4.7-7.0 microns	> 7.0 microns
1	5.3852	Land bridge area west of Negit Island	0.01	0.41	1.14	1.31	21.74	75.38
2	1.3934	Land bridge area west of Negit Island	0.04	0.41	0.52	1.24	30.01	67.78
3	5.8839	Along lower part of Ten-Mile Road	0.01	0.16	0.45	1.08	24.96	73.33
4, 5	3.2422	Along middle part of Ten-Mile Road	0.02	0.18	0.64	1.56	22.41	75.19
6	4.9621	Along upper part of Ten-Mile Road	0.01	0.21	0.22	0.28	32.97	66.31
7	5.3348	Along jeep road north of Warm Springs	0.02	0.28	0.40	0.46	30.33	68.51
8	5.4988	Warm Springs area	0.14	0.99	1.96	2.46	26.68	67.77
9	5.4669	Lee Vining	0.16	1.42	3.35	3.62	23.58	67.86
10	1.5180	West end of Navy Beach area	0.01	0.01	0.01	0.72	49.37	49.88

Notes: Sampling location descriptions interpreted from a map provided by LADWP.

Particle size ranges reflect aerodynamic cutpoint diameters of the size classification equipment rather than absolute particle aerodymanic diameter screening.

The largest particle size category includes particles with sieve diameters as large as 44 microns.

Source: Truesdail Laboratories 1981.

Table N-5. Summary of Mono County PM_{15} Samples Collected by UC Davis Researchers

Sampling Period	Sampling Station Location	Number of Days Sampled		Mean PM_{xx} Concentration ($\mu g/m^3$) by Size Fraction		
		Filter 2	Filter 1	Below 2.5 μm	2.5-15 μm	Total PM_{15}
05/13-05/19/80	Bridgeport	0	0	ND	ND	ND
	Bodie	ND	ND	ND	ND	ND
	Hansen	6	6	4.3	5.1	9.4
	Lee Vining	6	6	4.9	4.6	9.5
	Benton	6	6	3.0	10.3	13.3
05/19-05/26/80	Bridgeport	7	7	8.9	4.7	13.6
	Bodie	ND	ND	ND	ND	ND
	Hansen	7	7	4.2	7.4	11.6
	Lee Vining	7	7	5.1	3.0	8.1
	Benton	7	7	6.1	16.2	22.3
05/26-06/02-80	Bridgeport	7	7	7.0	8.4	15.4
	Bodie	ND	ND	ND	ND	ND
	Hansen	7	7	7.6	7.5	15.1
	Lee Vining	7	7	7.1	38.3	45.4
	Benton	7	7	4.7	18.8	23.5
06/02-06/09-80	Bridgeport	7	7	5.1	10.9	16.0
	Bodie	ND	ND	ND	ND	ND
	Hansen	7	7	4.1	26.2	30.3
	Lee Vining	7	7	2.1	71.6	73.7
	Benton	7	7	4.3	21.6	25.9
06/09-06/16/80	Bridgeport	7	7	4.4	14.0	18.4
	Bodie	ND	ND	ND	ND	ND
	Hansen	7	7	3.7	30.6	34.3
	Lee Vining	7	7	3.6	28.7	32.3
	Benton	7	7	4.4	12.5	16.9
06/19-06/23/80	Bridgeport	4	4	9.0	25.3	34.3
	Bodie	ND	ND	ND	ND	ND
	Hansen	4	4	5.8	19.5	25.3
	Lee Vining	4	4	4.8	28.9	33.7
	Benton	4	4	4.8	32.6	37.4
06/23-06/30/80	Bridgeport	7	7	5.2	23.1	28.3
	Bodie	ND	ND	ND	ND	ND
	Hansen	7	7	4.2	22.3	26.5
	Lee Vining	7	7	4.7	22.8	27.5
	Benton	7	7	4.5	46.5	51.0
06/30-07/07/80	Bridgeport	ND	ND	ND	ND	ND
	Bodie	7	7	4.4	17.6	22.0
	Hansen	7	7	4.2	14.9	19.1
	Lee Vining	7	7	4.7	18.9	23.6
	Benton	7	7	8.1	28.0	36.1
07/07-07/15/80	Bridgeport	ND	ND	ND	ND	ND
	Bodie	8	8	3.9	18.3	22.2
	Hansen	8	8	6.1	30.5	36.6
	Lee Vining	8	8	3.7	19.5	23.2
	Benton	8	8	4.7	62.5	67.2
07/15-07/21/80	Bridgeport	ND	ND	ND	ND	ND
	Bodie	0	0	ND	ND	ND
	Hansen	6	6	4.4	19.2	23.6
	Lee Vining	6	6	4.6	19.6	24.2
	Benton	6	6	4.5	50.8	55.3
07/21-07/28/80	Bridgeport	ND	ND	ND	ND	ND
	Bodie	7	7	6.2	40.6	46.8

Table N-5. Continued

Sampling Period	Sampling Station Location	Number of Days Sampled		Mean PM_{xx} Concentration ($\mu g/m^3$) by Size Fraction		
		Filter 2	Filter 1	Below 2.5 μm	2.5-15 μm	Total PM_{15}
	Hansen	7	7	8.3	17.0	25.3
	Lee Vining	7	7	7.5	33.9	41.4
	Benton	7	7	6.6	40.8	47.4
07/28-08/04/80	Bridgeport	ND	ND	ND	ND	ND
	Bodie	7	7	6.9	46.7	53.6
	Hansen	7	7	7.4	14.9	22.3
	Lee Vining	7	7	6.7	19.2	25.9
	Benton	7	7	6.3	17.9	24.2
08/05-08/11/80	Bridgeport	ND	ND	ND	ND	ND
	Bodie	6	6	4.2	54.6	58.8
	Hansen	6	6	5.1	14.1	19.2
	Lee Vining	6	6	5.0	24.6	29.6
	Benton	6	6	3.8	28.4	32.2
08/11-08/19/80	Bridgeport	ND	ND	ND	ND	ND
	Bodie	0	0	TWD	TWD	TWD
	Hansen	0	0	TWD	TWD	TWD
	Lee Vining	8	8	7.7	27.5	35.2
	Benton	0	0	TWD	TWD	TWD
08/19-08/25/80	Bridgeport	ND	ND	ND	ND	ND
	Bodie	0	0	TWD	TWD	TWD
	Hansen	0	0	TWD	TWD	TWD
	Lee Vining	6	6	7.3	26.6	33.9
	Benton	0	0	TWD	TWD	TWD
08/11-08/25/80	Bodie	14	14	4.3	47.4	51.7
	Hansen	14	14	13.9	25.3	39.2
	Benton	14	14	4.8	31.1	35.9
08/25-09/01/80	Bridgeport	ND	ND	ND	ND	ND
	Bodie	7	7	4.2	34.9	39.1
	Hansen	0	0	FWD	FWD	FWD
	Lee Vining	0	0	ND	ND	ND
	Benton	7	7	3.1	16.2	19.3
09/02-09/08/80	Bridgeport	ND	ND	ND	ND	ND
	Bodie	6	6	9.0	47.8	56.8
	Hansen	0	0	FWD	FWD	FWD
	Lee Vining	0	0	ND	ND	ND
	Benton	6	6	7.1	65.4	72.5
09/08-09/15/80	Bridgeport	ND	ND	ND	ND	ND
	Bodie	7	7	13.7	54.7	68.4
	Hansen	0	0	FWD	FWD	FWD
	Lee Vining	0	0	ND	ND	ND
	Benton	7	7	3.7	20.3	24.0
09/15-09/22/80	Bridgeport	ND	ND	ND	ND	ND
	Bodie	7	7	4.2	20.5	24.7
	Hansen	0	0	FWD	FWD	FWD
	Lee Vining	7	7	3.4	12.8	16.2
	Benton	7	7	1.5	20.1	21.6
09/22-09/29/80	Bridgeport	ND	ND	ND	ND	ND
	Bodie	7	7	4.1	24.0	28.1
	Hansen	0	0	FWD	FWD	FWD
	Lee Vining	7	7	5.0	21.1	26.1
	Benton	7	7	5.0	21.6	26.6

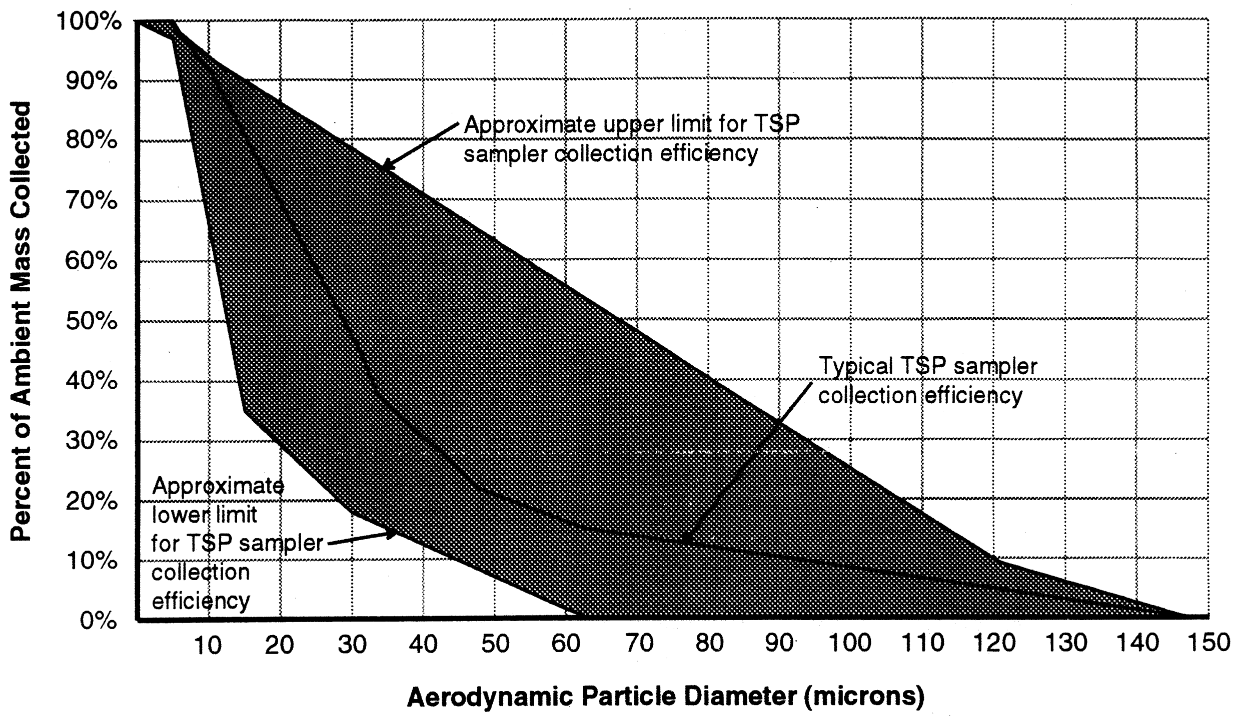
Table N-5. Continued

Sampling Period	Sampling Station Location	Number of Days Sampled		Mean PM_{xx} Concentration ($\mu g/m^3$) by Size Fraction		
		Filter 2	Filter 1	Below 2.5 μm	2.5-15 μm	Total PM_{15}
08/25-09/29/80	Hansen	34	34	9.2	18.8	28.0
09/30-10/06/80	Bridgeport	ND	ND	ND	ND	ND
	Bodie	0	0	ND	ND	ND
	Hansen	6	ND	5.0	ND	ND
	Lee Vining	6	6	6.6	36.8	43.4
	Benton	6	6	5.6	16.7	22.3
10/07-10/13/80	Bridgeport	ND	ND	ND	ND	ND
	Bodie	6	6	9.1	58.8	67.9
	Hansen	6	ND	19.9	ND	ND
	Lee Vining	6	6	8.0	28.5	36.5
	Benton	6	6	6.2	21.9	28.1
10/13-10/21/80	Bridgeport	ND	ND	ND	ND	ND
	Bodie	7	7	1.9	9.2	11.1
	Hansen	7	ND	2.4	ND	ND
	Lee Vining	7	7	5.6	10.1	15.7
	Benton	7	7	3.5	11.8	15.3
10/21-10/28/80	Bridgeport	ND	ND	ND	ND	ND
	Bodie	7	7	6.6	23.5	30.1
	Hansen	7	ND	4.8	ND	ND
	Lee Vining	7	7	8.3	14.8	23.1
	Benton	7	7	4.2	26.9	31.1
All weekly samples 05/13-10/28/80	Bridgeport	39	39	6.4	13.6	20.0
	Bodie	103	103	5.7	35.7	41.5
	Hansen	160	134	7.3	18.9	21.9
	Lee Vining	140	140	5.5	24.3	29.8
	Benton	160	160	4.8	27.9	32.7
Weeks when Bridgeport plus three stations operated	Bridgeport	39	39	6.4	13.6	20.0
	Hansen	39	39	4.9	18.9	23.7
	Lee Vining	39	39	4.5	32.5	37.0
	Benton	39	39	4.8	24.1	28.9
Weeks when Bodie plus three stations operated	Bodie	35	35	5.1	34.5	39.6
	Hansen	35	35	6.2	18.7	25.0
	Lee Vining	35	35	5.5	23.1	28.6
	Benton	35	35	5.9	36.5	42.4

Notes: Filter 2 collected fine particles passing through Filter 1 (aerodynamic cutpoint diameter of 2.5 microns).
Filter 1 collected particles passing through inlet (aerodynamic cutpoint diameter of 15 microns) but had a pore size (aerodynamic cutpoint diameter of 2.5 microns) allowing fine particles to pass to Filter 2.
FWD = 5 week data, summarized in separate table entries.
TWD = 2 week data, summarized in separate table entries.
ND = no data.

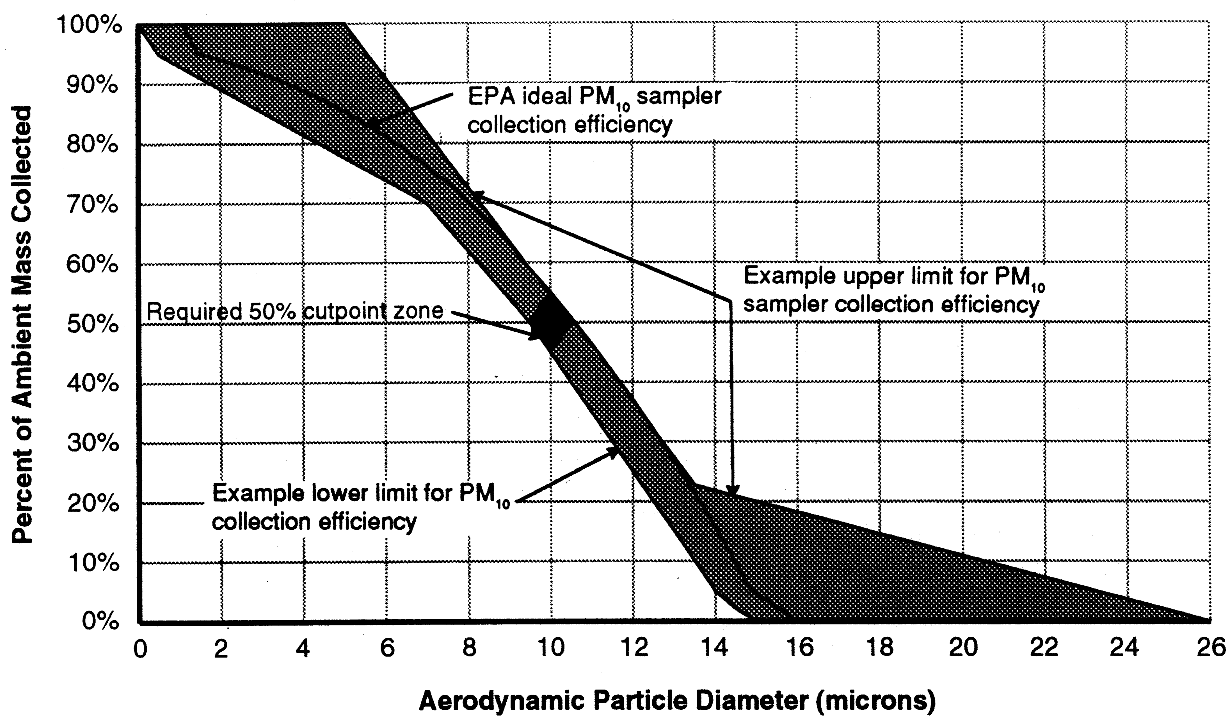
Source: Kusko et al. 1981.

Figure N-1.
TSP Sampler Collection Efficiency



Data Sources: Wedding, McFarland, and Cermak 1977; McFarland, Ortiz, and Rodes 1979

Figure N-2.
PM_{10} Sampler Collection Efficiency



Data Source: 40 CFR 53.40-53.43

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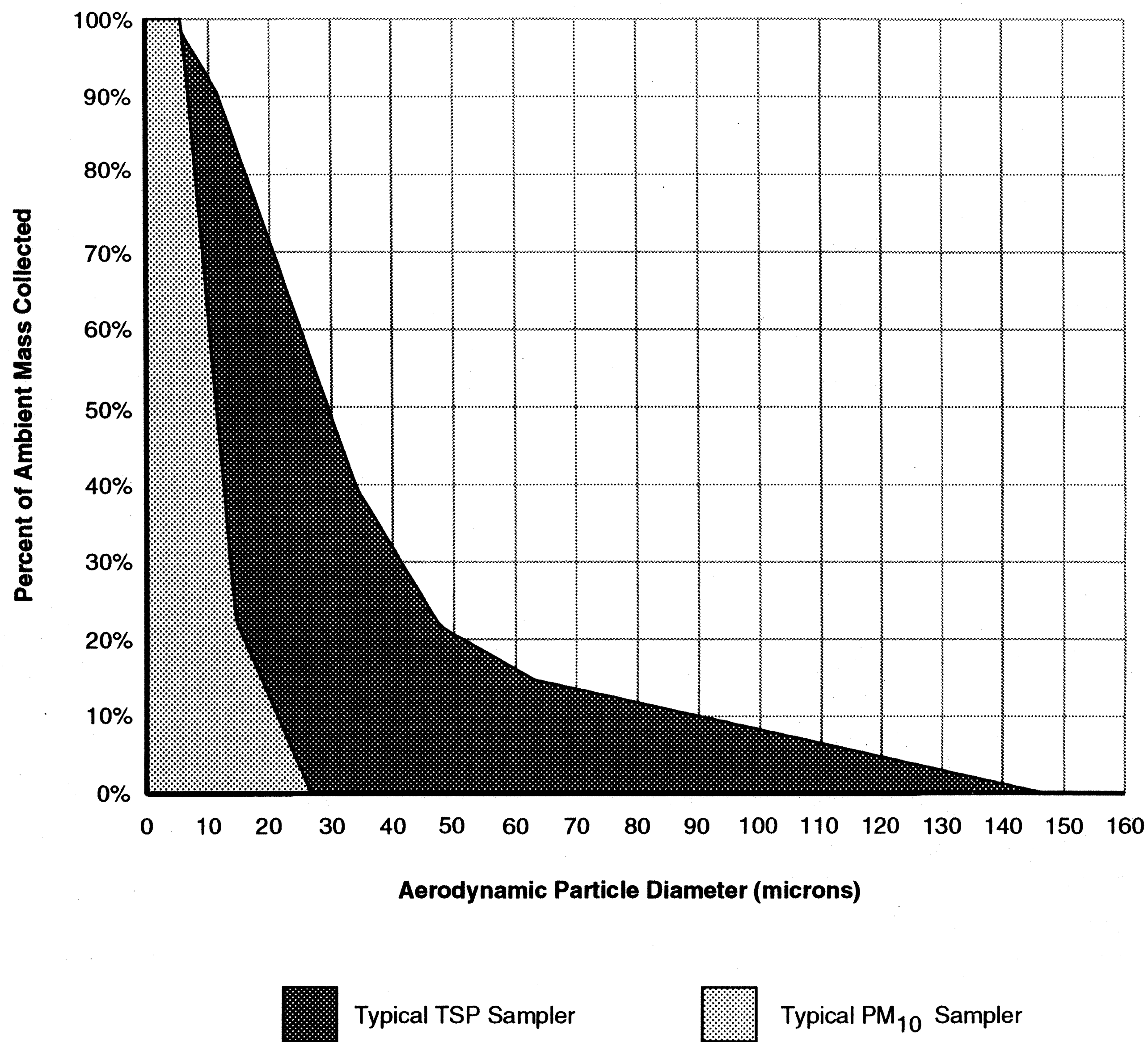
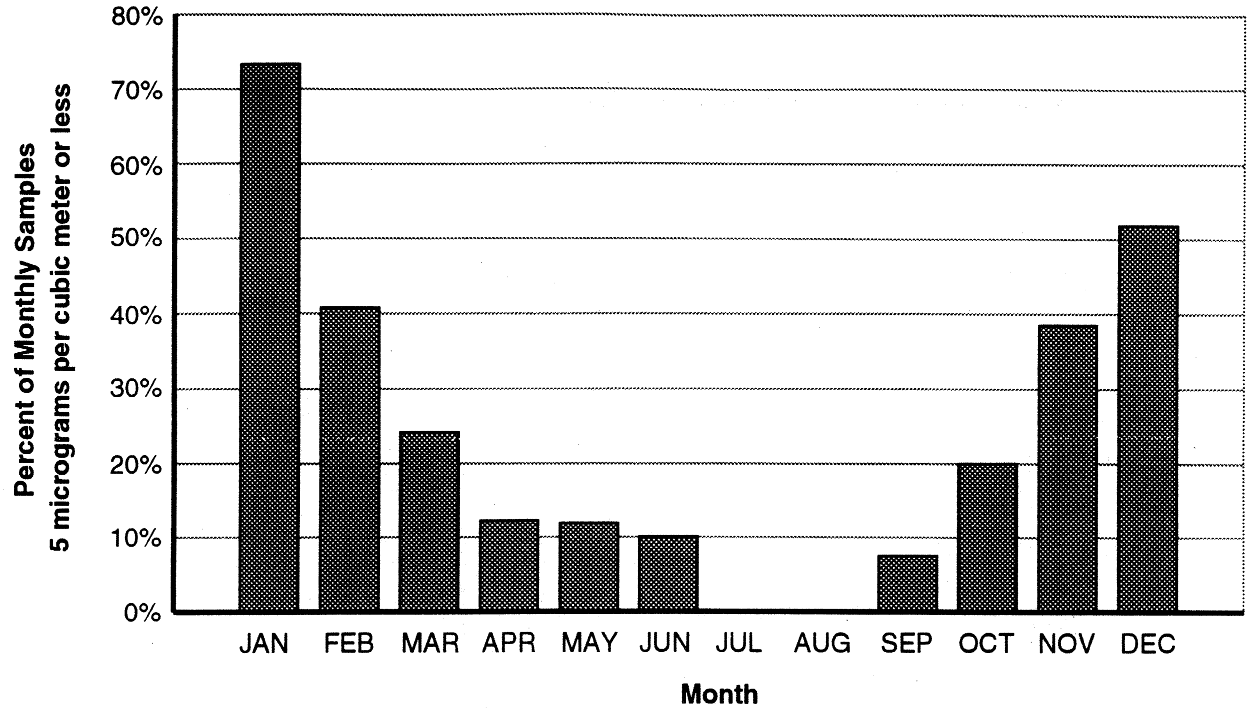


Data Sources: Wedding, McFarland, and Cermak 1977;
McFarland, Ortiz, and Rodes 1979;
40 CFR 53.40-53.43

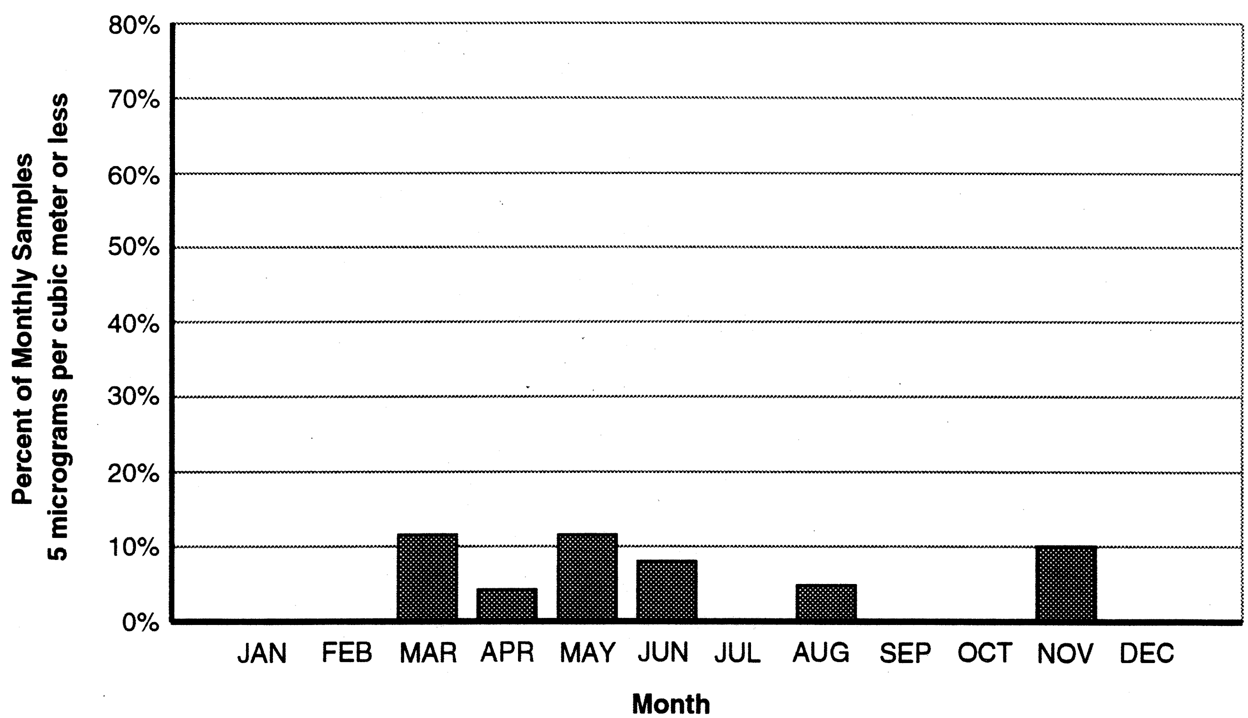
Figure N-3.
Comparison of Typical TSP and PM_{10} Sampler Collection Efficiency Curves

Figure N-4.
Monthly Frequency of Very Low PM_{10} Values at Simis Ranch, October 1986-June 1992



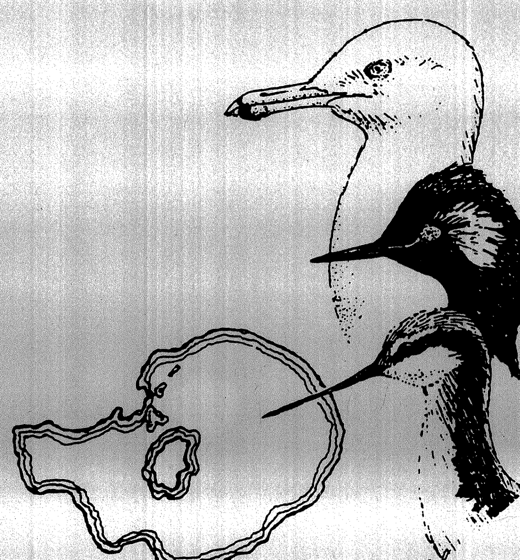
Data Source: California Air Quality Data, Volumes XXIX-XXIII and GPUAPCD Files

Figure N-5.
Monthly Frequency of Very Low PM_{10} Values at Lee Vining, March 1988-June 1992



Data Source: California Air Quality Data, Volumes XXIX-XXIII and GPUAPCD Files

Appendix O. Fisheries Technical Appendix



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Prepared by Jones & Stokes Associates

List of Tables

Table

Table O-1a. Average Monthly Habitat Conditions for Rush, Lee Vining, Parker, and Walker Creeks under Wet, Normal, and Dry Hydrologic Year-Type Conditions for No-Restriction Alternative (Based on Tennant Method)

Creek	Hydrologic Condition	April	May	June	July	August	September	October	November	December	January	February	March	Mean
Rush	Wet	0	0	2	2	3	0	0	0	0	0	0	0	0.6
	Normal	0	0	0	0	0	0	0	0	0	0	0	0	0
	Dry	0	0	0	0	0	0	0	0	0	0	0	0	0
Lee Vining	Wet	0	0	2	2	4	0	0	0	0	0	0	0	0.7
	Normal	0	0	0	0	0	0	0	0	0	0	0	0	0
	Dry	0	0	0	0	0	0	0	0	0	0	0	0	0
Parker	Wet	0	0	0	0	0	0	0	0	0	0	0	0	0
	Normal	0	0	0	0	0	0	0	0	0	0	0	0	0
	Dry	0	0	0	0	0	0	0	0	0	0	0	0	0
Walker	Wet	0	0	0	0	0	0	0	0	0	0	0	0	0
	Normal	0	0	0	0	0	0	0	0	0	0	0	0	0
	Dry	0	0	0	0	0	0	0	0	0	0	0	0	0

Habitat conditions are as follows:

5 = optimum.
4.5 = outstanding.
4 = excellent.
3 = good.
2 = fair.
1 = poor.
0 = severe degradation.

Table O-1b. Average Monthly Habitat Conditions for Rush, Lee Vining, Parker, and Walker Creeks under Wet, Normal, and Dry Hydrologic Year-Type Conditions for Point-of-Reference Alternative (Based on Tennant Method)

Creek	Hydrologic Condition	April	May	June	July	August	September	October	November	December	January	February	March	Mean
Rush	Wet	1	1	3	2	3	1	3	3	3	3	3	3	2.4
	Normal	1	1	1	1	1	1	3	3	3	3	3	3	2
	Dry	1	1	1	1	1	1	3	3	3	3	3	3	2
Lee Vining	Wet	0	0	2	2	4	0	0	0	0	0	0	0	0.7
	Normal	0	0	0	0	0	0	0	0	0	0	0	0	0
	Dry	0	0	0	0	0	0	0	0	0	0	0	0	0
Parker	Wet	0	0	0	0	0	0	0	0	0	0	0	0	0
	Normal	0	0	0	0	0	0	0	0	0	0	0	0	0
	Dry	0	0	0	0	0	0	0	0	0	0	0	0	0
Walker	Wet	0	0	0	0	0	0	0	0	0	0	0	0	0
	Normal	0	0	0	0	0	0	0	0	0	0	0	0	0
	Dry	0	0	0	0	0	0	0	0	0	0	0	0	0

Habitat conditions are as follows:

5 = optimum.
4.5 = outstanding.
4 = excellent.
3 = good.
2 = fair.
1 = poor.
0 = severe degradation.

Table O-1c. Average Monthly Habitat Conditions for Rush, Lee Vining, Parker, and Walker Creeks under Wet, Normal, and Dry Hydrologic Year-Type Conditions for the 6,372-Ft Alternative (Based on Tennant Method)

Creek	Hydrologic Condition	April	May	June	July	August	September	October	November	December	January	February	March	Mean
Rush	Wet	2	4	5	3	2	2	4.5	4	4	4	4	3	3.5
	Normal	2	4	5	3	2	2	4.5	4	4	4	4	3	3.5
	Dry	2	4	5	3	2	2	4.5	4	4	4	4	3	3.5
Lee Vining	Wet	2	4	4	5	3	1	3	3	3	3	3	3	3.1
	Normal	2	4	4	5	3	1	3	3	3	3	3	3	3.1
	Dry	2	4	4	5	3	1	3	3	3	3	3	3	3.1
Parker	Wet	2	4	3	4	5	3	4	3	3	3	3	3	3.3
	Normal	2	4	3	4	5	3	4	3	3	3	3	3	3.3
	Dry	2	4	3	4	5	3	4	3	3	3	3	3	3.3
Walker	Wet	1	2	4	5	3	1	4	4	4	3	3	3	3.1
	Normal	1	2	4	5	3	1	4	4	4	3	3	3	3.1
	Dry	1	2	4	5	3	1	4	4	4	3	3	3	3.1

Habitat conditions are as follows:

5 = optimum.
4.5 = outstanding.
4 = excellent.
3 = good.
2 = fair.
1 = poor.
0 = severe degradation.

Table O-1d. Average Monthly Habitat Conditions for Rush, Lee Vining, Parker, and Walker Creeks under Wet, Normal, and Dry Hydrologic Year-Type Conditions for the 6,377-Ft Alternative (Based on Tennant Method)

Creek	Hydrologic Condition	April	May	June	July	August	September	October	November	December	January	February	March	Mean
Rush	Wet	5	4	3	3	2	2	4.5	4	4	4	4	3	3.5
	Normal	2	4	3	3	2	2	4.5	4	4	4	4	3	3.3
	Dry	2	4	4	3	2	2	4.5	4	4	4	4	3	3.4
Lee Vining	Wet	5	4	2	5	3	1	3	3	3	3	3	3	3.2
	Normal	2	4	2	5	3	1	3	3	3	3	3	3	2.9
	Dry	2	4	3	5	3	1	3	3	3	3	3	3	3.0
Parker	Wet	2	4	2	4	5	3	4	3	3	3	3	3	3.2
	Normal	2	4	2	4	5	3	4	3	3	3	3	3	3.2
	Dry	2	4	3	4	5	3	4	3	3	3	3	3	3.3
Walker	Wet	1	2	2	5	3	1	4	4	4	3	3	3	2.9
	Normal	1	2	2	5	3	1	4	4	4	3	3	3	2.9
	Dry	1	2	3	5	3	1	4	4	4	3	3	3	3.0

Habitat conditions are as follows:

5 = optimum.
4.5 = outstanding.
4 = excellent.
3 = good.
2 = fair.
1 = poor.
0 = severe degradation.

Table O-1e. Average Monthly Habitat Conditions for Rush, Lee Vining, Parker, and Walker Creeks under Wet, Normal, and Dry Hydrologic Year-Type Conditions for the 6,383.5-Ft Alternative (Based on Tennant Method)

Creek	Hydrologic Condition	April	May	June	July	August	September	October	November	December	January	February	March	Mean
Rush	Wet	4	3	2	2	5	4	4.5	4	4	4	4	3	3.6
	Normal	5	4	3	5	2	2	4.5	4	4	4	4	3	3.7
	Dry	2	4	4	3	2	2	4.5	4	4	4	4	3	3.4
Lee Vining	Wet	5	2	2	2	5	2	3	3	3	3	3	3	3.0
	Normal	4	4	2	5	3	1	3	3	3	3	3	3	3.1
	Dry	2	4	3	5	3	1	3	3	3	3	3	3	3.0
Parker	Wet	2	4	2	4	5	3	4	3	3	3	3	3	3.2
	Normal	2	4	2	4	5	3	4	3	3	3	3	3	3.2
	Dry	2	4	3	4	5	3	4	3	3	3	3	3	3.3
Walker	Wet	1	2	2	5	3	1	4	4	4	3	3	3	2.9
	Normal	1	2	2	5	3	1	4	4	4	3	3	3	2.9
	Dry	1	2	3	5	3	1	4	4	4	3	3	3	3.0

Habitat conditions are as follows:

5 = optimum.
4.5 = outstanding.
4 = excellent.
3 = good.
2 = fair.
1 = poor.
0 = severe degradation.

Table O-1f. Average Monthly Habitat Conditions for Rush, Lee Vining, Parker, and Walker Creeks under Wet, Normal, and Dry Hydrologic Year-Type Conditions for the 6,390-Ft Alternative (Based on Tennant Method)

Creek	Hydrologic Condition	April	May	June	July	August	September	October	November	December	January	February	March	Mean
Rush	Wet	4	3	2	2	4	5	4.5	4.5	4	4	4.5	4.5	3.8
	Normal	5	4	3	4	4	3	4.5	4	4	4	4	3	3.9
	Dry	5	5	4	5	2	2	4.5	4	4	4	4	3	3.9
Lee Vining	Wet	5	2	2	2	5	3	4	4	3	3	3	3	3.2
	Normal	5	4	2	4	3	1	3	3	3	3	3	3	3.1
	Dry	3	4	3	5	3	1	3	3	3	3	3	3	3.1
Parker	Wet	2	4	2	4	5	3	4	3	3	3	3	3	3.2
	Normal	2	4	2	4	5	3	4	3	3	3	3	3	3.2
	Dry	2	4	3	4	5	3	4	3	3	3	3	3	3.3
Walker	Wet	1	2	2	5	3	1	4	4	4	3	3	3	2.9
	Normal	1	2	2	5	3	1	4	4	4	3	3	3	2.9
	Dry	1	2	3	5	3	1	4	4	4	3	3	3	3.0

Habitat conditions are as follows:

5 = optimum.
4.5 = outstanding.
4 = excellent.
3 = good.
2 = fair.
1 = poor.
0 = severe degradation.

Table O-1g. Average Monthly Habitat Conditions for Rush, Lee Vining, Parker, and Walker Creeks under Wet, Normal, and Dry Hydrologic Year-Type Conditions for the 6,410-Ft Alternative (Based on Tennant Method)

Creek	Hydrologic Condition	April	May	June	July	August	September	October	November	December	January	February	March	Mean
Rush	Wet	4	3	2	2	2	4	4	4	4.5	4.5	4.5	4.5	3.6
	Normal	5	3	2	4	5	5	5	5	4	4	4	3	4.1
	Dry	5	4	4	5	4	3	4.5	4.5	4	4	4	3	4.1
Lee Vining	Wet	4	2	2	2	3	5	5	5	4	4	4	3	3.6
	Normal	5	3	2	3	5	4	4.5	4	3	3	3	3	3.5
	Dry	4	4	3	5	3	2	4	3	3	3	3	3	3.3
Parker	Wet	2	4	2	4	5	3	4	3	3	3	3	3	3.2
	Normal	2	4	2	4	5	3	4	3	3	3	3	3	3.2
	Dry	2	4	3	4	5	3	4	3	3	3	3	3	3.3
Walker	Wet	1	2	2	5	3	1	4	4	4	3	3	3	2.9
	Normal	1	2	2	5	3	1	4	4	4	3	3	3	2.9
	Dry	1	2	3	5	3	1	4	4	4	3	3	3	3.0

Habitat conditions are as follows:

5 = optimum.
4.5 = outstanding.
4 = excellent.
3 = good.
2 = fair.
1 = poor.
0 = severe degradation.

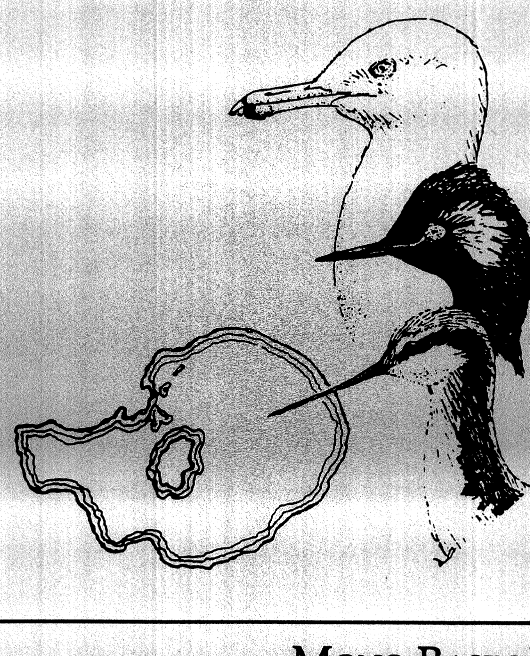
Table O-1h. Average Monthly Habitat Conditions for Rush, Lee Vining, Parker, and Walker Creeks under Wet, Normal, and Dry Hydrologic Year-Type Conditions for the No-Diversion Alternative (Based on Tennant Method)

Creek	Hydrologic Condition	April	May	June	July	August	September	October	November	December	January	February	March	Mean
Rush	Wet	4	3	2	2	4	5	5	5	5	5	5	5	4.2
	Normal	5	4	4	4	5	5	5	5	5	5	5	5	4.8
	Dry	5	4	3	3	3	3	4.5	4.5	4.5	4.5	4.5	4.5	4.0
Lee Vining	Wet	4	2	2	2	3	5	5	5	5	4.5	4.5	4.5	3.9
	Normal	5	3	2	3	5	4	4.5	4.5	4.5	4.5	4.5	4.5	4.1
	Dry	4	4	3	5	3	2	4.5	4.5	4	4	4	4	3.8
Parker	Wet	5	3	2	2	2	4	5	4.5	4.5	4.5	4.5	4.5	3.8
	Normal	4	4	2	2	4	5	4.5	4	4	4	4	4	3.8
	Dry	3	5	3	3	4	4	4	3	3	3	3	3	3.4
Walker	Wet	4	2	2	2	3	5	4	4	5	4.5	4.5	4.5	3.7
	Normal	3	4	2	3	5	4	5	5	4.5	4.5	4.5	4.5	4.1
	Dry	1	4	3	5	4	2	4.5	4.5	4	4	4	4	3.7

Habitat conditions are as follows:

5 = optimum.
4.5 = outstanding.
4 = excellent.
3 = good.
2 = fair.
1 = poor.
0 = severe degradation.

Appendix P. Riparian Vegetation Studies



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Appendix P. Riparian Vegetation Studies

SUMMARY OF RIPARIAN VEGETATION LITERATURE REVIEW

Introduction

This section summarizes information obtained from published literature and consultants' reports on the ecology of riparian plants in Mono Basin. This information is used in the EIR to support assumptions for assessing impacts on riparian vegetation and evaluating the feasibility of potential mitigation measures.

Growth Patterns of Riparian Species

Black Cottonwood

Habitat and Distribution. Black cottonwood is an obligate riparian species (i.e., it grows only along streams) and requires greater amounts of water than willows (Pezeshki and Hinckley 1988, Patten and Stromberg-Wilkins 1988). Juvenile black cottonwoods on Rush Creek occur mostly in coarse, rocky substrates just beyond channel edges or at the edges of floodplains, reflecting their requirements for both moisture and aeration. On other streams, cottonwood abundance increases with proximity to streams, reflecting their high demands for groundwater (Roe 1958, Patten and Stromberg-Wilkins 1988).

Drought Stress Tolerance. Growth-related indicators of drought stress in cottonwoods include reduced stem radial growth, reduced branch growth and branch or crown dieback, reduced leaf size, increased leaf senescence and loss of leaf area, and reduced seedling abundance (Albertson and Weaver 1945, Smith 1984, Patten and Stromberg-Wilkins 1988, Pezeshki and Hinckley 1988, Rood and Mahoney 1990).

Physiological responses to drought stress in cottonwoods include reduced transpiration, higher leaf temperatures, increased leaf thickness, and reduced size of stomata (leaf pores). Drought-stressed plants may adapt physiologically and morphologically to conserve water, but when these adaptations do not fully offset reduced water availability, leaves lose water potential and wilt or die (Smith 1984, McBride et al. 1989). Black cottonwoods in relatively dry sites may become better adapted to recover from drought stress than trees in relatively wet sites (Schulte et al. 1987).

Male black cottonwoods may more successfully survive periods of drought stress than females; therefore, sex ratios may affect survival and recovery following stress and may be affected by periods of stress (Patten and Stromberg-Wilkins 1988).

Stromberg and Patten (1991) concluded that black cottonwood growth rates on Bishop Creek depended strongly on growing season streamflow volumes.

Root Growth. Although most observations of cottonwood rooting depths and root growth rates have been in species other than black cottonwood, cottonwoods in similar habitats may have similar growth potentials. Fenner et al. (1984) observed Fremont cottonwood root growth up to 6 mm (0.2 inch) per day. Total rooting depth of seedlings reached 72 cm (2.4 feet) at the end of the first summer of their study and reportedly could have grown up to 162 cm (5.3 feet). Ware and Penfound (1949) observed roots 3 m (9.8 feet) deep in 2-year-old cottonwoods in Oklahoma. Dickman and Stuart (1983) observed roots growing 1 m (3.3 feet) or more a year in 3- to 5-year-old poplars in eastern North America. McBride and Strahan (1984) found that root growth in Fremont cottonwoods exceeded that in two willow species.

Fenner et al. (1984) determined that a declining water table promoted deepr root growth. McBride et al. (1989) observed Fremont cottonwood roots following a declining water table. Vertical growth stopped and lateral growth began when the roots reached a stable water table. Groeneveld and Griepentrog (1985) found that roots of juvenile black cottonwood that had adapted to a shallow water table did not elongate when the water table dropped; roots that had not adapted to a shallow water table grew 5 mm (0.2 inch) per day as the water table moved deeper in the soil. Broadfoot (1973) found that cottonwood root growth rates peaked when the water table was 58 cm (1.9 feet) below the ground surface. Robinson (1952) reported that cottonwoods and willows rarely grow where the water table is more than 20 feet deep.

Few observations of total root depth or optimal water table depth have been made for black cottonwood or other riparian species. Observations made at a number of wells in the Owens Valley in 1921 (Ecosat Geobotanical Surveys 1990) suggest that the water table in woody riparian communities is typically 3.9 ± 1.5 feet below the ground surface (see "Water Table Model" below).

Reproduction and Seedling Establishment. Black cottonwood typically reproduces by seed but can also reproduce vegetatively (Patten and Stromberg-Wilkins 1988). Seed maturation, dispersal, and germination is adapted to the timing of high spring flows (Fenner et al. 1985). Seed dispersal in the Lee Vining area typically occurs in June and July. Scouring by floods and ice may promote development of vegetative suckers in cottonwoods (Rood and Mahoney 1990). Stem segments that break off trees may occasionally root and generate new plants in black cottonwood (Galloway and Worrall 1979).

Recruitment occurs episodically following high spring flows; abnormally high summer flows can destroy seedlings (Stromberg and Patten 1989a). Seedlings do not tolerate prolonged flooding, and root growth is promoted by receding water levels; therefore, gradual subsidence of high flows is important for seedling survival and establishment (Fenner et al. 1985). Some cottonwoods require moist conditions at the ground surface for least 1 week to ensure germination and establishment (Moss 1938). Seed viability is short because of their small size (Fenner et al. 1984, Moss 1938). Conditions favoring germination and establishment are normally episodic, occurring at 2- to 10-year intervals. During such years, cottonwoods and willows may germinate successfully for periods of only 2-4 weeks (Rood and Mahoney 1990).

Cottonwood seedlings are generally poor competitors with other plants; therefore, recruitment occurs mostly on open, unvegetated sites with abundant sunlight and constant moisture for the first few weeks of growth (Rood and Mahoney 1990). Mortality of seeds and first-year seedlings most often results from drought or late frosts (Rood and Mahoney 1990, Stromberg and Patten 1989a). Northern cottonwood seedlings survive best on point bars and moist streambanks, where the plants have access to moisture but flooding is avoided (Bradley and Smith 1986, Noble 1987, Wilson 1970).

Quaking Aspen

Habitat and Distribution. Quaking aspen is considered an obligate riparian species in semi-arid regions (Rood and Mahoney 1990), but it occurs on hillsides watered by springs and snowmelt as well as along streams. Quaking aspen is intolerant of shade (Moss 1938). Quaking aspen occurs infrequently in coarse alluvial habitats below the terminal glacial moraines on Mono Lake's tributary streams but is common on all the tributary streams within the terminal moraines.

Drought Stress Tolerance. Indicators of drought stress reported in quaking aspen include reduced growth and reduced seedling abundance (Rood and Mahoney 1990). Quaking aspen may exhibit other growth-related and physiological drought stress indicators similar to those listed above for the closely related black cottonwood.

Root Growth. Quaking aspen seedlings develop extensive lateral root systems with limited tap roots. Extensive clones develop by suckering from lateral roots of a single plant, not by root grafting between separate plants. Mature stands (of one or more clones) are characterized by shallow, spreading, interconnected lateral roots with vertical sinkers descending from the lateral roots. Lateral roots may extend over 100 feet into adjacent open areas; sinker roots have been observed 9 feet deep in well-drained soils. Sinker roots may develop dense mats of fine roots at their lower extremities (Jones and DeByle 1985).

Reproduction and Seedling Establishment. Quaking aspen reproduces mostly by sprouting from the widely spreading lateral roots. Seedling establishment is rare in quaking aspens because seeds are viable for only brief periods and deteriorate rapidly without optimal conditions. Optimal conditions for germination and establishment include adequate drainage; moderate temperature; absence of competing vegetation; and a level, well-watered mineral soil surface. Seedlings are highly sensitive to small soil moisture deficits, and rapid drying of surface soil is the most common cause of seedling mortality (Patten and Stromberg-Wilkins 1988, Moss 1938).

Clonal sprouting is stimulated by heat, light, injury (Schier et al. 1985), and increased streamflows (Patten and Stromberg-Wilkins 1988).

Willows

Habitat and Distribution. The following willows have been reported to occur below the diversion points on Rush, Parker, Walker, and Lee Vining Creeks (Taylor 1982, Patten and Stromberg-Wilkins 1988, Stromberg and Patten 1989d):

- Coyote willow is common along streambanks and across dewatered floodplains. It is the most abundant and most drought-tolerant of the willows on these creeks.

- Arroyo, or white, willow was formerly abundant and is now uncommon, but it is reestablishing widely in the rewatered reaches. Arroyo willow is currently the second most common willow in diverted reaches of the creeks, especially on point bars in the lower reaches. In the Owens Valley, it is often associated with western birch.

- Yellow willow occurs mostly along reaches with little flow, surrounded by sagebrush and often found with Pacific willow. It is more common in the lower than the upper reaches of Rush Creek.

- Pacific willow is uncommon, occurring mostly in reaches little affected by dewatering. It often occurs with yellow willow along reaches with little flow and surrounded by sagebrush.

- Red willow is uncommon, but mature plants remain in reaches little affected by dewatering and young plants have established on point bars on lower Rush and Lee Vining Creeks. Red willow is more common in the Owens Valley than in Mono Basin.

Drought Stress Tolerance. Ranking of drought stress tolerance, from most tolerant to least tolerant, is:

- coyote willo,
- arroyo willow,
- yellow willow, and
- red and Pacific willows.

(Patten 1968, Patten and Stromberg-Wilkins 1988.) Coyote willow's presence on pre-incision floodplain terraces on Rush and Lee Vining Creeks and its dominance in dewatered sections of Parker and Walker Creeks reflect its tolerance of dewatering compared to other willows.

Coyote willow may also be more tolerant of grazing than other willows (Patten and Stromberg-Wilkins 1988).

Although red willow is less tolerant of stress than arroyo willow, it is better adapted to water table decline because it has a more effective root system (Williams and Matthews 1990).

Indicators of drought stress in willows include substantial leaf loss (Smith 1984), low predawn leaf water potential, high leaf temperature, and high transpiration rate (Leighton and Risser 1989).

Root Growth. Willows grown in experimental tanks (McBride et al. 1989) grew roots that followed an artificially receding water table. When water table decline ceased, downward growth stopped and many lateral roots were produced. Red willow and sandbar willow, closely related to coyote willow) developed fibrous root systems with many lateral roots (McBride et al. 1989). Root growth rates in sandbar willow and red willow were less than that in Fremont cottonwood (McBride and Strahan 1984).

Reproduction and Seedling Establishment. Coyote willow reproduces vigorously from both seeds and sprouts. Coyote willow is regenerating more than other willow species on Rush Creek (Stromberg and Patten 1989d). Patten (1986) observed that strong willow survival and growth was associated with sandy substrates. McBride and Strahan (1984) found that willows established best where the surface sediment size averaged less than 2 mm; cottonwoods established more often where the surface sediment size averaged 2-20 mm.

Arroyo willow requires abundant subsurface moisture throughout summer for seedlings to survive and establish. Other willows require at least temporarily saturated soils (Stromberg and Patten 1989a).

Mountain Rose

Habitat and Distribution. Mountain rose is a facultative riparian species that tolerates a wide range of soil moisture conditions. It tolerates both full sun and shade (Patten and Stromberg-Wilkins 1988). It grows most vigorously on well-watered streambanks with topsoil but also persists in former riparian areas now dominated by sagebrush. Mountain rose also invades areas where willows or cottonwoods have died or become decadent from dewatering (Stromberg and Patten 1989d).

Drought Stress Tolerance. Mountain rose is apparently much more tolerant of drought stress than willows or cottonwoods because it invades or persists in areas where obligate riparian plants have died. Like garden roses, however, mountain rose grows best with an ample water supply. No specific studies of drought stress tolerance in mountain rose are available.

Root Growth. No observations of mountain rose root growth are available.

Reproduction and Seedling Establishment. Mountain rose spreads vegetatively by root sprouts and also reproduces by seed. Fruit and seed production is abundant on the tributary streams, where large numbers of seeds are dispersed by robins and other birds (Patten and Stromberg-Wilkins 1988, Stromberg and Patten 1989d).

Mountain rose abundance on the tributary streams is highly correlated with woody litter abundance, indicating that organic matter from woody litter may promote rose germination and establishment (Patten and Stromberg-Wilkins 1988).

Buffalo Berry

Buffalo berry is a facultative riparian species in Mono Basin, occurring near streams and on the drier edges of floodplains. On Rush Creek, it tends to occur on the silty soils of raised terraces (Patten and Stromberg-Wilkins 1988, Stromberg and Patten 1989d).

Buffalo berry reproduces by seed and by clonal sprouting. Reproduction by both means has been observed on Rush Creek in response to rewatering (Patten and Stromberg-Wilkins 1988, Stromberg and Patten 1989d).

Jeffrey Pine

Jeffrey pine is a facultative riparian species in Mono Basin; in some areas, it is restricted to the streamside riparian strip and in other areas is a widespread upland forest tree. In both settings, it is intolerant of floods and requires well-drained soils. Its seedlings do not compete well with other species (Patten and Stromberg-Wilkins 1988).

Stumps of Jeffrey pines have been observed in the active channel of the West Walker River north of Pickle Meadows (Stine pers. comm.). These pines evidently established on the riverbanks when flows were lower and may have died in response to increased flows and drowning of their roots.

Conclusions Regarding Growth of Riparian Vegetation

Effects on Individuals

Individual riparian plants respond to drought stress through physiological and morphological adaptations such as the following:

- stomate size (affecting CO_2 exchange and water loss);
- transpiration rate and leaf shape (affecting leaf temperature and water uptake);

- leaf orientation, size, thickness, and hairiness (affecting energy gain); and
- growth rate (affecting root-shoot ratio and dormancy period).

Individuals of different species and sometimes of different populations in the same species differ in their capacity to tolerate drought stress without substantial dieback, reproductive failure, or mortality. Adult riparian plants are more tolerant of drought stress than young plants.

Roots can grow vertically to follow a receding water table, but root growth will not keep pace with a water table that recedes too rapidly.

Effects on Populations

Although willows and cottonwoods may be severely depleted by prolonged dewatering, they have strong potential to recolonize riparian areas. The following conditions are necessary for natural recolonization:

- overbank flows coinciding with seed dispersal,
- gradually receding flows following seed dispersal,
- accessible groundwater during periods of high water demand, and
- predominantly sandy or gravelly substrates for seedlings.

The availability of these conditions largely determines the rate and distribution of vegetation recovery from seeds.

Recruitment of new stands of willows and cottonwoods is intermittent, limited to years when moisture conditions are optimum. Prolonged periods of stress during which seedlings do not establish, however, can alter the age distribution of an existing population.

Substantial changes in channel or floodplain morphology (e.g., incision, lateral erosion, topsoil removal, or channel abandonment) may locally alter the long-term potential for riparian vegetation to reoccupy areas where prediversion riparian vegetation was abundant.

Changes in flow or other factors that reduce sand and gravel bar formation can reduce riparian vegetation recruitment by retarding development of favorable seedling sites.

RIPARIAN VEGETATION MAPPING

Methods

Vegetation Mapping

Jones & Stokes Associates prepared detailed maps of prediversion (1940) and existing (1989) riparian vegetation on the diverted segments of Rush, Lee Vining, Parker, and Walker Creeks. Prediversion vegetation was mapped using black-and-white aerial photographs taken in December 1929 and June 1940. No direct field verification of prediversion vegetation was possible; however, limited information on vegetative composition and condition was available from ground-based photographs, recollections of individuals who lived in the area at the time, written field notes from C. H. Lee, and the remains of formerly vigorous vegetation. Existing vegetation was mapped using color aerial photographs taken in August 1987 (Rush Creek only) and July 1990 (all creeks). Field surveys were conducted in summer and fall 1990 and 1991 to verify existing vegetative composition and condition.

Vegetation was mapped as polygons having generally uniform composition and condition. Composition was defined in terms of dominant woody species. Condition was characterized in terms of cover class, vigor, vegetative layering, and response to rewatering. All riparian vegetation was mapped on detailed topographic maps (scale = 1:1,200; contour interval = 2 feet) prepared from May 1991 aerial photographs.

The maps of prediversion and existing riparian vegetation were used to determine how riparian vegetation had changed after 50 years of diversions and to determine where riparian vegetation was already responding favorably to recent rewatering.

Composition. Dominant species and overall composition were characterized using the vegetation classification described in Appendix F.

Cover Class. Areas with less than about 10% vegetative cover (woody or herbaceous) were mapped as unvegetated. Areas with over 10% cover of herbaceous plants but less than 10% cover of woody plants were mapped as herbaceous vegetation. Areas with over 10% cover of woody plants were mapped as forest/woodland or scrub vegetation. Cover classes of woody vegetation were mapped as follows:

- class 1 = 10-25% cover,
- class 2 = 25-50% cover,
- class 3 = 50-75% cover, and
- class 4 = 75-100% cover.

Riparian Vigor. Three broad categories were used to describe overall community vigor for forest/woodland and scrub vegetation types. "Establishing" polygons were those in which the cover by seedlings and saplings of woody plants exceeded cover by mature plants. "Mature" polygons were those in which cover by mature plants exceeded cover by woody seedlings and saplings and cover by live stems and branches exceeded cover by dead wood. "Decadent" polygons were those in which cover by dead wood (usually cottonwood and willow) exceeded cover by live branches and stems of the same species. Vigor was not assessed for herbaceous vegetation types or individual plants.

Vegetative Layering. Four generalized vegetative layers were recognized in vegetated areas:

- layer A = groundcover (herbaceous plants only, mostly under 1 foot tall);
- layer B = low shrubs and tree saplings (mostly 1-4 feet tall);
- layer C = tall shrubs and short trees (mostly 4-12 feet tall); and
- layer D = tall trees (mostly over 12 feet tall).

Vegetation polygons were characterized in terms of the number of different layers present. Layers with less than about 10% cover were not counted. Herbaceous vegetation types, by definition, had only one layer present (layer A). Woody vegetation types could have one to four layers present, although tall trees (layer D) were present only in forest/woodland vegetation.

Acreage. Riparian vegetation polygon sizes were measured manually using an electronic planimeter, except for existing vegetation on Rush Creek below The Narrows, which was measured digitally using ArcInfo (GIS software). Minimum polygon sizes were influenced by patch isolation and density. Isolated patches of dense vegetation were mapped down to about 0.05 acre. Contiguous polygons of sparse to dense vegetation were generally at least 0.2 acre in size. Measured acreages were compiled in a database from which tables were prepared summarizing acreages by stream, reach, and habitat type.

Total mapped acreages for each reach varied slightly between the 1989 and 1940 maps. These discrepancies resulted from minor errors in the manual planimetry process. To eliminate these discrepancies, the mean of the 1940 and 1989 acreages was calculated for the entire mapped area on each stream. Each polygon acreage was multiplied by a correction factor (one for the 1940 data set and another for the 1989 data set) to obtain the same total for each year.

The corrected riparian vegetation acreages were considered accurate to approximately ±5%. In evaluating differences between 1940 and 1989 acreages, differences of less than 5% were considered undetectable; differences of 5-10% were considered detectable, but slight; differences greater than 10% were considered readily detectable.

Responses to Rewatering

The effect of recent court-ordered streamflows was assessed for each mature woody riparian vegetation polygon mapped on each stream. Four qualitative levels of response to rewatering were recognized.

- Response level 0 was "no response," indicated by no establishment of new plants and no increased growth of mature trees that had survived dewatering.

- Response level 1 was "slight response," indicated by sparse establishment of new seedlings, saplings, or suckers (with some searching needed to find them) or increased growth of mature survivor trees (if present).

- Response level 2 was "moderate response," indicated by the presence of numerous new seedlings, saplings, and suckers (easily found in moderate numbers) and increased growth of mature survivor trees (if present).

- Response level 3 was "strong response," indicated by an abundance of new seedlings, saplings, and suckers (dominant visually and in percent cover) and vigorous growth of mature survivor trees (if present).

These observations were used to develop estimates for minimum responses to alternatives under which flows would be similar to or greater than recent actual flows. These observations were also used to help evaluate the reliability of the riparian width, cottonwood growth, and water table depth models for predicting prediversion and point-of-reference conditions.

Results

Vegetation Mapping

Figures P-1 through P-8 show the extent and type of prediversion and point-of-reference riparian vegetation on Rush, Parker, Walker, and Lee Vining Creeks.

Tables P-1 through P-8 list prediversion and point-of-reference riparian vegetation acreages by habitat type and reach for each creek.

Responses to Rewatering

Tables P-9 through P-12 summarize observed responses of the riparian vegetation to rewatering as of summer 1991.

DESCRIPTIONS OF RIPARIAN VEGETATION BY REACH

Prediversion Conditions

Rush Creek

Reach R0 (above Grant Lake Reservoir). Despite highly variable water elevations during the 1920s and 1930s (eroded shorelines are visible well above the lake surface in the January 1930 aerial photograph), some patches of floating or emergent vegetation were present. These "plant beds" described by Vestal (1990, Court Testimony, Vol. I-XVIII) most likely occurred in the gently sloping shallows at the south end of the lake.

Above the spillway elevation of the 1926 dam, the 1929-1930 aerial photographs show riparian vegetation dominated by willows and cottonwoods, with scattered conifers (probably mostly lodgepole pines), small meadows, and probably some quaking aspens from the high water level of the lake to about 0.8 mile upstream. From this point to beyond the current south end of the lake, the vegetation appears to have been dominated by quaking aspens with scattered conifers.

Reach R1a (Grant Lake Dam to Mouth of Return Ditch). Prediversion aerial photographs indicate that the upper third of this reach supported a narrow stand (up to about 50 feet wide) of cottonwoods, quaking aspens, and willows that was apparently tall, dense, and nearly continuous in the 1930s. Quaking aspens occurred along the Grant Lake reservoir spillway in the uppermost portion of this reach. The photographs also indicate a wider zone (100-150 feet wide) of sparser vegetation in this reach, probably dominated by scattered clumps of willows.

The middle third of the reach appears to have supported narrower and less continuous riparian vegetation. The lower third of the reach supported dense strands of cottonwood forest, willow scrub, and quaking aspens on both sides of the channel and A-Ditch forebay. Riparian vegetation at the bottom of the reach was about 400 feet wide.

Reach R1b (Return Ditch). This channel was constructed shortly before 1940 and supported no riparian vegetation.

Reach R2a (Mouth of Return Ditch to Base of Moraine). This reach passes through a narrow ravine (100-500 feet wide at its rim) in the lowest of the Pleistocene moraines on Rush Creek. Riparian vegetation was confined to narrow strips along the banks and lower slopes of the channel. The upper quarter of the channel supported about 1.2 acres of willow scrub, mostly on the right bank of the stream. One minor overflow channel between this reach and the major overflow channel to the east (reach R2b below) supported about 1.1 acres of dense mountain rose.

The lower three-quarters of this reach supported about 6.5 acres of cottonwood forest, willow scrub, conifer-broadleaf forest with Jeffrey pines, and small quaking aspen groves. The riparian zone was mostly 70-150 feet wide.

Reach R2b (A-Ditch Supply Channel). Beginning in the early 1900s, this natural overflow channel east of reach R2a was regulated as a supply channel for the A-Ditch. The A-Ditch originated midway along this channel at about the 7,010-foot elevation and carried irrigation water eastward to Pumice Valley from before 1920 (when hydrographic records begin) every year until 1948, then intermittently until 1970.

In 1940, vegetation above the A-Ditch intake included willows and quaking aspens along the channel; quaking aspen groves with scattered willows on the hillside west of the channel; and small, linear meadows. Vegetation below the A-Ditch intake included a dense strip of willow scrub along the channel and meadows west of the channel.

Quaking aspens on the hillside west of the channel were associated with springs, possibly fed by water from the main channel of Rush Creek. The meadows were also partially supported by the springs but had probably been enlarged by irrigation from the springs and the overflow channel.

Reach R3 (Base of Moraine to Old Highway Bridge). Approximately 23 acres of cottonwood-willow forest and willow scrub lined the banks and floodplain of this reach in a riparian zone mostly 200-400 feet wide. Jeffrey pines were widely scattered throughout most of the cottonwood-willow forest and were locally dominant over about 1.0 acre near the upper end of this reach. Several small patches of willows or buffalo berry occurred on locally moist sites near but above the floodplain in this reach. The B-Ditch intake was located on the right side of the creek about 1,400 feet above the old highway bridge. Riparian vegetation appears to have been absent from about 600 feet above to 400 feet below the old highway bridge.

Reach R4 (Old Highway Bridge to Mouth of Parker Creek). Riparian vegetation was absent from one or both sides of the creek from the old highway bridge to U.S. Highway 395 (U.S. 395). Below U.S. 395, narrow but nearly continuous strips of willow scrub and cottonwood woodland occurred on both sides of the creek. The riparian zone was mostly 100-150 feet wide, and about 49% of the vegetation had less than 50% cover. Pines were widely scattered throughout the reach but were not dominant in any portion of the reach. One small stand of quaking aspens grew above the right bank of the stream near the middle of this reach.

Stine (1991) notes that, in the 1930s, Rush Creek was relatively dry from the B-Ditch intake to springs near The Narrows. Irrigation diversions above this reach, particularly during the Dust Bowl drought, may have caused some decline in riparian vegetation cover and vigor in this reach before 1940.

Reach R5 (Mouth of Parker Creek to The Narrows). Riparian vegetation was intermittent along Rush Creek for about 700 feet below the confluence with Parker Creek, alternating from one side of the creek to the other. From about 700 feet below Parker Creek to The Narrows, riparian vegetation was mostly continuous on both sides of the creek. Cottonwood-willow woodland and willow scrub were dominant over about 9.6 acres in a riparian zone averaging about 200-250 feet wide.

Charles Lee, a consulting hydrologist working for LADWP in the 1930s, visited Rush Creek near the confluence with Walker Creek on March 23, 1934. His notes record watercress "along margins of Walker and Rush Creeks and seepages entering . . . 6 inches to 1 foot above stream level." Lee also noted "big seepage flow into Rush Creek from both sides appreciably increasing flow" to 6-8 cubic feet per second (cfs) at The Narrows (Stine 1991).

Reach R6 (The Narrows to the Ford). The bottomlands of Rush Creek were characterized by extensive riparian forests, abundant springs at the bases of cliffs, and extensive wet meadows. Riparian vegetation and spring-fed vegetation in this reach were more extensive than in any other stream reach of comparable length in Mono Basin.

The farthest downstream stand of Jeffrey pines on Rush Creek was at the cliff base on the right side of the stream from The Narrows to near the "Big Wash" that enters the bottomlands from Pumice Valley about 2,500 feet below The Narrows. These trees were large and old (Vestal 1990, Court Testimony, Vol. I, pp. 251-252; Stine 1991).

From The Narrows to Big Wash and from the lower meadows to the ford, woody riparian growth was relatively dense, with extensive patches with over 75% cover on both sides of the stream. From Big Wash to the lower meadows, woody riparian vegetation was more patchy, with many small wooded areas separated by small meadows or gravel bars, many larger patches of sparse cover, and some large patches of dense cover. In all these areas, the vegetation was mostly cottonwood-willow forest and willow scrub.

Three major meadow areas occurred on the left side of Rush Creek in this reach. The uppermost meadows, from about 300 to 2,000 feet below The Narrows, were partially separated from Rush Creek by a large island of sagebrush scrub and were mostly 10-15 feet above the nearest elevation of the stream. These meadows appear to have been watered not by groundwater associated with Rush Creek but by springs fed by groundwater recharge at Cain Ranch and along Walker and Bohler Creeks.

The middle set of meadows, from about 2,000 to 4,000 feet below The Narrows, were adjacent to Rush Creek and mostly 2-10 feet above the nearest elevation of the stream. These meadows were probably supported partly by groundwater associated with Rush Creek and partly by groundwater seepage through the Bohler Creek delta deposits.

The lower meadows, from about 1,700 to 4,300 feet above the ford, were mostly less than 5 feet above the nearest elevation of the stream. The lower meadows were described by Charles Lee in his March 1934 notes as "swampy" with "springs and seepages all along [the stream] margin and cut meander channels" (Stine 1991). The lower meadow was irrigated during the 1930s with Rush Creek water diverted from the middle meadows area into the "Indian Ditch." This ditch ceased operation shortly after 1940 (Stine 1991).

Patches of meadow fragmented by narrow corridors of cottonwood-willow forest occurred along the right side of Rush Creek from about 3,000 to 4,800 feet below The Narrows, or just below Big Wash. These meadows were low on the floodplain and within a few feet of the nearby streambanks.

Additional springs and seeps occurred near the base of the high bluffs on the right side of the bottomlands, mostly from Big Wash to the lower end of the lower meadows (about 1,700 feet above the ford). Some of these springs are identified on a map from the Aitken case of 1931-1933 (Stine 1991). The springs are evident on the 1930 and 1940 aerial photographs as lines of dense willow thickets above the edge of the floodplain. Vestal recalled that the biggest springs issued from "around the downstream end of the big wash" (Stine 1991). Lee noted watercress along the margins of Rush Creek wherever he saw the creek in the bottomlands on his March 23, 1934 visit. A substantial portion of the water flowing from these springs originated from Rush Creek water diverted to irrigate Pumice Valley via the A- and B-Ditches (Stine 1991).

Small, scattered patches of cattail or bulrush probably occurred near the springs on the right side of the creek and along abandoned or subsidiary channels. Remnants of such vegetation are evident today but were not mentioned in the recollections or notes of persons present in the 1930s.

Reach R7 (the Ford to County Road). This reach was dominated by dense thickets of willow scrub and cottonwood-willow forest. Photographs from the bluffs overlooking the riparian thickets show several small, interconnected ponds among patches of willows, cottonwoods, and possibly quaking aspens, with wide, thick mats of what appear to be watercress. Few unvegetated or sparsely vegetated sand or gravel bars are visible in prediversion aerial photographs. A meadow of approximately 4.9 acres occurred immediately below the ford, and another of about 2.3 acres occurred above the Clover Ranch buildings. The Rush Creek Fish Hatchery was located on the right side of the creek near the middle of this reach.

Reach R8a (County Road to 1940 Lakeshore). The reach from County Road to the lakeshore (at elevation 6,417.5) was approximately 2,200 feet long in 1940. Willow scrub characterized the floodplain for half this distance, from County Road to about elevation 6,420. Meadows occurred between the willow scrub and the lakeshore.

Reach R8b (1940 Lakeshore to 1989 Lakeshore). This reach (approximately 2,200 feet long) was beneath the surface of the lake in 1940.

Parker Creek

Reach P0 (above Diversion). Riparian vegetation above the present location of the LADWP diversion pond was similar to current vegetation in the area. Willow scrub with several scattered pines (similar to that in upper reach P1) occupied the lower 0.2 mile of the reach. The remainder of the reach was dominated by conifer-broadleaf forest with quaking aspens and pines.

Reach P1 (Diversion to Base of Moraine). Parker Creek occupied two roughly parallel channels in this reach. The north channel (the main Parker Creek channel) supported approximately 7.5 acres of woody riparian vegetation, of which nearly all was willow scrub. The south channel (commonly called "South Parker Creek" but incorrectly identified as the main "Parker Creek" on the 1953 and 1986 U.S. Geological Survey [USGS] topographic maps) appears to have been a natural overflow channel and used as part of the irrigation system. South Parker Creek supported about 7.0 acres of woody riparian vegetation, of which about 6.5 acres was willow scrub. All this vegetation appears in the 1929-1930 and 1940 aerial photographs to have relatively dense, vigorous canopies; however, sheep grazing probably suppressed establishment of young willows during much of the early 1900s.

Reach P2 (Base of Moraine to Cain Ranch Road). About 61% of all the woody riparian vegetation in reaches P1-P4 occurred in this reach. Willow scrub occupied about 35 acres, most or all of which was not stressed by drought; however, sheep grazing probably suppressed recruitment of young plants as in reach P1. Small patches of conifer-broadleaf woodland, non-native cottonwoods, and mixed riparian scrub each occupied about 0.5 acre in this reach.

Reach P3 (Cain Ranch Road to U.S. 395). This reach supported approximately 2.5 acres of willow scrub in a narrow, nearly continuous strand similar to that in the middle of reach P2. A few scattered buffalo berries were probably also present.

Reach P4 (U.S. 395 to Rush Creek). The upper 0.5 mile of this reach supported about 1.6 acres of coyote willow scrub in a narrow, nearly continuous strand. About 2.6 acres of buffalo berry grew in a locally wide portion of this reach just below U.S. 395. Based on prediversion aerial photographs, the willows and buffalo berries appear to have had relatively dense canopies and predominantly live stems.

The lowest 0.2 mile of Parker Creek supported about 1.4 acres of willow and 0.3 acre of conifer-broadleaf forest. As today, this vegetation was associated with springs along lower Parker Creek that appear to have been fed by groundwater recharge and irrigation on Cain Ranch.

Walker Creek

Reach W0 (above Diversion). Immediately above the current aqueduct road, three narrow strips of willow and mixed riparian scrub converged through the meadow toward the downstream end of the quaking aspen grove. The middle strip followed the active main channel of the stream. The two lateral strips were associated with irrigation channels (which might have followed former natural channels). Above the present location of the diversion pond, the dense groves of tall quaking aspen and lodgepole pine were essentially the same as they are today.

Reaches W1 and W4 (Diversion to Cain Ranch Road, Main and Secondary Channels). These reaches supported the majority of woody riparian vegetation on Walker Creek, about 19 acres on the main channel and about 15 acres on the secondary channel. Most was willow scrub dominated by coyote willow and probably subdominated by mountain rose. Several patches of mixed riparian scrub dominated by buffalo berry, two small quaking aspen groves, and a few small stands of Jeffrey pine were also present. Based on aerial photographs, all this vegetation appears to have been in good condition, but willow reproduction may have been limited, as described above for Parker Creek.

Additional riparian vegetation (not mapped for this EIR) occurred north of Walker Creek along irrigation channels fed by Bohler Creek and perhaps in lesser part by the secondary channel of Walker Creek.

Large areas of sagebrush scrub were present in these reaches, particularly along the secondary channel at the base of the moraine between Walter and Bohler Creeks. Areas of meadow upslope from and within the sagebrush areas had probably been created through many years of flood irrigation on sagebrush-covered slopes.

Reaches W2 and W5 (Cain Ranch Road to U.S. 395, Main and Secondary Channels). These reaches are transitional between the narrow riparian strand surrounded by sagebrush of the preceding reach and the larger riparian patches surrounded by meadow of the following reaches. The upper halves of both channels supported small, scattered strips of willow scrub surrounded by meadow. The lower halves supported continuous to slightly interrupted strips of willow scrub surrounded by sagebrush scrub or irrigated pasture. The 3.7 acres of woody vegetation appear to have been in good condition.

Reach W3 (U.S. 395 to Rush Creek). The upper 0.7 mile of this reach supported about 5.9 acres of coyote willow scrub in a narrow but nearly continuous strand. Based on prediversion aerial photographs, the willows appear to have had relatively dense canopies and predominantly live stems.

The lowest quarter mile of Walker Creek supported about 4.6 acres of willow scrub and 0.9 acre of quaking aspen forest. As today, these quaking aspens were associated with springs in and along lower Walker Creek that appear to derive their flow largely from irrigation on Cain Ranch. The springs may also have temporarily received water from irrigation on several acres on the ridge between Walker and Bohler Creeks, just west of The Narrows.

Lee Vining Creek

Reach L0 (above Diversion). The site later occupied by the diversion dam and pond supported the same type of conifer-broadleaf forest and meadow that was present above and below the diversion site. Elden Vestal (1990, Court Testimony, Vol. I, p. 241) recalled a "grove of lodgepole pines and some of considerable size, well in excess of 20 inches . . . in diameter" at the site of the diversion dam. Vegetation above the diversion pond was probably essentially the same as it is today.

Reach L1 (Diversion to Highway 120). Riparian vegetation in this reach was essentially the same as that of today, dominated by lodgepole and Jeffrey pines and quaking aspens, with willows along the streambanks and meadow margins. Vestal (1990, Court Testimony, Vol. I, p. 240) described the vegetation as dense and noted the presence of moss-covered banks in some areas.

Reaches L2a (Highway 120 to U.S. 395) and L2b (U.S. 395 to 0.45 Mile below U.S. 395). These reaches are the steepest portions of Lee Vining Creek below the diversion. In reach 2a, riparian vegetation was confined to a narrow zone by canyon walls and morainal bluffs. The vegetation was mostly conifer-broadleaf forest. White fir and mountain mahogany added to the diversity of riparian vegetation in this reach. From the present location of the Highway 120 crossing to about 0.3 mile downstream on the east side of the creek was an overflow channel supporting a moderately dense strand of Jeffrey pine.

In reach 2b, Jeffrey pines were common among the cottonwoods, willows, and quaking aspens. Quaking aspens watered by hillside seepage occurred on bluffs on both sides of the creek in this reach. The lower end of reach 2b is at the bottom of the existing (1989) stand of riparian forest below U.S. 395.

Reaches L3a (0.45 Mile below U.S. 395 to Big Bend) and L3b (Big Bend to County Road). Vegetation on the broad, low-gradient floodplain in this reach was mostly black cottonwood-willow community, with patches and strands of conifer-broadleaf vegetation where Jeffrey pines grew. Quaking aspen was probably common among the cottonwoods. Riparian plants such as creek dogwood and bitter cherry (which remain only in sites above reach 3) and water birch (no longer present anywhere on Lee Vining Creek) were probably occasional to locally common in these reaches.

Groundwater seepage supported woody riparian vegetation at several locations on bluffs on either side of the floodplain. Quaking aspen forest and willow scrub occurred at the base of the bluff on the east side of Lee Vining Creek at County Road. A narrow strand of willow scrub occurred along the west side of the floodplain from about 0.1 to 0.5 mile above County Road. About 2.3 acres of riparian vegetation (mostly willow scrub) occurred on the high bluffs below the present location of the sewage ponds.

Evidence of these conditions is provided by dead wood and remnant vegetation visible in the area today and by photographs and recollections from prediversion times. Some pines are clearly identifiable in the winter 1929-1930 aerial photographs, primarily by their shadows, but most are not readily distinguishable from the deciduous trees in these images. A Burton Frasher photograph of the downstream reach of Lee Vining Creek taken from the hillside above Lee Vining in the late 1920s shows a multilayered canopy of tall deciduous trees with patches and strands of conifers along most of this reach. A more distant view of Lee Vining Creek's riparian zone from the Mono Inn area (Frasher Foto No. 8039) also shows scattered pines from County Road at least as far upstream as the high bluffs. Range vegetation survey data on an aerial photograph printed in Taylor (1982) indicate that quaking aspen was a dominant species throughout much of the Lee Vining Creek riparian zone.

Vestal recalled a "good distribution" of Jeffrey and lodgepole pines among cottonwoods along Lee Vining Creek near the town of Lee Vining and continuing along both sides of the stream to just above County Road. Vestal also recalled that quaking aspens were more common along Lee Vining Creek than Rush Creek and that water birch was a common constituent of the riparian vegetation on Lee Vining Creek (Stine 1991).

Reach L3c (County Road to 1940 Lakeshore). The reach from County Road to the lakeshore (at elevation 6,417.5) was approximately 0.2 mile long in 1940. Approximately 4.3 acres of cottonwood-willow woodland and forest existed along the creek, and a narrow strip of willows existed at the base of the hill east of the County Road crossing. Irrigated pastures and lake-fringing meadow vegetation occupied all unwooded ground above the beach. In the winter 1929-1930 aerial photographs, three narrow ponds (totaling about 0.5 acre) are evident behind lakeshore berms in meadows between the lake and the downstream end of the riparian forest. These ponds are not visible in the June 1940 photographs.

Little site-specific information is available on the condition of vegetation in this reach. Available photographs include the winter 1929-1930 and summer 1940 aerial photographs, a photograph taken at or near the County Road crossing by Joseph Dixon on July 14, 1916 (photograph no. 2176), and a Burton Frasher photograph from the late 1920s or early 1930s in which Lee Vining Creek vegetation is visible from the Mono Inn area (Frasher Foto No. 8039). All these photographs indicate a relatively tall, multi-layered, and dense canopy in this reach.

Wayne McAffee recalled collecting worms for sale as fishing bait on a regular basis near the mouth of Lee Vining Creek in the late 1920s (McAffee 1990, Court Testimony, Vol. II, p. 413). Woody Trihey interpreted this as indicating "very deep deposits of sandy loam soil" resulting from abundant leaf litter and organic material in the floodplain (McAffee 1990, Court Testimony, Vol. II, pp. 678-679). Vestal recalls no Jeffrey pines below County Road on Lee Vining Creek (Stine 1991).

Reach L3d (1940 Lakeshore to 1989 Lakeshore). This reach was beneath the surface of the lake in 1940 and supported no riparian vegetation.

Point-of-Reference Conditions

Rush Creek

Reach R0 (above Grant Lake Reservoir). Above the current spillway elevation of Grant Lake reservoir, the cottonwood-willow, quaking aspen, and conifer-broadleaf vegetation on Rush Creek is essentially the same as it was in 1940.

Woody riparian vegetation that was to be inundated along approximately 1.5 miles of Rush Creek by the enlargement of Grant Lake reservoir was felled and burned by LADWP in summer and fall 1940 (Vestal 1990, Court Testimony, Vol. I-XIII; Stine 1991). No riparian scrub or forest remains today. The inundated channel is periodically exposed when water levels fall in Grant Lake reservoir. Weedy grasses and forbs have established in some areas, but this section is an eroded and essentially unvegetated reservoir drawdown zone. No significant patches or beds of floating or emergent vegetation occur around the margins of Grant Lake reservoir.

Reach R1a (Grant Lake Dam to Mouth of Return Ditch). The upper third (1,100-1,300 feet) of this reach was eliminated by 1940-1941 construction of the existing Grant Lake Dam. An estimated 2-3 acres of riparian vegetation were eliminated along the main channel and spillway. The bottom end of this reach was filled to prevent water flowing out of the return ditch from forming a long backwater up the former stream channel.

Only about 1.6 acres of mature woody willow and mixed riparian scrub remain, mostly in the lower third of the remaining reach. Most is in poor condition with little canopy cover, stressed by dewatering, invaded by upland plants, and without an herbaceous groundcover. Another 1.6 acres of mostly dead or severely stressed willow and cottonwood-willow vegetation remains along the dry channel.

Reach R1b (Return Ditch). The Return Ditch is lined by sagebrush and rabbitbrush scrub and supports essentially no woody riparian vegetation. Only a few small, isolated willows are present. Seepage is insufficient to support riparian plants or significant meadow areas outside the ditch.

Reach R2a (Mouth of Return Ditch to Base of Moraine). This relatively narrow, steep section of Rush Creek supports about 6.0 acres of willow and mixed riparian scrub, cottonwood-willow, quaking aspen, and conifer-broadleaf vegetation in relatively good condition. Except where the channel has been disturbed at the mouth of the Return Ditch, canopy cover, plant vigor, and riparian plant diversity are relatively high in all vegetation types and are similar to prediversion conditions. Several factors have probably favored survival of riparian vegetation in this area, including substrates that minimize loss of streamflow, presence of seeps or colluvial aquifers, shading by steep slopes, and inaccessibility for tree harvesting.

Reach R2b (A-Ditch Supply Channel). Water was diverted from Rush Creek to the A-Ditch every year from before 1920 to 1948. The A-Ditch was again used almost continuously from 1952 to 1959 and intermittently through the 1960s. No water has been diverted to the A-Ditch for irrigation since October 1969. Natural overflows into the A-Ditch supply channel may have occurred during some unregulated high runoff events.

Approximately 5.6 acres of mature quaking aspen forest and willow scrub occur along this channel or on nearby hillsides. Most of this good-quality vegetation occurs along the middle third of this reach, supported by springs and soil moisture that are probably fed by seepage from Rush Creek. The adjacent spring-watered meadows are heavily grazed.

Approximately 1.7 acres of mostly decadent willow and mixed riparian scrub occur along the lower third of this channel. Many formerly vigorous willows are now dead or have a few live stems competing for water with drought-stressed mountain rose.

Reach R3 (Base of Moraine to Old Highway Bridge). Between 1940 and 1989, vegetation in this reach was affected by logging, irrigation diversions, and severe floods in addition to dewatering. Many of the largest and most accessible Jeffrey pines were logged by the Inyo Lumber Company in 1940-1942 (Vestal 1990, Court Testimony, Vol. I-XVIII; Stine 1991). Water was diverted from Rush Creek via the B-Ditch to irrigate pastures in Pumice Valley almost every year from before 1920 to 1967. Severe floods altered the path of Rush Creek in the lower 1,600 feet of this reach and eroded away the first 500 feet of the B-Ditch in 1967.

From the base of the moraine to about 1,600 feet above the old highway bridge, the riparian zone remains mostly 200-400 feet wide, but the vegetation has become patchy and varies greatly in condition. Overall condition is good, with about 33% of the 25.7 woody riparian acres having over 50% cover and about 14% having measurable cover of tall shrubs and short trees. Plant density and vigor have improved significantly in this reach since minimal flows were restored in 1985 (Patten and Stromberg-Wilkins 1988).

The severely scoured lower 1,600 feet of this reach is mostly unvegetated floodplain. Only a few very small patches of mature or establishing riparian scrub or woodland occur in this area. A few patches of sagebrush scrub, some with dead wood from former riparian forest, occur on islands that were not stripped of topsoil during the 1967 and 1969 floods. Establishment of new riparian and upland plants is severely suppressed in the lower portions of this reach by herds of sheep crossing Rush Creek.

Reach R4 (Old Highway Bridge to Mouth of Parker Creek). Riparian vegetation declined substantially in this reach during the 1950s, 1960s, and 1970s because of diminishing releases from Grant Lake reservoir and the absence of significant flow from springs.

Riparian vegetation is mostly absent from the old highway bridge to U.S. 395. Below U.S. 395, scattered small remnants of the 1940 riparian vegetation persist and narrow strips of willow and cottonwood seedlings are evident along the channel edges and on a few small islands in the channel.

Reach R5 (Mouth of Parker Creek to The Narrows). Riparian vegetation declined in this reach during the same period as in reach R4. Gravel mining began midway between Parker Creek and The Narrows in the 1960s, resulting in some localized loss of woody riparian vegetation. The 1967 and 1969 floods caused severe scouring and channel realignment throughout this reach, resulting in the loss of most of the remaining cottonwood-willow woodland and willow scrub.

Most of the existing woody riparian vegetation in this reach consists of young, vigorous willows and cottonwoods in intermittent strips 10-20 feet wide along both sides of the channel. Several widely scattered individuals or small clumps of mature cottonwoods survive throughout the cobble- and gravel-covered floodplain. Most of these trees have a few small suckers nearby but have improved only slightly since rewatering. A few small patches of relatively dense and vigorous willows occur in and around the quarries, evidently where water seeps from the cliffs. Overall response to rewatering has been negligible, except within a few feet of the main channel.

Reach R6 (The Narrows to the Ford). Riparian vegetation persisted with relatively minor losses in this reach until the early or mid-1960s because springs contributed significantly to surface water and groundwater in the riparian zone. The floods of 1967, 1969, and the early 1980s caused severe scouring and moderate to deep channel incision throughout this reach, resulting in the direct loss of much streamside vegetation and permanently lowered water tables in most of the remaining vegetated area.

Grazing has continued throughout the periods of dewatering and rewatering in this reach. Grazing has been heavier on the west side of the stream, which is easily accessible and has more meadows; the east side is less accessible and has less herbaceous forage.

This reach still contains the largest areas of live riparian vegetation on Rush Creek. The vegetation that suffered least from dewatering includes about 6.8 acres of dense willow scrub and mixed riparian scrub in good condition on slopes above the creek on the west side of The Narrows. About 5 acres of dense willow scrub remain at the cliff-base seeps on the east side of the creek from Big Wash to the lower end of the lower meadows, much of which appears moderately to severely stressed by reduced springflow.

Mature willow and mixed riparian scrub is scattered throughout another 75 acres of the bottomlands. The most vigorous of this vegetation is located between the stream and the middle meadows; most of the rest contains abundant dead wood and excessive amounts of rose, indicating several years of drought stress. Only about 2.0 acres of cottonwood-willow vegetation remain in this reach.

"Decadent" riparian vegetation occupies about 23 acres in this reach. These areas contain more dead than live wood (often enough to make walking difficult), little or no live cottonwood or willow, and larger amounts of rose and upland vegetation than were present before dewatering.

Establishing riparian vegetation occupies about 6.0 acres on gravel bars wetted by the stream along the existing active channel. Most areas of willow and cottonwood seedlings of saplings occur in the middle third of this reach.

The meadows on the west side of the creek are still present but have all declined as a result of reduced groundwater and continued grazing. The upper meadows cover about 6.8 acres, the middle meadows about 7.7 acres, and the lower meadows about 10.1 acres. Meadows on the east side of the creek below Big Wash are small and scattered.

Unvegetated floodplains are locally prominent where floods removed topsoil, channel incision and lateral cutting were severe, and subsidiary channels were abandoned after the main channel incised.

Reach R7 (the Ford to County Road). Riparian vegetation declined in this reach at the same time and under the same influences described for reach R6. Riparian vegetation characteristics in this reach are similar to those in reach R6, but the incised channel is deeper (8-10 feet in the vicinity of the former Clover Ranch meadows) and wider (up to 300 feet in several locations). Mature woody riparian vegetation is mostly mixed riparian scrub (6.7 acres), with a few small areas dominated by willows (7.0 acres). Decadent riparian vegetation occupies 12 acres, all several feet above the existing low flow channel. Willows and cottonwoods are establishing on about 1.5 acres of gravel bar near the middle of the reach. Meadows are no longer present.

Reaches R8a (County Road to 1940 Lakeshore) and R8b (1940 Lakeshore to 1989 Lakeshore). The reach from the lakeshore to County Road is approximately 0.8 mile long (August 1989). It was severely scoured and deeply incised during the floods of the late 1960s and early 1980s.

No mature riparian vegetation is present in this reach. Seedlings and young saplings of coyote willow have established extensively over approximately 25 acres of gravel bar habitat, mostly from about 400 to 2,200 feet above the lakeshore.

Outside the channel, widely scattered individuals of coyote willow or black cottonwood occur on some of the higher terraces that were formerly active floodplains. A patch of coyote willows occurs at a seep on the east side of the creek approximately 550-850 feet from the lakeshore. Above the 1940 lake elevation, several clumps of dead willows are scattered among sagebrush and rabbitbrush scrub beyond the edges of the incised channel.

Parker Creek

Reach P0 (above Diversion). Willow scrub dominates the riparian vegetation for about 0.2 mile above the diversion pond. Several Jeffrey and lodgepole pines also are scattered through this area. From about 0.2 mile above the diversion pond to near the Parker Creek campground, the riparian vegetation is predominantly conifer-broadleaf forest dominated by quaking aspens and pines.

Reach P1 (Diversion to Base of Moraine). Parker Creek occupies two roughly parallel channels in this reach. Combined, they support about 30% of the existing woody riparian vegetation below the LADWP diversion. The main Parker Creek channel (i.e., the north channel) supports approximately 6.3 acres of woody riparian vegetation, of which nearly all is willow scrub. South Parker Creek (i.e., the south channel) supports about 8.9 acres of woody riparian vegetation, of which about 90% is willow scrub. The riparian zone (both channels combined) is up to 600 feet wide in the upper half of this reach.

Some of the vegetation in this reach appears to be moderately stressed by drought, although significant amounts of water were conveyed through riparian areas in this reach before being diverted for meadow irrigation.

Reach P2 (Base of Moraine to Cain Ranch Road). Over 60% of the woody riparian vegetation on the diverted section of Parker Creek occurs in this reach. Willow scrub occupies about 30 acres, much of which is moderately to severely stressed by dewatering and grazing (the willows are mostly old plants with much dead wood, sparse canopies, and abundant competing mountain rose). Small patches of conifer-broadleaf woodland, non-native cottonwoods, and mixed riparian scrub also occur in this reach (less than 0.5 acre each). The riparian zone varies from 100 to 400 feet wide in this reach.

Reach P3 (Cain Ranch Road to U.S. 395). The stream channel in this reach is bordered almost entirely by meadow and sagebrush scrub. Only about 0.4 acre of willow scrub persists near the ranch buildings at the upper end of this reach.

Reach P4 (U.S. 395 to Rush Creek). The upper 0.5 mile of this reach has relatively few scattered, drought-stressed coyote willows. About 0.9 acre of stressed buffalo berry and 1.0 acre of meadow persist from about 250 to 1,000 feet below U.S. 395.

The lowest 0.2 mile of Parker Creek supports about 1.3 acres of mixed riparian scrub (mostly rose) and conifer-broadleaf forest (Jeffrey pines and black cottonwood). This vegetation is moderately stressed by dewatering but has persisted because of springs fed by groundwater from Parker Creek and irrigation on Cain Ranch.

Walker Creek

Reach W0 (above Diversion Site). Immediately above the aqueduct road is the LADWP diversion pond and adjacent disturbed ground that is unvegetated or supports weedy upland plants. Above the diversion pond, Walker Creek supports a large and continuous stand of dense quaking aspen woodland and small meadows in excellent condition. The forest flora is diverse, the vegetation is multilayered, no obvious drought stress is evident, and livestock grazing has not been severe. About 0.6 mile above the diversion pond, the quaking aspen forest shifts to conifer-hardwood forest dominated by quaking aspen and lodgepole pine.

Reaches W1 and W4 (Diversion to Cain Ranch Road, Main and Secondary Channels). These reaches still support the majority of woody riparian vegetation on Walker Creek, about 19 acres on the main (south) channel and about 13 acres on the secondary (north) channel. The coyote willow scrub is generally co-dominated by mountain rose and the mixed riparian scrub is dominated by mountain rose or buffalo berry. Two small quaking aspen groves and a few small stands of Jeffrey pine also persist. Most of this vegetation is in highly stressed condition, as described for Parker Creek. Additional riparian vegetation (not mapped for this EIR) occurs north of Walker Creek along irrigation channels watered mostly by Bohler Creek.

Large areas of sagebrush scrub are still present in these reaches. Meadow occurs in several areas that were dominated by sagebrush in 1940.

Reaches W2 and W5 (Cain Ranch Road to U.S. 395, Main and Secondary Channels). As noted under "Prediversion Conditions", these reaches are transitional between the broad, level pastures of Reaches W1 and W4 and the incised canyon of Reach W3. The main channel supports meadow vegetation throughout the reach and several scattered, mostly solitary willows and buffalo berries in stressed condition. The secondary channel supports remnants of willow shrub in stressed condition, with sparse canopies and many dead stems.

Reach W3 (U.S. 395 to Rush Creek). From U.S. 395 to the spring-fed quaking aspen and willow stands, about 4.8 acres of willow and mixed riparian scrub in narrow, fragmented strips are present. Many coyote willow and buffalo berry shrubs have sparse canopies and many dead stems resulting from several years of drought stress. Little or no reproduction of woody riparian plants is evident.

The lowest quarter mile of Walker Creek supports about 5.0 acres of mixed riparian and willow scrub and two small patches of quaking aspen forest. These quaking aspens are supported by springs along lower Walker Creek that continued to flow because of groundwater recharge by irrigation on Cain Ranch, even after the channel was dewatered.

Lee Vining Creek

Reach L0 (above LADWP Diversion Dam). The diversion pond, dam, and adjacent disturbed slopes occupy about 2.1 acres of reach L0. For more than 2 miles above the diversion pond, the riparian vegetation is dominated by quaking aspens and Jeffrey and lodgepole pines, with occasional cottonwoods and willows. The vigor of the plants and the condition of the riparian community is generally high in this reach.

Reach L1 (LADWP Diversion Dam to Highway 120). Vegetation along the stream in this reach is generally a high-quality stand of pines and quaking aspens (about 13.1 acres), containing many tall trees, intermittent willow shrubs along the banks, and a well-developed herbaceous layer. About 5.2 acres of meadows and 3.7 acres of willow scrub supported by shallow groundwater occur on the left side of the stream within 1,400 feet of the diversion dam. Additional meadows irrigated by the O-Ditch occur further upslope, closer to the highway. The vigor of the plants is high and little grazing occurs in this reach.

Reach L2a (Highway 120 to U.S. 395). Construction of the new Highway 120 partially filled and prevented the stream from entering the overflow channel on the right side of the creek just below the Highway 120 culvert. Riparian vegetation along the overflow channel decreased in area and density, particularly in its upper half. Scattered Jeffrey pines remain, but few or no willows persist.

Riparian vegetation (about 14 acres) on the main channel of this steep, narrow reach is essentially the same as in prediversion times. It is predominantly conifer-broadleaf forest dominated by quaking aspens (mostly in the upper half), cottonwoods (mostly in the lower half), and Jeffrey pines. Willows are scattered along the reach. In the lower half of the reach, white firs, creek dogwood, and bitter cherry are locally numerous among the other trees. The vigor of the plants is high and no grazing occurs in this reach.

The riparian zone is mostly 100-150 feet wide in Reach L2a, but it widens to about 300 feet from 800 to 1,200 feet upstream from U.S. 395. Jeffrey pine forest with an understory of upland rather than riparian plants occurs on higher slopes outside the riparian corridor.

Reach L2b (U.S. 395 to 0.45 Mile below U.S. 395). Vegetation in this reach is similar to that in the lower part of reach 2a but has a greater proportion of cottonwoods and quaking aspens than conifers and a greater average width (250-300 feet) because the canyon is wider. Both sides of the canyon support intermittent quaking aspen stands in this reach (about 4.4 acres), probably associated with seepage from the canyon sides. This reach ends where existing quaking aspen stands on the right side of the stream end.

Reach L3a (0.45 Mile below U.S. 395 to Big Bend). Woody and herbaceous riparian vegetation declined rapidly in this reach during the 1950s and early 1960s. Young cottonwoods and willows occur only in narrow, discontinuous strips along the banks of the main channel and near the middle of several subsidiary channels, including portions of the historical main channel. Older cottonwoods that have survived dewatering despite injuries from drought stress occur in the upper half of this reach in subsidiary channels on the right side of the floodplain. A narrow (4-12 feet wide) but locally vigorous strand of mountain rose occurs along both sides of a subsidiary channel just west of the older cottonwoods.

Unscoured surfaces within the floodplain are dominated by sagebrush. Scattered mountain rose occurs in some locations, especially where the trunks (mostly fallen) of long-dead cottonwoods and pines are present.

The steep bluffs below Lee Vining's wastewater treatment ponds support large stands of cottonwood and willow. Most of this vegetation is vigorous and clearly supported by seepage from the ponds. Vegetation immediately below the southernmost pond, which appears to have been unused for several years, is stressed from lack of water.

Reach L3b (Big Bend to County Road). Woody and herbaceous riparian vegetation declined rapidly during the 1950s in this reach, especially in the upper half. The existing main channel in this reach is wide, resulting from severe lateral erosion during the 1969 floods.

Woody riparian vegetation is essentially absent from the upper half of this reach. Sagebrush and scattered rose cover uneroded surfaces in the floodplain, and dead tree trunks are locally common. Scattered herbaceous vegetation (mostly saponaria and other weeds) is establishing on gravelly and cobbly surfaces within the wide channel above the summer flow.

In the lower half of this reach, the main channel supports widely scattered individuals and small clusters of young, vigorous cottonwoods and willows. Most of these plants have probably grown from seed since 1986, when flows became continuous in this reach. Some may have grown vegetatively from plants whose roots survived the dewatering and floods or from tree or shrub fragments introduced from upstream during the 1969 floods. A few Jeffrey pine seedlings have also established in this area.

Patches of locally dense herbaceous vegetation (mostly lupine, saponaria, wormwood, rushes, and grasses) occur on gravel bars in the existing main channel, historical main channel, and other subsidiary channels wetted by groundwater in this reach.

Portions of the historical main channel and other areas not stripped of topsoil during the 1969 floods are vegetated mostly with sagebrush rather than riparian plants. Mountain rose is often common among the sagebrush where woody riparian vegetation formerly grew. Formerly irrigated meadows on the west side of the floodplain have reverted to sagebrush scrub. A few healthy lodgepole pines remain at the former meadow margins.

Outside the floodplain, a stand of quaking aspens persists at the base of the bluff east of the County Road crossing. Mixed riparian scrub (rose) climbs part way up the bluffs on the right side of the creek near the middle of the reach. These areas are probably supported more by groundwater seepage and snowmelt than streamflows.

Reach L3c (County Road to 1940 Lakeshore). About 250 feet below County Road, the channel divides, with the main channel following the right side of the floodplain and a secondary channel following the left edge of the floodplain.

In the upper half of this reach, young cottonwoods and willows are locally numerous in the floodplain, as they are in the lower half of reach L3b. Outside the floodplain, several white cottonwoods and Lombardi poplars (both non-native), black cottonwoods, Jeffrey pines, and thickets of mountain rose occur on the left side of the creek near County Road.

In the lower half of this reach, a few young black cottonwoods are scattered on the scoured floodplain between the main and secondary channels, but overall, the floodplain is only sparsely vegetated. Scattered willow and cottonwood seedlings and forbs (mostly lupine, wormwood, and saponaria) occur in a band mostly 1-3 feet wide along the banks of the main channel.

Reach L3d 1940 Lakeshore to 1989 Lakeshore. This 1,800-foot-long reach emerged as the lake level dropped after 1940. The upper half of the reach is very cobbly, without topsoil, and mostly unvegetated. Scattered willow and cottonwood seedlings and forbs occupy a strip 1-3 feet wide along the banks of the main channel. A few small patches of mature willow occur at the edge of the floodplain in sites not scoured by the 1969 floods.

Dense thickets of willow saplings and forbs mostly sweet-clover occupy about 5 acres in the floodplain from 300 to 800 feet above the lakeshore. This vigorous young growth is supported by streamflow in several small channels, abundant shallow groundwater, and one or more small springs. Small amounts of topsoil are developing from trapping of sediments and organic materials among this vegetation.

Outside the current floodplain, a more mature stand of coyote willow occupies approximately 2 acres on a terrace west of the creek. The oldest of these willows probably date from 1971 or 1972, the first 2 years after ground occupied by these willows was above the lake level.

Lakeshore meadow vegetation dominated by salt grass, rushes, and bulrushes occupies about 3 acres of the wave-cut shoreline at the mouth of the creek.

RIPARIAN VEGETATION WIDTH MODEL

Methods

Taylor (1982) developed a model that relates streamflow to riparian zone width on eastern Sierran alluvial streams. The model is a simple linear regression equation based on measured riparian strip widths (from aerial photographs) and stream gage data from several eastern Sierran streams.

Taylor (1982) found this model to explain 67% of the variance in riparian strip width and recommended its use in assessment of the impacts of proposed streamflow diversions on riparian vegetation. Such use requires an assumption that vegetation impacts of changes in streamflow in a given stream system are predictable from study of smaller or larger stream systems. The model also makes use of an "incision index" that is not precisely defined and might not adequately account for the effects of stream incision along Rush and Lee Vining Creeks.

Jones & Stokes Associates used this model to preliminarily assess the potential for recovery of riparian vegetation under different streamflow alternatives on the tributary streams. Riparian vegetation widths were calculated in a spreadsheet using mean annual streamflows predicted by the Los Angeles Aqueduct Monthly Program (LAAMP) operations model for each alternative (Chapter 3A, "Hydrology") and gradient, incision index, and elevation values measured from 7.5-minute USGS topographic maps. Riparian widths were calculated for numerous points on each stream and average widths were calculated for each stream segment.

Results

Table P-13 lists the results of the model for selected points on Rush Parker, Walker, and Lee Vining Creeks. The approximate prediversion (1940) and point-of-reference (1989) widths of the riparian zone at each point are listed for comparison with the results of the model.

The following limitations of the model were considered in interpretation of the results of these analyses.

- The model is not valid for predicting riparian zone widths at mean annual streamflows higher than those included in Taylor's (1982) regression analysis, or above approximately 60 cfs.

- Topography controls riparian zone width more than streamflow does in most locations along all the modeled streams. The model is most reliable where a stream occupies a single channel over relatively uniform alluvium, is not gaining flow from springs, and is not confined in a canyon or against bluffs.

- Comparisons of existing or prediversion riparian widths may be misleading because they do not account for changes in vegetation condition.

Rush Creek

The model was run for the segment of Rush Creek from the base of the moraine to Mono Lake (reaches R3-R8). The segment from the dam to the base of the moraine was not modeled because of geomorphological conditions that do not fit the model's assumptions.

The model predicts riparian widths averaging about 70-80 meters (230-260 feet) under the No-Restriction Alternative. These results are inaccurate because flows are actually 0 cfs throughout most years. The LAAMP model's calculation of 25.3 cfs mean annual flow under this alternative results from averaging of infrequent and very large uncontrolled spills.

The model predicts riparian widths of:

- 100-110 meters (330-360 feet) under the 6,372-Ft Alternative;
- 125-130 meters (410-425 feet) under the 6,377-Ft Alternative; and
- 140-145 meters (460-475 feet) under the 6,383.5-Ft Alternative.

Higher flow alternatives could not be modeled because the model is not calibrated for mean annual flows over about 60 cfs. Had the model been calibrated for such flows, the higher alternatives would have resulted in successively greater widths.

Above The Narrows, actual widths in 1989 and 1940 were generally narrower than those predicted under the 6,372-Ft Alternative. Properly calibrated and applied, the model should not predict widths exceeding actual prediversion widths as frequently as it does. Possible reasons for these results are that the model may not be accurately calibrated for this area, it may not adequately account for topographic and geomorphic influences on riparian vegetation, and the calculation of mean annual flow may be excessively influenced by infrequent high flows.

Below The Narrows, actual widths in 1989 were scattered in their relationships to widths predicted under the alternatives because reductions in riparian zone width during the diversion period were highly variable in this area. Actual widths in 1940 were generally greater than widths predicted under the 6,383.5-Ft Alternative. Some of the prediversion riparian zone width was sustained by spring runoff, as well as streamflow.

Parker Creek

The model was run for all segments from the LADWP diversion point to Rush Creek (reaches P1-P4). The model was difficult to apply to reaches above U.S. 395, because the flatness of the terrain made the incision index difficult to measure.

The model predicts riparian widths ranging from 0-6 meters (0-20 feet) under the 6,372-Ft Alternative to 20-29 meters (66-95 feet) under the No-Diversion Alternative. The greatest widths are predicted in reach P2, where the terrain is flattest and actual widths in 1940 and 1989 were greatest.

Actual widths in 1940 and 1989 were closest to those predicted for the No-Diversion Alternative.

Walker Creek

The model was run for all segments from the LADWP diversion point to Rush Creek (reaches W1-W5). The incision index was difficult to measure above U.S. 395, as described for Parker Creek.

The model predicts no riparian vegetation under the No-Restriction Alternative through the 6,410-Ft Alternative and only 3-8 meters (10-26 feet) of riparian width under the No-Diversion Alternative. These results are clearly inaccurate, because actual widths in 1940 and 1989 were substantially greater than those predicted for the No-Diversion Alternative. Reasons for the model's inaccuracy on Walker Creek are not readily apparent.

Lee Vining Creek

The model was run for the segment of Lee Vining Creek from U.S. 395 to Mono Lake (reaches L2b-L3d). The segment from the diversion dam to U.S. 395 was not modeled because of geomorphological conditions that do not fit the model's assumptions. The segment from U.S. 395 to 0.5 mile below the highway (reach L2b) may only marginally meet the model's geomorphological assumptions.

The model predicts riparian widths averaging about 45-55 meters (150-180 feet) under the No-Restriction Alternative. As in the modeling of Rush Creek, these results are inaccurate because flows are actually 0 cfs throughout most years. The LAAMP model's calculation of 19.0 cfs mean annual flow under this alternative results from averaging of large, infrequent, uncontrolled spills.

The model predicts riparian widths ranging from 100-110 meters (330-360 feet) under the 6,372-Ft Alternative to 140-150 meters (460-490 feet) under the 6,410-Ft Alternative. The No-Diversion Alternative was not modeled because of limits on model calibration.

Actual widths in 1989 were generally closest to those predicted under the No-Restriction Alternative. Although a mean annual flow of 19 cfs does not accurately represent conditions that would occur under that alternative, 19 cfs does approximate flows that have occurred in Lee Vining Creek since the mid-1980s. Actual widths in 1940 were generally between those predicted for the No-Restriction and 6,372-Ft Alternatives.

Conclusions

The results of the riparian width model appear to be generally plausible for scattered locations on Rush Creek below The Narrows, and possibly Lee Vining Creek. In these areas, the model predicted widths generally within or near the range of prediversion conditions.

On Rush Creek, the model predicts riparian width increases of about 19% between the 6,372-Ft Alternative and the 6,377-Ft Alternative, and increases of about 11% between the 6,377-Ft Alternative and the 6,383.5-Ft Alternative. These comparisons appear to be within reason, but probably overestimate the actual potential for the riparian zone to widen in many areas, because of topographic factors (see "Groundwater Depth Model").

On Lee Vining Creek, the model predicts increases of about 15%, 10%, 4%, and 8%, respectively, for the intervals between the 6,372-Ft, 6,377-Ft, 6,383.5-Ft, 6,390-Ft, and 6,410-Ft Alternatives. These comparisons also appear to be within reason. Whether they represent high or low estimates of the potential for change is uncertain.

The results of the model appear to be implausible (i.e., substantially wider or narrower than under prediversion conditions) for all of Rush Creek above The Narrows, scattered locations on Rush Creek below The Narrows, all of Parker and Walker Creeks, and possibly Lee Vining Creek. The reasons for implausible results may include influences from groundwater from sources other than the stream channels, the presence of multiple channels, inaccurate input data, or inapplicability of conditions on measured streams to these particular streams.

COTTONWOOD GROWTH MODEL

Methods

Stromberg and Patten (1990, 1992) developed regression equations that relate streamflow to black cottonwood growth rates on Rush and Lee Vining Creeks. Six different regression equations (nonlinear univariate, linear univariate, and bivariate equations based on annual flows and summer flows) were developed from stream gage records and tree ring analysis for each of seven cottonwood populations.

Jones & Stokes Associates used the nonlinear univariate models based on annual flow to predict potential cottonwood growth rates under different streamflow alternatives on the tributary streams. (Annual flows generally explained more variance than summer flows; nonlinear equations generally explained more variance than linear equations; and univariate equations are more reliable than bivariate equations for predicting growth in future years, although bivariate equations sometimes explained more variance for past years.)

These models are valid over the range of streamflow values used to derive the models (0-222 cubic hectometers [hm^3] for Rush Creek and 0-80 hm^3 for Lee Vining Creek). Cottonwood growth rates were calculated in a spreadsheet using mean annual streamflows predicted by LAAMP for each alternative (Chapter 3A, "Hydrology").

Vigor was assessed using the assumption that growth rates less than 1 mm/year reflect declining vigor leading to tree death, growth rates of 1-2 mm/year reflect low vigor, and growth rates above 2 mm/year reflect high vigor (Stromberg and Patten 1992). Potential growth rates and vigor levels were calculated and graphed for each sample site.

Results

Table P-14 lists the results of the model for selected points on Rush and Lee Vining Creeks. Models were not developed for Parker and Walker Creeks, where cottonwoods are nearly absent.

The model predicts annual radial growth increments (i.e., tree ring widths) based on streamflow. Average growth rates were correlated with canopy vigor as follows (Stromberg and Patten 1992a):

- >2.0 mm/year: high canopy vigor (no significant drought stress and no harm to the trees);
- 1.5-2.0 mm/yr: lower canopy vigor (drought stress evident, but not lethal to the trees); and
- <1.5 mm/yr: severe stress or tree death (from sublethal to lethal drought stress).

Rush Creek

For both channel-side sites, the model predicts high canopy vigor (2.0-3.2 mm average growth) under all alternatives, even under the No-Restriction Alternative. Growth rates would increase proportionately with higher flows. These results suggest that any of the alternatives would provide favorable conditions for riparian vegetation; however, channel-side trees may not reliably indicate the effects of the alternatives throughout the riparian zone. Although channel-side trees may survive and grow under any alternative that provides water consistently, floodplain trees may require higher than average flows to ensure vigor.

For the floodplain site, the model predicts lower canopy vigor (1.6-1.8 mm average growth) under the 6,383.5-Ft through No-Diversion Alternatives and severe stress or tree death (1.1-1.5 mm average growth) under the No-Restriction through 6,377-Ft Alternatives.

Lee Vining Creek

For the two channel-side sites, the model predicts high canopy vigor (3.4-9.3 mm average growth) under all alternatives, including the No-Restriction Alternative. At Site LV1c, the model predicts that growth rates would increase proportionately with higher flows. At Site LV2c, the model predicts declining growth at higher flows. Two of these predictions, high canopy vigor under the No-Restriction Alternative, and declining growth at Site LV2c under mean annual flows higher than 42 cfs, are counterintuitive and probably inaccurate. These predictions suggest that growth rates in the relatively young trees at Site LV2c, which grew mostly under point-of-reference conditions, cannot be reliably extrapolated to the full range of alternatives in the EIR.

For the floodplain site above U.S. 395 (Site LV0f), the model predicts severe stress or tree death (0.8-1.3 mm average growth) under all alternatives, with tree death most likely under the No-Restriction and 6,372-Ft Alternatives. The prediction of near-lethal conditions for all alternatives appears inconsistent with the presence of mature cottonwoods in a site where the channel was not incised and where colluvial groundwater may have buffered the effects of streamflow diversions. The predicted growth rates may be reliable, but they are not accurately correlated with canopy vigor for this group of trees.

For the floodplain site above County Road (Site LV2f), the model predicts high canopy vigor (2.1-2.7 mm average growth) under all alternatives, including the No-Restriction Alternative. The result for the No-Restriction Alternative is again counterintuitive and suggests the same unreliability described for the Site LV2c model.

Conclusions

On Rush Creek, the model for the floodplain site is probably the best of the three models for predicting the effects of each alternative on vegetation throughout the riparian zone. On Lee Vining Creek, none of the models is clearly reliable for predicting both the range of expected growth rates and the associated levels of canopy vigor under the full range of alternatives.

While the models may be useful for predicting the effects of some alternatives at the specific sites sampled, the results cannot be extrapolated to sites without live, mature cottonwoods. Sites where the forest had died were not modeled. Cottonwoods that had survived many years of stream dewatering have in some cases been sustained by unmeasured sources of groundwater other than the stream. Many factors have caused geographical and temporal variations in streamflows on Rush Creek so that correlations between release flows and tree growth rates may be inaccurate for some periods, particularly at sites below The Narrows.

The models cannot predict the distribution of woody riparian vegetation under the alternatives and are limited in their ability to predict vigor; therefore, they are not used quantitatively in the impact assessment. The evidence that mean annual streamflow can substantially influence cottonwood growth and vigor was assumed to be valid and was considered qualitatively in the impact assessment.

WATER TABLE MODEL

Introduction

A site-specific water table depth model was developed by SWRCB consultants for Rush, Parker, Walker, and Lee Vining Creeks to predict the extent of primary woody riparian habitat for various levels of summer streamflow. The model was made possible by the acquisition of detailed topographic information and several groundwater profiles along these streams.

The model has the advantage of employing the actual spatial relationships from section to section along these particular stream systems, allowing direct estimation of water table depths and riparian suitability rather than relying upon streamflow-habitat correlations involving other streams. Accuracy of the model, considered good overall, can be improved principally through acquisition of additional water table profile data but also through increase of the density of topographic sampling.

The results of the model are relative increases or decreases of primary riparian habitat for various streamflows. The model neglects the presence of any zones of shallow groundwater flow derived from sources other than streamflow.

Model Elements

The model has five key elements:

- detailed topographic mapping,
- water table profiles and streamflow responses,
- water table boundary conditions,
- stage discharge relationships, and
- water table depth requirements of woody riparian vegetation.

The model combines observations of water table profiles with channel loss inferences from synoptic flow studies to estimate the configuration of the continuously varying water table along each stream. It uses observed relationships between streamflow releases and stream stage, and between changes in stream stage and water table depths, to allow depiction of water table elevations for various summer streamflows under the alternatives.

This water table elevation model is then compared to the detailed topographic elevation data to yield water table depths for each streamflow. After selection of the maximum depth of water table generally needed for the vigorous growth of woody riparian vegetation, an acreage of "primary riparian habitat" is then estimated for each stream reach under each alternative. These five key elements and their information sources are described in the following sections.

Fluvial Topography

Detailed topographic mapping of the stream corridors using a contour interval of 2 feet was developed from aerial photography and ground reference-point surveys performed in 1991 (Aerial Photometrics 1991). Coverage also included distributary channels and flood-channels. The photos were taken after local snowmelt and before leafing on May 6, 1991. For this project, photogrammetric contours were used in the form of CAD-generated maps at a scale of 1 inch = 100 feet; because they exist in electronic digital format they can also be processed numerically or printed at any map scale.

This topographic data provides a detailed picture of the configuration of the fluvial system. Based on spot checks by SWRCB consultants, it appears to accurately depict the relative elevations of floodplain areas with respect to adjacent stream elevations. (Flood-channel elevations are less reliable, however, and require field evaluation.) The mapped terrain configuration, if compared to a model of groundwater elevation, is sufficiently detailed to distinguish small changes in shallow groundwater zones for different water table elevations.

Water Table Profiles and Streamflow Responses

Observations. In the spring of 1991, five piezometer arrays were installed along the tributary streams by SWRCB subcontractors for purposes of characterizing water table profiles and identifying responses to changing streamflow. Water table elevations and some stream surface elevations were monitored continuously with data loggers, and the changes over the 1991 snowmelt period were observed (Balance Hydrologics 1993).

Observations of water table responses to changes in streamflow lead to the conclusion that changes in streamflow water surface elevation are almost always rapidly followed by similar changes in water table elevation (Figures P-9, P-10, and P-11). These observations underscore the highly permeable nature of the fluvial substrates and the overriding importance of stream stage to nearby water table elevations. This relationship also allows a simple geometric approach to modeling the alternatives.

Water table elevation observations also corroborate earlier conclusions of synoptic flow studies that the tributary streams are generally losing flow to a deeper water table. The profiles for Parker and Walker Creeks where they pass over alluvial fan and Pleistocene delta material show downward sloping water tables perpendicular to the streams of about 2-3% slope when corrected for local stream geometry (Figures P-12 and P-13). Readings of piezometers on Rush Creek above U.S. 395 also indicate streamflow loss, but apparently with much less water table slope.

Observations in the Rush Creek bottomlands, however, indicate only a very slowly losing or equilibrium condition, with water table profiles almost level away from the stream (Figure P-14). Both bottomland profiles show this condition, but one of them appears to have had an amplified response to changes in stream stage (Figure P-15). This apparent phenomenon is probably the result of the piezometer being located just downstream of a major stream bend, where site-specific factors mask typical responses.

Extrapolations. The sample size of this water table depth information is obviously small. Gathering similar information at several other locations would greatly enhance the predictive capability of this model.

Extrapolation of these observations to water table profiles through all stream reaches is somewhat subjective, but it can be guided by results of synoptic flow measurements by DFG contractors (California Department of Fish and Game 1991, 1992a, 1992b, 1993). Relative rates of streamflow loss should be proportional to groundwater slopes, according to D'Arcy's law. Based on the piezometer profiles and this information, water table slopes for particular stream reaches were estimated for model use (Table P-15).

Water Table Boundary Conditions

Analysis of stream configuration and piezometer data shown in Figures P-12, P-13, and P-14 demonstrates the complexity of water table surfaces near the meandering streams. The observations could be reconciled, however, with a simple geometric model of the water table at greater distances from the streams, sloping uniformly away (and down-profile) from the stream as shown.

In the model, as in most groundwater flow models, the downward-sloping water table is imposed as a boundary condition, requiring a specific water table depth at a specific, relatively-large distance from the general trend of the watercourse, corresponding to the estimated perpendicular water table slope (Table P-15). The water table depths in the near-stream locations as dictated by the sequence of stream centerline elevations are required to transition smoothly to the boundary conditions (as shown, for example, on Figures P-12, P-13, and P-14).

The process to establish the "stream trend" and therefore the locations to impose the boundary conditions required the use of averaging algorithms to remove the meander of the actual stream. The steps to accomplish this using an appropriate visual approach are described in the "Methods" section below.

Stage-Discharge Relationships

Stream stage in relation to flow releases from the diversion structures provides an essential tie from flow releases of the alternatives to water table depths. Stage-discharge data were obtained directly or derived from reports of DFG contractors cited above. In some cases, the derivation required use of Manning's law to estimate streamflow from cross-sectional area and shape, channel slope, and roughness characteristics. In all cases, averaging of data from several sections was required, but significant differences between distinct reaches were retained.

The stage-discharge data for each creek were compiled in such a manner as to facilitate assessment of particular streamflows (the July-August average streamflow release projected for each alternative by the LAAMP model). Fortunately, most of the published stage-discharge data is in terms of release flows at the diversions.

To represent the range of alternatives but to keep the task manageable, two reference flow releases for each stream were established for evaluation (Table P-16). They were chosen to encompass the range of streamflows of interest. The model results for these two reference conditions were then linearly interpolated to the intermediate July-August flows of the alternatives. Some loss of accuracy occurs with this interpolation approach, but the increased accuracy obtained by employing more model runs is not needed for the purposes of this assessment.

Water Table Depth Requirements of Woody Riparian Vegetation

To employ the model, it is necessary to make a general estimate of the maximum depth of groundwater needed to sustain woody riparian vegetation during the growing season, but this need not be a precise estimate. The model is intended to estimate relative changes in riparian habitat from point-of-reference conditions, which it can do adequately if the same depth estimate is applied to all alternatives and scenarios.

Information about direct observations of groundwater depths under various plant communities is scarce. Fortunately, such data was collected in the Owens Valley in 1921 (Ecosat Geobotanical Surveys 1990) from an array of observation wells drilled for this purpose. Woody riparian communities had a water table at an average depth of 3.9 feet. The standard deviation of the observations was ±1.5 feet. This suggests that a "primary riparian habitat" can be assumed to have a shallow water table throughout the growing season at a depth of up to 3.9 + 1.5 feet, or about 5 1/2 feet.

Methods

The methods used to construct and execute the model were a combination of computerized and manual techniques, although the entire model could be computerized. Stream trends in plan view were established manually, and manual topographic cross-sections were used as a basis for manual generation of water table profiles. The development of the profile of the stream trend and the model output calculations were accomplished using computerized spreadsheets. The steps of the entire procedure can be summarized as follows:

1. Manually draw stream centerlines along the photogrammetrically-derived topographic maps.

2. Manually draw smooth curve in plan view to approximate a smooth stream trend, changing directions slowly.

3. Identify points along the stream centerlines at 2-foot elevation increments from contour crossings.

4. Project each of these stream centerline points onto the vertical surface along the stream trend at the same elevation. Measure horizontal distances between each projected point and enter elevations and stream-trend distances into a database.

5. Develop a stream trend profile point corresponding to each projected stream centerline point by computing the vertical coordinate of a point on a line representing a least-squares fit of the seven nearest projected stream centerline points.

6. Manually generate topographic cross-sections every 500 feet in the Rush and Lee Vining Creek bottomlands and every 1,000 feet elsewhere.

7. Locate each corresponding stream trend point in each cross-section, using both the offset distance from the stream centerline and the elevation obtained in item 5 above. From this trend point, drawn lines using the selected groundwater slopes (Table P-15) to represent the trend groundwater profile at each location.

8. Beginning at the stream, superimpose an estimated groundwater profile on the section beginning at the specified stage offset above or below the stream centerline (Table P-16) and, through smooth transitions, becoming asymptotic with the trend groundwater profile several hundred feet from the stream. Repeat for two stream stages corresponding to the evaluation streamflows.

9. Locate and measure all portions of the section where the estimated groundwater profile is less than 5 1/2 feet from the topographic profile. Repeat for the two evaluation streamflows.

10. Multiply the section lengths of this primary riparian habitat by the intersectional distance and combine all sections in a reach to estimate acreages of habitat for the two evaluation streamflows.

11. Using linear interpolation, estimate from the reference data the primary riparian habitat acreages corresponding to the average growing season streamflow for each of the alternatives.

12. For the higher lake level alternatives, subtract acreages in the lower reaches of Rush and Lee Vining Creeks to account for submergence of point-of-reference vegetation by the normal highstands of the lake:

    - 6,372-Ft Alternative: 6,378 feet, 0 acres submerged.
    - 6,377-Ft Alternative: 6,383 feet, 9 acres submerged.
    - 6,383.5-Ft Alternative: 6,389 feet, 18.5 acres submerged.
    - 6,390-Ft Alternative: 6,397 feet, 29 acres submerged.

- 6,410-Ft Alternative: 6,415 feet, 36 acres submerged.
- No-Diversion Alternative: 6,436 feet, 42 acres submerged.

13. Compare derived primary habitat acreages for each stream reach with prediversion and point-of-reference acreages from the mapping program. Screen the model results against the known acreages according to the following criteria:

    - where the model acreage lies between prediversion and point-of-reference acreages (which was the case for most of the reaches), accept the model acreage;

    - where the model acreage exceed the prediversion acreage (which occurred only where the water table profile was not directly observed), use the prediversion acreage; and

    - where the model acreage is less than the point-of-reference acreage (which occurred in one reach), use the point-of-reference acreage.

    Treat the results as the maximum potential acreages of riparian habitat over the long term if streamflows remained at the point-of-reference levels. These acreages could remain vegetated with xeric plant communities (i.e., sagebrush scrub) for long periods of time until optimum conditions for recruitment occurred or intervention (through overflow channel watering or planting and irrigating) occurred.

14. For minimum potential acreages, generally use the point-of-reference condition.

15. Apply the percentage increases in riparian habitat for each reach under each alternative, as obtained in step 11, to both the maximum and minimum point-of-reference scenario acreages. Allocate increases to both woody riparian and meadow/ wetland acreages according to the point-of-reference ratio of these types.

Table P-17 shows acreages of the important parameters in steps 13-15 by stream reach for each alternative except the No-Restriction Alternative.

Results

The range of estimated riparian vegetation increases due to stage effects from the point of reference under the alternatives (except the No-Restriction Alternative, which cannot be modeled) for Rush and Lee Vining Creeks combined is 8 acres (for the 6,372-Ft Alternative) to 30 acres (for the 6,410-Ft Alternative). These acreage increases are not substantial, being 2-8% of the point-of-reference acreages along these streams. Based on stage effects alone, an estimated difference of 31 acres of primary riparian habitat separates the lowest streamflow (6,372-Ft) alternative and the No-Diversion Alternative:

- 12 acres on Rush Creek,
- 7 acres on Lee Vining Creek,
- 8 acres on Parker Creek, and
- 4 acres on Walker Creek.

These increases in riparian acreage resulting from streamflow changes are more than offset by decreases caused by newly established willow-covered floodplains near the mouths of Rush and Lee Vining Creeks being submerged by the rising lake. If the lake rose to the level of the No-Diversion Alternative, about 30 acres of riparian vegetation on Rush Creek and 12 acres on Lee Vining Creek would be lost.

No estimates have been made of the extent of shallow water table associated with the north (overflow) channel of Walker Creek. It is assumed that with continued blockage of this channel inlet and substantial reduction of irrigation below the Lee Vining conduit a shallow water table supporting the existing riparian vegetation along this channel will be lost. In the model context, this loss would be compensated by expansion of woody riparian vegetation along the entire main channels of Walker and Parker Creeks once meadow irrigation and grazing were largely curtailed.

The combined effects of these factors, as represented by the results of the water table model, are presented in Table 3C-14 and Figure 3C-11 of Chapter 3C.

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Table P-1. Woody Riparian Acreages on Rush Creek in 1940 and 1989

Year/ Vegetation Type	Reach Number 1a	2a	2b	3	4	5	6	7	8	All Reaches
1940 acreages										
Conifer-broadleaf	–	1.3	–	1.0	0.6	11.4	1.1	–	–	15.4
Cottonwood-willow	2.5	2.1	–	11.9	3.5	5.3	104.9	29.7	–	159.9
Aspen	–	0.6	3.4	0.3	0.1	–	–	–	–	4.4
Willow scrub	3.4	1.3	5.7	10.6	7.2	4.5	39.2	0.6	7.5	79.9
Mixed riparian	0.4	4.0	0.1	1.9	–	0.9	4.4	–	–	11.7
All types	6.3	9.3	9.2	25.7	11.4	22.0	149.5	30.3	7.5	271.2
1989 acreages (mature)										
Conifer-broadleaf	–	1.3	–	1.0	–	–	–	–	–	2.3
Cottonwood-willow	–	1.5	–	0.6	0.6	2.9	2.0	0.4	–	8.0
Aspen	–	0.6	3.2	0.3	0.1	–	–	–	–	4.2
Willow scrub	0.5	1.1	2.4	6.6	1.4	0.9	46.1	2.0	2.2	63.2
Mixed riparian	1.1	1.5	0.6	4.3	2.1	0.2	41.1	6.7	–	57.7
All types	1.6	6.0	6.2	12.8	4.3	4.0	89.1	9.1	2.2	135.4
1989 acreages (decadent)										
Conifer-broadleaf	–	–	–	0.3	–	–	–	–	–	0.3
Cottonwood-willow	1.3	–	–	1.4	0.1	–	10.7	2.3	–	15.8
Aspen	–	–	–	–	–	–	–	–	–	–
Willow scrub	0.3	–	0.8	1.1	–	–	12.6	9.5	0.6	24.8
Mixed riparian	–	–	–	0.4	–	–	–	–	–	0.4
All types	1.6	–	0.8	3.2	0.1	–	23.3	11.7	0.6	41.3
1989 acreages (establishing)										
Conifer-broadleaf	–	–	–	–	–	–	–	–	–	–
Cottonwood-willow	–	–	–	–	0.2	–	–	–	0.4	0.6
Aspen	–	–	–	–	–	–	–	–	–	–
Willow scrub	–	0.02	–	0.1	0.8	–	6.0	1.5	24.1	32.6
Mixed riparian	–	–	–	–	0.2	–	–	–	–	0.2
All types	–	0.02	–	0.1	1.2	–	6.0	1.5	24.5	33.3
Changes from 1940 to 1989 (mature only)										
Conifer-broadleaf	–	–	–	–	-0.6	-11.4	-1.1	–	–	-13.1
Cottonwood-willow	-2.5	-0.6	–	-11.3	-2.9	-2.4	-102.9	-29.3	–	-151.9
Aspen	–	–	-0.2	–	–	–	–	–	–	-0.2
Willow scrub	-2.9	-0.2	-3.3	-4.0	-5.8	-3.6	6.9	1.4	-5.3	-16.7
Mixed riparian	0.7	-2.5	0.5	2.4	2.1	-0.7	36.7	6.7	–	46.1
All types	-4.7	-3.2	-3.0	-12.9	-7.1	-18.0	-60.4	-21.2	-5.3	-135.8
Percent loss or gain	-75%	-35%	-32%	-50%	-62%	-82%	-40%	-70%	-71%	-50%
Changes from 1940 to 1989 (mature and establishing)										
Conifer-broadleaf	–	–	–	–	-0.6	-11.4	-1.1	–	–	-13.1
Cottonwood-willow	-2.5	-0.6	–	-11.3	-2.7	-2.4	-102.9	-29.3	0.4	-151.2
Aspen	–	–	-0.2	–	–	–	–	–	–	-0.2
Willow scrub	-2.9	-0.2	-3.3	-3.9	-5.0	-3.6	12.9	2.9	18.8	15.8
Mixed riparian	0.7	-2.5	0.5	2.4	2.3	-0.7	36.7	6.7	–	46.2
All types	-4.7	-3.2	-3.0	-12.8	-5.9	-18.0	-54.4	-19.6	19.2	-102.4
Percent loss or gain	-75%	-34%	-32%	-50%	-52%	-82%	-36%	-65%	256%	-38%

Table P-1. Continued

Year/ Vegetation Type	Reach Number 1a	2a	2b	3	4	5	6	7	8	All Reaches
Changes from 1940 to 1989 (mature, establishing, and decadent)										
Conifer-broadleaf	--	--	--	0.3	-0.6	-11.4	-1.1	--	--	-12.8
Cottonwood-willow	-1.2	-0.6	--	-9.9	-2.6	-2.4	-92.2	-27.1	0.4	-135.5
Aspen	--	--	-0.2	--	--	--	--	--	--	-0.2
Willow scrub	-2.6	-0.2	-2.5	-2.8	-5.0	-3.6	25.5	12.4	19.3	40.7
Mixed riparian	0.7	-2.5	0.5	2.8	2.3	-0.7	36.7	6.7	--	46.6
All types	-3.1	-3.2	-2.2	-9.5	-5.8	-18.0	-31.1	-7.9	19.8	-61.1
Percent loss or gain	-49%	-34%	-24%	-37%	-51%	-82%	-21%	-26%	264%	-23%

Notes:

Reach 1a = Grant Lake Dam to return ditch.
Reach 2a = return ditch to base of moraine.
Reach 2b = A-Ditch supply channel.
Reach 3 = base of moraine to old highway bridge.
Reach 4 = old highway bridge to Parker Creek.
Reach 5 = Parker Creek to The Narrows.
Reach 6 = The Narrows to the ford.
Reach 7 = the ford to County Road.
Reach 8 = County Road to lakeshore.

Acreages measured by Jones & Stokes Associates from interpretation of 1929-1930, 1940, and 1990 aerial photographs and 1990-1991 field surveys.

Table P-2a. Mature Woody Riparian Vegetation with Less than 50% Cover on Rush Creek in 1940 and 1989

Year/ Vegetation Type	Reach Number 1a	2a	2b	3	4	5	6	7	8	All Reaches
1940 acreages										
Conifer-broadleaf	–	–	–	0.7	0.6	10.5	–	–	–	11.8
Cottonwood-willow	–	0.2	–	1.6	1.6	1.0	27.1	1.0	–	32.5
Aspen	–	0.4	–	–	0.1	–	–	–	–	0.5
Willow scrub	–	–	0.5	4.9	3.3	1.1	5.9	0.4	5.2	21.3
Mixed riparian	–	–	0.1	–	–	–	2.7	–	–	2.8
All types	–	0.6	0.6	7.2	5.6	12.6	35.7	1.4	5.2	68.9
1989 acreages										
Conifer-broadleaf	–	–	–	0.6	–	–	–	–	–	0.6
Cottonwood-willow	–	0.1	–	0.4	0.6	2.3	1.1	0.4	–	5.0
Aspen	–	0.4	–	–	0.1	–	–	–	–	0.5
Willow scrub	0.3	0.1	0.2	1.3	1.0	0.3	7.2	1.0	2.2	13.6
Mixed riparian	0.9	0.1	0.1	1.8	0.5	–	7.4	3.8	–	14.7
All types	1.2	0.7	0.3	4.2	2.3	2.6	15.7	5.2	2.2	34.3
Changes from 1940 to 1989										
Conifer-broadleaf	–	–	–	-0.1	-0.6	-10.5	–	–	–	-11.2
Cottonwood-willow	–	-0.1	–	-1.2	-1.0	1.3	-26.0	-0.6	–	-27.6
Aspen	–	–	–	–	–	–	–	–	–	–
Willow scrub	0.3	0.1	-0.3	-3.6	-2.3	-0.8	1.3	0.6	-3.0	-7.7
Mixed riparian	0.9	0.1	–	1.8	0.5	–	4.7	3.8	–	11.9
All types	1.2	0.1	-0.3	-3.0	-3.3	-10.0	-20.0	3.8	-3.0	-34.6
Percent loss or gain	100%	17%	-50%	-42%	-60%	-80%	-56%	261%	-58%	-50%

Notes:

Reach 1a = Grant Lake Dam to return ditch.
Reach 2a = return ditch to base of moraine.
Reach 2b = A-Ditch supply channel.
Reach 3 = base of moraine to old highway bridge.
Reach 4 = old highway bridge to Parker Creek.
Reach 5 = Parker Creek to The Narrows.
Reach 6 = The Narrows to the ford.
Reach 7 = the ford to County Road.
Reach 8 = County Road to lakeshore.

Differences in quality of prediversion and recent aerial photographs may reduce accuracy of percent cover comparisons.

Some calculations of acreage change may appear inaccurate by 0.1 acre because of rounding error.

Acreages measured by Jones & Stokes Associates from interpretation of 1929-1930, 1940, and 1990 aerial photographs and 1990-1991 field surveys.

Table P-2b. Mature Woody Riparian Vegetation with Greater than 50% Cover on Rush Creek in 1940 and 1989

Year/ Vegetation Type	Reach Number									All Reaches
	1a	2a	2b	3	4	5	6	7	8	
1940 acreages										
Conifer-broadleaf	--	1.3	--	0.3	--	0.9	1.1	--	--	3.6
Cottonwood-willow	2.5	1.9	--	10.3	1.9	4.3	77.8	28.7	--	127.4
Aspen	--	0.2	3.4	0.3	--	--	--	--	--	3.9
Willow scrub	3.4	1.3	5.2	5.7	3.9	3.4	33.3	0.2	2.3	58.6
Mixed riparian	0.4	3.9	--	1.9	--	0.9	1.7	--	--	8.8
All types	6.3	8.6	8.6	18.5	5.8	9.5	113.9	28.9	2.3	202.3
1989 acreages										
Conifer-broadleaf	--	1.3	--	0.4	--	--	--	--	--	1.7
Cottonwood-willow	--	1.4	--	0.1	--	0.6	0.9	--	--	3.1
Aspen	--	0.2	3.2	0.3	--	--	--	--	--	3.7
Willow scrub	0.2	1.0	2.2	5.3	0.4	0.6	38.8	1.0	--	49.6
Mixed riparian	0.2	1.4	0.5	2.5	1.7	0.2	33.7	2.9	--	43.1
All types	0.4	5.3	5.9	8.6	2.0	1.4	73.4	3.9	--	101.2
Changes from 1940 to 1989										
Conifer-broadleaf	--	--	--	0.1	--	-0.9	-1.1	--	--	-1.9
Cottonwood-willow	-2.5	-0.5	--	-10.1	-1.9	-3.7	-76.9	-28.7	--	-124.3
Aspen	--	--	-0.2	--	--	--	--	--	--	-0.2
Willow scrub	-3.2	-0.3	-3.0	-0.4	-3.5	-2.8	5.6	0.8	-2.3	-9.0
Mixed riparian	-0.2	-2.5	0.5	0.6	1.7	-0.7	32.0	2.9	--	34.3
All types	-5.9	-3.3	-2.7	-9.8	-3.8	-8.0	-40.4	-24.9	-2.3	-101.1
Percent loss or gain	100%	-38%	-31%	-53%	-65%	-85%	-36%	-86%	-100%	-50%

Notes:

Reach 1a = Grant Lake Dam to return ditch.
Reach 2a = return ditch to base of moraine.
Reach 2b = A-Ditch supply channel.
Reach 3 = base of moraine to old highway bridge.
Reach 4 = old highway bridge to Parker Creek.
Reach 5 = Parker Creek to The Narrows.
Reach 6 = The Narrows to the ford.
Reach 7 = the ford to County Road.
Reach 8 = County Road to lakeshore.

Differences in quality of prediversion and recent aerial photographs may reduce accuracy of percent cover comparisons.

Some calculations of acreage change may appear inaccurate by 0.1 acre because of rounding error.

Acreages measured by Jones & Stokes Associates from interpretation of 1929-1930, 1940, and 1990 aerial photographs and 1990-1991 field surveys.

Table P-3. Woody Riparian Acreages on Parker Creek in 1940 and 1989

Year/ Vegetation Type	Reach Number 1	2	3	4	All Reaches
1940 acreages					
Conifer-broadleaf	0.6	0.2	--	0.3	1.1
Cottonwood-willow	--	0.1	--	--	0.1
Aspen	0.2	--	--	--	0.2
Willow scrub	13.7	34.9	2.5	3.0	54.2
Mixed riparian	--	0.2	--	2.6	2.8
All types	14.5	35.4	2.5	5.9	58.4
1989 acreages					
Conifer-broadleaf	0.8	0.3	--	0.3	1.4
Cottonwood-willow	--	0.2	--	--	0.2
Aspen	0.2	--	--	--	0.2
Willow scrub	13.7	30.4	0.5	--	44.6
Mixed riparian	0.5	0.4	--	1.9	2.8
All types	15.2	31.3	0.5	2.2	49.2
Changes from 1940 to 1989					
Conifer-broadleaf	0.2	0.1	--	--	0.3
Cottonwood-willow	--	0.1	--	--	0.1
Aspen	--	--	--	--	--
Willow scrub	-0.1	-4.5	-2.1	-3.0	-9.7
Mixed riparian	0.5	0.2	--	-0.7	--
All types	0.6	-4.1	-2.1	-3.7	-9.3
Percent loss or gain	4%	-12%	-84%	-63%	-16%

Notes: Reach 1 = diversion to foot of moraine.
Reach 2 = foot of moraine to Cain Ranch Road.
Reach 3 = Cain Ranch Road to U.S. 395.
Reach 4 - U.S. 395 to Rush Creek.

No decadent vegetation was mapped for 1940; 0.1 acre of decadent willow scrub vegetation is included in the Reach 3 acreage for 1989.

Acreages measured by Jones & Stokes Associates from interpretation of 1929-1930, 1940, and 1990 aerial photographs and 1990-1991 field surveys.

Table P-4a. Mature Woody Riparian Vegetation with Less than 50% Cover on Parker Creek in 1940 and 1989

Year/ Vegetation Type	Reach Number 1	2	3	4	All Reaches
1940 acreages					
Conifer-broadleaf	0.3	--	--	--	0.3
Cottonwood-willow	--	--	--	--	--
Aspen	--	--	--	--	--
Willow scrub	3.5	3.1	0.4	--	7.0
Mixed riparian	--	--	--	--	--
All types	3.8	3.1	0.4	--	7.3
1989 acreages					
Conifer-broadleaf	--	--	--	--	--
Cottonwood-willow	--	--	--	--	--
Aspen	--	--	--	--	--
Willow scrub	2.1	6.4	--	--	8.5
Mixed riparian	0.2	0.2	--	--	0.4
All types	2.3	6.6	--	--	8.9
Changes from 1940 to 1989					
Conifer-broadleaf	-0.3	--	--	--	-0.3
Cottonwood-willow	--	--	--	--	--
Aspen	--	--	--	--	--
Willow scrub	-1.4	3.3	-0.4	--	1.5
Mixed riparian	0.2	0.2	--	--	0.4
All types	-1.5	3.5	-0.4	--	1.6
Percent loss or gain	-40%	112%	-100%	--	21%

Notes: Reach 1 = diversion to foot of moraine.
Reach 2 = foot of moraine to Cain Ranch Road.
Reach 3 = Cain Ranch Road to U.S. 395.
Reach 4 - U.S. 395 to Rush Creek.

Differences in quality of prediversion and recent aerial photographs may reduce accuracy of percent cover comparisons.

Some calculations of acreage change may appear inaccurate by 0.1 acre because of rounding error.

Acreages measured by Jones & Stokes Associates from interpretation of 1929-1930, 1940, and 1990 aerial photographs and 1990-1991 field surveys.

Table P-4b. Mature Woody Riparian Vegetation with Greater Than 50% Cover on Parker Creek in 1940 and 1989

Year/ Vegetation Type	Reach Number 1	2	3	4	All Reaches
1940 acreages					
Conifer-broadleaf	0.3	0.2	--	0.3	0.8
Cottonwood-willow	--	0.1	--	--	0.1
Aspen	0.2	--	--	--	0.2
Willow scrub	10.2	31.8	2.1	3.0	47.1
Mixed riparian	--	0.2	--	2.6	2.8
All types	10.7	32.3	2.1	5.9	51.0
1989 acreages					
Conifer-broadleaf	0.8	0.3	--	0.3	1.4
Cottonwood-willow	--	0.2	--	--	0.2
Aspen	0.2	--	--	--	0.2
Willow scrub	11.6	24.0	0.4	--	36.0
Mixed riparian	0.3	0.2	--	1.9	2.4
All types	12.9	24.7	0.4	2.2	40.2
Changes from 1940 to 1989					
Conifer-broadleaf	0.5	0.1	--	--	0.6
Cottonwood-willow	--	0.1	--	--	0.1
Aspen	--	--	--	--	--
Willow scrub	1.3	-7.8	-1.7	-3.0	-11.1
Mixed riparian	0.3	--	--	-0.7	-0.4
All types	2.1	-7.6	-1.7	-3.7	-10.9
Percent loss or gain	20%	-23%	-81%	-63%	-21%

Notes: Reach 1 = diversion to foot of moraine.
Reach 2 = foot of moraine to Cain Ranch Road.
Reach 3 = Cain Ranch Road to U.S. 395.
Reach 4 - U.S. 395 to Rush Creek.

Differences in quality of prediversion and recent aerial photographs may reduce accuracy of percent cover comparisons.

Some calculations of acreage change may appear inaccurate by 0.1 acre because of rounding error.

Acreages measured by Jones & Stokes Associates from interpretation of 1929-1930, 1940, and 1990 aerial photographs and 1990-1991 field surveys.

Table P-5. Woody Riparian Acreages on Walker Creek in 1940 and 1989

Year/ Vegetation Type	Reach Number 1	2	3	4	5	All Reaches
1940 acreages						
Conifer-broadleaf	--	--	--	0.5	--	0.5
Cottonwood-willow	--	--	--	--	--	--
Aspen	0.4	--	0.9	--	--	1.3
Willow scrub	17.8	0.6	10.5	10.6	2.8	42.4
Mixed riparian	1.2	0.3	--	4.1	--	5.6
All types	19.4	0.9	11.4	15.2	2.8	49.7
1989 acreages						
Conifer-broadleaf	--	--	--	0.6	--	0.6
Cottonwood-willow	0.1	--	--	0.1	--	0.2
Aspen	0.4	--	0.9	--	--	1.3
Willow scrub	11.8	--	5.5	7.7	1.2	26.2
Mixed riparian	6.6	0.1	3.4	4.5	--	14.6
All types	19.0	0.1	9.8	12.9	1.2	42.9
Changes from 1940 to 1989						
Conifer-broadleaf	--	--	--	0.1	--	0.1
Cottonwood-willow	0.1	--	--	0.1	--	0.2
Aspen	--	--	--	--	--	--
Willow scrub	-6.0	-0.6	-5.0	-2.9	-1.6	-16.2
Mixed riparian	5.5	-0.2	3.4	0.4	--	9.0
All types	-0.5	-0.8	-1.6	-2.3	-1.6	-6.8
Percent loss or gain	-2%	-89%	-14%	-15%	-58%	-14%

Notes: Reach 1 = diversion to Cain Ranch Road, main (south) channel.
Reach 2 = Cain Ranch Road to U.S. 395, main (south) channel.
Reach 3 = U.S. 395 to Rush Creek.
Reach 4 = diversion to Cain Ranch Road, secondary (north) channel.
Reach 5 = Cain Ranch Road to U.S. 395, secondary (north) channel.

All mapped vegetation is mature. No decadent or establishing vegetation was mapped.
Acreages measured by Jones & Stokes Associates from interpretation of 1929-1930, 1940, and 1990 aerial photographs and 1990-1991 field surveys.

Table P-6a. Mature Woody Riparian with Less than 50% Cover on Walker Creek in 1940 and 1989

Year/ Vegetation Type	Reach Number 1	2	3	4	5	All Reaches
1940 acreages						
Conifer-broadleaf	--	--	--	0.5	--	0.5
Cottonwood-willow	--	--	--	--	--	--
Aspen	--	--	--	--	--	--
Willow scrub	10.7	0.6	2.9	4.6	2.6	21.5
Mixed riparian	--	0.3	--	0.4	--	0.7
All types	10.7	0.9	2.9	5.5	2.6	22.6
1989 acreages						
Conifer-broadleaf	--	--	--	0.6	--	0.6
Cottonwood-willow	0.1	--	--	0.1	--	0.2
Aspen	--	--	--	--	--	--
Willow scrub	5.1	--	1.6	2.7	1.2	10.6
Mixed riparian	4.3	0.1	1.1	0.2	--	5.7
All types	9.5	0.1	2.8	3.6	1.2	17.1
Changes from 1940 to 1989						
Conifer-broadleaf	--	--	--	0.1	--	0.1
Cottonwood-willow	0.1	--	--	0.1	--	0.2
Aspen	--	--	--	--	--	--
Willow scrub	-5.6	-0.6	-1.3	-2.0	-1.4	-10.9
Mixed riparian	4.3	-0.2	1.1	-0.2	--	5.0
All types	-1.2	-0.8	-0.2	-1.9	-1.4	-5.5
Percent loss or gain	-11%	-88%	-6%	-35%	-54%	-24%

Notes: Reach 1 = diversion to Cain Ranch Road, main (south) channel.
Reach 2 = Cain Ranch Road to U.S. 395, main (south) channel.
Reach 3 = U.S. 395 to Rush Creek.
Reach 4 = diversion to Cain Ranch Road, secondary (north) channel.
Reach 5 = Cain Ranch Road to U.S. 395, secondary (north) channel.

Differences in quality of prediversion and recent aerial photographs may reduce accuracy of percent cover comparisons.
Some calculations of acreage change may appear inaccurate by 0.1 acre because of rounding error.
Acreages measured by Jones & Stokes Associates from interpretation of 1929-1930, 1940, and 1990 aerial photographs and 1990-1991 field surveys.

Table P-6b. Mature Woody Riparian with Greater than 50% Cover on Walker Creek in 1940 and 1989

Year/ Vegetation Type	Reach Number 1	2	3	4	5	All Reaches
1940 acreages						
Conifer-broadleaf	--	--	--	--	--	--
Cottonwood-willow	--	--	--	--	--	--
Aspen	0.4	--	0.9	--	--	1.3
Willow scrub	7.2	--	7.5	6.0	0.2	20.9
Mixed riparian	1.2	--	--	3.7	--	4.9
All types	8.7	--	8.4	9.7	0.2	27.1
1989 acreages						
Conifer-broadleaf	--	--	--	--	--	--
Cottonwood-willow	--	--	--	--	--	--
Aspen	0.4	--	0.9	--	--	1.3
Willow scrub	6.7	--	3.9	5.0	--	15.6
Mixed riparian	2.3	--	2.2	4.3	--	8.9
All types	9.5	--	7.0	9.3	--	25.8
Changes from 1940 to 1989						
Conifer-broadleaf	--	--	--	--	--	--
Cottonwood-willow	--	--	--	--	--	--
Aspen	--	--	--	--	--	--
Willow scrub	-0.4	--	-3.7	-1.0	-0.2	-5.3
Mixed riparian	1.2	--	2.2	0.6	--	4.0
All types	0.7	--	-1.4	-0.4	-0.2	-1.3
Percent loss or gain	8%	--	-17%	-4%	-100%	-5%

Notes: Reach 1 = diversion to Cain Ranch Road, main (south) channel.
Reach 2 = Cain Ranch Road to U.S. 395, main (south) channel.
Reach 3 = U.S. 395 to Rush Creek.
Reach 4 = diversion to Cain Ranch Road, secondary (north) channel.
Reach 5 = Cain Ranch Road to U.S. 395, secondary (north) channel.

Differences in quality of prediversion and recent aerial photographs may reduce accuracy of percent cover comparisons.

Some calculations of acreage change may appear inaccurate by 0.1 acre because of rounding error.

Acreages measured by Jones & Stokes Associates from interpretation of 1929-1930, 1940, and 1990 aerial photographs and 1990-1991 field surveys.

Table P-7. Woody Riparian Acreages on Lee Vining Creek in 1940 and 1989

Year/ Vegetation Type	Reach Number 1a	1b	2a	2b	3a	3b	3c	3d	All Reaches
1940 acreages									
Conifer-broadleaf	12.5	1.3	13.6	7.1	–	–	–	–	34.5
Cottonwood-willow	0.5	–	1.4	3.0	21.4	32.0	2.6	–	60.9
Aspen	0.1	0.8	–	4.4	–	1.3	–	–	6.7
Willow scrub	5.1	–	–	0.2	1.8	1.4	1.7	–	10.3
Mixed riparian	–	–	–	0.2	–	–	–	–	0.2
All types	18.2	2.1	15.0	14.9	23.2	34.7	4.3	–	112.5
1989 acreages (mature)									
Conifer-broadleaf	11.9	1.1	11.9	2.9	–	–	–	–	27.8
Cottonwood-willow	0.5	–	1.5	3.3	3.6	0.5	0.5	–	9.9
Aspen	0.1	0.7	–	4.0	–	0.8	–	–	5.6
Willow scrub	5.5	–	–	0.1	0.1	–	0.2	4.8	10.6
Mixed riparian	–	–	–	0.7	2.9	2.2	0.5	–	6.3
All types	18.0	1.8	13.4	10.9	6.6	3.5	1.2	4.8	60.2
1989 acreages (establishing)									
Conifer-broadleaf	–	–	–	–	–	–	–	–	–
Cottonwood-willow	–	–	–	–	0.3	3.1	1.7	–	5.1
Aspen	–	–	–	–	–	–	–	–	–
Willow scrub	–	–	–	–	–	0.9	0.4	3.8	5.1
Mixed riparian	–	–	–	–	–	–	–	–	–
All types	–	–	–	–	0.3	4.0	2.1	3.8	10.1
Changes from 1940 to 1989 (mature only)									
Conifer-broadleaf	-0.6	-0.2	-1.7	-4.2	–	–	–	–	-6.7
Cottonwood-willow	–	–	0.1	0.3	-17.8	-31.4	-2.1	–	-51.0
Aspen	–	-0.1	–	-0.5	–	-0.5	–	–	-1.1
Willow scrub	0.3	–	–	-0.1	-1.7	-1.4	-1.5	4.8	0.3
Mixed riparian	–	–	–	0.5	2.9	2.2	0.5	–	6.1
All types	-0.3	-0.3	-1.6	-4.0	-16.6	-31.2	-3.1	4.8	-52.3
Percent loss or gain	-2%	-16%	-11%	-27%	-71%	-90%	-72%	100%	-46%
Changes from 1940 to 1989 (mature and establishing)									
Conifer-broadleaf	-0.6	-0.2	-1.7	-4.2	–	–	–	–	-6.7
Cottonwood-willow	–	–	0.1	0.3	-17.5	-28.3	-0.4	–	-45.9
Aspen	–	-0.1	–	-0.5	–	-0.5	–	–	-1.1
Willow scrub	0.3	–	–	-0.1	-1.7	-0.5	-1.1	8.5	5.4
Mixed riparian	–	–	–	0.5	2.9	2.2	0.5	–	6.1
All types	-0.3	-0.3	-1.6	-4.0	-16.3	-27.2	-1.0	8.5	-42.2
Percent loss or gain	-2%	-16%	-11%	-27%	-70%	-78%	-23%	100%	-37%

Notes: Reach 1a = diversion to ranger station bridge.
Reach 1b = ranger station bridge to Highway 120.
Reach 2a = Highway 120 to U.S. 395.
Reach 2b = U.S. 395 to bottom of 1989 vegetation.
Reach 3a = bottom of 1989 forest to big bend.
Reach 3b = big bend to County Road.
Reach 3c = County Road to 1940 lakeshore.
Reach 3d = 1940 lakeshore to 1989 lakeshore.

No decadent vegetation was mapped for 1940 or 1989.

Acreages measured by Jones & Stokes Associates from interpretation of 1929-1930, 1940, and 1990 aerial photographs and 1990-1991 field surveys.

Table P-8a. Mature Woody Riparian Vegetation with Less Than 50% Cover on Lee Vining Creek in 1940 and 1989

Year/ Vegetation Type	Reach Number 1a	1b	2a	2b	3a	3b	3c	3d	All Reaches
1940 acreages									
Conifer-broadleaf	1.7	–	2.4	–	–	–	–	–	4.1
Cottonwood-willow	0.2	–	–	2.2	2.1	5.1	–	–	9.7
Aspen	0.1	–	–	–	–	–	–	–	0.1
Willow scrub	2.1	–	–	–	0.3	0.9	0.2	–	3.5
Mixed riparian	–	–	–	–	–	–	–	–	–
All types	4.1	–	2.4	2.2	2.4	6.0	0.2	–	17.4
1989 acreages									
Conifer-broadleaf	1.9	–	–	–	–	–	–	–	1.9
Cottonwood-willow	0.2	–	–	0.5	1.1	0.2	–	–	2.0
Aspen	0.1	–	–	–	–	–	–	–	0.1
Willow scrub	2.2	–	–	–	–	–	0.1	2.9	5.2
Mixed riparian	–	–	–	0.3	0.3	0.1	–	–	0.7
All types	4.4	–	–	0.8	1.4	0.3	0.1	2.9	9.9
Changes from 1940 to 1989									
Conifer-broadleaf	0.2	–	-2.4	–	–	–	–	–	-2.2
Cottonwood-willow	–	–	–	-1.7	-1.0	-4.9	–	–	-7.7
Aspen	–	–	–	–	–	–	–	–	–
Willow scrub	0.1	–	–	–	-0.3	-0.9	-0.1	2.9	1.6
Mixes riparian	–	–	–	0.3	0.3	0.1	–	–	0.7
All types	0.2	–	-2.4	-1.4	-1.0	-5.7	-0.1	2.9	-7.5
Percent loss or gain	6%	–	-100%	-64%	-41%	-94%	-51%	–	-43%

Notes: Reach 1a = diversion to ranger station bridge.
Reach 1b = ranger station bridge to Highway 120.
Reach 2a = Highway 120 to U.S. 395.
Reach 2b = U.S. 395 to bottom of 1989 vegetation.
Reach 3a = bottom of 1989 vegetation to big bend.
Reach 3b = big bend to County Road.
Reach 3c = County Road to 1940 lakeshore.
Reach 3d = 1940 lakeshore to 1989 lakeshore.

Differences in quality of prediversion and recent aerial photographs may reduce accuracy of percent cover comparison.
Some calculations of acreage change may appear inaccurate by 0.1 acre because of rounding error.
Acreages measured by Jones & Stokes Associates from interpretation of 1929-1930, 1940, and 1990 aerial photographs and 1990-1991 field surveys.

Table P-8b. Mature Woody Riparian Vegetation with Greater Than 50% Cover on Lee Vining Creek in 1940 and 1989

Year/ Vegetation Type	Reach Number 1a	1b	2a	2b	3a	3b	3c	3d	All Reaches
1940 acreages									
Conifer-broadleaf	10.8	1.3	11.2	7.1	–	–	–	–	30.3
Cottonwood-willow	0.3	–	1.4	0.8	19.3	26.8	2.6	–	51.2
Aspen	–	0.8	–	4.4	–	1.3	–	–	6.6
Willow scrub	3.0	–	–	0.2	1.5	0.5	1.5	–	6.8
Mixed riparian	–	–	–	0.2	–	–	–	–	0.2
All types	14.1	2.1	12.6	12.7	20.8	28.6	4.1	–	95.0
1989 acreages									
Conifer-broadleaf	10.0	1.1	11.9	2.9	–	–	–	–	25.9
Cottonwood-willow	0.3	–	1.5	2.8	2.5	0.3	0.5	–	7.9
Aspen	–	0.7	–	4.0	–	0.8	–	–	5.5
Willow scrub	3.3	–	–	0.1	0.1	–	0.1	1.9	5.5
Mixed riparian	–	–	–	0.4	2.6	2.1	0.5	–	5.6
All types	13.6	1.8	13.4	10.1	5.2	3.2	1.1	1.9	50.3
Changes from 1940 to 1989									
Conifer-broadleaf	-0.8	-0.2	0.7	-4.2	–	–	–	–	-4.4
Cottonwood-willow	–	–	0.1	2.0	-16.8	-26.5	-2.1	–	-43.3
Aspen	–	-0.1	–	-0.5	–	-0.5	–	–	-1.1
Willow scrub	0.3	–	–	-0.1	-1.4	-0.5	-1.4	1.9	-1.3
Mixes riparian	–	–	–	0.2	2.6	2.1	0.5	–	5.4
All types	-0.5	-0.3	0.8	-2.6	-15.6	-25.4	-3.0	1.9	-44.8
Percent loss or gain	-4%	-16%	6%	-20%	-75%	-89%	-73%	100%	-47%

Notes: Reach 1a = diversion to ranger station bridge.
Reach 1b = ranger station bridge to Highway 120.
Reach 2a = Highway 120 to U.S. 395.
Reach 2b = U.S. 395 to bottom of 1989 vegetation.
Reach 3a = bottom of 1989 vegetation to big bend.
Reach 3b = big bend to County Road.
Reach 3c = County Road to 1940 lakeshore.
Reach 3d = 1940 lakeshore to 1989 lakeshore.

Differences in quality of prediversion and recent aerial photographs may reduce accuracy of percent cover comparison.
Some calculations of acreage change may appear inaccurate by 0.1 acre because of rounding error.
Acreages measured by Jones & Stokes Associates from interpretation of 1929-1930, 1940, and 1990 aerial photographs and 1990-1991 field surveys.

Table P-9. Responses to Rewatering Observed in Mature Woody Riparian Vegetation on Rush Creek in 1990-1991

Response Level/ Vegetation Type	Reach Number 1a	2a	2b	3	4	5	6	7	8	All Reaches
No response										
Conifer-broadleaf	–	1.1	–	0.1	–	–	–	–	–	1.2
Cottonwood-willow	–	0.3	–	0.2	–	0.2	–	0.3	–	1.0
Aspen	–	0.6	3.2	0.2	–	–	–	–	–	4.0
Willow scrub	0.3	0.1	2.4	0.9	–	0.7	24.6	1.1	2.2	32.3
Mixed riparian	1.0	0.3	0.6	2.6	0.3	0.1	35.5	5.5	–	45.9
All types	1.3	2.4	6.2	4.0	0.3	1.0	60.0	7.0	2.2	84.4
Percent of total mapped	81%	40%	100%	31%	7%	26%	67%	77%	100%	62%
Slight response										
Conifer-broadleaf	–	0.2	–	0.9	–	–	–	–	–	1.1
Cottonwood-willow	–	1.2	–	0.1	0.4	0.4	1.0	–	–	3.1
Aspen	–	–	–	–	0.1	–	–	–	–	0.1
Willow scrub	0.2	–	–	2.0	0.2	–	3.7	0.7	–	6.8
Mixed riparian	–	0.3	–	0.9	1.0	0.1	3.6	1.1	–	7.1
All types	0.2	1.7	–	3.9	1.7	0.5	8.3	1.8	–	18.2
Percent of total mapped	12%	28%	–	31%	40%	13%	9%	20%	–	13%
Moderate response										
Conifer-broadleaf	–	–	–	–	–	–	–	–	–	–
Cottonwood-willow	–	0.04	–	0.3	0.2	2.0	1.0	–	–	3.5
Aspen	–	–	–	0.1	–	–	–	–	–	0.1
Willow scrub	–	0.9	–	2.5	1.0	0.1	9.8	–	–	14.4
Mixed riparian	–	0.9	–	0.8	0.7	–	1.2	–	–	3.7
All types	–	1.8	–	3.8	2.0	2.1	11.9	–	–	21.7
Percent of total mapped	–	30%	–	29%	46%	53%	13%	–	–	16%
Strong response										
Conifer-broadleaf	–	–	–	–	–	–	–	–	–	–
Cottonwood-willow	–	–	–	–	–	–	–	–	–	–
Aspen	–	–	–	–	–	–	–	–	–	–
Willow scrub	–	0.1	–	1.1	0.1	–	6.7	0.2	–	8.2
Mixed riparian	–	–	–	–	0.1	–	0.5	–	–	0.6
All types	–	0.1	–	1.1	0.2	–	7.2	0.2	–	8.8
Percent of total mapped	–	2%	–	9%	4%	–	8%	2%	–	6%

Notes: 73% (31.1 acres) of establishing vegetation showed a strong response to rewatering, 1.2% (0.5 acre) showed a slight response, and 1.6% (0.7 acre) showed a moderate response.

89% (36.8 acres) of decadent vegetation showed no response to rewatering, 9% (3.6 acres) showed a slight response, and 2% (0.7 acre) showed a moderate response.

See Appendix F for explanation of response categories.

Reach 1a = Grant Lake Dam to return ditch.
Reach 2a = return ditch to base of moraine.
Reach 2b = A-Ditch supply channel.
Reach 3 = base of moraine to old highway bridge.
Reach 4 = old highway bridge to Parker Creek.
Reach 5 = Parker Creek to The Narrows.
Reach 6 = The Narrows to the ford.
Reach 7 = the ford to County Road.
Reach 8 = County Road to lakeshore.

Percentages may not total 100% because of rounding error.

Acreages measured by Jones & Stokes Associates from interpretation of 1929-1930, 1940, and 1990 aerial photographs and 1990-1991 field surveys.

Table P-10. Responses to Rewatering Observed in Mature Woody Riparian Vegetation on Parker Creek in 1991

Response Level/ Vegetation Type	Reach Number 1	2	3	4	All Reaches
No response					
Conifer-broadleaf	0.8	--	--	0.3	1.1
Cottonwood-willow	--	--	--	--	--
Aspen	0.2	--	--	--	0.2
Willow scrub	2.4	9.7	0.5	--	12.6
Mixed riparian	0.2	0.2	--	0.9	1.3
All types	3.6	9.9	0.5	1.2	15.2
Percent of total mapped	24%	32%	100%	55%	31%
Slight response					
Conifer-broadleaf	--	0.3	--	--	0.3
Cottonwood-willow	--	0.2	--	--	0.2
Aspen	--	--	--	--	--
Willow scrub	5.0	20.1	--	--	25.1
Mixed riparian	0.3	0.2	--	1.0	1.5
All types	5.3	20.8	--	1.0	27.1
Percent of total mapped	35%	67%	--	45%	55%
Moderate response					
Conifer-broadleaf	--	--	--	--	--
Cottonwood-willow	--	--	--	--	--
Aspen	--	--	--	--	--
Willow scrub	6.3	--	--	--	6.3
Mixed riparian	--	--	--	--	--
All types	6.3	--	--	--	6.3
Percent of total mapped	41%	--	--	--	13%
Strong response					
All types	--	--	--	--	--
Percent loss or gain	--	--	--	--	--

Notes: See Appendix F for explanation of response categories.

Reach 1 = diversion to foot of moraine.
Reach 2 = foot of moraine to Cain Ranch Road.
Reach 3 = Cain Ranch Road to U.S. 395.
Reach 4 - U.S. 395 to Rush Creek.

Percentages may not total 100% because of rounding error.
Acreages measured by Jones & Stokes Associates from interpretation of 1929-1930, 1940, and 1990 aerial photographs and 1990-1991 field surveys.

Table P-11. Responses to Rewatering Observed in Mature Woody Riparian Vegetation on Walker Creek in 1991

Response Level/ Vegetation Type	Reach Number 1	2	3	4	5	All Reaches
No response						
Conifer-broadleaf	--	--	--	0.6	--	0.6
Cottonwood-willow	0.1	--	--	0.1	--	0.2
Aspen	0.2	--	--	--	--	0.2
Willow scrub	7.0	--	3.0	7.7	0.4	18.1
Mixed riparian	2.0	--	1.6	4.5	--	8.2
All types	9.4	--	4.6	12.9	0.4	27.2
Percent of total mapped	49%	--	47%	100%	34%	64%
Slight response						
Conifer-broadleaf	--	--	--	--	--	--
Cottonwood-willow	--	--	--	--	--	--
Aspen	0.2	--	0.9	--	--	1.1
Willow scrub	4.6	--	2.2	--	0.8	7.6
Mixed riparian	4.6	0.1	1.7	--	--	6.4
All types	9.4	0.1	4.9	--	0.8	15.2
Percent of total mapped	49%	102%	50%	--	68%	35%
Moderate response						
Conifer-broadleaf	--	--	--	--	--	--
Cottonwood-willow	--	--	--	--	--	--
Aspen	--	--	--	--	--	--
Willow scrub	0.2	--	0.3	--	--	0.5
Mixed riparian	--	--	--	--	--	--
All types	0.2	--	0.3	--	--	0.5
Percent of total mapped	1%	--	3%	--	--	1%
Strong response						
All types	--	--	--	--	--	--
Percent of total mapped	--	--	--	--	--	--

Notes: See Appendix F for explanation of response categories.

Reach 1 = diversion to Cain Ranch Road, main (south) channel.
Reach 2 = Cain Ranch Road to U.S. 395, main (south) channel.
Reach 3 = U.S. 395 to Rush Creek.
Reach 4 = diversion to Cain Ranch Road, secondary (north) channel.
Reach 5 = Cain Ranch Road to U.S. 395, secondary (north) channel.

Percentages may not total 100% because of rounding error.

Acreages measured by Jones & Stokes Associates from interpretation of 1929-1930, 1940, and 1990 aerial photographs and 1990-1991 field surveys.

Table P-12. Responses to Rewatering Observed in Mature Woody Riparian Vegetation on Lee Vining Creek in 1990-1991

Response Level/ Vegetation Type	Reach Number 1a	1b	2a	2b	3a	3b	3c	3d	All Reaches
No response									
Conifer-broadleaf	0.4	–	–	–	–	–	–	–	0.4
Cottonwood-willow	0.3	–	–	0.2	2.8	–	–	–	3.3
Aspen	0.1	–	–	2.2	–	0.8	–	–	3.1
Willow scrub	1.5	–	–	0.1	0.1	–	–	3.0	4.7
Mixed riparian	–	–	–	0.2	1.5	1.2	0.3	–	3.2
All types	2.3	–	–	2.7	4.4	2.0	0.3	3.0	14.6
Percent of total mapped	13%	–	–	25%	67%	56%	24%	63%	24%
Slight response									
Conifer-broadleaf	11.5	1.1	11.9	–	–	–	–	–	24.5
Cottonwood-willow	0.2	–	–	0.3	0.5	0.4	0.5	–	1.9
Aspen	–	0.7	–	–	–	–	–	–	0.7
Willow scrub	4.0	–	–	–	–	–	0.1	1.3	5.4
Mixed riparian	–	–	–	0.2	0.3	0.8	0.1	–	1.4
All types	15.7	1.8	11.9	0.5	0.8	1.2	0.7	1.3	33.9
Percent of total mapped	87%	100%	89%	5%	12%	35%	60%	27%	56%
Moderate response									
Conifer-broadleaf	–	–	–	2.9	–	–	–	–	2.9
Cottonwood-willow	–	–	1.5	2.8	0.3	0.1	–	–	4.7
Aspen	–	–	–	1.8	–	–	–	–	1.8
Willow scrub	–	–	–	–	–	–	–	0.1	0.1
Mixed riparian	–	–	–	0.3	1.1	0.2	–	–	1.6
All types	–	–	1.5	7.7	1.4	0.3	–	0.1	11.1
Percent of total mapped	–	–	11%	71%	22%	8%	–	2%	18%
Strong response									
Conifer-broadleaf	–	–	–	–	–	–	–	–	–
Cottonwood-willow	–	–	–	–	–	–	–	–	–
Aspen	–	–	–	–	–	–	–	–	–
Willow scrub	–	–	–	–	–	–	0.1	0.4	0.5
Mixed riparian	–	–	–	–	–	–	–	–	–
All types	–	–	–	–	–	–	0.1	0.4	0.5
Percent loss or gain	–	–	–	–	–	–	8%	8%	1%

Notes: See Appendix F for explanation of response categories.

Reach 1a = diversion to ranger station bridge.
Reach 1b = ranger station bridge to Highway 120.
Reach 2a = Highway 120 to U.S. 395.
Reach 2b = U.S. 395 to bottom of 1989 vegetation.
Reach 3a = bottom of 1989 vegetation to big bend.
Reach 3b = big bend to County Road.
Reach 3c = County Road to 1940 lakeshore.
Reach 3d = 1940 lakeshore to 1989 lakeshore.

Percentages may not total 100% because of rounding error.
Acreages measured by Jones & Stokes Associates from interpretation of 1929-1930, 1940, and 1990 aerial photographs and 1990-1991 field surveys.

Table P-13. Summary of Riparian Widths Predicted by Taylor's Model

Stream and Reach	Predicted Flows (cfs) and Widths (m)							Actual Widths (m)	
	No-Restriction Alternative	6,372-Ft Alternative	6,377-Ft Alternative	6,383.5-Ft Alternative	6,390-Ft Alternative	6,410-Ft Alternative	No-Diversion Alternative	Prediversion (1940)	POR (1989)
Rush Creek flow	25.3	38.4	48.2	60.0	69.1	84.8	84.5		
Reach 3 width	70	106	126	141	NM	NM	NM	64	46
Reaches 4-5 width	71	107	127	142	NM	NM	NM	42	21
Reaches 6-7 width	75	112	131	146	NM	NM	NM	162	109
Reach 8 width	74	110	130	145	NM	NM	NM	165	82
Parker Creek flow	0.0	7.2	7.9	7.9	7.9	7.9	12.6		
Reach 1 width	-36	-2	1	1	1	1	21	27	27
Reach 2 width	-28	6	9	9	9	9	29	44	42
Reach 3 width	-37	-3	0	0	0	0	20	10	10
Reach 4 width	-37	-3	0	0	0	0	20	25	10
Walker Creek flow	0.0	3.1	3.7	3.7	3.7	3.7	7.5		
Reaches 1 and 4 width	-31	-16	-13	-13	-13	-13	4	34	36
Reaches 2 and 5 width	-27	-12	-9	-9	-9	-9	8	13	0
Reach 3 width	-32	-17	-15	-15	-15	-15	3	31	28
Lee Vining Creek flow	19.0	35.8	42.3	48.6	51.8	62.0	67.0		
Reach 2b width	49	101	116	128	132	143	NM	88	73
Reach 3a width	49	101	116	128	133	144	NM	98	22
Reach 3b width	53	105	120	131	136	147	NM	165	53
Reaches 3c-d width	56	108	123	135	140	151	NM	90	113

Notes: Streamflow predictions (cfs) are based on LAAMP model results for EIR alternatives. Flows under the No-Restriction Alternative are actually 0 cfs throughout most years. The flow used here is an average of infrequent large spilling flows.
Riparian width predictions (m) are averages of model results for several points in each reach.
NM indicates "not modeled" for predicted flows that exceed the calibration limits of the model (approximately 60 cfs).
Reaches not listed were not modeled because of geomorphology not appropriate for the assumptions of this model.
Prediversion and 1989 riparian widths were rounded to nearest 5 m from Jones & Stokes Associates' mapping.

Table P-14. Results of the Cottonwood Growth Models
for the EIR Alternatives

	Alternative						
	No-Restriction	6,372-Ft	6,377-Ft	6,383.5-Ft	6,390-Ft	6,410-Ft	No-Diversion
Rush Creek streamflows							
Mean annual cfs	25.3	38.4	48.2	60.0	69.1	84.8	84.5
Annual hm^3	28.3	43.0	54.0	67.2	77.4	95.0	94.6
Cottonwood radial growth rates (mm/yr)							
Site RC1c	2.3	2.5	2.6	2.8	2.9	3.2	3.1
Site RC2c	2.1	2.4	2.5	2.7	2.9	3.1	3.1
Site RC2f	1.2[a]	1.4[a]	1.5[b]	1.6[b]	1.7[b]	1.8[b]	1.8[b]
Lee Vining Creek streamflows							
Mean annual cfs	19.0	35.8	42.3	48.6	51.8	62.0	67.0
Annual hm^3	21.3	40.1	47.4	54.4	58.0	69.4	75.0
Cottonwood radial growth rates (mm/yr)							
Site LV0f	0.8[a]	0.9[a]	1.0[a]	1.0[a]	1.1[a]	1.2[a]	1.3[a]
Site LV1c	3.4	3.6	3.8	3.9	4.0	4.2	4.3
Site LV2c	7.4	9.2	9.3	9.2	9.0	8.0	7.2
Site LV2f	2.1	2.4	2.5	2.6	2.6	2.7	2.7

[a] Radial growth <1.5 mm/year was associated with severe stress or tree death.

[b] Radial growth from 1.5 to 2.0 mm/year was associated with low canopy vigor.

Notes: Streamflow predictions (cfs) are based on LAAMP model results for EIR alternatives. Flows under the No-Restriction Alternative are actually 0 cfs throughout most years. The flows used here are averages of infrequent large spilling flows.

The equations are nonlinear univariate equations developed by Stromberg and Patten (1992a, Table 6).

The equations for each site are:

Site RC1c	$(0.0146*flow)-((1.16*10^{-5})*flow^2)+1.87$
Site RC2c	$(0.0218*flow)-((5.68*10^{-5})*flow^2)+1.53$
Site RC2f	$(0.0101*flow)-((1.4*10^{15})*flow^2)+0.97$
Site LV0f	$((-1.99*10^{-4})*flow)+((1.03*10^{-4})*flow^2)+0.74$
Site LV1c	$((8.35*10^{-3})*flow)+((9.86*10^{-5})*flow^2)+3.15$
Site LV2c	$(0.264*flow)-((2.78*10^{-3})*flow^2)+3.08$
Site LV2f	$(0.0285*flow)-((1.71*10^{-4})*flow^2)+1.53$

Radial growth >2.0 mm/year was associated with high canopy vigor.

Table P-15. Estimated Water Table Slopes for Groundwater Model Use

Reach	Water Table Slope	Comments
Parker and Walker Creeks		
Upper reaches	2.5%	Piezometers indicated 2.0% for Parker Creek and 3.1% for Walker Creek; synoptic flows show similar total losses; alluvial fan, delta deposits
Delta-canyon reaches	Same	Can omit; steep topographic sections provide little habitat differences among alternatives
Rush Creek		
Above upper canyon	1.0%	Glacial till; assume intermediate permeability
Upper canyon	Omit	Narrow defile; may be gaining
Upper canyon to near old U.S. 395	1.5%	Xeric conditions in adjacent topographic lows require slope of at least this value
Near old U.S. 395 to quarries	1.7%[a]	Synoptic flows show high loss rate
Quarries to The Narrows	0.5%	Synoptic flows show low loss rate
The Narrows to culvert crossing	0.1%	Maximum slope inferred from piezometer observations; synoptic flows indicate slowly losing reach
Culvert crossing to 1,000 feet below County Road	1.0%[a]	Synoptic flows show moderate to high loss rate; loss associated with pyroclastic landslide deposit
1,000 feet below County Road to lake	0.1%	Similar to general bottomlands
Lee Vining Creek		
Above U.S. 395 reach	Omit	Synoptic flows indicate gaining
Below U.S. 395	0.1%	Losing reach; assume same as Rush Creek bottomlands

[a] Slope estimated using D'Arcy's law from bottomlands observed slope and ratio of synoptic flow losses.

Table P-16. Stream Stage-Discharge Factors Used in the Groundwater Model

Reach	Flow at Time of Mapping (cfs)	Evaluation Flows: Low Flow (cfs)	Stage[a] (ft)	High Flow (cfs)	Stage[a] (ft)
Parker Creek					
Middle reach[b]	4.5	9	+0.23	26	+0.84
Upper and lower reaches	4.5	9	+0.21	26	+0.71
Walker Creek					
Upper reach[c]	2.75	4	+0.07	10.6	+0.32
Lower reach	2.75	4	+0.10	10.6	+0.44
Rush Creek					
Most	24	19	-0.05	106	+0.62
Lower bottomlands	24	19	-0.05	106	+0.74
Lee Vining Creek					
Below U.S. 395	29.9	5	-0.43	85	+0.39

[a] Stage above or below stage during aerial photography for contour mapping.

[b] 6,990-foot elevation to 6,874-foot elevation.

[c] Diversion to 6,874-foot elevation.

Table P-17. Assumptions for Estimating Extent of Riparian Habitats from the Water Table Model by Reach for the Alternatives

	Reach									
	1a	2a	2b	3	4	5	6	7	8	Total
Rush Creek										
Prediversion extent (acres)										
Woody riparian	6.3	9.3	9.2	25.7	11.4	22.0	149.5	30.3	7.5	271.2
Meadow and wetland	0.0	0.0	7.7	2.0	0.7	0.0	89.3	7.1	24.4	131.2
Point-of-reference extent (acres)										
Woody riparian	1.6	6.0	6.2	13.8	5.6	4.0	97.5	11.5	26.7	172.9
Meadow and wetland	0.0	0.0	5.6	2.9	0.1	0.0	31.2	0.0	0.0	39.8
Extent of shallow groundwater (acres)	1.3	?	?	30.2	16.5	14.6	172.5	15.9	28.3	–
Point-of-reference scenario extent (acres)										
Woody riparian	3.0	6.0	6.2	25.7	11.4	14.6	130.7	15.9	28.3	241.7
Meadow and wetland	0.0	0.0	5.6	2.0	0.7	0.0	41.8	0.0	0.0	50.1
Percent increase from point-of-reference scenario										
6,372-Ft Alternative	2.8	0.0	0.0	1.3	1.3	1.9	1.2	1.4	0.2	–
6,377-Ft Alternative	2.8	0.0	0.0	1.3	1.3	1.9	1.2	1.4	0.2	–
6,383.5-Ft Alternative	6.4	0.0	0.0	3.0	2.9	4.4	2.8	3.3	0.4	–
6,390-Ft Alternative	11.8	0.0	0.0	5.6	5.4	8.0	5.1	6.1	0.8	–
6,410-Ft Alternative	16.0	0.0	0.0	6.5	7.2	11.0	6.8	8.3	1.0	–
No-Diversion Alternative	12.7	0.0	0.0	6.0	5.8	8.7	5.5	6.6	0.8	–

	1a	1b	2a	2b	3a	3b	3c	Total
Lee Vining Creek								
Prediversion extent (acres)								
Woody riparian	18.2	2.1	15.0	14.9	23.2	34.7	4.3	112.4
Meadow and wetland	21.6	0.0	0.0	0.0	0.0	12.8	9.2	43.6
Point-of-reference extent (acres)								
Woody riparian	18.2	1.8	13.4	10.9	6.9	7.5	11.9	70.6
Meadow and wetland	21.2	0.0	0.0	0.2	1.3	4.7	5.1	32.5
Extent of shallow groundwater (acres)	?	?	?	8.0	22.3	32.1	22.8	–
Point-of-reference scenario extent (acres)								
Woody riparian	18.2	1.8	13.4	10.9	21.0	27.4	17.7	110.4
Meadow and wetland	21.2	0.0	0.0	0.2	1.3	4.7	5.1	32.5

Table P-17. Continued

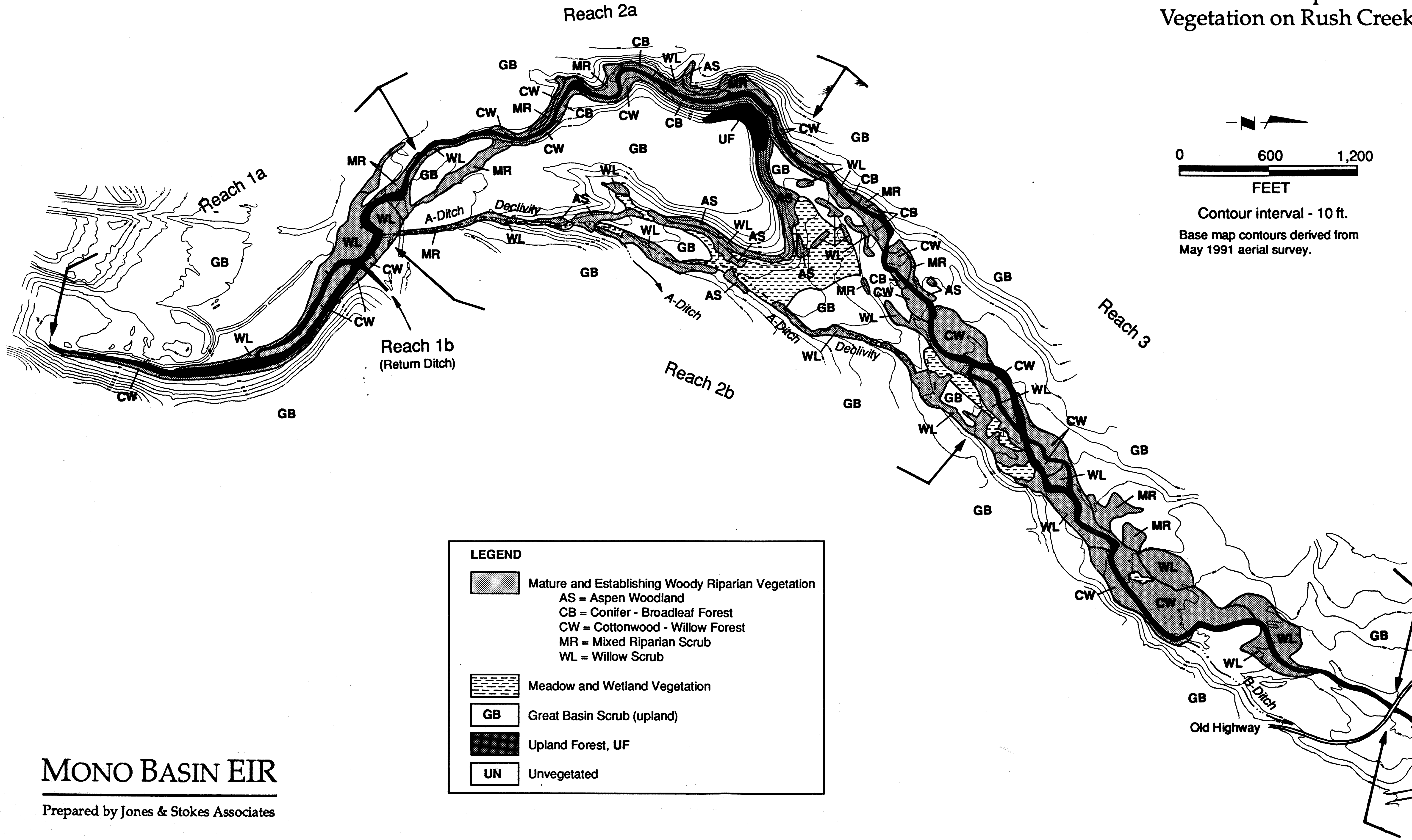
Percent increase from point-of-reference scenario								
6,372-Ft Alternative	?	?	?	7.5	6.0	5.2	5.3	–
6,377-Ft Alternative	?	?	?	7.5	6.0	5.2	5.3	–
6,383.5-Ft Alternative	?	?	?	7.7	6.1	5.3	5.4	–
6,390-Ft Alternative	?	?	?	10.7	8.5	7.3	7.5	–
6,410-Ft Alternative	?	?	?	18.2	14.4	12.5	12.8	–
No-Diversion Alternative	?	?	?	18.2	14.4	12.5	12.8	–

	1	2	3	4	Total
Parker Creek (Woody Riparian Only)					
Prediversion extent (acres)	14.5	35.4	2.5	5.9	58.3
Point-of-reference extent (acres)	15.2	31.3	0.5	2.2	49.2
Extent of shallow groundwater (acres)	6.6	40.1	5.0	5.1	56.8
Point-of-reference scenario extent (acres)	15.2	31.3	5.0	5.1	56.6
Extent of alternatives (acres)					
6,372-Ft Alternative	15.2	31.3	5.0	5.1	56.6
Other target lake level alternatives	15.7	32.2	5.1	5.2	58.2
No-Diversion Alternative	16.1	33.1	5.5	5.6	60.3

	1	2	3	4	5	Total
Walker Creek (Woody Riparian Only)						
Prediversion extent (acres)	19.4	0.9	11.4	15.2	2.8	49.7
Point-of-reference extent (acres)	19.0	0.1	9.8	12.9	1.2	43.0
Extent of shallow groundwater (acres)	27.9	5.2	7.0	?	?	–
Point-of-reference scenario extent (acres)	27.9	5.2	11.4	0.0	0.0	44.5
Extent of alternatives (acres)						
Most alternatives	27.9	5.2	11.4	0.0	0.0	44.5
No-Diversion Alternative	30.9	5.8	12.5	0.0	0.0	49.2

? = unknown.

Figure P-1a. Prediversion Riparian Vegetation on Rush Creek



MONO BASIN EIR

Prepared by Jones & Stokes Associates

Figure P-1b.
Prediversion Riparian Vegetation on Rush Creek

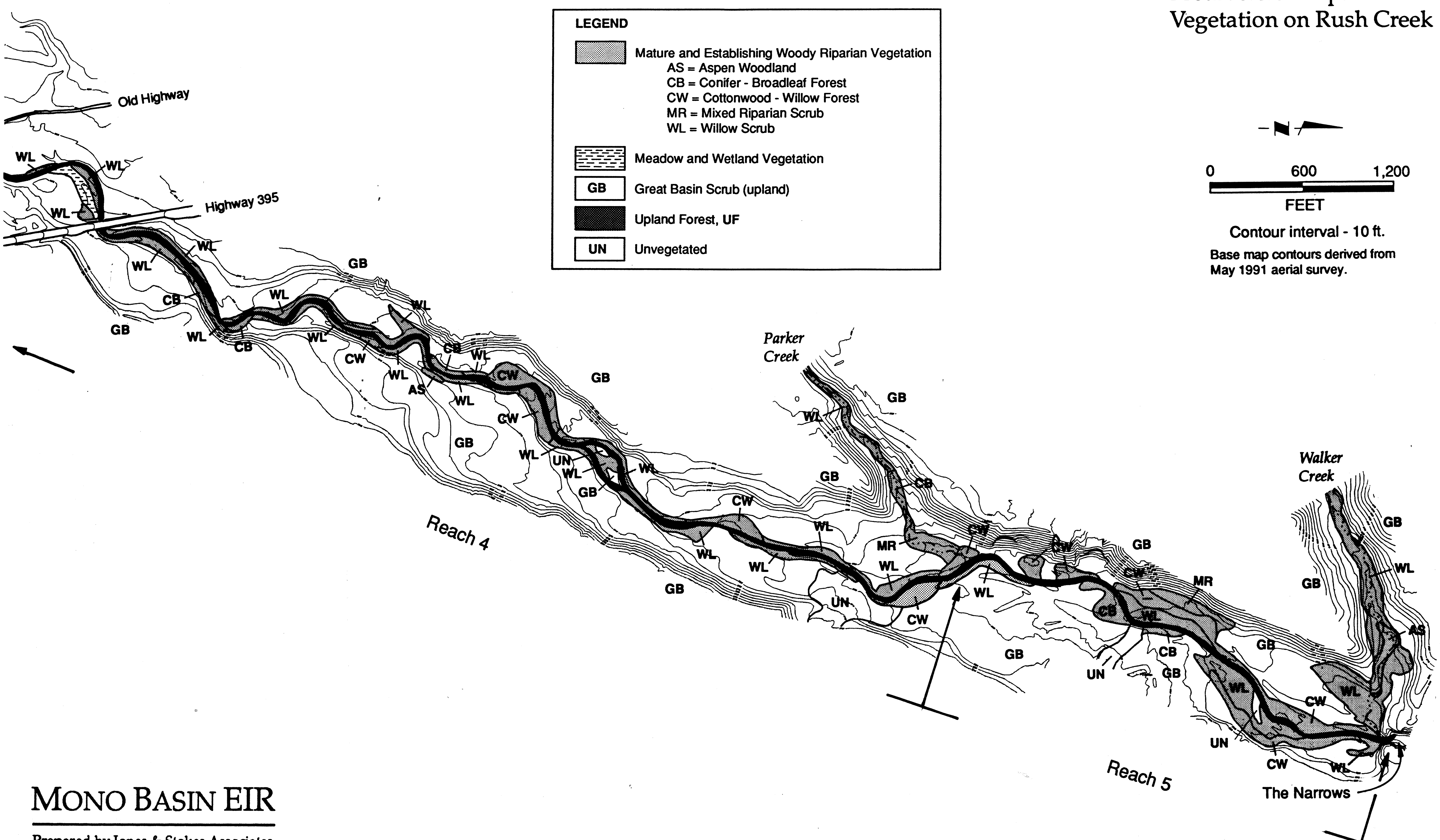
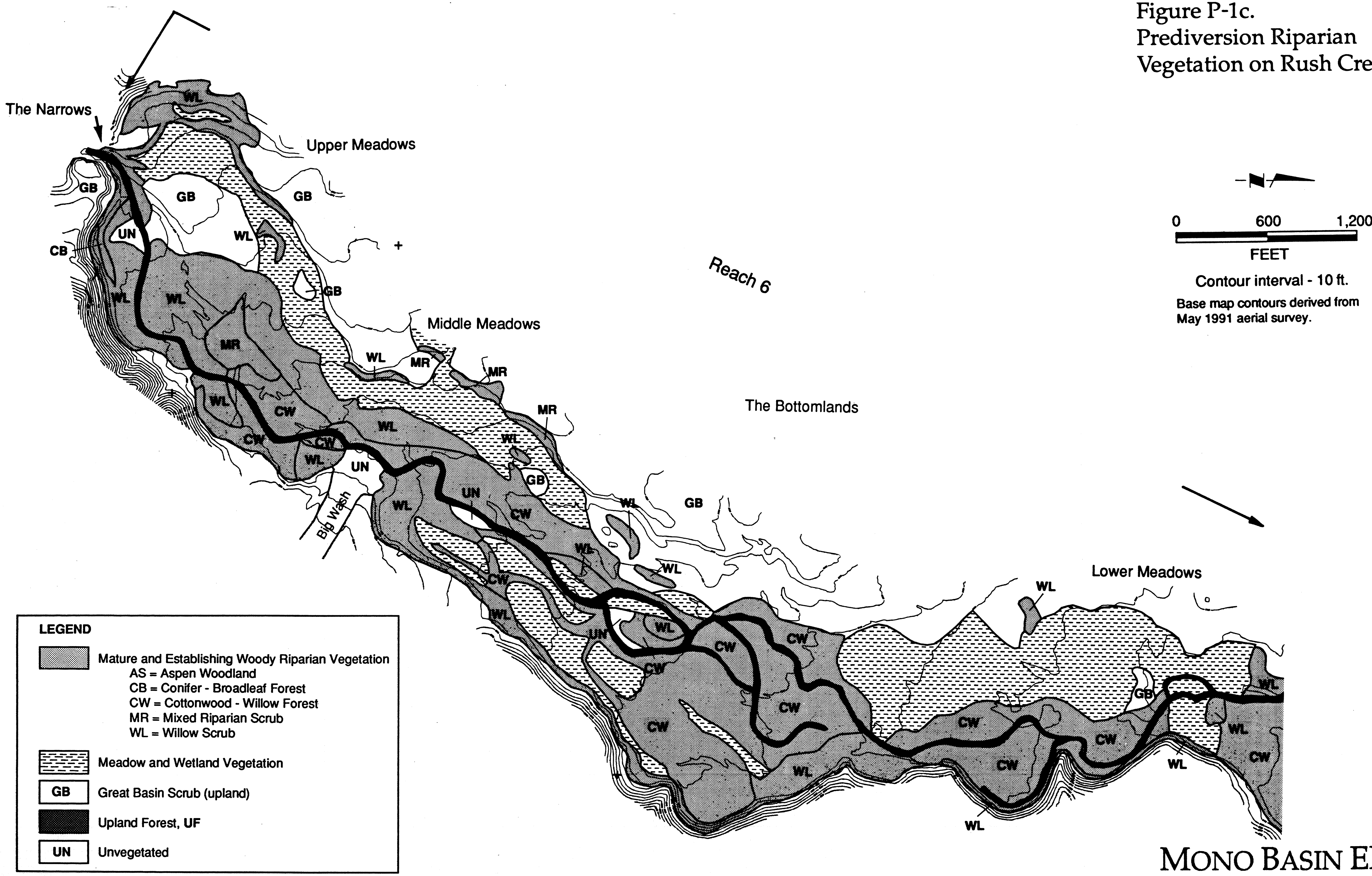


Figure P-1c.
Prediversion Riparian
Vegetation on Rush Creek



MONO BASIN EIR

Prepared by Jones & Stokes Associates

Figure P-1d. Prediversion Riparian Vegetation on Rush Creek

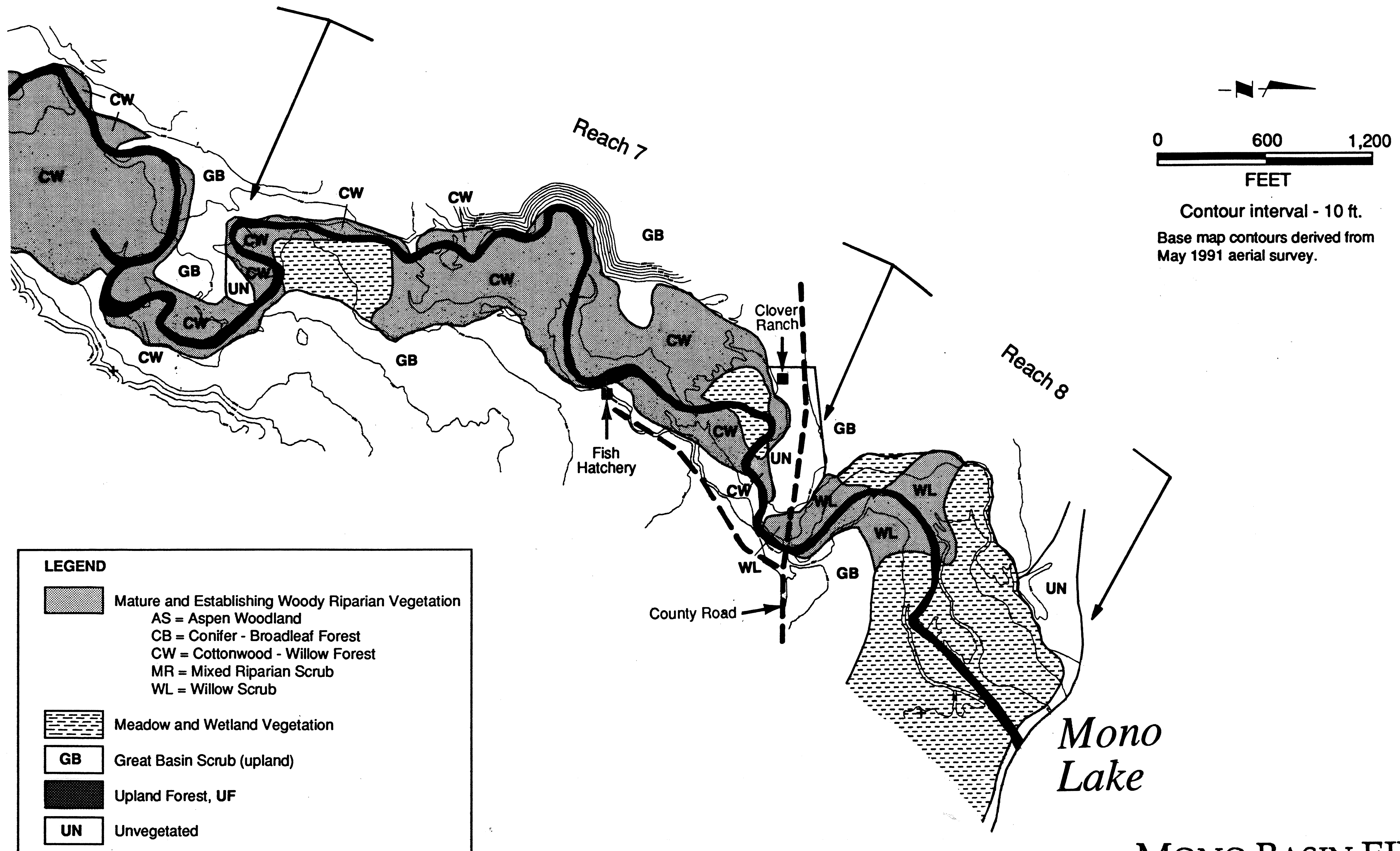
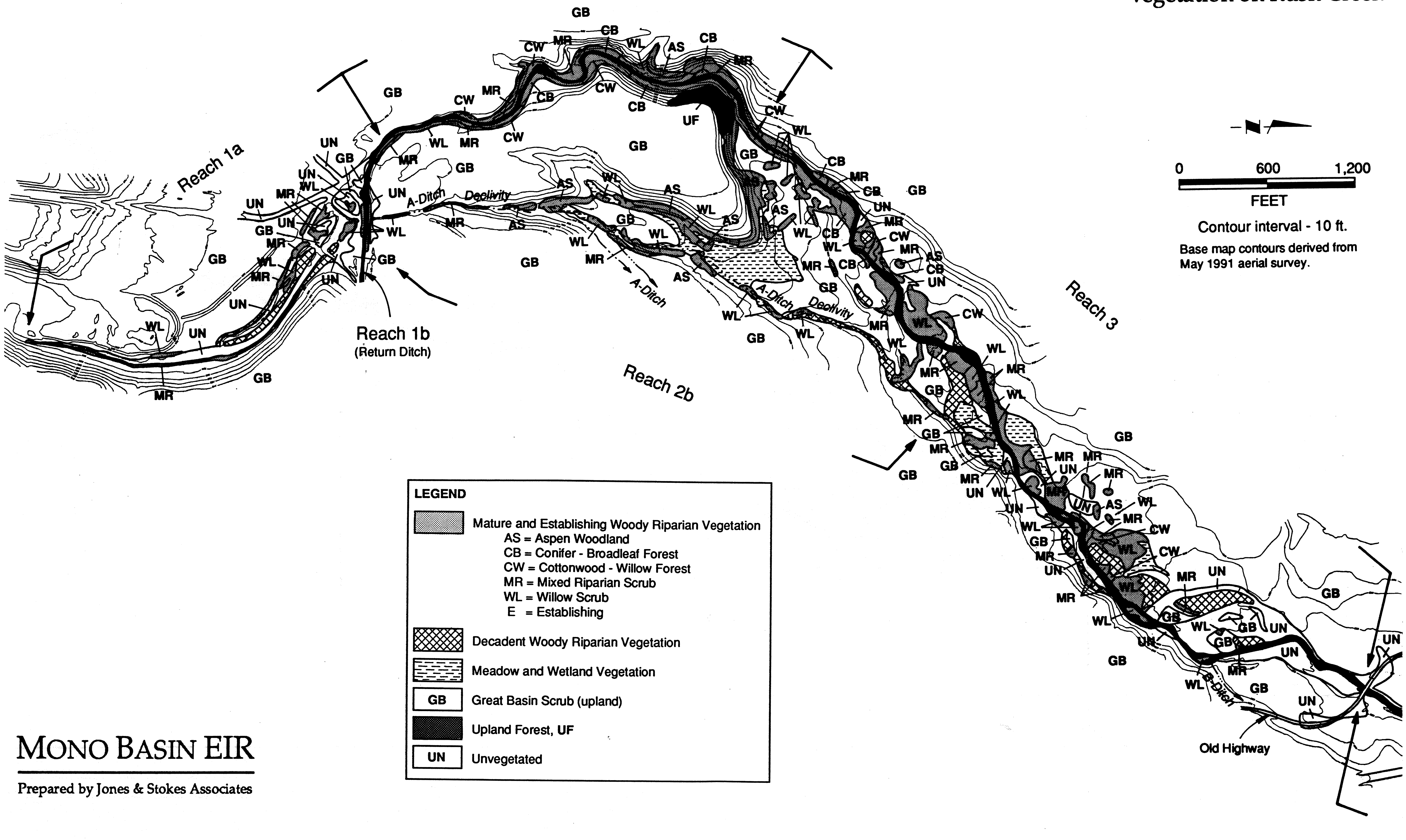


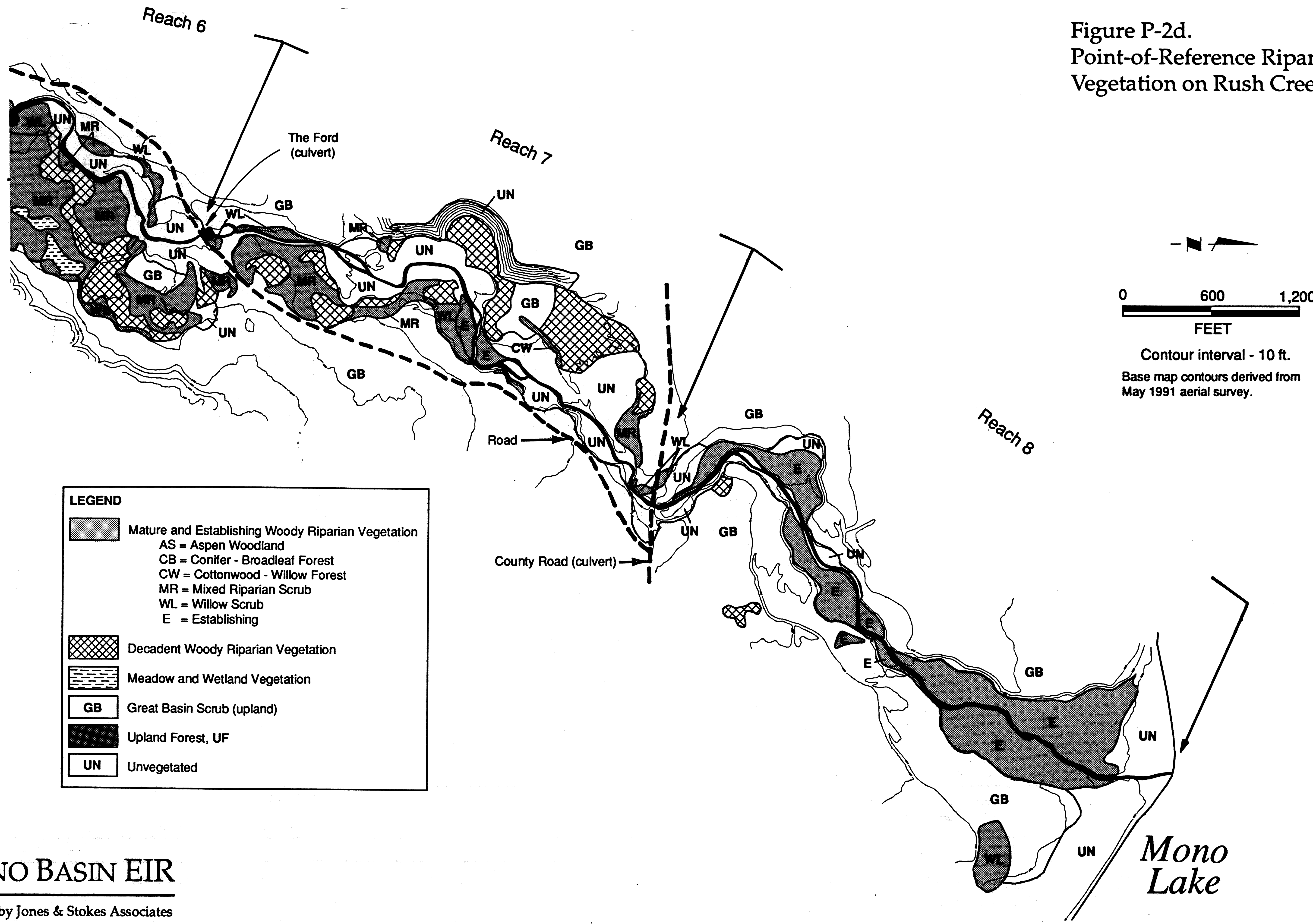
Figure P-2a. Point-of-Reference Riparian Vegetation on Rush Creek



MONO BASIN EIR

Prepared by Jones & Stokes Associates

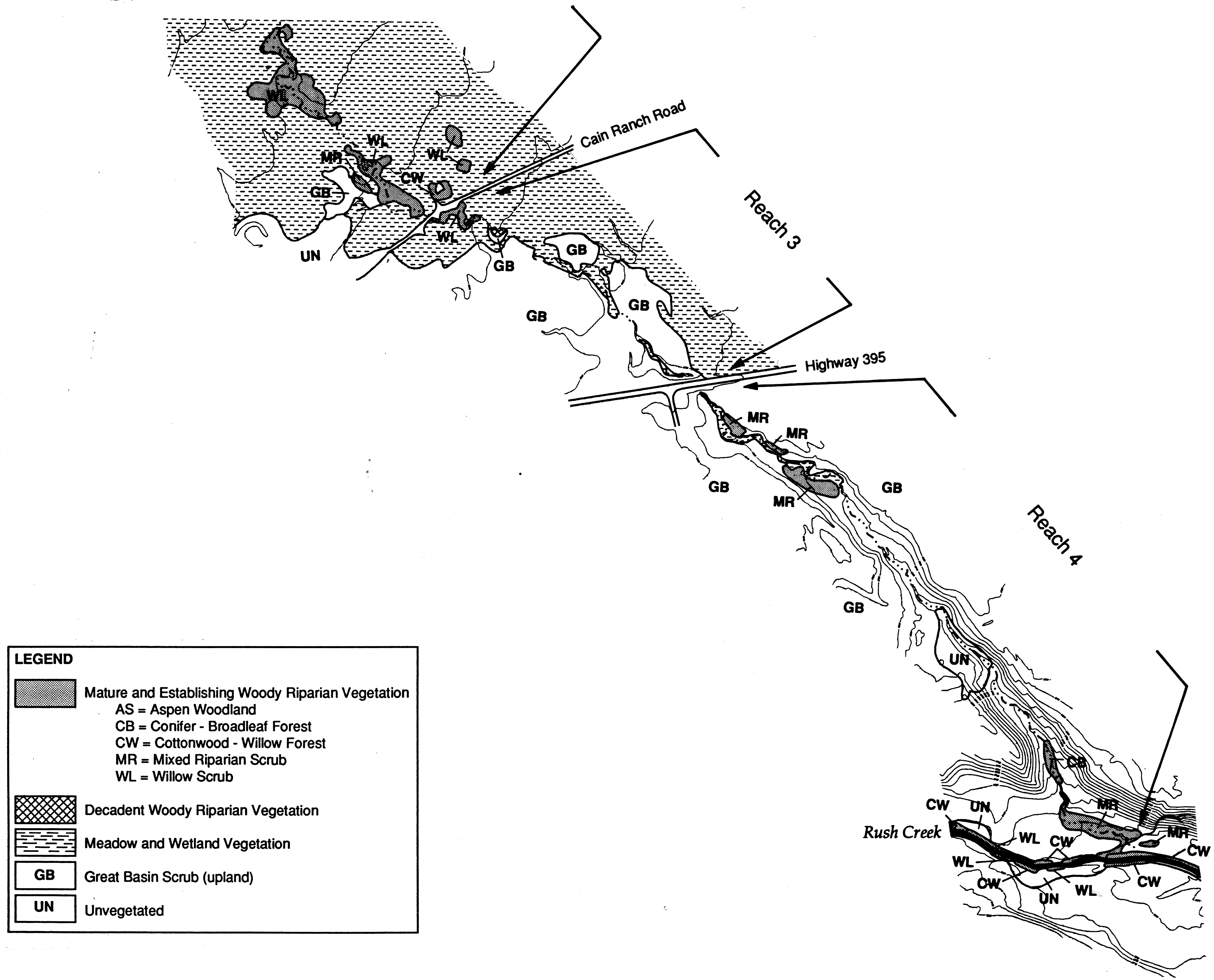
Figure P-2d.
Point-of-Reference Riparian Vegetation on Rush Creek



MONO BASIN EIR

Prepared by Jones & Stokes Associates

Figure P-4b.
Point-of-Reference Riparian Vegetation on Parker Creek



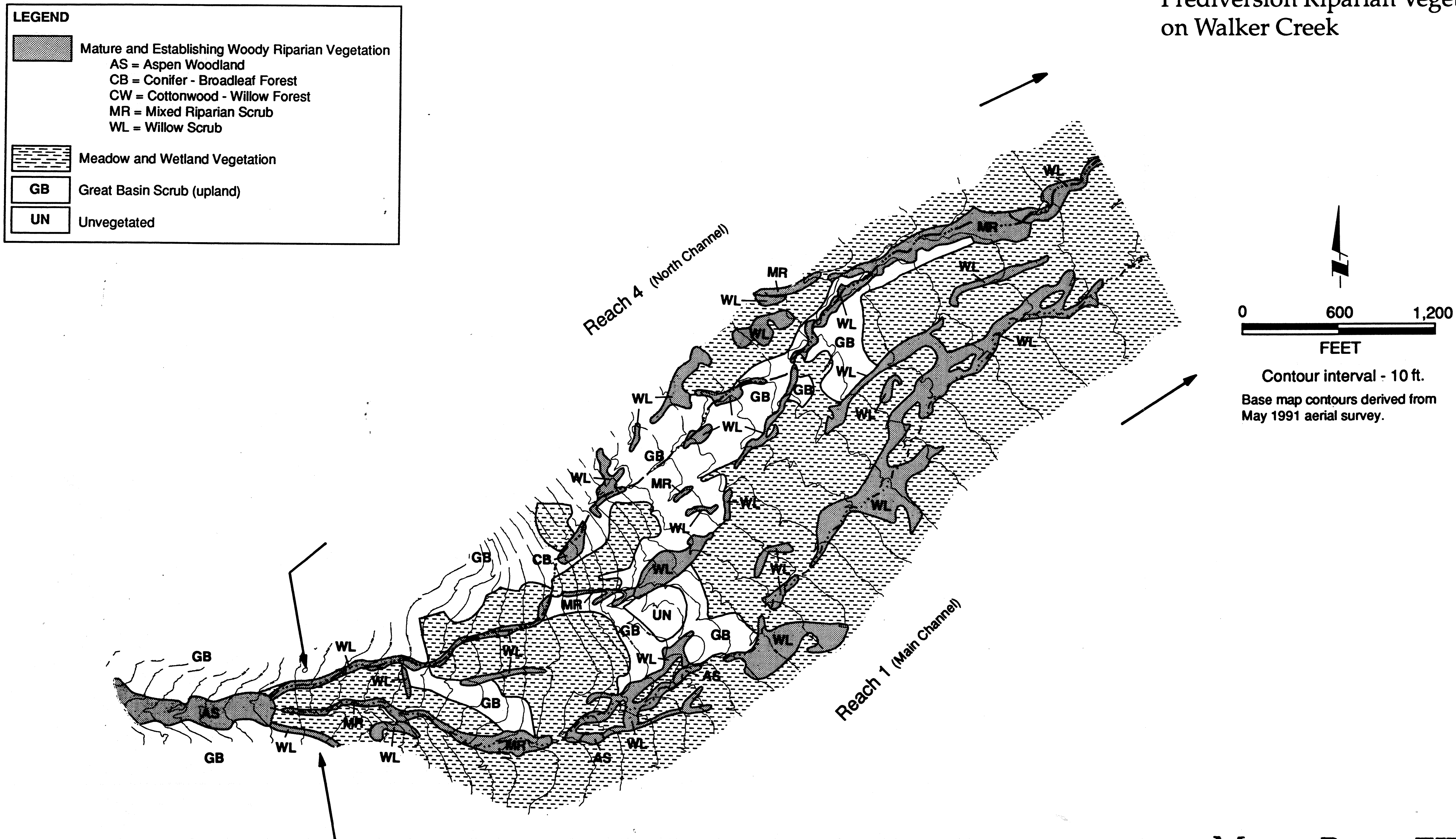
Contour interval - 10 ft.

Base map contours derived from May 1991 aerial survey.

MONO BASIN EIR

Prepared by Jones & Stokes Associates

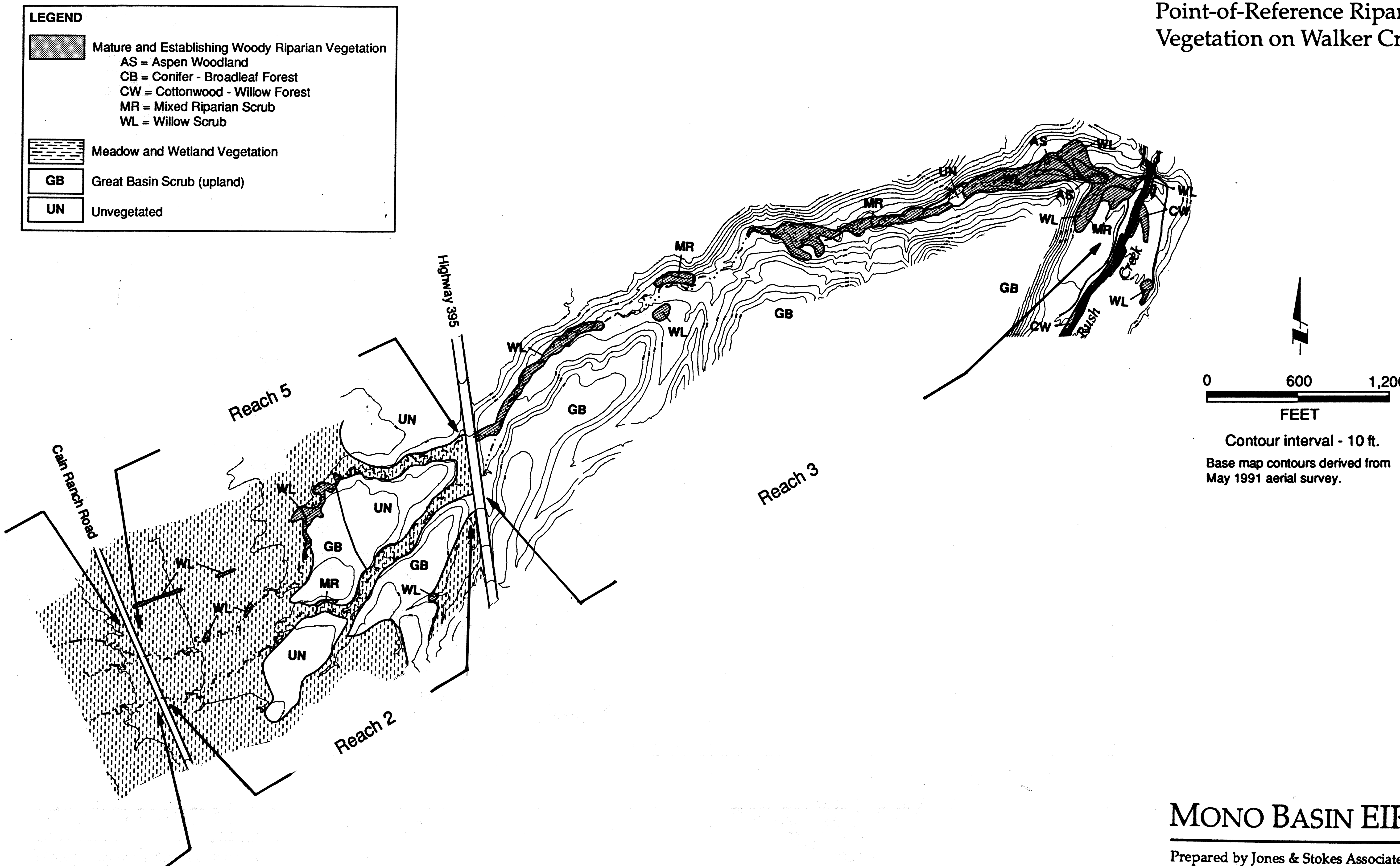
Figure P-5a.
Prediversion Riparian Vegetation
on Walker Creek



MONO BASIN EIR

Prepared by Jones & Stokes Associates

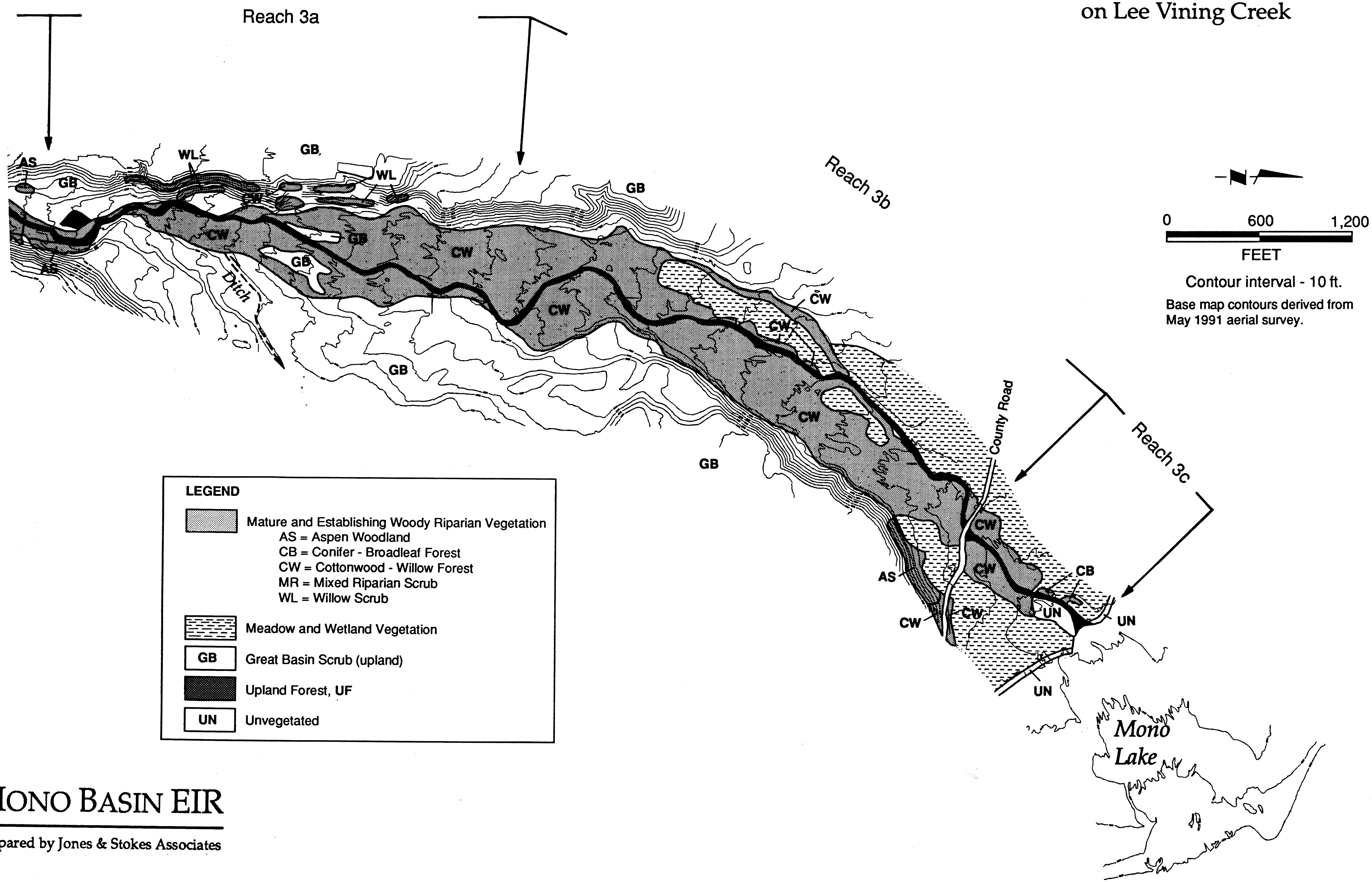
Figure P-6b.
Point-of-Reference Riparian Vegetation on Walker Creek



MONO BASIN EIR

Prepared by Jones & Stokes Associates

Figure P-7b.
Prediversion Riparian Vegetation
on Lee Vining Creek



MONO BASIN EIR

Prepared by Jones & Stokes Associates

Figure P-8a.
Point-of-Reference Riparian
Vegetation on Lee Vining Creek

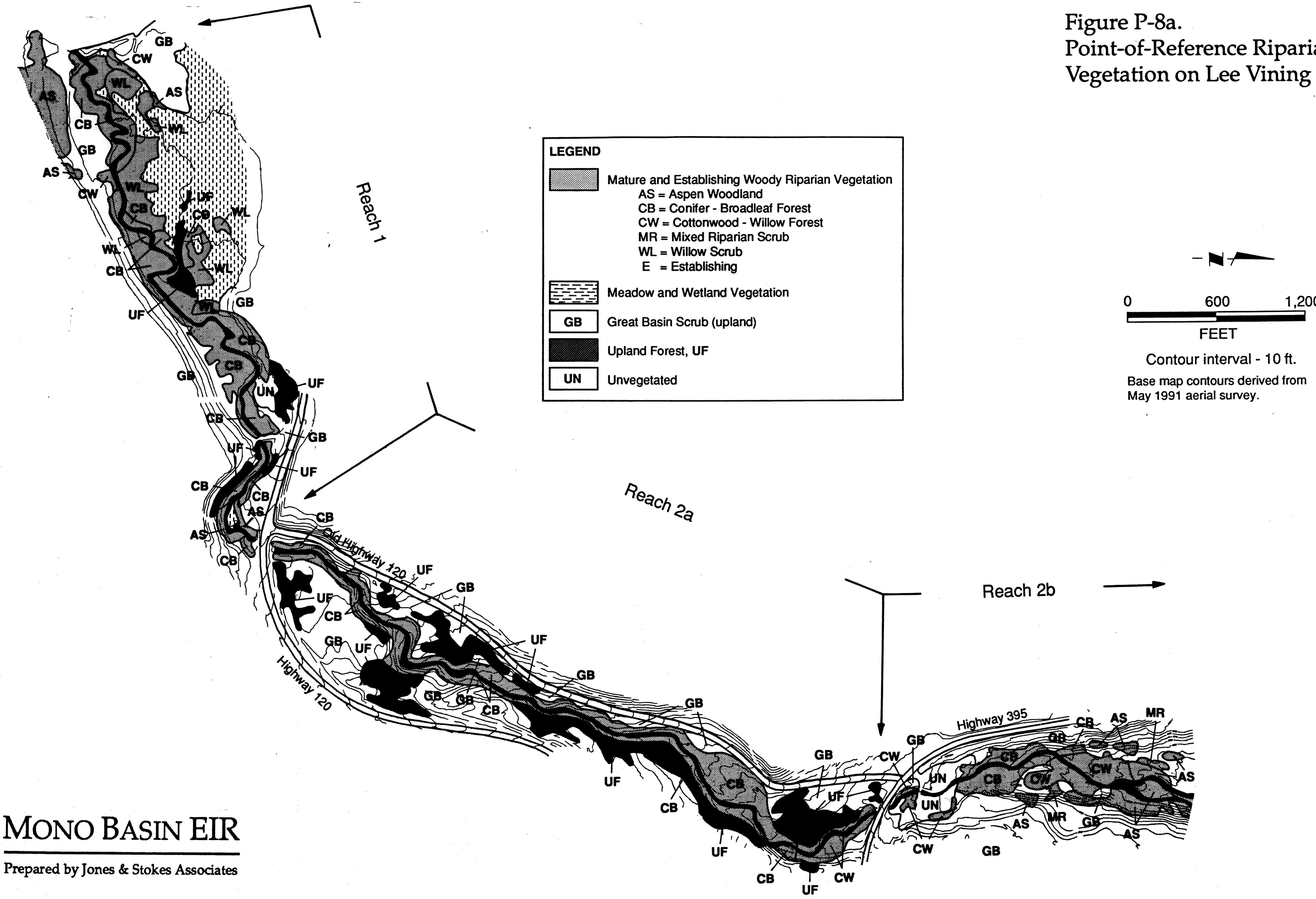
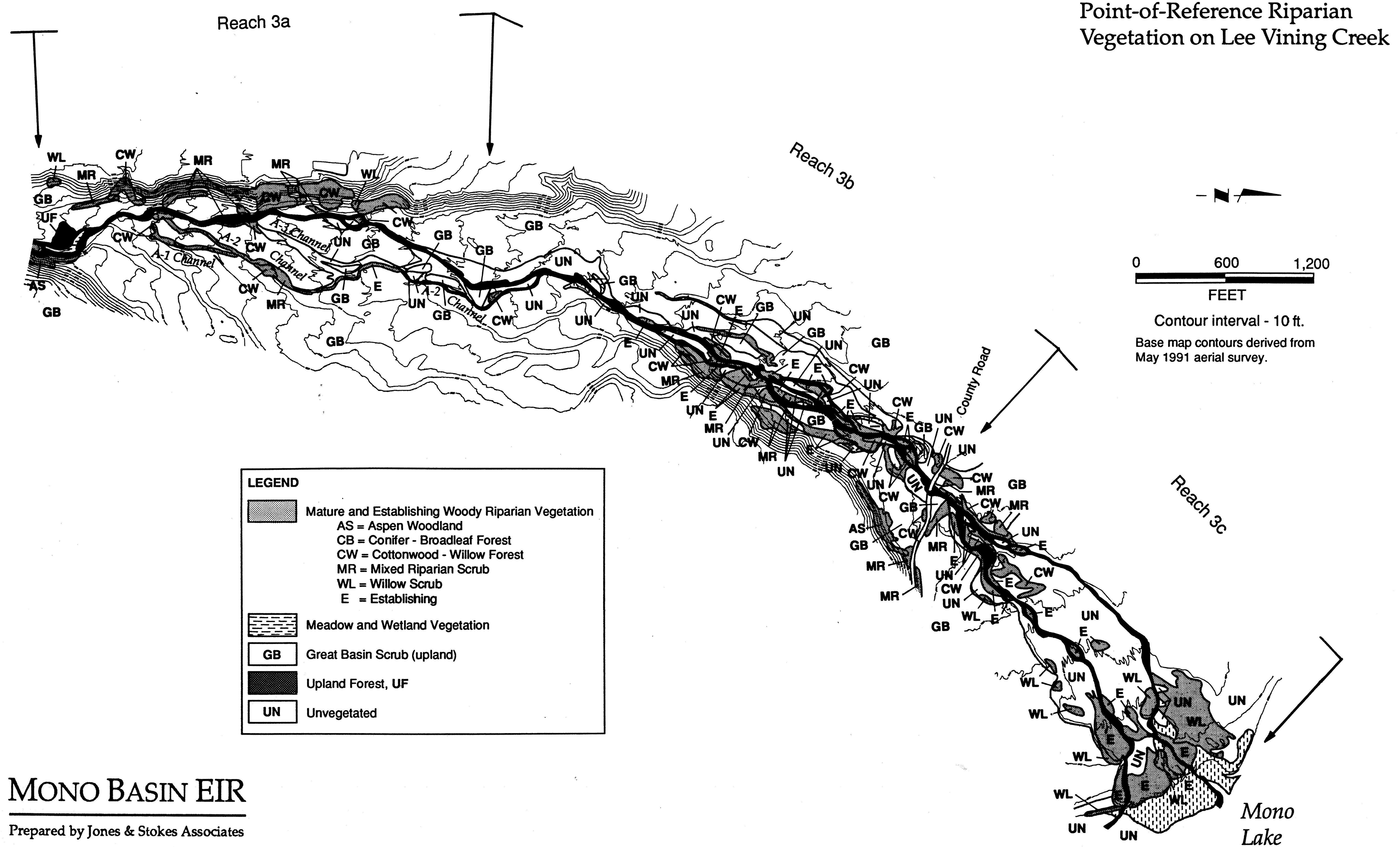
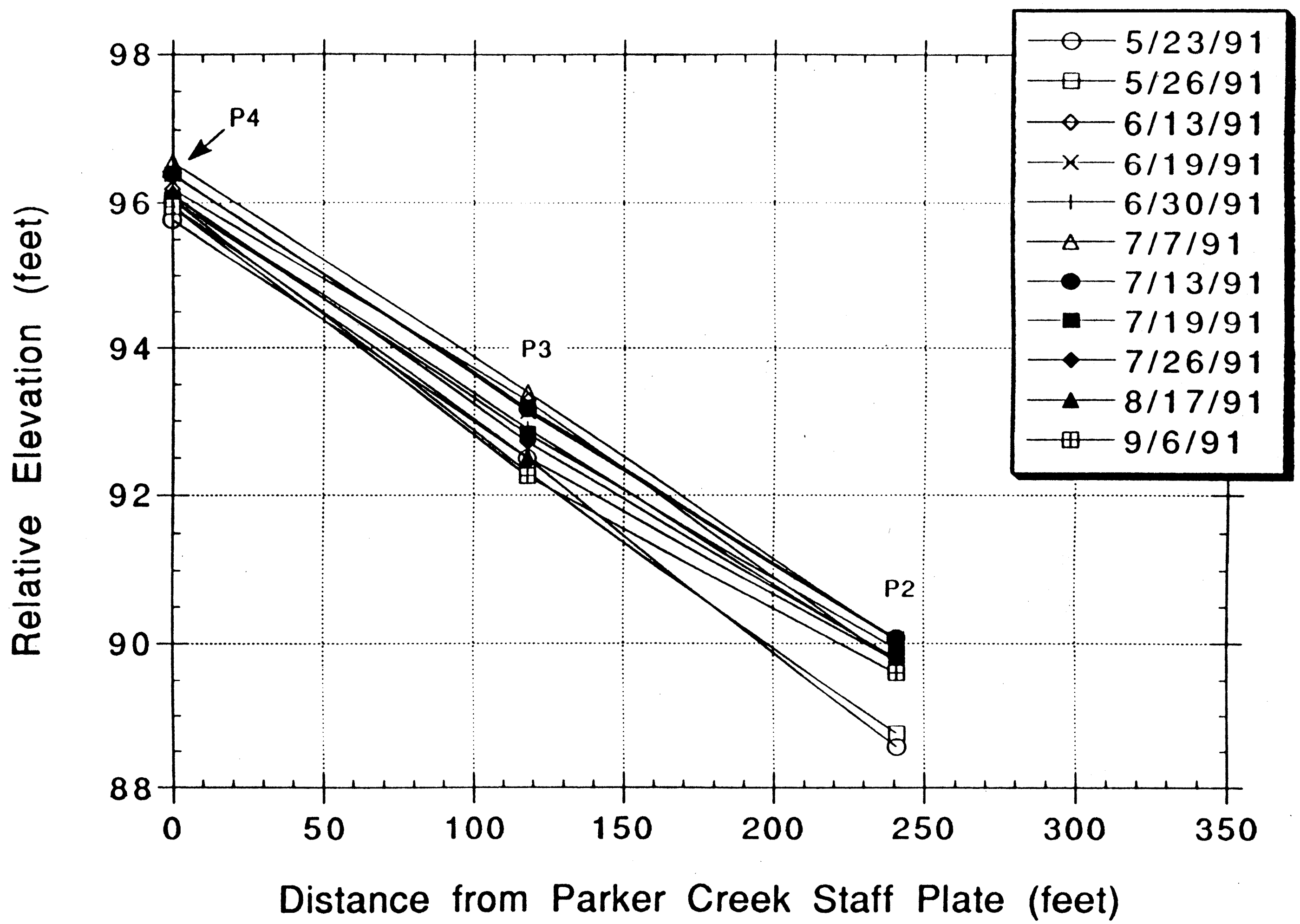


Figure P-8b.
Point-of-Reference Riparian
Vegetation on Lee Vining Creek



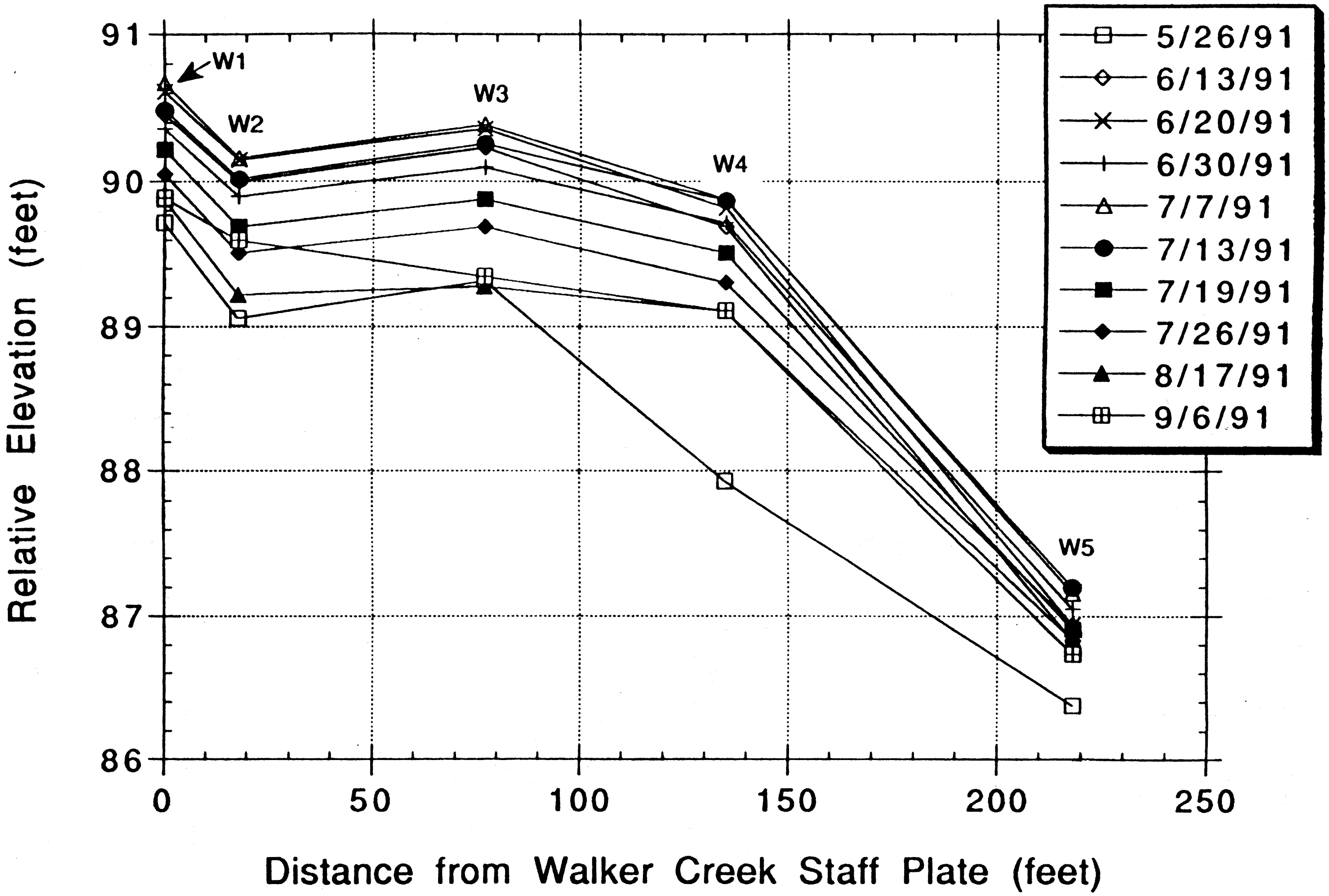
MONO BASIN EIR

Prepared by Jones & Stokes Associates



Source: Balance Hydrologics 1993

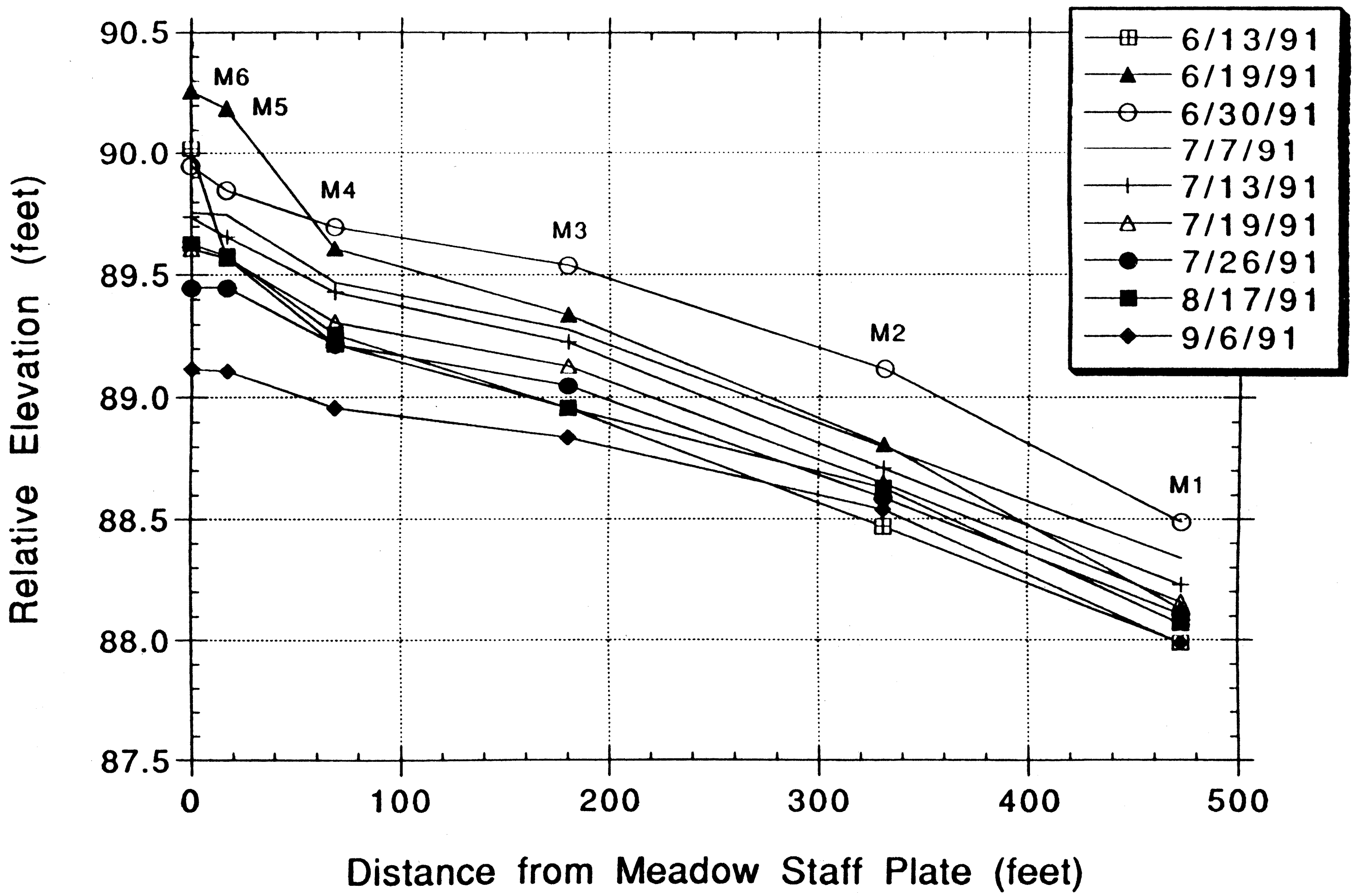
Figure P-9.
Groundwater Profiles at the Parker Creek Transect



Source: Balance Hydrologics 1993

Figure P-10.
Groundwater Profiles at the Walker Creek Transect

MONO BASIN EIR
Prepared by Jones & Stokes Associates

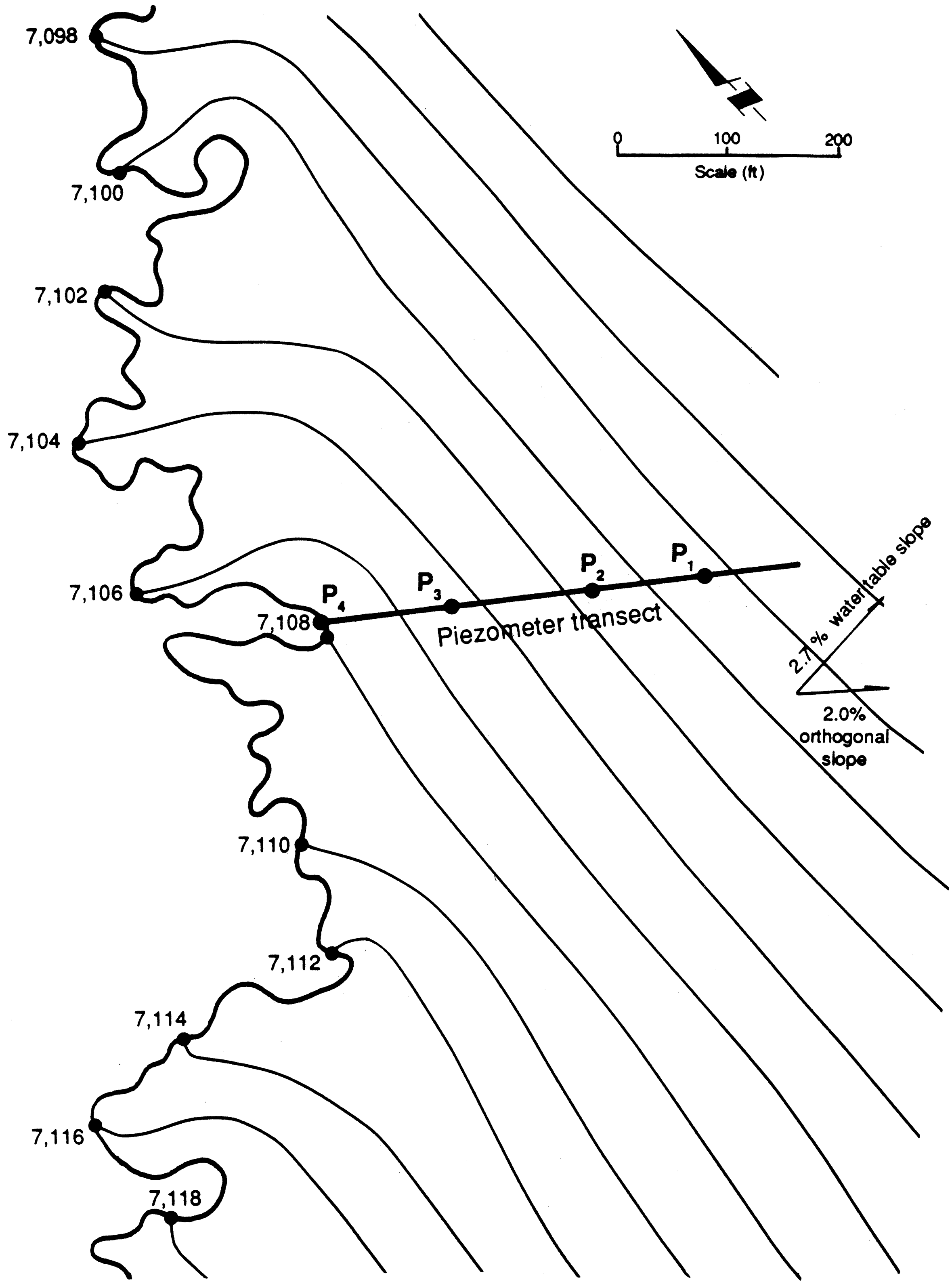


Source: Balance Hydrologics 1993

Figure P-11.
Groundwater Profiles at the Rush Creek Bottomlands
"Meadow" Transect

MONO BASIN EIR

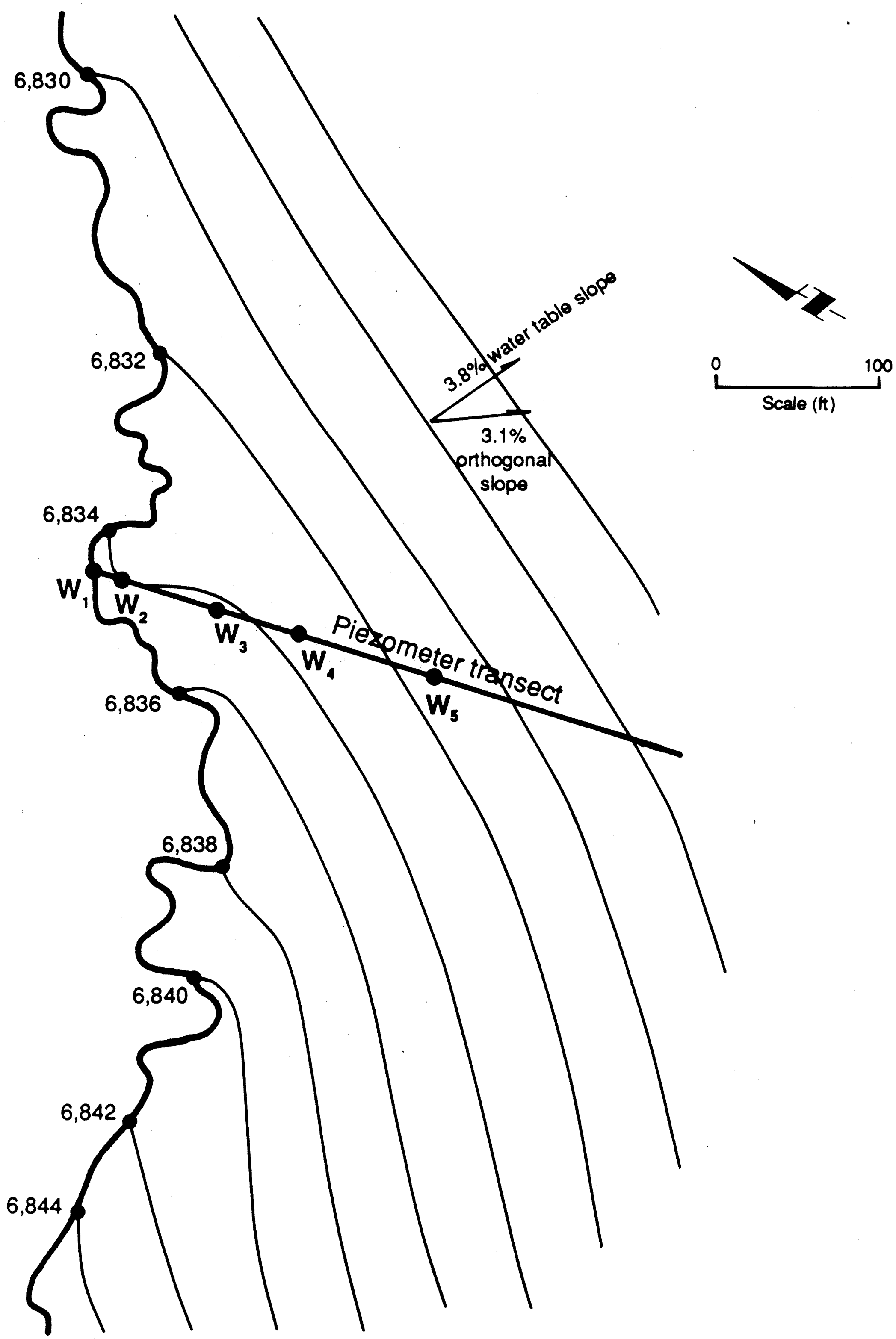
Prepared by Jones & Stokes Associates



Notes: Approximate elevation of P_4 is 7,108 ft. Water table contour interval = 2 ft.

Sources: Transects from Balance Hydrologics 1993; water table inferences from SWRCB Consultants

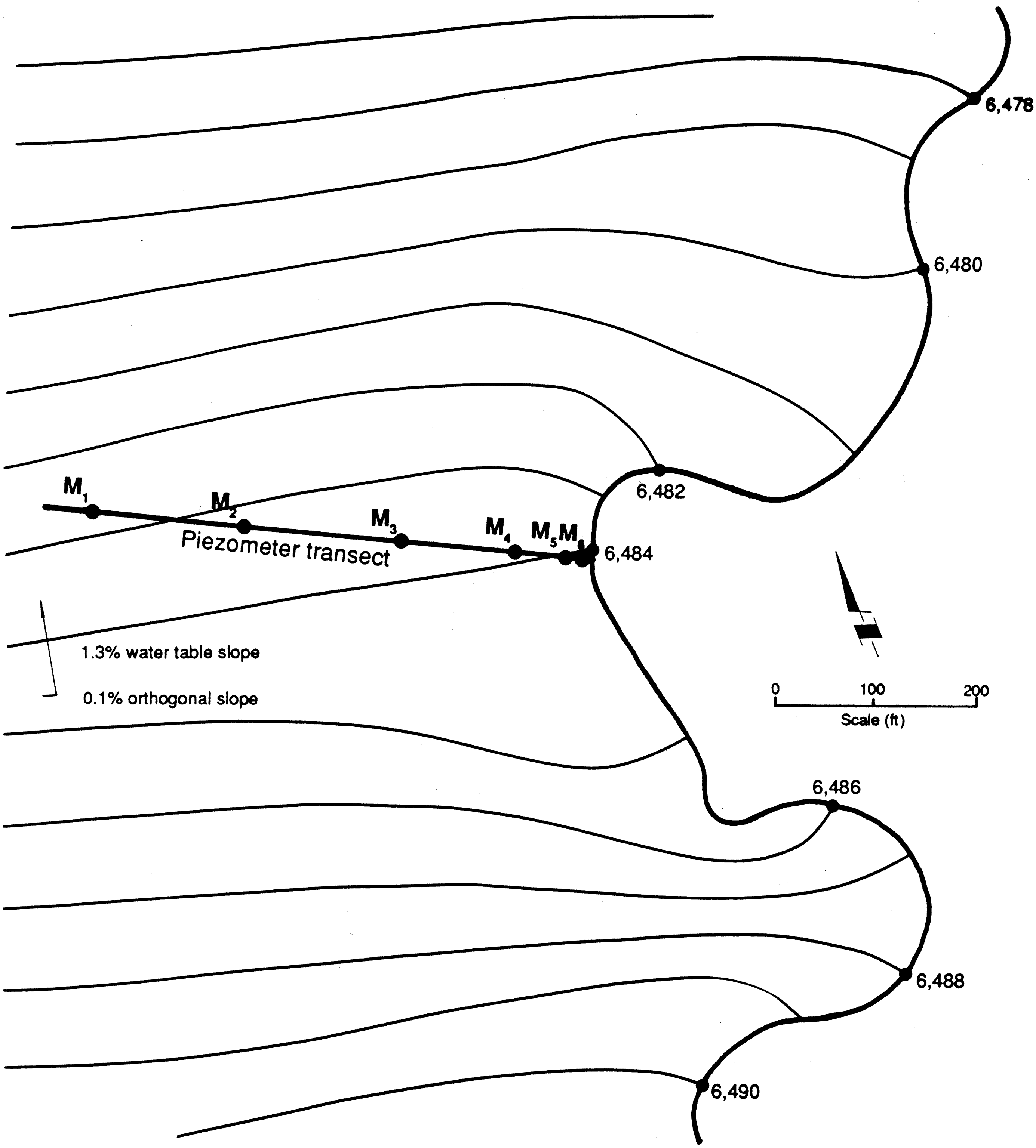
Figure P-12.
Parker Creek Piezometer Transect and Inferred Water Table



Notes: Approximate elevation of W_1 is 6,835 ft. Water table contour interval = 2 ft.

Sources: Transects from Balance Hydrologics 1993; water table inferences from SWRCB Consultants

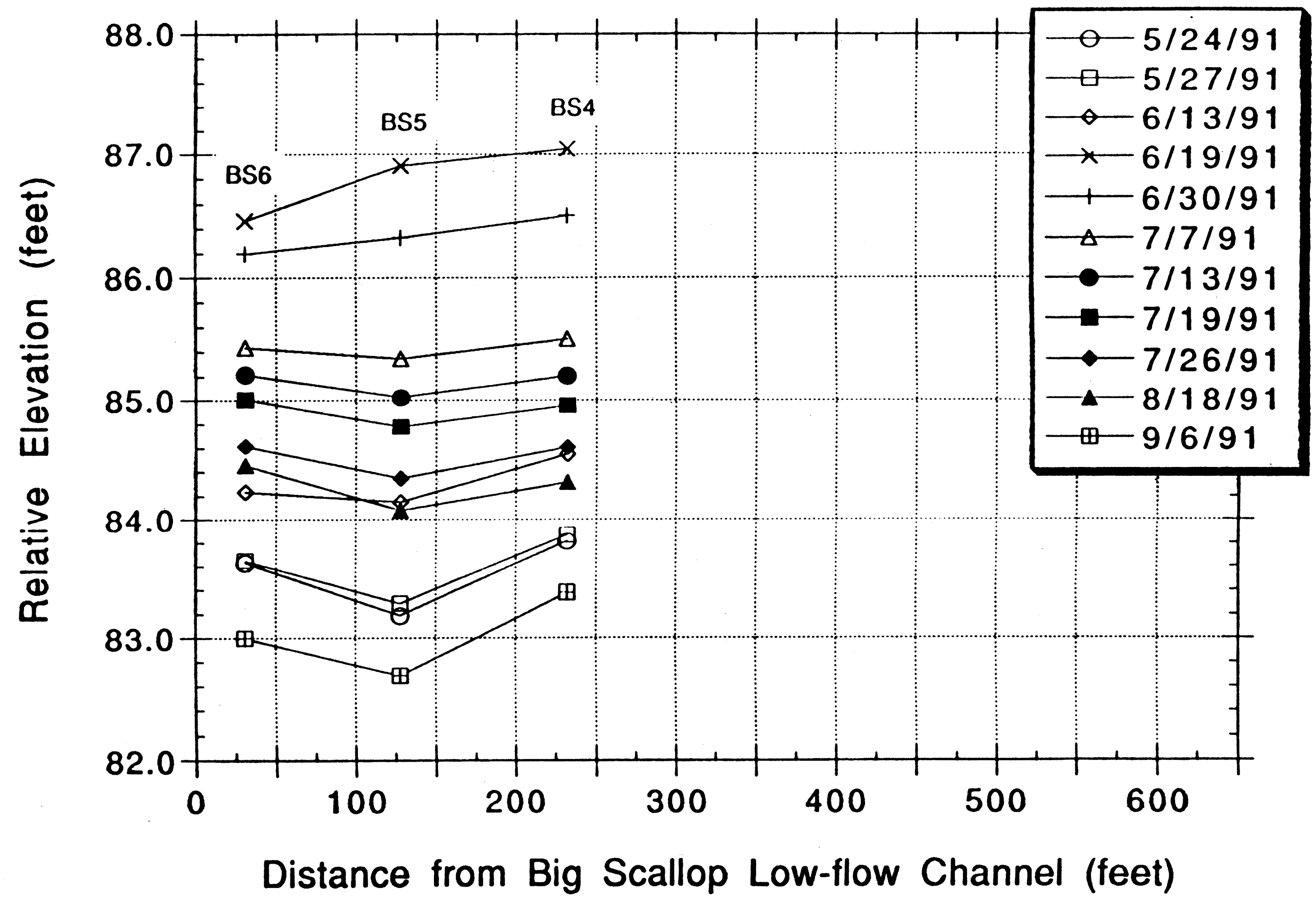
Figure P-13.
Walker Creek Piezometer Transect and Inferred
Water Table



Notes: Approximate elevation of M_6 is 6,484 ft. Water table contour interval = 1 ft.

Sources: Transects from Balance Hydrologics 1993; water table inferences from SWRCB Consultants

Figure P-14.
Rush Creek "Meadows" Piezometer Transect and Inferred Water Table



Source: Balance Hydrologics 1993

Figure P-15.
Groundwater Profiles at the Rush Creek Bottomlands
"Big Scallop" Transect

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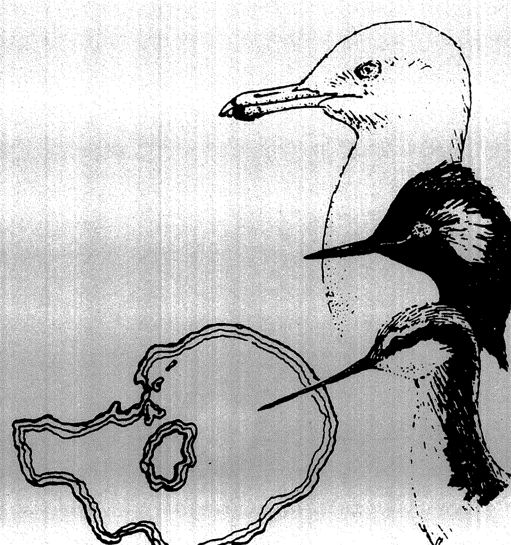
Appendix Q. Vegetation and Geohydrology of the Mono Lake Shoreline, with Emphasis on Lake-Fringing Wetlands



MONO BASIN EIR

Prepared by Jones & Stokes Associates

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Appendix Q. Vegetation and Geohydrology of the Mono Lake Shoreline, with Emphasis on Lake-Fringing Wetlands

INTRODUCTION

This appendix describes the vegetation and geohydrology of vegetated and unvegetated shoreline habitats of Mono Lake that have become exposed since the lake's 1917 highstand of 6,428 feet (i.e., the relicted lakebed). This characterization provides background data supporting preparation of the vegetation assessment described in Chapter 3C, "Vegetation". This appendix is divided into sections on vegetation, geohydrology, the methods used to predict lake-fringing wetland type and extent under the EIR alternatives, and the results of applying the predictive methods.

The vegetation section describes the vegetated and unvegetated habitats fringing Mono Lake at the 1989 point of reference, with emphasis on wetlands. The distribution and areal extent of habitats on the relicted lakebed are described, together with assessment methods and mapping techniques.

The geohydrology section focuses on wetlands fringing Mono Lake. It includes a description of the relationship between lake-fringing wetland type and geohydrology and an assessment of the relationship between the hydrology of each wetland site and lake level fluctuation.

The impact assessment section includes details of the impact assessment methods and site-specific predictions of the lake-fringing wetland type and areal extent for the seven EIR alternatives.

SHORELINE HABITATS

Habitat Classification

Vegetated and unvegetated habitats of the relicted lakebed are described in detail in Appendix F of the EIR. Vegetated habitats are classified in scrub and herb formations; wetland scrub, marsh, wet meadow, alkali meadow, dry meadow and forb subformations, and 23 different plant associations, or series (Appendix F). Sixteen of the series qualify as wetlands under the U.S. Fish and Wildlife Service (USFWS) definition in Cowardin et al. (1979). DFG uses the same definition.

Unvegetated habitats are classified as barrens in Appendix F. Sites with less than 2% plant cover were mapped as barrens. The barrens category was divided into 13 subcategories based on differences in substrate salinity, alkalinity, and texture.

Lake-Fringing Wetlands

Groundwater discharged along the Mono Lake shoreline creates wetlands. Freshwater springs and seeps support marsh, meadow, and wooded wetlands (described in Appendix F). Highly saline groundwater in basin sediment from prior Mono Lake continue to drain and form unvegetated seep wetlands and alkali lakebeds.

Wetland Definition

For this study, the term "wetland" is based on the USFWS definition: "Lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water." Wetlands must have one or more of the following three attributes:

- the land predominantly supports hydrophytes,
- the substrate is predominantly undrained hydric soil, and
- the substrate is nonsoil and saturated with water or covered by shallow water at some time during the growing season each year (Cowardin et al. 1979).

The USFWS definition of a wetland encompasses the range of water-dependent habitats that could be affected by the EIR alternatives. Some habitats that qualify as wetlands under this definition do not meet the U.S. Environmental Protection Agency (EPA) and U.S. Army Corps of Engineers (Corps) regulatory definition intended for implementation of Section 404 of the Clean Water Act (33 CFR 328.3). Examples include habitats dominated by phreatophytes (i.e., plants dependent on deeper groundwater) such as saltgrass or Nevada bulrush. These habitats support a predominance of hydrophytes but the soil surface is neither saturated, flooded, or ponded for a long duration during the growing season.

Unvegetated lagoons and alkali lakebeds qualify as wetlands under the USFWS definition. Lagoons are unvegetated because they contain water that is too saline and alkaline to support plants. Some alkali lakebeds, also referred to as alkali flats, qualify as wetlands. They have shallow groundwater that saturates the soil to the surface via capillary rise. Evaporation at the surface concentrates salts. Some of the areas treated as alkali lakebeds for this study have been drained of groundwater and consequently no longer qualify as wetlands. Alkali lakebeds lack vegetation because of the extreme salinity and alkalinity of the substrate and groundwater.

Geography of Lake-Fringing Wetlands

For discussion and analysis purposes, the Mono Lake shoreline was divided into 18 areas (Figure 3C-2 in Chapter 3C, "Vegetation"). Each area contains one or more geographically isolated vegetated wetlands.

Habitat Mapping Techniques

The EIR vegetation assessment is based in part on maps of habitats encircling Mono Lake at the prediversion (1940) and the point of reference (1989). Prediversion vegetation was mapped from historical aerial photographs by Stine (1993). Jones & Stokes Associates mapped vegetated and unvegetated habitats at the point of reference for shoreline areas below 6,440 feet (Jones & Stokes Associates 1993).

Point-of-reference habitats were mapped using unrectified, true-color, 1:6,000-scale aerial photographs taken on May 23, 1991. After devising the vegetation and habitat classification system (Appendix F), lake-fringing vegetation and habitats were mapped in the field. The classification system was refined during the field surveys to reflect new information. Each lake-fringing wetland was surveyed on foot. Shorelines between wetlands were mapped based on field examination followed by an extrapolation of these observations using aerial photograph interpretation to cover areas not observed in the field. Field mapping methodology employed the following approach:

- Vegetation boundaries visible on the photographs were tentatively delineated.
- Each delineated polygon was examined in the field to determine vegetation type (i.e., series) and verify whether the tentative boundaries reflected conditions on the ground.
- Polygon boundaries were finalized on the aerial photographs while in the field.

Mapping polygons were determined based on the uniformity of plant species composition for vegetated communities and substrate uniformity for unvegetated habitats. Mapped vegetation polygons delimit areas of homogeneous plant species composition and therefore also delimit areas with similar hydrology and sediment lithology. Vegetation boundaries were subjectively determined when plant species composition changed gradually along broad environmental gradients.

The minimum polygon size was generally about 0.25 acre for the marsh subformation and 0.5 acre for other vegetated subformations. When related vegetation types (i.e., series of the same subformation) intermingled in complex patterns, larger polygons were sometimes delineated. In these instances, the vegetation type was determined based on the dominant series within the polygon.

Some mapped polygons include intergrades between two vegetation series. For example, rabbitbrush scrub on the relicted lakebed generally supports upland species in the forb layer. Occasionally, the forb layer consists of various types of meadow or marsh vegetation. In these instances, the polygons were labeled as a scrub type, followed by a listing of the particular meadow or marsh series in parentheses (Jones & Stokes Associates 1993).

Saltgrass dry meadows were extensive at the point of reference. Although they qualify as a wetland using the USFWS definition, they are of limited importance regionally because they support common species not restricted to wetlands, are sparsely vegetated, and are regionally abundant. Therefore, saltgrass dry meadows were mapped in three cover classes: 2-5% cover, 5-10% cover, and greater than 10% cover.

Vegetation and habitat boundaries and polygon attributes (i.e., vegetation type and condition) were entered into a geographic information system (GIS) database with a Unix operating system (ARCINFO). Data were digitized directly from the aerial photographs after scale-rectifying each photograph to the GIS base map using topographic features (e.g., lake shoreline and roads) common to both the aerial photograph and base map. Minor error exists in the precise location and size of mapped polygons because of variations in the scale of the photographs.

Previous mapping by Dummer and Cowell (1985) and Hargis (1986) were not used because they do not adequately represent the 1989 condition. Field observations in 1991 revealed that either the vegetation had changed dramatically since mapped or some mapping polygons were misclassified. The mapping was completed 5-7 years before the point of reference, the classification categories are broad, and the two maps are inconsistent. Furthermore, small wetlands between the well-known wetland complexes were excluded.

The point-of-reference type and extent of lake-fringing wetlands is based on 1991 aerial photographs and field analyses. The 1991 photographs were used because aerial photography from 1989 was inadequate. The 1991 data are considered representative of the 1989 point-of-reference condition because only a limited area of new lakebed has been exposed by the 1.2-foot drop in lake level since 1989, and the downward expansion of wetland vegetation onto newly exposed lakebed during the intervening 2 years would be minimal except perhaps along the Sierran Front.

Point-of-Reference Habitat Distribution and Extent

The point-of-reference extent of each type of shoreline habitat (at the series level) below 6,400 feet was calculated using the GIS. Habitat type and extent for each of the 18 wetland areas are provided in Table Q-1.

GEOHYDROLOGY OF LAKE-FRINGING WETLANDS

Information in this section is based on existing studies of lake-fringing wetlands as cited below and on studies conducted recently for the EIR (Stine 1993, Balance Hydrologics 1993).

The Mono Lake Groundwater Basin

Mono Lake occupies the bottom of a large, internally drained basin. As a result, the lake is a regional groundwater sink receiving subsurface water inflow from all upslope regions within its watershed. The principal water sources are ongoing precipitation and snowmelt in the watershed and drainage of relict lake water in basin sediments from previous high lake levels.

Creeks draining the Sierra Nevada have perennial flows that reach the lake in most years. Streams draining the Bodie Hills and Cow Track Mountains are generally ephemeral on emerging from the mountains because surface flow infiltrates alluvial fan and delta deposits (Vorster 1985). Stream losses from both regions are major contributors to the basin's groundwater supply, but infiltration from the Sierra Nevada runoff is the dominant contributor (Kondolf 1989).

Mono Basin contains over 7,000 feet of accumulated sediment (Pakiser 1976). Most groundwater recharge to the valley fill aquifer infiltrates alluvial fans and streambeds along the basin's edge where mountain canyons enter the valley (Hollett et al. 1989). The permeable alluvial fan, delta, and glacial deposits of the valley fill function as aquifers, which transmit groundwater downslope toward the lake under the influence of gravity. Near the lake, these permeable sediments interfinger horizontally with relatively impermeable fine-grained lacustrine (i.e., lakebed) deposits from past Mono Lake highstands. Clayey lacustrine layers function as aquacludes, impeding the downward movement of groundwater. Because Mono Basin lacks an outlet drainage, water-soluble compounds carried by surface and groundwater have concentrated in Mono Lake over geologic time, creating the extremely saline and alkaline conditions observed today.

Factors Influencing the Location and Nature of Lake-Fringing Wetlands

The location and extent of lake-fringing wetlands are determined by the locations of groundwater discharge sites around the lake. Groundwater reaches the shoreline along six different pathways. The location of discharge sites is controlled by shoreline geohydrology, landforming processes, and lake level. The types of wetlands that develop at a particular groundwater discharge site are determined by:

- groundwater salinity and alkalinity;
- the volume of groundwater reaching the site, which determines the degree of leaching of saline-alkali compounds from the relicted lakebed; and
- the amount of water available for plant growth.

Pattern and Nature of Groundwater Inflows

Four regional groundwater discharge patterns have been identified, which vary with respect to recharge, evaporation, response to lake level, geomorphology, and subsurface lithology (Rogers et al. 1992). Factors controlling groundwater movement interact differently at each region and together influence the development of vegetated wetlands (Groeneveld 1991) and alkali flats (Rogers et al. 1992).

Most of the groundwater reaching the eastern, southeastern, and southern shorelines travels through shallow and deep circulation routes and is delivered to the shoreline via faults and fractures. These groundwater sources are recharged from precipitation and snowmelt in the nearby Cow Track Mountains. Channel losses concentrate groundwater below Dry Creek and other ephemeral drainages. These springs produce moderate groundwater inflows that have only partially leached shoreline sediment.

Infiltration of diffuse runoff and streamflow are the principal sources of groundwater affecting the southwestern, western, and northwestern shorelines below the Sierra Nevada. Abundant faulting and structural disconformities provide conduits for groundwater to reach the shoreline. High-volume inflows have leached relict lake water and most saline-alkali compounds from shoreline sediments in these regions.

The northern shoreline has limited faulting and contains saline-alkali groundwater from former lake highstands that continues to drain from basin sediments upgradient from the current lake shoreline. Vegetated wetlands exist only where moderate freshwater inflows have leached some of the saline-alkali groundwater and sediments. Vegetation is precluded over much of the area by elevated salinity, alkalinity, and phytotoxins (Groeneveld 1991).

Groundwater Sources and Pathways

The three sources of groundwater in Mono Basin are:

- precipitation,
- relict lake water from former highstands, and
- lake water.

Groundwater supporting lake-fringing wetlands can be divided into six source-pathway types (Table Q-2). Four types are springs providing relatively freshwater inflows and supporting vegetated wetlands:

- gravity basin-sediment springs,
- fractured rock gravity springs,
- deltaic artesian springs, and
- deep-fracture artesian springs.

Most of Mono Lake's wetlands are supported by at least two of these sources.

Unvegetated wetlands are supported by two other source-pathway types:

- intruding lake water in nearshore sediments and
- seeping relict lake water from sediments upgradient from the lake.

(The basin groundwater is largely moderately saline relict lake water from earlier highstands of the lake.) These water sources support unvegetated lagoon and alkali flat wetlands.

Basin-Sediment Gravity Springs. Surface water infiltrates alluvial fan and delta sediments around the northern, eastern, and southern shores of Mono Lake and moves downslope via gravity to discharge in arch-shaped littoral springlines.

Springlines form at wave-cut scarps generally 1-5 feet high that develop at the upslope edge of wave-cut platforms. When the lake rises, the highly erodible littoral sediments are eroded by wave wash, creating gentle beach slopes. (Stine 1988, 1993.)

Four prominent wave-cut platforms are visible on portions of the lakebed exposed since 1941. Remnants of the upper edge of each platform are represented by scarps and embankments at the 6,409-foot; 6,402-foot; 6,390-foot; and 6,381-foot elevations. Older platform remnants are present above the 1941 shoreline.

Aquifers truncated by these scarps discharge groundwater. Depending on aquifer-aquaclude sequences and the volume of inflowing groundwater, one or more littoral scarps can be actively discharging groundwater. Water discharged at upper scarps can reinfiltrate lakeshore sediment and reemerge at lower springlines. Vegetated wetlands develop below littoral springlines if sediment chemistry and water quality are amenable (see below) (Stine

1993, Groeneveld 1991). Wetland width below the springline is determined by slope and sediment permeability.

Groundwater is forced to discharge at shoreline littoral springs either by aquacludes or the lakeshore water table. Springlines form upslope of the lakeshore if aquacludes prevent groundwater from continuing to move down through shoreline sediments. Under this circumstance, groundwater moves laterally and discharges where the aquaclude intercepts the beach, typically at a wave-cut scarp.

If aquacludes are absent, groundwater will continue to move downslope toward the lakeshore through beach sediment. On approaching the lake water level, relatively fresh groundwater flows above the more saline lake water intruded into nearshore sediments and forms a springline very near the lakeshore.

Fractured Rock Gravity Springs. Fractured rock gravity springs characterize the western Mono Lake shoreline at the base of the Sierra Nevada. These springs discharge large volumes of groundwater infiltrated from stream channels and diffuse surface runoff. Groundwater moves to the lake along complex pathways of intersecting faults and fractures. Groundwater in unconfined aquifers discharges above the shoreline in bands whose location is determined by the lakeshore water table and aquifer-aquaclude sequences. Water from confined aquifers emerges as underwater or terrestrial artesian springs.

Deltaic Artesian Springs. Deltaic artesian springs occur on the Lee Vining, Rush, and Mill and Wilson Creek deltas of the western shore. Groundwater deep under the delta is trapped below impermeable aquacludes. Water is delivered to the surface, where faults and fractures intercept the pressurized aquifer. Deltaic artesian spring vents generally occur in groups, many of which originally discharged under Mono Lake giving rise to tufa groves such as those that occur at Lee Vining Tufa and on the Wilson Creek delta. Underwater springs that have become terrestrial because of the Mono Lake recession now support luxuriant vegetated wetlands.

Deep-Fracture Artesian Springs. Numerous faults along the northern, eastern, and southern shorelines of Mono Lake provide conduits to the surface for the discharge of pressurized groundwater in deep, confined aquifers. These differ from deltaic artesian springs in having a deeper water pathway (and thus elevated levels of dissolved salts) and higher water temperatures. Examples include Martini Spring at the DeChambeau Embayment, the hot springs east of South Tufa, and those at Warm and Simon's Spring.

Intruding Lake Water. Mono Lake waters intrude permeable sediments near the shoreline where water table gradients are low (Rogers and Dreiss 1991). This intruding water may pond in lagoons when the lake stands at elevations above the lagoon floor. Lagoons also intercept water tables from lakeward-moving groundwater, reducing salinity, but the lagoon water is still too saline-alkali to support vegetation and thus forms unvegetated lagoons.

Seeping Relict Lake Water. After Mono Lake regresses following a highstand, water is left upgradient from the lake as groundwater in moderately to slowly permeable silty and clayey lacustrine sediments (Groeneveld 1991, Rogers et al. 1992).

Lake water saturated basin sediments extensively during the Pleistocene, and less so during the prehistorical and prediversion highstands and subsequent highstands of 1952, 1958, and 1967-1969 (Stine 1993). The relict lake water drains slowly toward the lake. At the point of reference, relict lake water was emanating as seeps the northern and eastern shorelines.

Rates of drainage of relict lake water are determined by permeability, water table gradient, and the rate of freshwater flushing from infiltrating precipitation. Relict lake water is rapidly drained from the steeply sloped, highly permeable sediments of the Sierra Nevada by high-volume infiltration of the mesic watersheds. Drainage is extremely slow on the north and east side of the lake where the shoreline is gently sloped and comprised of fine-grained lacustrine sediment. Infiltration is low because of watershed aridity (Groeneveld 1991, Rogers et al. 1992, Balance Hydrologics 1992).

Influence of Landform and Landforming Processes on Lake-Fringing Wetlands

Climate and hydrography produce and deliver water to the sediments filling the Mono Lake basin while geology and stratigraphy influence its movement lakeward (Stine 1993, CORI 1988). Stine (1993) provides site-specific documentation of the relationship between the nature, location, and extent of lake-fringing wetlands and landforming processes.

Influence of Groundwater on Substrate Chemistry of Lake-Fringing Wetlands

Relict lake water and the saline-alkali sediments are strong influences on lakeshore wetland vegetation. High salinity and boron and arsenic levels in relict lake water apparently limit plant establishment (Groeneveld 1991). Groundwater and substrate salinity and alkalinity are related to the volume of freshwater discharged at a site (Rogers et al. 1992). In high recharge zones such as along the Sierran Front and below the high-volume springs, such as Simon's Spring, relict lake water and salts in lacustrine sediments are rapidly flushed lakeward. Leaching is slow on the arid east side of the lake where scant precipitation and surface runoff are the only sources of freshwater and where relict saline-alkali lake water discharges from a large area of basin sediments (Groeneveld 1991, Rogers et al. 1992).

Seasonality of Groundwater Inflows

Groundwater inflows to Mono Lake vary seasonally and in response to lake level. The water table above the lakeshore is generally low in late summer and high in fall, winter, and spring (Rogers et al. 1992, NAS 1987); however, an exception is documented at the DeChambeau Embayment wetland (referred to as Rancheria Gulch) (Balance Hydrologics 1993). Some springs flow relatively constantly year round and others have highly seasonal flows. The volume and duration of inflows interact with shoreline gradient and substrate texture to determine the degree of leaching of saline-alkali compounds and the amount of water available to sustain wetland vegetation.

Influence of Lake Level on Lake-Fringing Wetlands

The character and extent of lake-fringing wetlands are governed by groundwater discharge volume and location, surface drainage characteristics, substrate texture and chemistry, water quality (salinity and phytotoxin levels), and processes of lagoon formation and maintenance. Groundwater discharge and surface drainage determine wetland location and extent, and sediment chemistry and water quality determine vegetation cover, composition, and structure. Each of these factors can be influenced by lake level.

Groundwater Discharge

The influence of lake level on the location and volume of groundwater discharged from gravity water springs and artesian springs varies for gravity and artesian springs.

Basin Sediment Gravity Springs. Littoral springline locations change as the lake rises and falls. Lake transgressions cause littoral springlines to move upslope as the base level of groundwater inflow rises and the high-density, saline-alkali lake-influenced water table forces the fresher, low-density spring water to move laterally toward the surface. Unless pervasive, unfractured aquacludes prevent gravity water from moving downward. Groundwater levels throughout a wetland decline as the lake regresses and base level falls.

Effects of Lowering Lake Level. The shoreline at the 6,368-foot elevation has a nickpoint where the gradient changes from gentle to steep. The gently sloped Scholl Terrace (see Stine 1988 for developmental history) lies above this elevation and supports the widespread lake-fringing wetlands observed at the point of reference. The submerged, lakeward edge of this terrace is truncated at 6,368 feet by a steeply inclined slope.

If Mono Lake dropped below 6,368 feet, each unit decrease in lake volume (from evaporation and water export) would result in a larger increment of lake level drop compared to rates of decline at higher elevations (Stine 1993, CORI 1988, NAS 1987). Thus, if the lake regressed below 6,368 feet, the shoreline water tables would decline significantly faster.

Lowering the lake below the nickpoint would cause the shoreline water table to drain from the Scholl Terrace. Removing the shoreline water table eliminates the base elevation that forces lakeward-moving gravity water to discharge onto the gently sloped terrace surface. Water tables that sustain existing wetlands would be drained by this and the rilling and stream incision induced by the lower lake level (see "Surface Water Drainage" below). Although wetlands would reform at new springlines below the 6,368-foot nickpoint, the steep shoreline below this elevation indicates that their extent would be much less compared to that which is sustained by the same volume of water when discharged onto the flatter Scholl Terrace (Stine 1988, 1993).

Effects of Rising Lake Level. When the lake rises, it erodes a new wave-cut platform. The upper edge of the transgression is marked by the deposition of littoral embankments or erosion of new scarps. When the lake regresses from a highstand, new springlines form where actively changed aquifers are exposed at the new scarps.

New springlines formed by lake transgressions can sap groundwater from older springlines upslope by lowering the water table. New springlines have been observed to dry older upslope springlines when the lake regresses from a highstand (Stine 1993). Alternatively, new springlines at sites with abundant groundwater inflow may simply provide a new active springline.

Artesian Springs. Artesian springs at Mono Lake generally occur in clusters with multiple discharge points (or vents) at fracture zones or along fault alignments. The presence of discharge at a vent can be influenced by lake level if some vents within a cluster are underwater.

The discharge rate within a spring complex is determined by the relationships between aquifer pressure and atmospheric pressure (for terrestrial springs) or hydrostatic pressure (for underwater springs) pressure. Hydrostatic pressure on underwater springs increases with increasing water depth. (LADWP 1987.) Hydrostatic pressure on underwater springs can affect discharge rates at terrestrial springs that tap the same artesian aquifer.

Pressures decline when underwater vents become terrestrial and are exposed to the relatively low atmospheric pressure. Thus, lake regressions can be accompanied by reduced discharge at terrestrial springs and the relocation of active discharge to lower elevation vents. Highly pressurized artesian spring complexes could be immune from lake level change, however, if pressures are sufficient to maintain flow from most or all available vents.

Surface Drainage

Wetlands develop where water is supplied faster than it can drain. Surface drainage at lake-fringing wetlands is largely a function of slope and sediment permeability. Steeply sloped land drains rapidly. Highly permeable substrate, such as coarse granitic or pumice sands, are more efficiently drained via infiltration than fine-grained silty and clayey lacustrine sediments.

With the exception of Sierran creek deltas, the shoreline gradient of Mono Lake decreases in a lakeward direction (Stine 1993). More gently sloped land is exposed as lake level declines until the 6,368-foot elevation is attained, increasing the land area potentially available for wetland formation as the lake regresses (Stine 1993).

Although the efficiency of surface drainage decreases with decreasing slope and lake level, the gradual formation of rills and incision of drainages that accompany lake level declines partially counteract this effect over the long term. Rilling and stream incision are time-driven processes whose rate is governed by runoff and substrate characteristics.

Rills and streams seek an equilibrium grade determined by the base elevation (Stine 1993). The base elevation of rills and streams entering Mono Lake is generally determined by the lake level. Lake regression stimulates rilling and stream incision as the grade reequilibriates to the lower lake level. The effect of rilling and stream incision would be magnified if the lake dropped below the 6,368-foot elevation.

Drainage incision and groundwater base-level lowering described previously instigated by lowering of the lake below 6,368 feet would completely drain water tables below the surface of the Scholl Terrace. Although the location of wetlands controlled by faults and fractures may be unaffected by lake level, these changes would eliminate sources of wetland hydrology from large areas.

Substrate Chemistry

As described previously, substrate chemistry influences the type and extent of vegetation that establishes in lake-fringing wetlands. Because lacustrine sediments deposited by Mono Lake are highly saline and alkali and contain high phytotoxin concentrations, wetland vegetation does not establish on exposed lakebed until the sediment is adequately leached by fresher waters.

Lake-level fluctuation influences shoreline sediment chemistry. Lacustrine sediments deposited during highstands are reexposed when the lake regresses, providing a different shoreline substrate than was present before the lake-rise. As leaching progresses on newly exposed substrates, salt-tolerant plants establish on partially leached sediment and are later replaced by those typical of less saline conditions.

Water Quality

As with sediment, highly saline or alkali water limits or precludes vegetation establishment. Littoral springlines along North Beach that discharge relict lake water can be distinguished from other springs by their elevated salinity and presence of boron and arsenic (Groeneveld 1991). They are barren of vegetation.

Lake level influences the quality of groundwater because it recharges shoreline sediment with highly saline-alkali water. After the lake recedes from a highstand, stored lake water slowly drains. Freshwater advancing toward Mono Lake becomes brackish where it contacts this relict lake water. Wetlands formed exclusively of relict lake water do not support vegetation; those diluted by inflowing freshwater are eventually flushed and become vegetated.

Lagoons

Longshore drift creates depositional embankments or wave-cut platforms, depending on sediment load and the energy of shoreline currents (Stine 1993). Lagoons develop where longshore drift deposits coarse-grained, highly permeable littoral embankments (e.g., hooks barrier bars and berms). Water impounds on the landward side of littoral embankments when lagoon bottoms are below the shoreline water table.

Embankment formation is most active at specific lake elevations because critical sediment sources are exposed to wave action and transport by longshore currents. Embankments form at specific locations where shoreline slopes are conducive to sediment deposition.

Prominent littoral embankments develop, for example, along the northern shoreline when the lake stands above 6,400 feet. At this elevation, the lake's clockwise longshore currents erode the colluvial apron at the base of Black Point. The largest and most numerous lagoons formed historically along the northern shoreline. Smaller lagoons formed on the gently sloped "plains" of the Rush, Mill, and Lee Vining Creek deltas, which are also located above the 6400-foot elevation contour.

Lagoons pond water from direct precipitation, surface runoff, and groundwater inflows. Precipitation and runoff in Mono Basin are insufficient to maintain ponding for extended periods or on a predictable basis. Predictable and long-term ponding occurs in lagoons when the lake surface is near the elevation of the lagoon bottom. Under these circumstances, the shoreline water table is intercepted and exposed in the lagoon bottom. Most lagoons have brackish water because intruding Mono Lake salinity is diluted by inflowing less-saline groundwater (Lee 1912, Brandbury in Stine 1993).

The large lagoon at the DeChambeau Embayment supports brackish water when lake surface elevations range from about 6,400 to 6,412 feet. The other lagoons of the northern shoreline impound water when the lake is at or above approximately 6,405 feet (Stine 1993). When the lake stands below these elevations, these lagoons pond water ephemerally during high runoff years. Minor brackish lagoons form at various lake elevations around Mono Lake. They develop behind minor littoral embankments and are generally narrow, linear shoreline features. Their extent is inconsequential when compared to the large lagoons that exist when the lake is above 6,400 feet.

Lagoons form on Sierran deltas when Mono Lake stands above 6,400 feet. At this level, the lake occupies the gently sloped delta plains. Below 6,400 feet, the lakeshore abuts the precipitous delta face. When the lake occupies the delta plain, it maintains high water tables for lakeward-flowing gravity water in the delta. At lake levels below 6,400 feet, the groundwater which that lagoons drains as the water table declines and streams and rills incise (Stine 1993).

GEOHYDROLOGIC CHARACTERIZATION OF LAKE-FRINGING WETLANDS

To accurately predict the response of lake-fringing wetlands to lake level fluctuation, it is necessary to characterize the source, seasonality, and quality of groundwater and the texture, lithology, and chemistry of lakebed sediments at each lake-fringing wetland.

The geohydrology of each of Mono Lake's 18 lake-fringing wetlands is summarized in Table Q-3. Data in Table Q-3 reveal that lakeshore wetlands can be grouped into six geographically based units with similar water sources, sediment lithology, and geomorphology (Table Q-4).

RESPONSE OF INDIVIDUAL LAKE-FRINGING WETLANDS TO LAKE LEVEL FLUCTUATION

The response of individual lake-fringing wetlands to lake level fluctuation can be ascertained by determining their water sources, landforms, and landforming processes (Table Q-3) and ascertaining how that particular water source is influenced by lake level (Table Q-2). These predictions were modified based on historical responses to lake level regression and transgression revealed on aerial photographs and documented by Stine (1993).

Prediction Methods

Refer to Chapter 3C, "Vegetation", for a description of prediction methodology.

Predicted Effects of EIR Alternatives

Table Q-2 summarizes the predicted response of individual lake-fringing wetlands to lake level fluctuations. The areal extent of lake-fringing wetlands predicted for each EIR alternative is provided in Table Q-1 separately for each of the 18 analysis areas described above.

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Table Q-1. Habitat Type and Extent Documented for the Prediversion and Point-of-Reference Conditions and Predicted for the EIR Alternatives

Condition or Alternative	North Mono Shorelands					East Mono Shorelands			South Mono Shorelands		Sierran Delta				Sierran Front			Mono Islands	
	Black Point	DeChambeau Embayment	Bridgeport Creek	North Beach	Dune Lagoons	Warm Springs	East Beach	Simon's Spring	South Beach	South Tufa	Wilson-Mill Creek Delta	Lee Vining Creek Delta	Lee Vining Tufa	Rush Creek Delta	Horse Creek Embayment	Sierran Escarpment	County Park	Paoha Island	Total
Prediversion[a]																			
Marsh, meadow, and wetland scrub	0	1	0	1	0	34	1	43	7	7	12	45	3	0	63	71	67	1	356
Ponds and lagoons	4	6	29	0	175	0	0	0	0	0	3	0	0	38	0	0	0	5	260
Alkali flat	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	4	7	29	1	175	34	1	43	7	7	15	45	3	38	63	71	67	6	617
Point of reference[b]																			
Marsh	1	68	20	1	0	55	6	496	6	3	43	6	43	2	27	125	83	3	988
Wet meadow	0	0	14	0	0	0	0	2	0	0	0	0	1	0	0	27	7	0	51
Alkali meadow	187	208	255	122	0	134	90	200	242	30	4	0	0	0	0	16	33	0	1,521
Wetland scrub	0	8	0	0	0	0	0	3	2	1	19	13	7	41	17	63	62	0	236
Subtotal	188	284	289	123	0	189	96	701	250	34	66	19	51	43	44	231	185	3	2,796
Dry meadow	103	73	295	63	24	406	169	164	785	53	58	10	2	88	27	51	23	3	2,397
Ponds and lagoons	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Alkali lakebed	1,249	421	546	1,176	0	1,055	249	114	13	5	16	0	0	0	0	31	28	1,056	5,959
Total	1,541	778	1,130	1,362	0	1,650	514	979	1,048	92	140	29	53	131	71	313	236	1,062	11,152
No-Restriction[c]																			
Marsh, meadow, and wetland scrub	1-2	0	0	1-2	0	30-60	1-2	40-80	7-14	7-14	12-24	5-10	3-6	5-10	60-120	70-140	70-140	1-2	313-626
Dry meadow	103	73	295	63	24	406	169	164	242	30	58	10	2	88	27	51	23	3	1,831
Ponds and lagoons	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Alkali lakebed	2,451	668	1,146	1,935	0	1,296	284	383	340	92	95	19	37	44	42	206	88	386	9,512
Total	2,555-2,556	741	1,141	1,999-2,000	24	1,732-1,762	454-455	587-627	589-596	129-136	165-177	34-39	42-45	137-142	129-189	327-397	181-251	390-395	11,332-11,649
6,372-Ft[c]																			
Marsh	1	68	20	1	0	69	0	700	6	5	0	6	53	0	22	125	83	3	1,161
Wet meadow	0	0	14	0	0	0	0	0	0	0	0	3	0	0	0	27	8	0	52
Alkali meadow	187	208	255	123	0	94	88	195	187	28	4	0	0	0	0	16	33	0	1,417
Wetland scrub	0	8	0	0	0	0	0	1	2	1	18	1	6	50	17	63	62	0	228
Subtotal	188	284	289	124	0	163	88	896	194	34	23	10	59	50	39	231	186	3	2,859
Dry meadow	103	73	295	63	24	456	371	207	785	70	0	2	4	109	47	51	24	4	2,687
Ponds and lagoons	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2
Alkali lakebed	946	320	368	838	0	748	198	42	13	0	14	0	0	0	0	31	28	536	4,081
Total	1,238	677	952	1,025	24	1,366	657	1,145	991	104	36	12	63	158	85	313	238	543	9,629
6,377-Ft[c]																			
Marsh	1	68	20	1	0	61	6	452	6	2	36	2	36	0	22	109	75	2	898
Wet meadow	0	0	14	0	0	0	0	0	0	0	0	0	0	0	0	20	8	0	42
Alkali meadow	187	208	255	122	0	212	99	202	147	25	0	0	0	0	0	5	33	0	1,495

Table Q-1. Continued

Condition or Alternative	North Mono Shorelands: Black Point	North Mono Shorelands: DeChambeau Embayment	North Mono Shorelands: Bridgeport Creek	North Mono Shorelands: North Beach	North Mono Shorelands: Dune Lagoons	East Mono Shorelands: Warm Springs	East Mono Shorelands: East Beach	East Mono Shorelands: Simon's Spring	South Mono Shorelands: South Beach	South Mono Shorelands: South Tufa	Sierran Delta: Wilson-Mill Creek Delta	Sierran Delta: Lee Vining Creek Delta	Sierran Delta: Lee Vining Tufa	Sierran Delta: Rush Creek Delta	Sierran Front: Horse Creek Embayment	Sierran Front: Sierran Escarpment	Sierran Front: County Park	Mono Islands: Paoha Island	Total
Wetland scrub	0	8	0	0	0	0	0	3	2	1	18	13	5	9	15	55	62	0	190
Subtotal	188	284	289	124	0	273	105	657	155	28	54	15	41	9	37	189	178	2	2,625
Dry meadow	103	73	295	63	24	509	365	164	742	63	48	9	3	101	33	54	24	4	2,677
Ponds and lagoons	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Alkali lakebed	46	58	82	388	0	400	58	0	0	0	0	0	0	0	0	0	0	460	1,492
Total	338	415	666	575	24	1,182	527	821	898	90	101	24	44	110	70	242	202	466	6,795
6,383.5-Ft[c]																			
Marsh	0	75	53	1	0	85	0	385	9	16	19	13	15	1	12	78	63	1	827
Wet meadow	0	0	0	0	0	0	0	26	0	0	0	5	0	4	0	21	5	0	61
Alkali meadow	52	70	176	103	0	412	39	196	157	2	0	0	0	0	0	7	21	0	1,233
Wetland scrub	0	7	0	0	0	0	0	3	2	0	13	(TM/GIS)	1	41	17	57	62	0	204
Subtotal	52	152	229	104	0	497	39	610	167	18	32	18	16	46	29	164	152	1	2,325
Dry meadow	30	120	320	63	24	281	271	198	591	53	37	5	1	58	34	17	24	4	2,132
Ponds and lagoons	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	1	6
Alkali lakebed	46	0	0	24	0	0	56	0	0	0	0	0	0	0	0	0	0	395	521
Total	128	272	548	191	24	779	366	808	758	71	69	23	18	110	63	181	175	400	4,984
6,390-Ft[c]																			
Marsh	0	53	33	1	0	59	0	279	6	8	24	4	7	1	21	85	43	1	626
Wet meadow	0	0	0	0	0	0	0	0	0	0	6	4	0	4	0	6	2	0	22
Alkali meadow	9	157	110	58	0	175	73	227	90	0	0	0	0	0	0	7	16	0	920
Wetland scrub	0	8	0	0	0	0	0	3	2	0	10	0	1	14	14	47	59	0	157
Subtotal	9	217	144	60	0	449	204	508	98	8	39	8	8	20	35	144	121	1	2,072
Dry meadow	115	16	221	61	24	215	168	110	377	55	24	6	11	49	22	5	23	4	1,507
Ponds and lagoons	0	0	0	0	0	0	0	0	0	0	0	0	0	15	0	0	0	1	16
Alkali lakebed	46	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	331	377
Total	170	233	365	120	24	664	372	618	475	63	64	14	19	84	57	150	144	337	3,972
6,410-Ft[c]																			
Marsh	0	24	12	0	0	25	0	68	18	6	17	6	5	0	10	47	24	1	264
Wet meadow	0	0	0	0	0	0	0	89	0	2	4	3	0	11	0	0	0	0	110
Alkali meadow	0	34	80	0	0	28	21	11	94	1	2	0	0	0	0	0	2	0	272
Wetland scrub	0	8	0	0	0	0	0	7	1	0	9	0	1	15	5	25	37	0	108
Subtotal	0	66	92	0	0	53	21	175	113	10	32	9	6	26	15	72	63	1	754
Dry meadow	0	93	136	7	24	68	33	48	140	14	9	0	0	21	1	0	23	4	620
Ponds and lagoons	4	7	29	0	175	0	0	1	0	4	3	2	0	32	0	0	0	5	261
Alkali lakebed	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	151	151
Total	4	166	257	7	199	121	54	225	252	27	43	11	6	79	16	72	85	160	1,786
No-Diversion[c]																			
Marsh, meadow, and wetland scrub	1	1	0	1	0	34	1	43	7	7	12	45	3	0	64	71	67	1	358

Table Q-1. Continued

Condition or Alternative	North Mono Shorelands					East Mono Shorelands			South Mono Shorelands		Sierran Delta				Sierran Front			Mono Islands	
	Black Point	DeChambeau Embayment	Bridgeport Creek	North Beach	Dune Lagoons	Warm Springs	East Beach	Simon's Spring	South Beach	South Tufa	Wilson-Mill Creek Delta	Lee Vining Creek Delta	Lee Vining Tufa	Rush Creek Delta	Horse Creek Embayment	Sierran Escarpment	County Park	Paoha Island	Total
Ponds and lagoons	4	7	29	0	175	0	0	0	0	0	3	0	0	38	0	0	0	5	261
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Alkali lakebed																			
Total	4	7	29	0	175	0	0	0	0	0	3	0	0	38	0	0	0	5	261

[a] Based on areas planimetered from the map in Stine (1993).

[b] Based on Jokerst, Helm, and Whiting (1993).

[c] Predicted using methods and assumptions described in Chapter 3C, "Vegetation".

Table Q-2. Groundwater Sources for Lake-Fringing Wetlands

Spring or Groundwater Type	Water Source and Pathway	Water Quality	Seasonality of Discharge	Relationship to Lake Level	Effect of Increased Lake Level (Other than Inundation)	Effect of Decreased Lake Level (Other than Providing More Suitable Wetland Habitat)	Ameleorating Factors
Gravity water springs and seeps	Unconfined aquifers that are recharged by infiltrated channel losses and diffuse runoff in upslope catchments, including reinfiltrated water from the other spring types described below; may now include relict wastewater	Variable; generally good with low electrical conductivity except where flow paths intersect unleached alkali lakebed sediment (below 6,390 ft elevation)	Widely variable to somewhat constant; sensitive to seasonal variation in rainfall and local rainfall patterns	Shoreline water table (see below) is the hydraulic floor that forces gravity water to the surface at littoral springlines	Littoral springlines migrate upslope	Littoral springlines migrate downslope at wetlands without sufficient groundwater inflow to sustain discharge at multiple springlines	Impermeable and unfractured aquacludes can prevent or greatly impede the rapid downward migration of springlines
Deltaic artesian springs	Confined aquifers deep under delta surfaces that are recharged by infiltrated channel losses and diffuse runoff in upslope portions of the delta and abutting alluvial fans; water reaches the surface via faults	Good; generally with low electrical conductivity comparable to water in creeks	Somewhat constant year round but pressure varies with runoff (LADWP 1987)	Hydrostatic pressure on underwater springs influences flow volume on terrestrial springs tapping the same aquifer	Can reactivate discharge from dormant terrestrial vents or increase flow rates on active vents	Can eliminate or reduce flows from terrestrial spring vents	Aquifers with very high pressure heads may be immune to minor or even significant changes in hydrostatic pressure
Deep-fracture artesian springs	Confined aquifers deep under Mono Basin that are recharged by infiltrated channel losses and diffuse runoff in distant areas; water reaches the surface via faults	Moderate to poor; elevated electrical conductivity; hot and warm water temperatures	Somewhat constant; some fluctuation related to wet and dry climate cycles	Not influenced by lake level	None	None	Not applicable
Fractured-rock gravity springs	Unconfined aquifers that are recharged by infiltrated channel losses and diffuse runoff in upslope catchments	Good; electrical conductivity comparable to water in creeks	Fluctuates seasonally with runoff cycle and annually due to climatic differences	Lakeshore water table determines the lower edge of discharge sites, but some aquifers are sufficiently pressurized to force discharge directly into Mono Lake	May or may not cause the upper edge of the zone of groundwater discharge to move upslope	May or may not cause the upper edge of the zone of groundwater discharge to move downslope	

Table Q-2. Continued

Spring or Groundwater Type	Water Source and Pathway	Water Quality	Seasonality of Discharge	Relationship to Lake Level	Effect of Increased Lake Level (Other than Inundation)	Effect of Decreased Lake Level (Other than Providing More Suitable Wetland Habitat)	Ameleorating Factors
Shoreline water table	Mono Lake; underlies shoreline and saturates soil at or near the surface	Poor; high electrical conductivity and pH, same as Mono Lake; unable to support vegetation	Year round	Location relative to shoreline dependent on lake level; extent of shoreline hydrologically affected by water table dependent on shoreline gradient and substrate permeability	Causes water table to move upslope	Causes water table to move downslope	Relict lake water (see below) moving lakeward can substitute for shoreline water table
Relict lake water	Mono Lake water that infiltrated basin sediments during prior highstands	Poor; high electrical conductivity and pH, same as Mono Lake when it stood at the higher level; unable to support vegetation	Year round, except if frozen during winter (high salinity inhibits freezing relative to pure water)	Location of discharge areas independent of lake level; determined by sediment permeability and shoreline gradient	None	None	Not applicable

Table Q-3. Geohydrologic Characterization of Lake-Fringing Wetlands

Georegion and Wetland Site	Spring/ Groundwater Type	Recharge Volume and Seasonality of Freshwater Sources	Water Quality	Sediment Lithology	Sediment Texture	Sediment Salinity/ Alkalinity	Landform	Comments	References
North Mono Shorelands									
Black Point	Gravity water from under Black Point; possibly relict lake water	Low volume; probably fluctuates with seasonal rainfall patterns	Gravity water unknown; below 6,390 ft likely with moderate to high EC and alkalinity as groundwater leaches relict lakebed	Lacustrine sediment overlain in places with colluvial material from Black Point	Fine-grained clays alternating with sandy layers	Saline-alkali, limited leaching below 6,390 ft	Gently sloped lakebed truncated by steep colluvial apron at base of Black Point		Stine pers. comm.
DeChambeau Embayment	Gravity water (principally infiltrated from Rancheria Gulch); deep-fracture artesian spring; relict lake water	High volume from deep-water spring, moderate volume from springlines; fluctuates with season, climate, and the presence/absence of irrigation at DeChambeau Ranch	Gravity water good to fair; above 6,390 ft, 1.0-2.1 mmhos; below 6,390 ft, 5.7-19.5 mmhos; deep-fracture artesian spring, 1.0-3.3 mmhos; B 5.0-11.5 ppm; As 0.2 ppm	Interbedded sandy and clayey lacustrine sediment creating aquaclude-aquifer sequences; overlain in places with aeolian sand	Fine-grained, silty to clayey sediment interbedded with sands and gravels	Moderately saline-alkali; leached above 6,390 ft; highly saline-alkali below 6,390 ft	Downthrust block bound by faults that are perpendicular to shoreline; gently sloped lakebed with littoral springlines at prior highstands	Diverted Wilson Creek water used to irrigate DeChambeau Ranch and likely augmented natural groundwater inflows; extensive alkali flat below 6,381 ft, partial alkali flat between 6,381 ft and 6,390 ft	Balance Hydrologics 1993, Stine pers. comm., Groeneveld 1991a, Los Angeles Department of Water and Power 1987, Parrat 1931
Bridgeport Creek	Gravity water (principally infiltrated from Cottonwood and Bridgeport Creeks); deep-fracture artesian springs; relict lake water	High volume from deep-water springs, moderate volume from springlines; fluctuates seasonally, surface discharge concentrated at small, local springs	Fair, 1.0-2.7 mmhos; B 6.5-16.5 ppm; As 0.06-1.6 ppm	Interbedded sandy and clayey lacustrine sediment creating aquaclude-aquifer sequences; overlain in places with aeolian sand	Fine-grained, silty to clayey sediment interbedded with sands and gravels	Moderately saline-alkali; leached above 6,390 ft; highly saline-alkali below 6,390 ft	Gently sloped shoreline with littoral clifflines at prior highstands; dissected by some faults	Tufa near the 6,428-ft highstand suggests that groundwater has discharged at the site in the past; most discharge is currently from littoral springline at 6,390 ft; extensive alkali flat below 6,381 ft, partial alkali flat between 6,381 ft and 6,390 ft	Stine pers. comm., Groeneveld 1991a, Basham 1988
North Beach	Relict lakewater; minor amounts of gravity water; deep-fracture artesian springs (rare and small)	Low volume along springlines with few small, moderate-volume deep-water springs; fluctuates seasonally	Poor; 3.0-31 mmhos; B 13-240 ppm; As 1.2-8.3 ppm	Interbedded sandy and clayey lacustrine sediment creating aquaclude-aquifer sequences; overlain in places with aeolian sand	Fine-grained, silty to clayey sediment interbedded with sands and gravels	Limited leaching; highly saline-alkali below 6,400 ft	Gently sloped shoreline with littoral clifflines at prior highstands; dissected by some faults	Most discharge as subsurface seepage; principal area of discharge below the 6,390-ft littoral springline; groundwater too saline-alkali for vegetation; extensive alkali flat below 6,390 ft	Groeneveld 1991a, Basham 1988, Stine 1990, Rogers et al. 1992, Rogers and Dreiss 1991
Warm Springs	Gravity water (infiltrated in the Cow Track Mountains); deep-fracture artesian springs; relict lake water	High volume at deep-water springs, moderate from springlines; fluctuates seasonally and with annual climate	Fair; 1.8-3.9 mmhos; B 3.6-16.5 ppm; As 0.3-1.6 ppm	Interbedded sandy and clayey lacustrine sediment creating aquaclude-aquifer sequences; overlain in places with aeolian sand	Fine-grained, silty to clayey sediment interbedded with sands and gravels	Limited leaching; highly saline-alkali below 6,400 ft	Gently sloped shoreline dissected by prominent fault somewhat tangential to current shoreline; lagoons formed behind fault and adjacent littoral embankment when the lake stands above 6,400 ft; with littoral embankments and clifflines	Old tufa remains above and below the 6,328-ft highstand indicates groundwater has discharged at this site for many millenium; extensive alkali flat below 6,381 ft	Groeneveld 1991a, Basham 1988, Stine 1990, Rogers et al. 1992, Sinclair 1988, Los Angeles Department of Water and Power 1987, Parratt 1931
East Beach	Gravity water (principally from Simon's Spring), relict lake water	Moderate to low volume along springlines; fluctuates seasonally and with annual climate	Fair; 1.4-14.0 mmhos; B 4.4-12.6 ppm; As 0.2-0.9 ppm	Lacustrine sediment overlain in places with aeolian sand; stratification undocumented	Interbedded fine sand and coarser tephra sediment; no near-surface clayey aquacludes as at the North Mono Shorelands	Limited leaching; highly saline-alkali throughout	Gently sloped shoreline with littoral clifflines and embankments	Southern portion possibly receives gravity water reinfiltrated from springs in Simon's Spring complex	Groeneveld 1991a, Stine 1993

Table Q-3. Continued

Georegion and Wetland Site	Spring/ Groundwater Type	Recharge Volume and Seasonality of Freshwater Sources	Water Quality	Sediment Lithology	Sediment Texture	Sediment Salinity/ Alkalinity	Landform	Comments	References
Mill-Wilson Creek Delta	Gravity water infiltrated from creeks and overbank flood-flows; deltaic artesian springs	High volume on Wilson Creek delta; fluctuates seasonally and with annual climate cycles	Good; 0.1-0.3 mmhos; B 0.04-0.17 ppm	Granodiorite and allied metamorphic rocks	Coarse-grained sands with abundant gravel and cobble	Well leached except below 6,390 ft, where moderately alkali from lakebed sediments	Moderately sloped delta with incised creek; sloped gently to shoreline	Substantial groundwater discharge at the mouth of Mill Creek before LADWP diversions; incision of Wilson Creek breached clayey aquacludes draining delta water table in places; tufa towers evidence of underwater discharge in the past	Basham 1988, Stine 1993, Los Angeles Department of Water and Power 1987
Sierran Front									
Horse Creek Embayment	Gravity water; deep-fracture artesian springs; groundwater historically augmented by artificial irrigation in upslope area	Low to high volume; lowermost littoral springline with highest levels	No data available; presumably similar to Sierran Escarpment	Granodiorite and allied metamorphic rocks interbedded with Mono Craters tephra	Coarse-grained sands with abundant gravel and cobble	Well leached except below 6,390 ft, where moderately alkali from lakebed sediments	Somewhat steep shoreline within sheltered embayment with littoral clifflines	Site of historical discharge from upslope irrigation; natural groundwater sources fluctuate with lake level	Stine 1993, pers. comm.
Sierran Escarpment	Fractured rock gravity springs that charge downslope gravity water springs	High volume; fluctuates seasonally and with annual climate cycles	Good; 0.1-1.0 mmhos; B 0.3-6.8 ppm; As 0.2-0.3 ppm	Granodiorite and allied metamorphic; tufa-cemented cobbles above 6,385 ft	Coarse-grained sands with abundant gravel and cobble	Highly leached, except below 6,390 ft, where moderately to highly saline-alkali	Steeply sloped shoreline of colluvial and alluvial deposits above 6,390 ft; highly fractured and faulted	Freshwater inflows with such head that they drive saline lake water below the lake level, allowing freshwater to seep at the shoreline	Basham 1988, Stine 1993, Winkler 1977, Rogers et al. 1992, Groeneveld 1991a, Los Angeles Department of Water and Power 1987
County Park	Fractured rock gravity springs, deep-fracture artesian springs; sustained in part by irrigation of Conway Ranch	High volume; fluctuates seasonally and with annual climate cycles	Good; 0.3 mmhos; B 1.2 ppm; As 0.2 ppm	Granodiorite and allied metamorphic; some tufa-cemented cobbles	Coarse-grained sands with abundant gravel and cobble	Highly leached, except below 6,390 ft, where moderately to highly saline-alkali	Moderately sloped shoreline with littoral clifflines; faulted	Spring discharge from the tops of tufa towers ceased in 1980s; discharge partially related to diversion structures and weirs in feeder creeks	Basham 1988, Stine 1993, Winkler 1977, Rogers et al. 1992, Groeneveld 1991a, Los Angeles Department of Water and Power 1987
Mono Islands									
Paoha Island	Gravity water, deep-fracture artesian springs, relict lake water	High volume at deep-fracture springs; low volume at spring-line	Poor; 1.9-2.2 mmhos; As 1.6-78.9 gm/l	Lacustrine sediment; interbedded fine-grained lacustrine sediment and Mono Craters tephra	Fine-grained sediment with clayey aquacludes	Highly saline-alkali	Moderately sloped shoreline with littoral embankments and clifflines	Springwater possibly a mix of deep-fracture aquifer water and lake water	Basham 1988, Los Angeles Department of Water and Power 1987

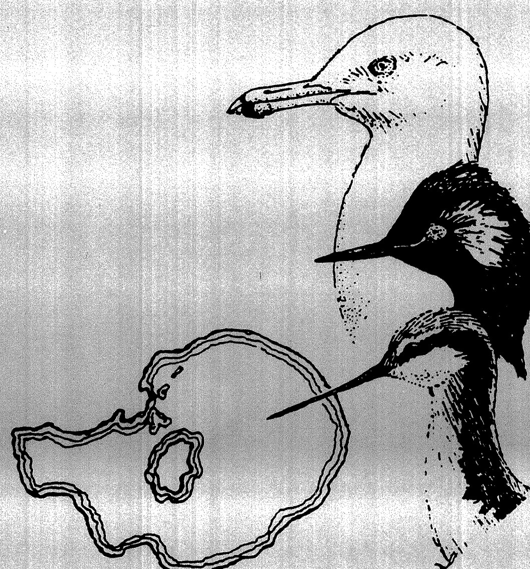
Table Q-3. Continued

Georegion and Wetland Site	Spring/ Groundwater Type	Recharge Volume and Seasonality of Freshwater Sources	Water Quality	Sediment Lithology	Sediment Texture	Sediment Salinity/ Alkalinity	Landform	Comments	References
Simon's Spring	Gravity water, deep-fracture artesian springs; relict lake water (likely only consequential below 6,381 ft)	High volume deep-fracture springs and littoral springlines; fluctuates seasonally and with annual climate	Good; from 0.2 to 2.7 mmhos; B 0.2-12 ppm; As 0.1 ppm	Lacustrine sediments interbedded with tephra sand, overlain in places with aeolian sand	Interbedded fine sand and coarser tephra sediment; no near-surface clayey aquacludes like at the North Mono Shorelands	Moderately saline-alkali to neutral and well leached	Gently sloped shoreline with littoral embankments and cliff-lines; bisected by major fault with downthrust fault to west and upthrust block to east	Recharge likely from Cow Track Mountains and Dry Creek; lacks an extensive alkali flat; water temperature and chemistry indicate groundwater circulation in the faults is shallow; extensive tufa hardpan prevents infiltration of springwater and is responsible for the extensive marshes because drainage from rill formation is precluded	Stine 1993, Groeneveld 1991a, Rogers et al. 1992, Basham 1988, Sinclair 1988, Los Angeles Department of Water and Power 1987, Parratt 1931
South Mono Shorelands									
South Beach	Gravity water, deep-fracture artesian springs (small, uncommon)	Both spring types low volume; water table fluctuates seasonally and with annual climate and lake level	Good; 0.1-3.2 mmhos; B 0.4-8 ppm; As 0.1-2.1 ppm	Interbedded tephra and sand layers, overlain in places with aeolian sand	Coarse-grained, highly permeable	Moderately saline-alkali, fairly well leached	Gently sloped shoreline with littoral embankments and cliff-lines, bisected by several faults	Coarse-grained, porous sediments leached rapidly despite limited groundwater inflow; possibly recharged by groundwater infiltrated in the Mono Craters	Rogers et al. 1992, Basham 1988, Sinclair 1988, Stine 1993, Gradek 1983, Groeneveld 1991a, Vorster 1985, Los Angeles Department of Water and Power 1987
South Tufa	Gravity water (infiltrated in Mono Craters); deep-fracture artesian springs	High volume, fluctuates seasonally and with annual climate and lake level	Fair; 1.0-3.2 mmhos; B 2.9-19 gm/l	Interbedded tephra and sand layers, overlain in places with aeolian sand	Coarse-grained, highly permeable	Moderately saline-alkali, fairly well leached	Gently sloped shoreline with littoral embankments and cliff-lines, bisected by a fault	Littoral embankments have slowed drainage from deep-fracture springs, thereby allowing more extensive marshes to form	Rogers et al. 1992, Basham 1988, Sinclair 1988, Stine 1993, Gradek 1983, Vorster 1985, Los Angeles Department of Water and Power 1987
Sierran Delta									
Rush Creek Delta	Gravity water infiltrated from Rush Creek and overbank floodflows; artificial diversions supported some wetlands historically	Low volume at point of reference, historically high volume, fluctuating with creek discharge	No data available; presumably similar to Lee Vining Creek delta	Granodiorite and allied metamorphic rocks interbedded with Mono Craters tephra and clayey lacustrine strata at depth	Coarse-grained sands with abundant gravel and cobble	None, well leached	Gently sloped delta plain above 6,400 ft with steep delta face below; Rush Creek presently deeply incised into the delta	Incision of Rush Creek drained water table that supported more extensive wetlands before LADWP water exports began	Stine 1993, pers. comm.
Lee Vining Tufa	Gravity water infiltrated from Lee Vining Creek and deltaic artesian springs	High volume; fluctuates seasonally and with annual climate cycles	Good; 0.1-0.4 mmhos	Granodiorite and allied metamorphic rocks interbedded with Mono Craters tephra; tufa-cemented cobbles	Coarse-grained sands with abundant gravel and cobble	Saline-alkali but moderately well leached above 6,381 ft; saline-alkali below	Narrow, moderately sloped shoreline bisected by numerous parallel faults with alternating upthrust and downthrust blocks	Site of long-term groundwater discharge with wetlands that move downslope with lake level	Stine 1993, pers. comm.; Balance Hydrologics 1993; Basham 1988; Los Angeles Department of Water and Power 1987
Lee Vining Creek Delta	Gravity water infiltrated from Lee Vining Creek and overbank floodflows; deltaic artesian springs; artificial diversions supported some wetlands historically	Low volume at point of reference; historically high volume and fluctuating with creek discharge	Good; 0.3-1.2 mmhos; B 0-2.8 ppm	Granodiorite and allied metamorphic rocks	Coarse-grained sands with abundant gravel and cobble	None, well leached	Gently sloped delta plain above 6,400 ft with steep delta face below Lee Vining Creek presently deeply incised into the delta	Water was historically diverted from Lee Vining Creek to sustain wetlands; incision of Lee Vining Creek drained water table that supported more extensive wetlands before LADWP diversions	Stine 1993, pers. comm.; Basham 1988; Los Angeles Department of Water and Power 1987; Parratt 1931

Table Q-4. Lake-Fringing Wetland Types

Wetland Georegion	Wetland Site (Analysis Units)	Spring Types/ Water Source	Geomorphology	Sediment	Supplemental Water
North Mono shorelands	Black Point, DeChambeau embayment, Bridgeport Beach, North Beach	Nearshore water table, deep fracture artesian, relict lake basin water	Littoral berms, littoral springlines, faults, lakebed	Fine-grained lake sediment below 6,400 feet, coarse Black Point sand above 6,400 feet interbedded with lacustrine clay, well-leached to highly saline-alkali	No
North Mono lagoons	Dune lagoons, DeChambeau lagoons	Nearshore water table	Lagoons	Sand dune or gravel, alkali crust in basins	No
East Mono shoreland	Warm Spring, East Beach, Simon Spring	Nearshore water table, deep fracture artesian, relict lake basin water	Littoral berms, littoral springlines, lagoons, faults, lakebed	Five-grained lake sediment interbedded with lacustrine clay, well-leached to highly saline-alkali	No
South Mono shoreland	South Beach, South Tufa	Nearshore water table, deep fracture artesian, relict lake basin water	Littoral berm, littoral springline, lagoon, faults, pumice sands	Coarse pumice sand inter-bedded with impermeable lacustine clay	South Tufa received inflow from upslope pasture irrigation
Sierran Delta	Wilson-Mill Creek Delta, Lee Vining Creek Delta, Rush Creek Delta, Lee Vining Tufa	Nearshore water table deltaic artesian	Tufa cemented beach, rock, lagoons, delta plain	Coarse, well drained sands or gravels interbedded with impermeable lacustine days	Diversion from creeks and inflows from upslope pasture irrigation
Sierran Front	Horse Creek embayment, Sierran Escarpment, County Park	Fractured rock gravity, deep fracture artesian	Faults, colluvium		Some receive groundwater inflow from upslope pasture irrigation
Mono Islands	Paoha Island	Nearshore water table, deep fracture artesian	Littoral springline, faults, lakebed		No

Appendix R. Legal History of the Mono Lake Controversy



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Appendix R. Legal History of the Mono Lake Controversy

INTRODUCTION

This appendix identifies legal actions relating to Mono Basin and the Mono Lake tributary diversions and summarizes the major legal directives from the court decisions. The objective of this appendix is to describe how those directives relate to the California State Water Resources Control Board's (SWRCB's) proposed revision of the Los Angeles Department of Water and Power's (LADWP's) water right licenses and to this environmental impact report (EIR). This appendix also contains a summary of the legal issues concerning water rights in the Owens River Basin.

A 1928 state constitutional amendment provides that all waters of the state must be put to reasonable and beneficial use (California Constitution Article X, Section 2). Any waters in excess of the reasonable and beneficial use are surplus waters available for use by others, under appropriative water rights administered by SWRCB. A water right is initiated by an application to appropriate water; if SWRCB approves the application, it issues a permit to the applicant to allow construction of the project needed to divert the water according to the terms and conditions of the permit. The applicant must file periodic progress reports with SWRCB regarding application of the water to beneficial use. Following completion of the project, SWRCB may issue a license confirming the right to the appropriation of the water according to the terms and conditions of the license.

SWRCB is proposing to revise the terms and conditions of LADWP's water right licenses to divert water for municipal and power generation from four tributary streams of Mono Lake. SWRCB will base this revision on the establishment of instream flow requirements for the Mono Lake tributaries and on lake surface elevation requirements for Mono Lake, as necessary to comply with California Fish and Game Code Sections 5937 and 5946, the public trust doctrine, and the constitutional requirement of reasonable use. Compliance with these requirements is directly related to the past litigation and recent court orders that concern water diversions from the Mono tributaries. This legal history is presented below, first in summary form, followed by detailed discussion of the Mono Basin and Owens Basin diversions.

SUMMARY

Mono Basin

- In *National Audubon Society v. Superior Court* 33 Cal.3d 419, cert. denied, 464 U.S. 977 (1983), the California Supreme Court held that the public trust mandated reconsideration of LADWP's Mono Basin water diversions and the diversions' impact on Mono Lake.

- In *California Trout, Inc. v. State Water Resources Control Board* 207 Cal.App.3d 584 (1989) (*Caltrout I*), the Court of Appeal found that Section 5946 of the California Fish and Game Code applied to LADWP water right licenses for appropriation of the Mono Lake tributaries. California Fish and Game Code Section 5946 states that no license to appropriate water in portions of Mono or Inyo Counties can be issued after September 9, 1953, unless conditioned on full compliance with Section 5937 of the California Fish and Game Code. California Fish and Game Code Section 5937 requires sufficient bypass flows around dams, including diversion dams, to maintain in good condition any fish that may be planted or exist below the dam.

- In *California Trout, Inc. v. Superior Court* 218 Cal.App.3d 187 (1990) (*Caltrout II*), the Court of Appeal held that its opinion in *Caltrout I* foreclosed any argument that SWRCB had authority to balance the public interest in competing water uses and to set instream flow requirements that are sufficient to maintain fish in good condition. The court directed SWRCB to exercise its ministerial duty to amend LADWP's water right licenses for appropriation of the Mono Lake tributaries to include the condition that, in accordance with Section 5946, the requirements of the California Fish and Game Code, the licenses must comply with Section 5937. Interpreting the application of Section 5937, the court further specified that licenses should require LADWP to "release sufficient water . . . to reestablish and maintain the fisheries that existed in them prior to its diversion of water". SWRCB amended LADWP's licenses to include the specified condition on April 4, 1990. SWRCB did not specify numerical flow rates needed to comply with Section 5937, pending completion of the present process.

- *In the Matter of Mono Lake Water Rights Cases* (El Dorado County Superior Court Coordinated Proceeding Nos. 2284 and 2288), coordinated action in the El Dorado County Superior Court includes the lawsuits described above and *Dahlgren v. City of Los Angeles* (Mono County Superior Court No. 8092 concerning the adequate flow of water in Rush Creek to sustain fish, pursuant to Section 5937 of the California Fish and Game Code) and *Mono Lake Committee v. City of Los Angeles* (Mono County Superior Court No. 8608 concerning the adequate flow of water in lower Lee Vining Creek to sustain fish, pursuant to Section 5937 of the California Fish and Game Code).

- On August 22, 1989, the court ruled that a preliminary injunction should be issued prohibiting LADWP from causing the level of Mono Lake to fall below 6,377 feet as a result of its diversions for the remainder of the runoff year ending March 30, 1990. This preliminary injunction continued in effect by stipulation of the parties until the court's April 17, 1991 ruling on the motion to extend the preliminary injunction.

- On August 29, 1989, the court issued a stay until completion of SWRCB proceedings or September 1993, whichever comes first, on further litigation on the merits of any of the coordinated cases. This ruling was based on the court's review of SWRCB's Mono Basin work plan, which calls for preparation of this EIR and adoption of a water right decision amending LADWP water right licenses by December 1992.

- On June 14, 1990, pursuant to *Caltrout II*, the court entered a preliminary injunction establishing interim flow rates for Rush Creek, Lee Vining Creek, and two Rush Creek tributaries, Parker and Walker Creeks. The net result of this interim streamflow order compels LADWP to release approximately 60,000 acre-feet (af) of water yearly down the Mono Lake tributaries.

- On April 17, 1991, the court issued a preliminary injunction requiring LADWP to allow sufficient water to pass its diversion facilities to maintain the level of Mono Lake at or above 6,377 feet. In effect, this order renewed the August 22, 1989 preliminary injunction, which required a lake level of 6,377 feet as a condition of LADWP diverting water out of Mono Basin. The parties to the litigation stipulated that the April 17, 1991 order shall remain in effect pending the completion of the SWRCB hearing.

- On December 17, 1992, the court extended the stay order until September 1, 1994 or completion of the SWRCB proceedings, whichever comes first.

Owens Basin

- In *County of Inyo v. Yorty*, 32 Cal.App.3d 795 (1973), the Court of Appeal held that the California Environmental Quality Act (CEQA) required the City of Los Angeles to prepare an EIR on LADWP aqueduct operations completed in 1970.

    - In succeeding years, the city unsuccessfully attempted to satisfy the court order, with the court directing each time that certain further steps must be taken to comply with CEQA (*County of Inyo v. City of Los Angeles*, 71 Cal.App.3d 185 [1977] and *County of Inyo v. City of Los Angeles*, 124 Cal.App.3d 1 [1981]).

  - In 1984, the County of Inyo and the City of Los Angeles entered into an interim agreement that suspended litigation and called for cooperative studies and development of a long-term groundwater management plan.

  - In September 1990, pursuant to the interim agreement, a draft EIR was released in conjunction with the long-term groundwater management plan.

- On May 29, 1991, in accordance with the court directive of the *Caltrout I* and *Caltrout II* decisions, SWRCB amended LADWP's water right license for diversion of water from the Owens River to include the condition requiring, in accordance with Section 5946, compliance with Section 5937 of the California Fish and Game Code (SWRCB Order 91-04). SWRCB did not, however, establish numerical instream fishery protection flow requirements as a condition of the license. SWRCB required that LADWP consult with the staff of SWRCB; the California Department of Fish and Game; and the California Regional Water Quality Control Board, Lahontan Region to determine appropriate instream flows. The consultations are required to include consideration of an appropriate method of restoring flows that will not create unreasonable impacts on instream resources or adversely affect any state-listed or federally listed endangered species.

LEGAL HISTORY OF THE MONO BASIN DIVERSIONS

In 1940, the City of Los Angeles, through LADWP, was granted permits allowing appropriation of the entire flow of four creeks tributary to Mono Lake for municipal use and hydropower generation. However, because LADWP lacked the appropriate conveyance facilities, it could not appropriate and transport the amounts of water that the permits had granted at that time. In 1963, the City of Los Angeles authorized the construction of a new aqueduct to transport the water as contemplated by the permits. The aqueduct was completed in 1970 to be filled from three sources: increased surface diversion from Mono Basin and Owens Basin, reduced irrigation acreage of Los Angeles-owned lands in Mono and Inyo Counties, and increased pumping of groundwater from Owens Basin.

In 1974, SWRCB issued licenses confirming LADWP's right to divert water from Mono Lake tributaries. LADWP has diverted approximately 83,000 af per year of water from Mono Basin since completion of the aqueduct.

National Audubon Society v. Superior Court 33 Cal.3d 419, cert. denied, 464 U.S. 977 (1983)

Background. In 1979, the National Audubon Society (Audubon), along with the Mono Lake Committee, Friends of the Earth, the Los Angeles Audubon Society, and four Mono Basin landowners, initiated a lawsuit against LADWP seeking to force the city to allow more water to flow into Mono Lake and thereby protect the Mono Lake ecosystem.

Audubon argued that LADWP's diversions of the Mono Lake tributaries violated the state's public trust over navigable water and that LADWP was creating a public and private nuisance. The public trust doctrine's origins can be traced to early English and Roman law. It has been traditionally used to protect the public interest in navigation, commerce, and fishing on navigable waters, and had been extended to protect waters in their natural state for recreation, scientific study, wildlife habitat, and scenery (*Marks v. Whitney* [1971] 6 Cal.3d 251). Audubon argued that the public trust applies when water bodies are altered as a result of water diversions.

Court Decision. In 1983, the California Supreme Court issued the decision on the Audubon lawsuit, focusing on the role of the public trust doctrine in California water law. The court agreed with Audubon that the public trust mandated reconsideration of LADWP's Mono Basin water diversions and the diversion's impact on Mono Lake.

The court stated that Mono Lake is a scenic and ecological treasure of national significance and that the lake's value as a recreational and scenic resource was diminished by recession of the water level. The court found that the water rights enjoyed by LADWP were granted and have continued without any consideration of the impact on this resource. The court held that an objective study and reconsideration of the water rights in Mono Basin were required because the water law of California integrates both the public trust doctrine and the appropriative rights system.

The court found that SWRCB and the courts had concurrent powers to undertake the reconsideration of water rights and the public trust doctrine. The court recognized that within this reconsideration, the concerns of LADWP and "the City's need for water, its reliance upon the 1940 board decision, and the cost both in terms of money and environmental impact of obtaining water elsewhere must enter into the allocation decision". Thus the court ruled that the public trust obligates the state to protect physical environments such as Mono Lake "whenever feasible". The court stated:

> The prosperity and habitability of much of this state requires the diversion of great quantities of water. The state must have the power to grant rights to appropriate water even if diversions harm public trust uses. [However,] approval of such diversion without considering public trust values may result in needless destruction of those values. Accordingly, before state courts and agencies approve water diversions they should consider the effect of such diversions upon interests protected by the public trust, and attempt, so far as feasible, to avoid or minimize any harm to those interests.

Current Status. On March 23, 1989, the Judicial Council coordinated the Mono Lake case with the Mono Lake tributary cases under the title of "Mono Lake Water Right Cases" in El Dorado County Superior Court, with Judge Finney assigned as the coordination judge.

***California Trout, Inc. v. State Water Resources Control Board* 207 Cal.App.3d 584 (1989) (*Caltrout I*)**

Background. California Fish and Game Code Section 5946 states that no license to appropriate water in portions of Mono or Inyo Counties can be issued after September 9, 1953, unless conditioned on full compliance with Section 5937 of the California Fish and Game Code. Section 5937 requires releases or bypass of sufficient water around, over, or through dams, including diversion dams, to maintain in good condition any fish that may be planted or exist below the dam.

California Trout, Audubon, and the Mono Lake Committee brought suit against SWRCB to rescind the 1974 water right license held by LADWP that had granted the right to appropriate all the water for streams tributary to Mono Lake. It was argued that SWRCB, in violation of Section 5946 of the California Fish and Game Code, failed to establish bypass requirements at LADWP's diversions in Mono Basin to protect fish that exist below LADWP's points of diversion on the four Mono Lake tributaries. (Another case with similar issues, *National Audubon Society v. the State Water Resources Control Board* [Sacramento County Superior Court No. 336712], was consolidated for appeal with *Caltrout I.*)

Court Decision. The Court of Appeal rejected several arguments of LADWP in finding that Section 5946 of the California Fish and Game Code applied to the water right licenses. The court found that Section 5946 applies to all licenses, even if they purportedly authorized appropriation of all the available water from a stream; the court found that Section 5946 expressly applied to the licenses for the appropriation of the water of the Mono Lake tributaries. The court also found that Section 5946 operates as a legislative choice to protect fish resources in consideration of the competing uses of water, including domestic and hydropower uses. Section 5946 represents the legislative concern over the drying up of the Owens River; it was passed as emergency legislation to avoid the destruction of the fish in the streams and the interference with a recreation-dependent economy that could occur with the proposals for diversion of water of the Mono Lake tributaries.

The court determined that Section 5937 of the California Fish and Game Code was a legislative expression of the public trust to protect fish resources and therefore creates an ongoing duty of SWRCB to protect public trust values when making water allocation decisions. The court found that a variety of public trust interests, including Section 5937, pertain to nonnavigable streams that sustain a fishery; therefore, because the Mono Lake tributaries are capable of sustaining natural fisheries, the public trust interest of Section 5937 applies to the Mono Lake tributaries.

Current Status. Following the issuance of the writ of mandate by the Sacramento County Superior Court, the *Caltrout I* case was transferred on August 29, 1989, by Judge Finney to El Dorado County Superior Court and coordinated with the Mono Lake and Mono Lake tributary cases under the title of "Mono Lake Water Right Cases".

***California Trout, Inc. v. Superior Court* 218 Cal.App.3d 187 (1990) (*Caltrout II*)**

Background. In 1989, California Trout, Audubon, and the Mono Lake Committee petitioned the Court of Appeal challenging the writ of mandate the Sacramento County Superior Court had entered pursuant to *Caltrout I.* The questions presented concerned the content of the conditions that should be added to LADWP water right licenses, the establishment of permanent or long-term numerical instream flow requirements, and the interim instream flow requirements to be maintained pending the establishment of the long-term requirements.

Court Decision. The Court of Appeal entered a writ of mandate that set aside the writ from the trial court. The court stated that its opinion in *Caltrout I* foreclosed any argument that SWRCB had authority to balance the public interest in competing water uses so as to set instream flow requirements that are insufficient to maintain fish in good condition; the court held that the legislature had already balanced the competing water uses when it enacted Section 5946 of the California Fish and Game Code. The court directed SWRCB to exercise its ministerial duty to amend LADWP's Mono Lake tributaries water right licenses to include the following:

> In accordance with the requirements of Fish and Game Code Section 5946, this license is conditioned upon full compliance with Section 5937 of the Fish and Game Code. The licensee shall release sufficient water into the streams from its dams to reestablish and maintain the fisheries that existed in them prior to its diversion of water.

The court recognized a division of responsibility between the trial court and SWRCB, and directed the trial court to set interim flow requirements pending the establishment and implementation of long-term release rates by SWRCB.

Current Status. Because the *Caltrout I* case was transferred to El Dorado County Superior Court and coordinated under the title of "Mono Lake Water Right Cases", Judge Finney incorporated the directive of *Caltrout II* within the other Mono Lake issues. On April 4, 1990, SWRCB amended LADWP's water right licenses to include the language specified by the Court of Appeal.

***Dahlgren v. City of Los Angeles* (Mono County Superior Court No. 8092)**

Background. Since the start of LADWP's water diversions in lower Rush Creek, a tributary of Mono Lake, the creek has not contained significant flows. After the heavy rains in the mid-1980s, water and fish spilled over an LADWP dam into the creekbed. To sustain the small population of fish, the plaintiffs, including the Mono Lake Committee and Audubon, brought suit to stop LADWP from reducing the flow of water in Rush Creek, based on Section 5937 of the California Fish and Game Code.

Court Decision. On March 7, 1985, the Mono County Superior Court issued a preliminary order to LADWP to allow flows for fish in Rush Creek of at least 19 cubic feet per second (cfs).

Current Status. In 1986, the parties involved agreed to postpone trial pending completion of fish habitat studies by the California Department of Fish and Game. On March 23, 1989, the case was transferred to El Dorado County Superior Court, assigned to Judge Finney, and coordinated with the Mono Lake and other Mono Lake tributary cases under the title of "Mono Lake Water Right Cases".

Mono Lake Committee v. City of Los Angeles **(Mono County Superior Court No. 8608)**

Background. Since the start of LADWP's water diversions in lower Lee Vining Creek, another tributary of Mono Lake, the creek has not contained significant flows. After the heavy rains in the mid-1980s, water and about 300 adult trout spilled over the LADWP dam into the creekbed. To sustain the small population of trout, the Mono Lake Committee brought suit to stop LADWP from reducing the flow of water in lower Lee Vining Creek below 20 cfs, based on Section 5937 of the California Fish and Game Code.

Court Decision. On October 22, 1987, the Mono County Superior Court issued a preliminary injunction requiring a water release of 4-5 cfs for fish in Lee Vining Creek.

Current Status. On March 23, 1989, the case was transferred to El Dorado County Superior Court, assigned to Judge Finney, and coordinated with the Mono Lake and other Mono Lake tributary cases under the title of "Mono Lake Water Right Cases".

In the Matter of Mono Lake Water Right Cases **(El Dorado County, Superior Court Coordinated Proceeding Nos. 2284 and 2288)**

Background. This coordinated action includes the five lawsuits described above. The lawsuits seek various forms of relief, including establishing a minimum water elevation for Mono Lake; providing instream flows on Rush and Lee Vining Creeks, which are tributary to Mono Lake; and amending LADWP's water right licenses to require instream flows. The activities of the coordinated cases are as follows:

- On March 23, 1989, the Judicial Council coordinated the *National Audubon Society v. Superior Court, Dahlgren v. City of Los Angeles,* and *Mono Lake Committee v. City of Los Angeles* cases and assigned them to Judge Finney in the El Dorado County Superior Court.

- On August 22, 1989, the El Dorado County Superior Court issued an order granting a preliminary injunction prohibiting LADWP from causing the level of Mono Lake from falling below 6,377 feet for the remainder of the current runoff year ending March 31, 1990.

- On August 29, 1989, Judge Finney ordered that *California Trout, Inc. v. State Water Resources Control Board* and *National Audubon Society v. the State Water Resources Control Board* be coordinated with the other three cases and issued a stay until completion of SWRCB proceedings or September 1993 (whichever comes first) on further litigation on the merits of any of the coordinated cases. This ruling was based on the court's review of SWRCB's Mono Basin work plan, which calls for preparation of this EIR and adoption of a water right decision amending LADWP water right licenses by December 1992. The court ruled on December 17, 1992 to extend the stay order until September 1, 1994 or completion of the SWRCB proceedings, whichever comes first.

- On December 6, 1989, the El Dorado County Superior Court entered a preliminary injunction in accordance with the August 22, 1989 order. The court ordered that LADWP must allow sufficient water to pass its diversion facilities on Rush Creek and Lee Vining Creek to maintain the level of Mono Lake at or about 6,377 feet. Water is to be released into Rush Creek at a rate between 85 and 100 cfs. Water is to be released into Lee Vining Creek at 60 cfs or the rate of inflow into LADWP's diversion facility, if it is less.

- On April 4, 1990, SWRCB amended LADWP water right licenses for the appropriation of Mono Lake tributaries to include the mandated language regarding fish protection flows, pursuant to *Caltrout II* (SWRCB Order 90-3).

Court Decision. On June 14, 1990, pursuant to the *Caltrout I* and *Caltrout II* decisions, the El Dorado County Superior Court entered a preliminary injunction that established interim flow rates for the diverted Mono Lake tributaries (Table R-1). The net result of this interim streamflow order compels LADWP to release approximately 60,000 af of water yearly down Mono Lake tributaries. Because of these new requirements, the prior preliminary injunctions requiring minimum flows were superseded.

On April 17, 1991, the El Dorado County Superior Court issued a preliminary injunction that requires LADWP to allow sufficient water to pass its diversion facilities to maintain the level of Mono Lake at or above 6,377 feet. The court noted that the extra 60,000 af required by the June 14, 1990 order would not sustain the level of Mono Lake at 6,377 feet.

LEGAL HISTORY OF THE OWENS BASIN DIVERSIONS

Summary of Litigation

Owens River drains the Owens Valley, with its headwaters in Long Valley in Mono County and its terminus at Owens Lake. In 1940, the City of Los Angeles, through LADWP, was granted a permit that allowed for the appropriation of water from the Owens

River. In 1963, the City of Los Angeles authorized the construction of a new aqueduct to transport the water as contemplated by the permit; the aqueduct was completed in 1970.

In 1972, the County of Inyo brought suit against the City of Los Angeles, claiming that LADWP operations, in supplying the new aqueduct, were harming the environment of Owens Valley and that CEQA required preparation of an EIR. In 1973, the Court of Appeal held that the City of Los Angeles had to prepare an EIR (*County of Inyo v. Yorty*, 32 Cal.App.3d 795). In succeeding years, the city unsuccessfully attempted to satisfy the court order, with the court directing each time that certain further steps must be taken to comply with CEQA (*County of Inyo v. City of Los Angeles*, 71 Cal.App.3d 185 [1977] and *County of Inyo v. City of Los Angeles*, 124 Cal.App.3d 1 [1981]).

The County of Inyo and the City of Los Angeles in 1984 entered into an interim agreement that suspended litigation and called for cooperative studies and development of a long-term groundwater management plan. The court approved this interim agreement in a court order; a draft EIR, prepared in conjunction with the long-term groundwater management plan, was released in September 1990. The final EIR will be submitted to the court; on certification of the final EIR by LADWP and the County of Inyo, the court may discharge the litigation between the County of Inyo and the City of Los Angeles.

SWRCB issued LADWP a license in 1974 confirming the right for diversion of water from the Owens River at Long Valley Dam. As in the case of the Mono Basin diversion water right licenses also issued in 1974, the Owens River water right license did not contain any terms or conditions requiring bypass of water for any purposes. As described above, the California Court of Appeal ruled that with respect to water right licenses issued after September 9, 1953, SWRCB has a ministerial duty to condition the licenses to require compliance with Sections 5937 and 5946 of the California Fish and Game Code (*Caltrout I* and *Caltrout II*).

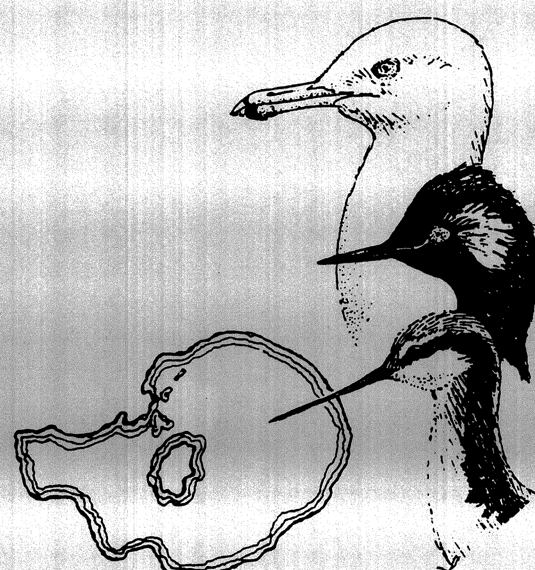
On May 29, 1991, SWRCB amended LADWP's water right license for diversion of water from the Owens River to include the condition requiring, in accordance with Section 5946, compliance with Section 5937 of the California Fish and Game Code (SWRCB Order 91-04). SWRCB did not, however, establish numerical instream fishery protection flow requirements as a condition of the license because requirements could be established only "based on an adequate evidentiary record and following notice and opportunity for hearing". Until numerical flow requirements are established, SWRCB requires that LADWP consult with the staffs of SWRCB; the California Department of Fish and Game; and the California Regional Water Quality Control Board, Lahontan Region to determine appropriate instream flows. The consultations should include consideration of an appropriate method of restoring flows that will not create unreasonable impacts on instream resources or adversely affect any state-listed or federally listed endangered species.

Table R-1. Court-Ordered Interim Flows for Mono Lake Tributaries

Stream	Time Period	Flows (cfs)
Rush Creek	April-September	40
	October-March	28
	Spring flushing flow[a]	165
Lee Vining Creek	April-September	35
	October-March	25
	Spring flushing flow[a]	160
Parker Creek	April-September	9
	October-March	6
	Spring flushing flow[a]	23
Walker Creek	April-September	6
	October-March	4.5
	Spring flushing flow[a]	15

[a] For 3 days every "below normal runoff year" or for 30 days every "normal to above normal runoff year", water intended for "channel maintenance" purposes (only in even-numbered years for Rush and Lee Vining Creeks).

Appendix S. Auxiliary Reports List



Appendix S. Auxiliary Reports List

1. Stine, S. 1991. Extent of riparian vegetation on streams tributary to Mono Lake, 1930-1940; an assessment of the streamside woodlands and wetlands, and the environmental conditions that supported them.

2. Morrison, M. 1991. Vertebrate surveys on Paoha Island and adjacent mainland, Mono Lake and basin, California.

3. Harris, J. H. 1991. Wildlife surveys in riparian and wetland habitats in the Mono Lake basin and Upper Owens Valley, California.

4. Stromberg, J., and D. Patten. 1991. Response of *Salix lasiolepis* to augmented stream flows in the Upper Owens River.

5. Luhdorff & Scalmanini Consulting Engineers. 1992. LAAMP (Los Angeles Aqueduct Monthly Program) Documentation, Version 2.

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10. Balance Hydrologics, Inc. 1992. Changes over time in geomorphic conditions, sediment transport and riparian cover in the Owens River below Pleasant Valley Dam, Inyo County, California.

11. Rubega, M. 1992. Feeding limitations and ecology of red-necked phalaropes at Mono Lake, with incidental observations on other species.

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15. Jellison, R., and J. M. Melack. 1992. Meromixis in hypersaline Mono Lake, California; 1: Stratification and vertical mixing during the onset, persistence, and breakdown of meromixis.

16. Jellison, R., and J. M. Melack. 1992. Algal photosynthetic activity and its response to meromixis in hypersaline Mono Lake, California.

17. Jones & Stokes Associates, Inc. 1993. Water quality data report.

18. Jones & Stokes Associates. 1993. Summary of Hydrologic Simulations.

19. Balance Hydrologics, Inc. 1993. Associations between shallow groundwater levels, salinities, and vegetation at two wetlands fringing Mono Lake, Mono County, California.

20. Stine, S. 1993. Distribution of substrate types at Mono Lake, California.

21. Stine, S. 1993. Historic and modern distribution of shore-fringing wetlands, Mono Lake, California.

22. Stine, S. 1992. Lake fluctuation-induced changes in the size and configuration of the Mono Islands.

23. Jones & Stokes Associates, Inc. 1992. Middle Owens Instream Flow Incremental Methodology Study.

24. EDAW, Inc. 1993. Visual resources of the Mono Lake Basin and the Owens River Basin.

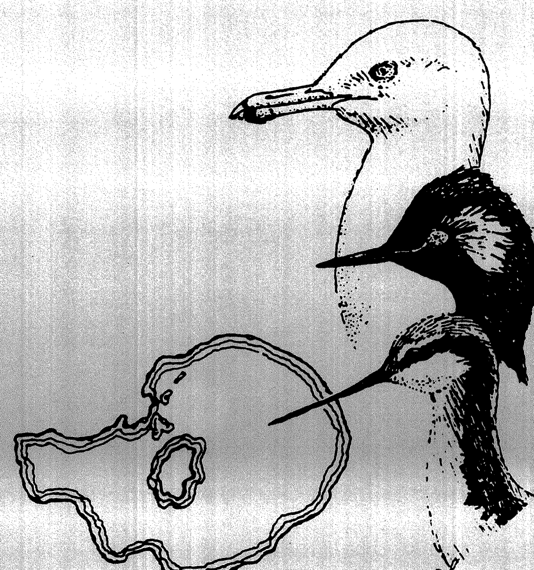
25. Balance Hydrologics, Inc. 1993. Interactions between surface and groundwater in potential riparian habitat zones of the Mono Basin, Mono County, California.

26. Jones & Stokes Associates, Inc. 1993. Dust storm modeling impacts and results.

27. Jones & Stokes Associates, Inc. 1993. Lake-fringing wetland vegetation and substrate classification, description, and mapping.

28. Michael Hanemann. 1992. Projected M&I demand 1990-2010.

Appendix T. Hydrologic Characteristics of the Owens River Basin below the Upper Owens River



MONO BASIN EIR

Prepared by Jones & Stokes Associates

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Appendix T. Hydrologic Characteristics of the Owens River Basin below the Upper Owens River

The hydrology of Mono Basin is described in detail in Chapter 3A. This appendix describes the Owens River basin hydrology that is indirectly affected by Mono Basin exports.

Lake Crowley Reservoir Watershed Runoff

The watershed of Lake Crowley reservoir includes the Upper Owens River and several tributary creeks (Figure 1-1). Mammoth Creek joins Hot Creek near the Hot Creek Hatchery, upstream of Hot Springs. Convict and McGee Creeks join just upstream of Lake Crowley reservoir. Hilton and Crooked Creeks flow directly into Lake Crowley reservoir. Excess streamflow from Rock Creek can be diverted to Lake Crowley reservoir.

The average annual runoff from Lake Crowley reservoir watershed (Long Valley) is about 118 thousand acre-feet per year (TAF/yr), not including the Hot Creek Hatchery and Hot Springs flow of 30 TAF/yr and the Mono Tunnel groundwater flow of 12 TAF/yr.

Because of significant geothermal activity, several large hot springs have formed in the basin. The largest is Hot Springs, located along Hot Creek. The average annual discharge from Hot Springs (and the cool springs at Hot Creek Hatchery located upstream) of about 30 TAF/yr (41.5 cfs) flows directly into Hot Creek, which joins the Owens River just above Lake Crowley reservoir.

Significant diversions are made from the Owens River and Hot Creek for irrigation of LADWP and private grazing pasturelands. LADWP records indicate that an average of 20 TAF/yr are diverted for irrigation of its lands. This represents significantly more than the actual evapotranspiration losses, however. Excess diverted water returns to the Owens River or recharges the groundwater flowing to Lake Crowley reservoir. LADWP records suggest that unaccounted gains that may include irrigation return flows upstream of Lake Crowley reservoir average 39 TAF/yr.

The LADWP station at Long Valley Dam (elevation 6,700 feet) measures average rainfall of about 10 inches, and a station at Lake Mary measures 28.8 inches. Snowpack water content on April 1 ranges from 20 to 42 inches in the surrounding watersheds at elevations of 8,300-9,500 feet and shows the increase in snowpack with elevation on the east side of the Sierra Nevada.

Evaporative losses at Lake Crowley reservoir are estimated from observations at an evaporation pan station located at Long Valley Dam, where records are kept only for ice-free months of the year. The average monthly evaporations for the land and lake pans are given in Table 3A-4.

Round Valley Runoff

The major Owens River tributaries in Round Valley are Rock, Pine, and Horton Creeks. The combined runoff from these creeks is approximately 66 TAF/yr. Birchim Canyon springs, located on Rock Creek just upstream of its confluence with the Owens River, has a long-term annual flow volume of about 17 TAF/yr. This spring discharge is not included in the runoff measurements used by LADWP to index water-year types.

Snow course measurements are available from three stations in Round Valley. Rock Creek 3 (elevation 10,000 feet) has an average April 1 water content of 15 inches. Rock Creek 2 (elevation 9,050 feet) has an average water depth of 10.4 inches, and Rock Creek 1 (elevation 8,700 feet) has an average water depth of 7.4 inches. These measurements illustrate the decrease in snowpack with decreasing elevation. Rainfall at Rock Creek averages 17.1 inches per year. Several other rainfall and snow course measurement stations are listed in Table 3A-2.

Major diversions are made from Rock, Pine, and Horton Creeks for irrigated pasture-lands in Round Valley. LADWP records for 1970-1989 were used to estimate a total irrigation diversion of approximately 9 TAF/yr. Pine Creek joins Rock Creek at the bottom of Round Valley and flows through Birchim Canyon to the Owens River. Some of Horton Creek's runoff is diverted by Southern California Edison (SCE) to Bishop Creek for hydropower generation.

Middle Owens River Runoff

The Middle Owens River is the segment between Pleasant Valley Reservoir and the Los Angeles Aqueduct (LA Aqueduct) intake downstream of Tinemaha Reservoir. Because river diversions and groundwater pumping for irrigated pastureland and recreational uses are made in three distinct areas (Laws, Bishop, and Big Pine), these in-basin water use areas are considered separately in the Los Angeles Aqueduct Monthly Program (LAAMP) operations model.

Laws Area Runoff

Laws area runoff is the sum of several small creeks that flow out of the White Mountains, with an average annual volume of less than 4 TAF. Two White Mountain rainfall stations average 13.1 and 18.8 inches per year (Table 3A-2). Very little of the water actually flows into the Owens River, as most is diverted for irrigation use or infiltrates to groundwater. Fish Slough is a wetland and stream located in the Laws area with a relatively constant flow of approximately 6 TAF/yr.

Laws area irrigation diversions from the Owens River are made from upper and lower McNally canals in normal and wet years. Irrigation requirements of approximately 5 TAF/yr are satisfied with groundwater pumping in dry years. The McNally canals are used to divert Owens River flow for spreading to allow groundwater recharge in the Laws area during wet years. The combined capacity of the canals is approximately 100 cubic feet per second (cfs), allowing about 6,000 acre-feet (af) of spreading per month of available excess flow. LADWP records indicate that the unaccounted-for losses in the Laws area total 5 TAF/yr. These surface water losses presumably infiltrate and recharge groundwater.

Groundwater pumping in the Laws area is often greater than the irrigation requirements. The wellfield capacity is limited by the Long-Term Groundwater Management Plan for the Owens Valley and Inyo County (Inyo County and City of Los Angeles 1990) to approximately 38 TAF/yr, including several "enhancement and mitigation" wells that pump water to be used at other locations within the Owens Valley. The excess pumping is conveyed in the McNally canals to Laws Ditch, which flows into the Owens River just north of the town of Bishop.

Bishop Area Runoff

Bishop area runoff averages 82 TAF/yr and is dominated by runoff from Bishop Creek (69 TAF/yr). Seasonal storage by SCE for hydropower generation occurs in Lake Sabrina, with a maximum storage capacity of about 20 TAF. Diversions are made from Horton, McGee, and Birch Creeks. Several SCE hydropower plants are located along Bishop Creek. The releases from the lowest hydropower plant, which include diversions from several nearby creeks, average 80.5 TAF/yr. Bishop Creek splits into several distributaries as it flows across the alluvial fan deposits and through the town of Bishop toward the Owens River.

Artesian groundwater wells along the Owens River discharge approximately 4.5 TAF/yr into the Owens River in the Bishop area. These wells were drilled by LADWP during the 1920s to supplement Owens River flows. They essentially discharge the excess groundwater recharge from Bishop Creek. Additional inflow of groundwater seepage occurs along the Middle Owens River, but a net loss of streamflow in the Owens River between the towns of Bishop and Big Pine is caused by evapotranspiration and infiltration of streamflow to groundwater.

Bishop area irrigation diversions from the Owens River are made just downstream of Horton Creek into the Bishop Canal. The canal capacity is approximately 80 cfs, and average annual diversions are about 25 TAF/yr. Diversions are greater in dry years (30 TAF/yr) and less in wet years (15 TAF/yr) when Bishop Creek runoff supplies more of the Bishop area irrigation requirements. Irrigation diversions are made from a network of canals and drains that connect with Bishop Creek. The major return for excess runoff or unused canal diversions is the A-drain, located several miles south of the town of Bishop, just downstream from the Big Pine canal diversion from the Owens River. LADWP records indicate that the unaccounted-for losses in the Bishop area total about 23 TAF/yr. These losses presumably recharge the groundwater.

Groundwater pumping in the Bishop area is limited to irrigation requirements within the Bishop area, according to the Bishop Cone Settlement Agreement. The wellfield capacity is approximately 20 TAF/yr, although annual pumping is limited to 12 TAF/yr (Inyo County and City of Los Angeles 1990).

Irrigation requirements in the Bishop area are approximately 21 TAF/yr, with an additional recreation and wildlife use of 4.5 TAF/yr, and uses of 3.25 TAF/yr on Indian lands. All these uses are seasonal, with peak usage in summer.

Precipitation averages 16.8 inches per year at Lake Sabrina (elevation 9,065 feet) but only 5.7 inches per year at Bishop (elevation 4,108 feet). Bishop Pass (elevation 11,200 feet) has an average April 1 snow pack water content of 33.2 inches (Table 3A-2).

Big Pine Area Runoff

Big Pine area runoff totals approximately 52 TAF/yr. Most of this is from Big Pine Creek. LADWP operates a hydropower plant on Big Pine Creek. Tinemaha Creek flows directly into Tinemaha Reservoir. The runoff from these creeks is natural; no seasonal storage facilities are located upstream.

Big Pine canal diverts water from the Owens River to supply water for irrigation and recreation (including water for use on Indian lands) in the Big Pine area, and to allow spreading for groundwater recharge. The total requirement for irrigation and recreational use is approximately 15 TAF/yr. The canal capacity for spreading is about 4.5 TAF per month (75 cfs). LADWP records indicate that unaccounted-for losses in the Big Pine area total about 20 TAF/yr, including Tinemaha Reservoir evaporation.

Fish Springs Hatchery, located south of the town of Big Pine, was originally supplied by natural springflow. As groundwater pumping for irrigation and export was increased, however, the natural springflow was reduced. The hatchery supply was augmented by two wells that now supply most of the water (24 TAF/yr) for the hatchery. Once used in the hatchery, the water flows down the Fish Springs canal to the Owens River just upstream of Tinemaha Reservoir.

The combination of releases and storage changes at Tinemaha Reservoir provides a complete record of Owens River streamflow there. The net losses along the Middle Owens River between Pleasant Valley and Tinemaha Reservoirs is estimated at approximately 37 TAF/yr.

The total wellfield capacity in the Big Pine area is approximately 42 TAF/yr. Most of the water is used for the hatchery supply and so is not lost to evapotranspiration. The excess pumping and return from the Big Pine canal and Big Pine Creek diversions flow to the Owens River in the Fish Springs canal.

Rainfall at Tinemaha Reservoir is 6.6 inches per year. Rainfall at Big Pine Power Plant has averaged 9.0 inches per year. Snow course measurements made in the Big Pine Creek watershed range from 15.2 to 22.7 inches (Table 3A-2).

Tinemaha Reservoir

Tinemaha Reservoir was constructed by LADWP to provide short-term regulation of Owens River flows, to allow the maximum amount of flow to be diverted into the LA Aqueduct. The maximum storage is approximately 16 TAF, although earthquake safety concerns have limited the usable storage to 10 TAF in recent years. The monthly pattern of evaporation of Tinemaha Reservoir is given in Table 3A-4.

Releases from Tinemaha Reservoir are usually diverted into the LA Aqueduct intake at Aberdeen, but excess water occasionally flows down the Owens River channel toward Owens Lake, south of Lone Pine.

Tinemaha-to-Haiwee Area Runoff

The remainder of the Owens Valley runoff occurs in the segment of the basin between Tinemaha Reservoir and Haiwee Reservoir. The LA Aqueduct intake from the Owens River is located just downstream of Tinemaha Reservoir near Aberdeen. Runoff from several eastern Sierra Nevada creeks, from Taboose Creek in the north to Haiwee Creek in the south, are intercepted by the LA Aqueduct. Lone Pine Creek drains the eastern slopes of Mount Whitney. LADWP has hydropower plants that divert water from Division Creek and Cottonwood Creek. The combined runoff from these creeks is about 105 TAF/yr. Springs and artesian wells along the aqueduct supply additional flow during wet periods but are limited in dry years.

Diversions from the creeks and releases from the aqueduct total approximately 23 TAF/yr, including water for Indian lands and recreation and enhancement uses. Some returns from irrigation west of the aqueduct may be captured by the aqueduct or groundwater pumping, but releases and returns from uses east of the aqueduct flow toward Owens Lake and are not returned to the LA Aqueduct.

Groundwater pumping occurs in several wellfields between Tinemaha and Haiwee Reservoirs, with a total annual limit of about 100 TAF/yr (Inyo County and City of Los Angeles 1990). Most of this groundwater is pumped directly into the LA Aqueduct for export to Los Angeles. The Black Rock Hatchery is supplied by groundwater pumping.

Pumping is lowest during the runoff period in wet years and increases in fall and winter to help maintain a constant water supply for the aqueduct.

Spreading of excess Tinemaha-to-Haiwee runoff is used to recharge groundwater for later pumping into the aqueduct. The spreading capacity in the Tinemaha-to-Haiwee area is about 20 TAF per month (335 cfs) and is accomplished with diversions from several of the creeks over the alluvial fans at the base of the mountains west of the aqueduct. During periods of excess runoff, operational spills must also be made east of the aqueduct toward Owens Lake. In most cases the creek runoff bypasses the aqueduct diversions. At other times releases are made from the aqueduct. LADWP estimates that unaccounted-for losses in the Tinemaha-to-Haiwee segment of the Owens River basin average 32.5 TAF/yr.

Haiwee Reservoir

Located south of Owens Lake, North and South Haiwee Reservoirs provide a combined storage volume of 60 TAF. Dam earthquake safety concerns have limited the usable storage to 15 TAF in recent years. Releases from Haiwee Reservoir flow down the LA Aqueduct conduits to Los Angeles. A series of power plants is located along the aqueduct conduits (see Chapter 3M, "Power Generation", for a description of these aqueduct power plants).

Rainfall, measured at South Haiwee Reservoir (elevation 3,825 feet), averages 6.5 inches per year (Table 3A-2). The monthly evaporation rates are given in Table 3A-4.

Other Los Angeles Aqueduct Facilities

Bouquet Reservoir is located west of Palmdale in the Sierra Madre Mountains north of San Fernando. The reservoir provides storage for short-term regulation and for emergency supply should something interrupt the aqueduct between it and Haiwee Reservoir (the San Andreas fault crosses the LA Aqueduct north of Bouquet Reservoir). The aqueduct terminates at the Van Norman Reservoir in the northern San Fernando Valley. The LA Aqueduct filtration plant is now located just north of the Van Norman Reservoir.

These aqueduct facilities south of Haiwee Reservoir are not considered in the aqueduct operations model. The hydrologic effects of the EIR alternatives are traced only to the Haiwee Reservoir exports to Los Angeles.

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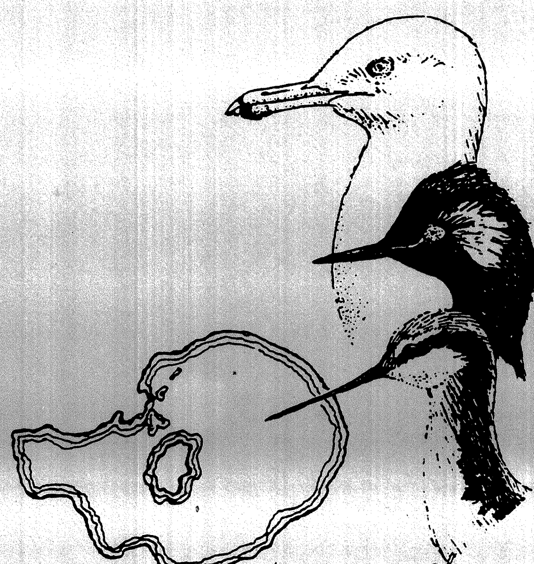
Appendix U. Efflorescence Persistence



Mono Basin EIR

Prepared by Jones & Stokes Associates

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Appendix U. Efflorescence Persistence

Since the surface of Mono Lake was lowered by diversion of the tributary streams, large areas of the relicted lands have exhibited ongoing salt efflorescence. The persistence of efflorescence around much of the eastern lakeshore is a limiting factor to the colonization of relicted lands by plants and to the eventual reduction in severe dust storms. Because inflowing saline groundwater from basin sediments is the probable cause of efflorescence, an estimate of the time required for the groundwater table to equilibrate with the drawn-down lake surface can provide a reasonable order-of-magnitude estimate of its duration.

ESTIMATE OF GROUNDWATER RESPONSE PERIOD

A simple model of the groundwater in the basin sediments can be developed and applied for this purpose (Figure U-1) although the sediments are, in fact, a complex sequence of aquifers and aquitards. Assuming the lowering of the lake surface by 41 feet must be followed by a similar lowering of the water table near the lake, with a gradual lessening of the water table lowering toward the upper edge of the adjacent basin sediments, the volume of water (per unit cross-sectional area) to be drained in this wedge is:

0.5 x 41 ft x 4-8 miles x average sediment specific yield

The specific yield of silts, which make up the bulk of the observed lakebeds (LaJoie 1966), is generally about 20-35% (Davis and DeWiest 1966). A value of 30-45% holds for fine sands.

The rate at which groundwater drainage occurs (per unit cross-sectional area) is proportional to the slope of the groundwater table (where unconfined), as well as to the transmissivity (K) of the medium. Measured groundwater slope at a piezometer transect near Ten-Mile Road is now about 0.8% (NAS 1987), and the groundwater levels estimated several miles east of the lake suggest an average water table slope to the lakeshore of 0.6% (Lee 1969).

Transmissivity of sediments can vary substantially, but a range of average values can be estimated. Transmissivities of silts have been reported as 0.2-0.3 darcys, or 10^{-5} feet per second (Davis and DeWiest 1966). In order-of-magnitude terms, clayey sands and fine sands have transmissivities of 10^{-5} to 10^{-8} feet per second, as opposed to higher values for "clean sands" (Davis and DeWiest 1966). A transmissivity of 10^{-5} feet per second can therefore be used as the maximum estimated value.

The time period for equilibration is obtained from the water volume drained divided by the average discharge rate. The formula thus becomes:

T(sec) = [specific yield (%) s discharging sediment distance (ft)]/
[transmissivity (ft/sec) X averange slope (ft/ft)]

(where factors of 0.5 in both unit volume and average discharge rate cancel.)

Employing the values for these variables described above, recognizing the groundwater slope after equilibration will be only slightly greater and using the fact that 1 year = 3.1×10^7 sec, the calculated equilibration period is:

T (yrs) = 3,500-7,000 years

Because of the uncertainty in assumed transmissivity, the uncertainty of this estimate is probably one order of magnitude.

It is concluded that the efflorescence process initiated by the drawdown of Mono Lake by stream diversions will persist for at least hundreds of years. During this period, the band of efflorescence will gradually narrow toward the current shoreline, gradually allowing the higher elevations to support vegetative colonization.

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NAS. 1987. See Mono Basin Ecosystem Study Committee of the National Research Council, National Academy of Sciences.

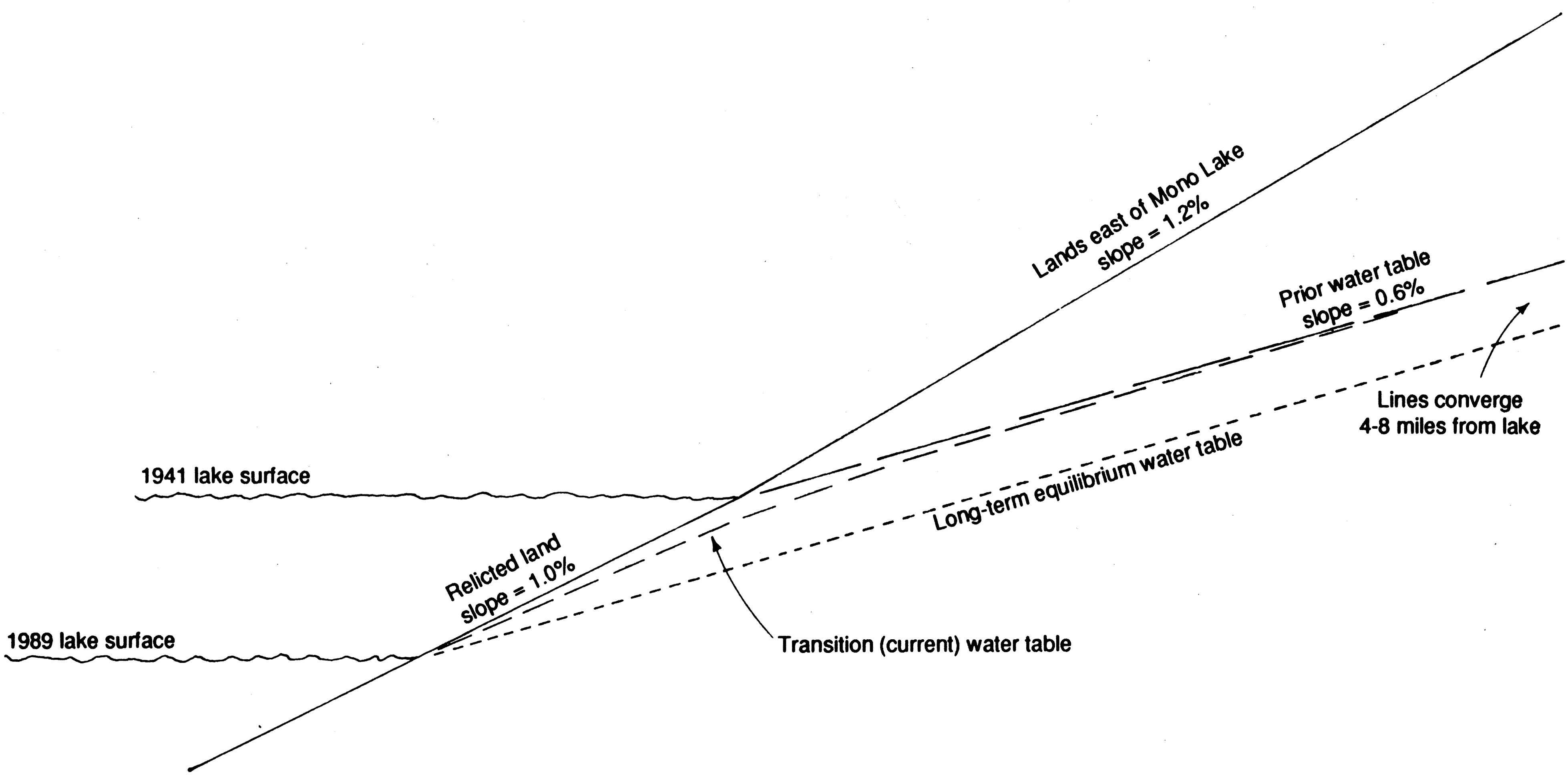
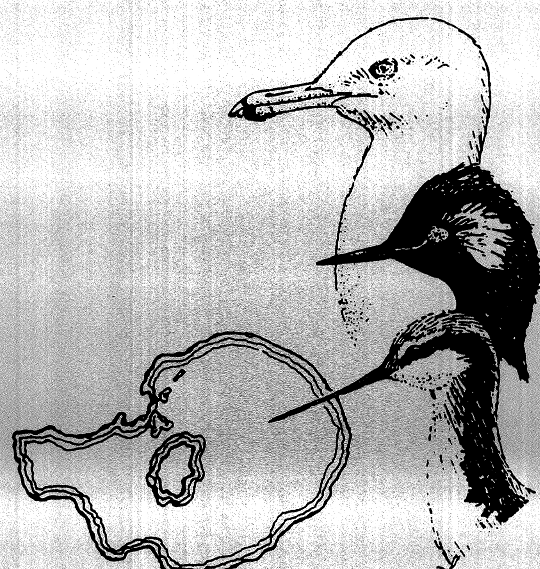


Figure U-1.
Conceptual Water Table at the East Shore of Mono Lake

Appendix V. Visual Resources



Mono Basin EIR

Prepared by Jones & Stokes Associates

List of Tables and Figures

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Appendix V. Visual Resources

This technical appendix describes the procedures followed in conducting the visual preference survey of Mono Lake visitors and summarizes the results of the survey. The photosimulations of Mono Lake under alternative lake level conditions that were used in the preference survey also are shown.

The objectives of the visual preference survey were to obtain judgments of scenic quality of scenes depicting Mono Lake at different lake levels, to determine preferences for those scenes, and to identify key elements that affect scenic quality. The surveys used a total of 25 photographic images of Mono Lake (Table V-1). Five different scenes were represented, including South Tufa, Mono Lake County Park, the Mono Lake Vista Point along U.S. Highway 395 (U.S. 395) near Conway Summit, the U.S. Forest Service Visitors Center, and U.S. 395 at a point west of the Old Marina. Five variations of each of the scenes named above were simulated, each depicting a different lake surface elevation: 6,372 feet, 6,374.5 feet (the lake elevation that existed at the time the baseline photographs were taken), 6,380 feet, 6,390 feet, and 6,410 feet (Figures V-1 through V-5).

In September 1992, interviews of Mono Lake visitors were conducted at South Tufa (at the parking lot), Mono Lake County Park (at the parking lot or immediately adjacent areas such as the deck on the east side of the county park building or the large lawn area just south of the parking lot), and at the Mono Lake vista point. Respondents were randomly selected. Interviews were conducted during the hours of approximately 9:00 a.m. to 5:00 p.m. A total of 30-35 persons were interviewed at each of the three sites. Interviews were conducted at the same site for consecutive days until a total of approximately 33 responses were obtained.

Each interview consisted of three presentations. First, a random order presentation of images was made. The goal of this step was to obtain the public's judgment of scenic beauty for each of the 25 scenes. The images were presented in random order according to the scene being represented (i.e., vista point, South Tufa, and others), as well as lake surface elevation depicted. Respondents were shown all 25 images, one at a time. The scenes presented were 9.5-inch-by-13.5-inch photographic prints of single-frame scenes (i.e., of South Tufa, the Mono Lake County Park, and U.S. 395 near Old Marina). For the two-frame panorama from the Forest Service Visitors Center, two 8.5-inch-by-23.5-inch photographs were used, and, for the three-frame panorama from the vista point, 6.5-inch-by-23.5-inch photographs were used. The scenes were shuffled between interviews. For each of the 25 scenes, respondents were asked to provide their judgments of the scenic beauty by rating each scene on a response scale of 1 to 10 and marking their responses on a printed form. Respondents were told to consider a rating of 1 to mean very low scenic beauty and a rating of 10 to indicate very high scenic beauty. Each of the 25 scenes were rated by each respondent.

Once all 25 scenes had been individually rated, a comparative presentation of the images was made. The goal of this step was to determine if, among five variations of one scene, members of the public had a preference, and if so, what their preferences were. Five display boards were used for this component of the survey. Each of the five boards displayed the photographic images depicting the five lake surface elevations from one location. For example, one board displayed all five lake elevations as depicted in the scene from the Forest Service Visitors Center (Figure V-4). Another displayed all five as seen from Mono Lake County Park (Figure V-2). The images were arranged on the display board in order from lowest to highest lake surface elevation to allow direct comparison. The display boards were presented to respondents one at a time and in random order of scene depicted (viewpoint). The display boards were shuffled between interviews. For each board, after viewing the images, respondents were asked if they had a preference for any of the images among the five being displayed. If they responded positively, they were asked to rank the five images on a scale of 5 to 1 with 5 the most preferred and 1 the least preferred. This procedure was repeated for each of the five display boards, one at a time, for each interview.

Finally, respondents were shown a series of photographs, each focusing on one of the landscape elements (such as water-based tufa, land-based tufa, or playa) and asked to rate the importance of the element to the overall scenic beauty of the study area. The goal of this step was to identify, among the specific landscape features that are expected to be changed by project alternatives, those that contribute positively to the scenic quality of Mono Basin and their degree of importance, as well as the features that detract from scenic beauty. The rating scale for this step was from -5 to +5. Positive or negative ratings indicated a beneficial or adverse influence of an element on scenic beauty, and the number rating indicated the strength of the effect.

For each member of the public surveyed, the random presentation component of this study yielded one response (rating of scenic beauty) for each of the 25 scenes. For the comparative component, five responses (ranked from 1 to 5) were provided by each respondent for each of the five scenes (viewpoints). This process produced 2,500 responses for each component. These raw data were organized in tabular format, and, using the concepts and methods discussed in the USFS's Research Paper RM-293 and employing the USFS's analysis of ratings computer program, known as RMRATE, mean ratings were produced. From these data an analysis of variance (ANOVA) by stimuli (viewpoints and lake surface elevations) and by observer (respondents) was performed. The open-ended question yielded a list of features or conditions. Correlations between these responses were analyzed.

The results of these analyses are summarized in Tables V-2 through V-4.

Table V-1. List of Photographic Images Used in the Visual Preference Survey

MONO LAKE VISITOR SURVEY

Scene No.	Location	Elevation (feet)
Scene 1	South Tufa	6410
Scene 2	South Tufa	6390
Scene 3	South Tufa	6380
Scene 4	South Tufa	6374.5
Scene 5	South Tufa	6372
Scene 6	Old Marina	6410
Scene 7	Old Marina	6390
Scene 8	Old Marina	6380
Scene 9	Old Marina	6374.5
Scene 10	Old Marina	6372
Scene 11	Visitor Center	6410
Scene 12	Visitor Center	6390
Scene 13	Visitor Center	6380
Scene 14	Visitor Center	6374.5
Scene 15	Visitor Center	6372
Scene 16	County Park	6410
Scene 17	County Park	6390
Scene 18	County Park	6380
Scene 19	County Park	6374.5
Scene 20	County Park	6372
Scene 21	Vista Point	6410
Scene 22	Vista Point	6390
Scene 23	Vista Point	6380
Scene 24	Vista Point	6374.5
Scene 25	Vista Point	6372

Table V-2. Results of Visual Preference Survey at Mono Lake: Average Scenic Beauty Score for each Scene (1-10 Scale)

Scene	Average Score
1	5.63
2	6.61
3	6.68
4	6.23
5	7.40
6	7.40
7	7.23
8	6.01
9	7.16
10	6.52
11	6.81
12	6.60
13	6.35
14	7.30
15	6.51
16	7.47
17	7.73
18	6.08
19	6.87
20	6.41
21	6.46
22	5.99
23	7.07
24	5.70
25	7.51

Table V-3. Results of Visual Preference Survey at Mono Lake: Ranking of Scenes from Most Preferred to Least Preferred

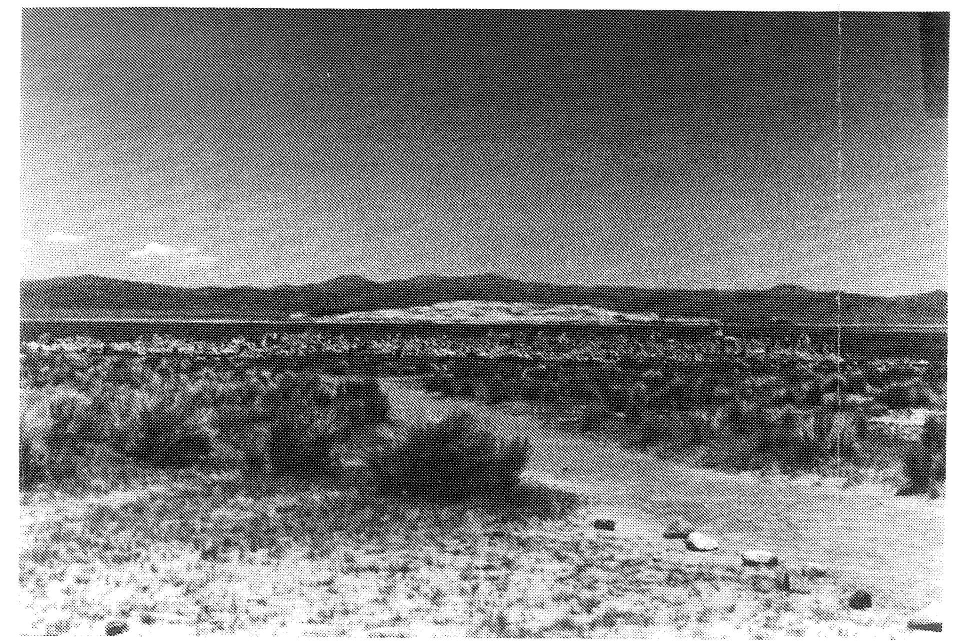
	First (Most Preferred)	Second	Third	Fourth	Fifth (Least Preferred)	No Preference
Board 1, Scene 1	8	4	10	9	32	39
2	6	2	14	28	11	41
3	11	7	39	5	0	40
4	22	34	4	3	3	36
5	42	14	9	2	3	32
Board 2, Scene 1	7	8	6	8	66	7
2	8	12	7	58	7	10
3	8	11	64	5	4	10
4	17	51	10	12	3	9
5	66	13	3	3	14	3
Board 3, Scene 1	17	6	6	7	51	15
2	3	10	14	51	6	18
3	15	16	51	3	3	14
4	14	51	6	9	5	17
5	53	11	6	4	13	15
Board 4, Scene 1	7	15	13	26	31	10
2	4	13	41	29	3	12
3	13	40	29	12	1	7
4	69	20	2	7	0	4
5	18	14	8	5	54	3
Board 5, Scene 1	19	17	11	19	20	16
2	11	17	36	19	3	16
3	20	36	23	8	1	14
4	43	26	13	9	3	8
5	32	10	9	5	43	3

Table V-4. Results of Visual Preference Survey at Mono Lake: Rating of Visual Elements of Scenic Quality

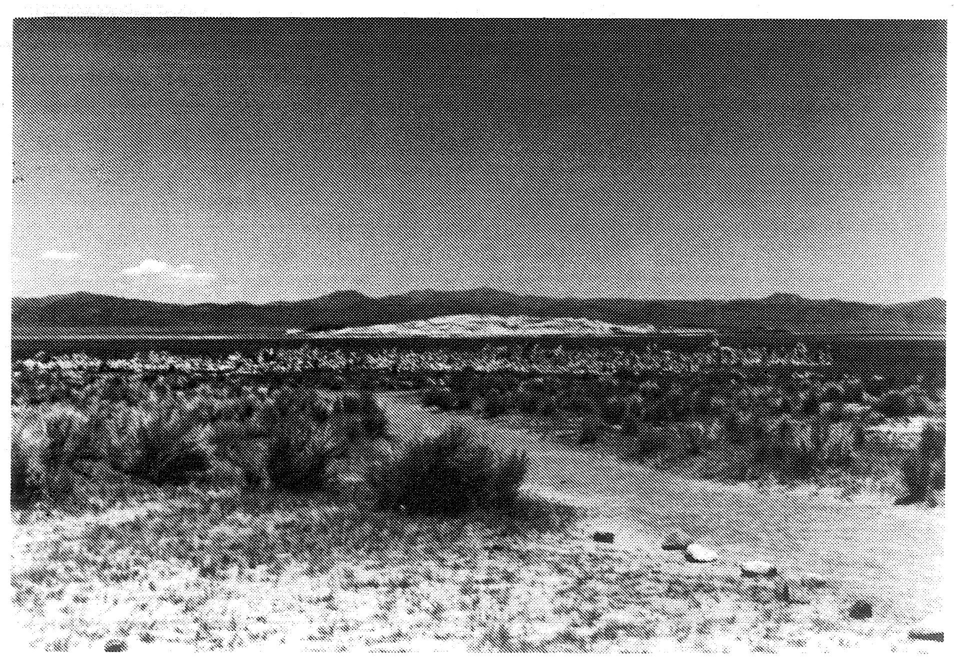
Element	Rating (-5 to +5 Scale)
Birds	4.25
Land-based tufa	3.91
Wetland vegetation	3.31
Playa	1.28
Water-based tufa	4.49
Brine flies and shrimp	1.94
Islands	3.87
Pumice blocks	2.37
Human-made features	0.08
Sand tufa	3.99

Figure V-1.
Photograph Simulations of Mono Lake at South Tufa

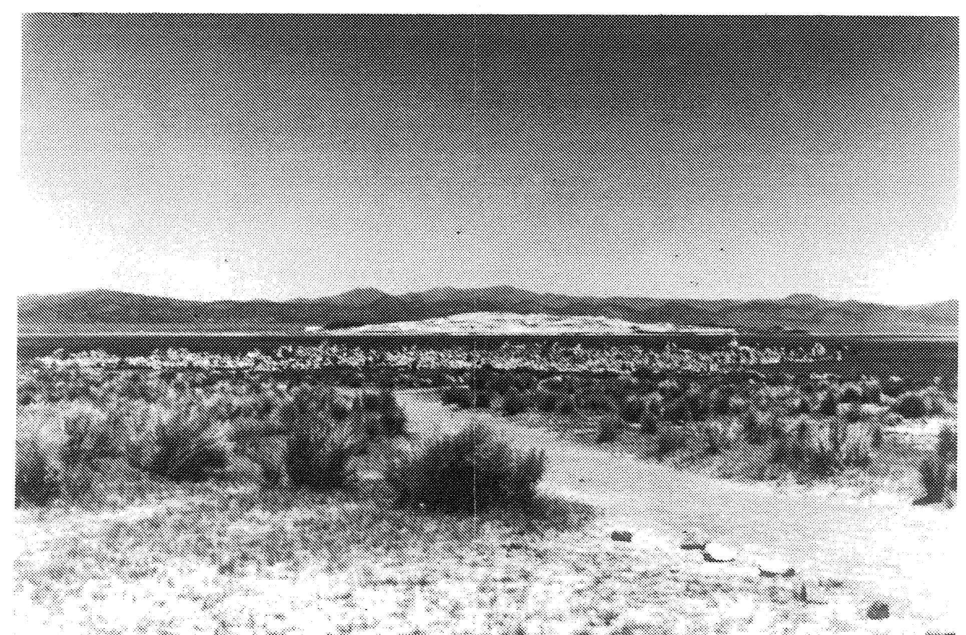
6,372'



6,374.5' (lake level as of August 1991)



6,380'



6,390'

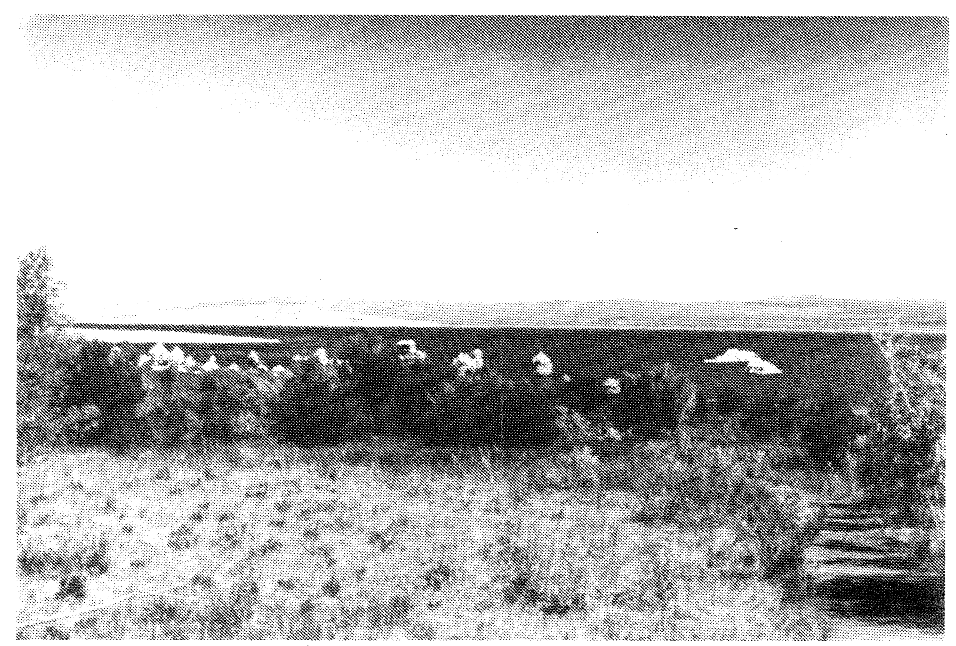
6,410'

Figure V-2.
Photograph Simulations
of Mono Lake at
Mono Lake County Park

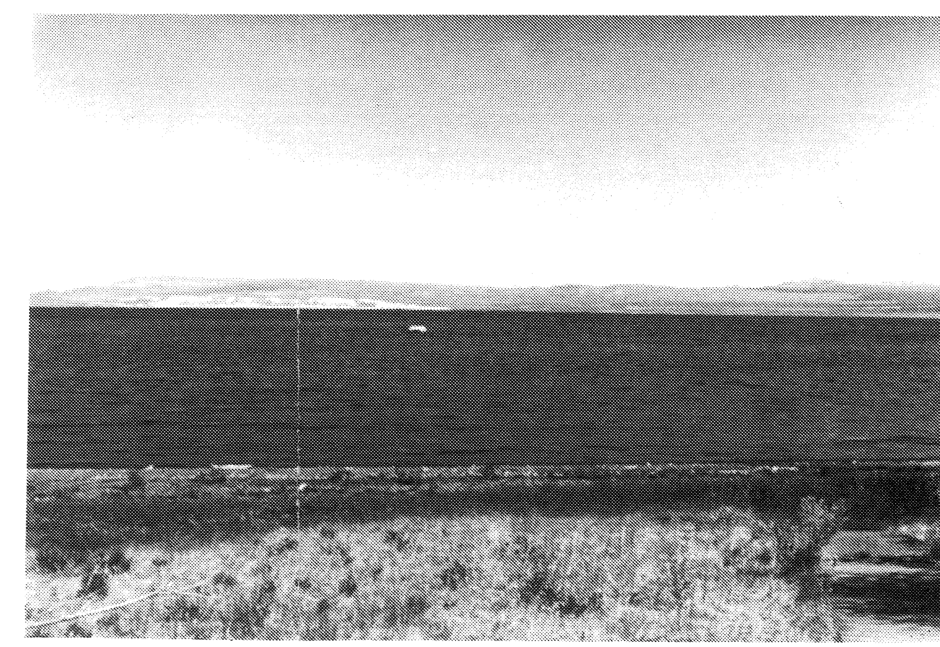
6,372'

6,374.5' (lake level as of August 1991)

6,380'



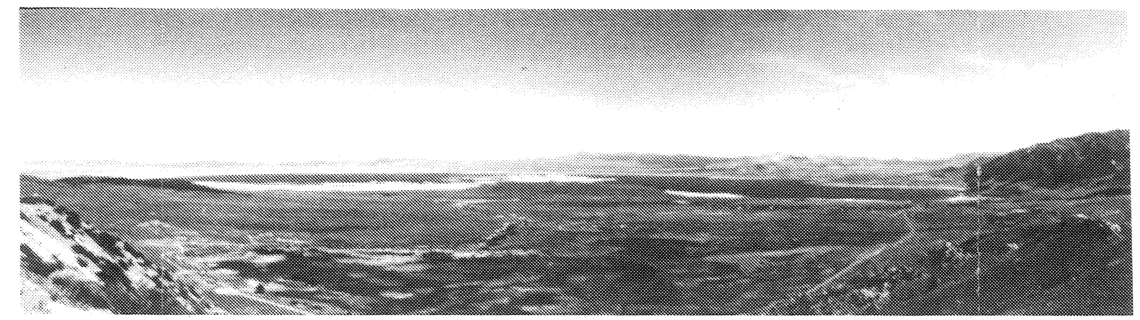
6,390'



6,410'

Figure V-3.
Photograph Simulations of Mono Lake at Vista Point along U.S. 395 near Conway Summit

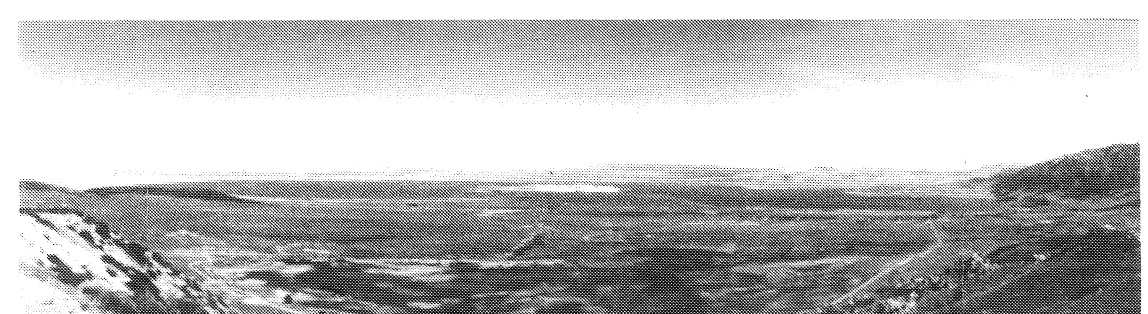
6,372'



6,374.5' (lake level as of August 1991)

6,380'

6,390'



6,410'

Figure V-4.
Photograph Simulations of Mono Lake at U.S. Forest Service Visitor Center

6,372'

6,374.5' (lake level as of August 1991)

6,380'

Note: Riparian vegetation along lower Rush Creek (dark area at the center of the photograph) has been enhanced to depict the expected effects of habitat restoration.

6,390'

6,410'

Figure V-5.
Photograph Simulations of Mono Lake at U.S. 395 near Old Marina

6,372'

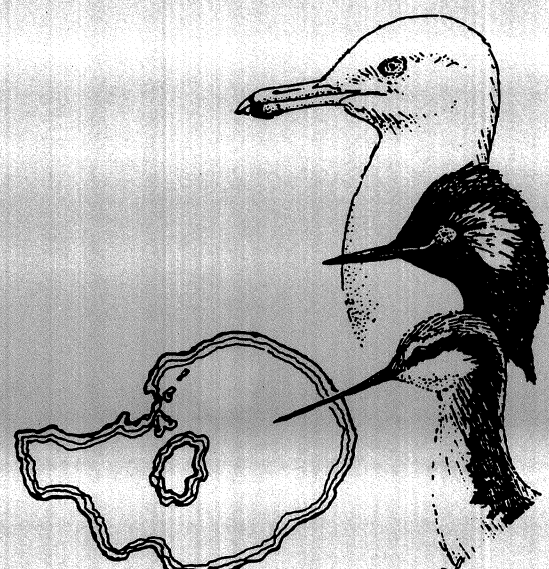
6,374.5' (lake level as of August 1991)

6,380'

6,390'

6,410'

Appendix W. Recreation Resources



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Appendix W. Recreation Resources

This technical appendix describes the methods used to estimate recreation use effects at directly affected recreation areas (i.e., Mono Lake, the lower tributaries, Grant Lake reservoir, and Lake Crowley reservoir). Changes in per-capita recreation use were used as one criterion to assess the significance of effects on recreation at the directly affected recreation areas. The data obtained from onsite user surveys of visitors to Mono Lake, the lower tributaries, Grant Lake reservoir, and Lake Crowley reservoir were used to determine whether and how much visitor use would change in response to variable hydrologic conditions (i.e., lake levels for Mono Lake, Grant Lake and Lake Crowley reservoirs, and streamflow for Rush Creek). Because user surveys were not conducted along the Upper Owens River, changes in per-capita recreation use could not be estimated for this recreation area. Summary results of the user surveys are included in this appendix.

OVERVIEW

Overall changes in the use of a recreation area can be assessed by examining the average change in per-visitor use and the average change in the number of annual visitors. For evaluating the significance of potential impacts on recreation, we focused on expected changes in per-visitor use. Some respondents to the user surveys indicated that they would spend no days at an area under certain hydrologic conditions; thus, they would not be considered a part of the annual visitor population. Such use changes, however, were considered to be part of the change in per-visitor use and not part of the change in number of visitors.

The methods used to predict the effects of changes in hydrologic conditions on per-visitor use for each directly affected recreation area are described below.

MONO LAKE

Use-Estimating Methodology

The Mono Lake visitor survey was conducted during May and June 1992. The survey provided information on use levels at lake elevations of 6,372, 6,375, 6,390, and 6,410 feet. No information was obtained on use changes associated with levels lower than 6,372 feet or higher than 6,410 feet.

Average annual per-visitor use of Mono Lake in 1992, when the lake stood at elevation 7,375 feet, was 3.14 visitor days. Of the 279 respondents with whom interviews were completed, only 9% indicated that their use of the lake would change if its level decreased from its 1992 level to 6,372 feet. Of these respondents, 96% indicated their use would be less at the lower level. The average per-visitor change in use resulting from the 3-foot decline in lake level was 0.28 days per year, a reduction in per-visitor use of 9%.

An estimated 20% of visitors would change their use if the lake elevation increased from 6,375 feet to 6,390 feet. Of those indicating their use would change, 82% stated that their use would increase at 6,390 feet. Average per-visitor annual use would increase by 0.52 days (16%) if the lake level increased to 6,390 feet.

Increases in lake level above 6,390 feet are likely to result in reductions in per-visitor use. Approximately 29% of the respondents indicated their use would change if the lake level increased from 6,375 to 6,410 feet. Of these respondents, 63% indicated their use would decline. Average annual per-visitor use is the same at 6,410 feet as at 6,375 feet (3.23 days). Thus, increasing the lake level from 6,390 to 6,410 feet would, in effect, negate the increase in use that would result from raising it from 6,375 to 6,390 feet.

These results indicate that use of Mono Lake could vary in response to lake level changes associated with diversion alternatives but that the average change in per-visitor use would not exceed 16% of use under the point-of-reference scenario for lake levels ranging from 6,372 to 6,410 feet. Specifically, average use would decrease by an estimated 0.093 days per foot of decline in lake level from 6,375 to 6,372 feet, increase by 0.035 days per foot increase up to 6,390 feet, and decrease by 0.026 days per foot increase between 6,390 and 6,410 feet.

Small changes in use likely would result from changes in lake level. This conclusion is consistent with the unique recreation opportunities featured at Mono Lake. Visitors for whom Mono Lake is an incidental destination are relatively unlikely to be aware of lake level fluctuations.

Summary of User Survey Results

Results from the user surveys conducted at Mono Lake in June 1992 are summarized below.

1. Location of interview:

	Number
South Tufa	103
Mono Lake County Park	158
Old Marina	36
Total	297

2. Place of residence:

	Number
Metropolitan Southern California	61
San Francisco Bay area	70
Mono Basin	2
Elsewhere in California	71
Other states	73
Outside U.S.	20
Total	297

3. Mean number of people in vehicle of respondent: 2.63

4. Mean length of current trip (days): 13.2

5. Mean length of time visiting Inyo and Mono Counties this trip (days): 3.62

6. Other destinations on this trip:

Other Destinations on This Trip	Number
Mammoth Lakes	103
Yosemite National Park	79
June Lake Loop	74
Bodie State Park	58
Bridgeport	36
Bishop	33
Lee Vining/Lee Vining Creek	24
Convict Lake/Convict Creek	17
Death Valley	15
Devil's Postpile	13
Saddlebag/Tioga/Ellery Lakes	12
Hot Creek	11
Lake Tahoe	10
Lundy Lake	10
Mono Craters	7
Mt. Whitney	7
Bristlecone Pine Forest	6
Lone Pine	5
Rock Creek	5
Panum Crater	3
Twin Lakes	3
Lake Crowley reservoir	3
Lake Mary	3
Owens River	3
Lookout Mountain	3
Other	39

7. Mean expenditures in Mono and Inyo Counties on this trip ($/person/day):

Groceries and supplies	$2.46
Restaurants	4.01
Lodging	6.37
Camping	0.59
Auto expenses	2.26
Other	0.09
Total	$15.79

8. Importance of Mono Lake as a destination for current trip:

	Number
Principal destination	76
One of several important destinations	153
An incidental stop	68
Total	297

9. Mean time spent at Mono Lake today (hours): 2.45

10. Percent of respondents for whom current visit to Mono Lake is one day or less: 77

11. Activities participated in at Mono Lake this trip:

Activity	Number Participating	Number for Whom Activity is Main Reason for Visiting
See what lake is like	213	154
Sightseeing	222	74
Organized nature hiking	28	2
Self-directed nature hiking	112	10
Birdwatching or nature study	122	25
Boating or canoeing	11	2
Picnicking	24	6
To rest	40	9
Photography	9	14

12. Mean number of trips to Mono Lake in 3 previous years: 2.01

13. Mean number of days spent at, or expected to be spent at, Mono Lake in 1992: 3.14

14. Likelihood of visit to Mono Lake in 1993

	Number
Definitely visit	70
Probably visit	98
Probably not	79
Definitely not	48
Refused	2
Total	297

15. Reasons for probably not or definitely not visiting in 1993:

	Number
Curiosity about lake has been satisfied	16
Expect to visit other areas instead	50
Moving away	8
Other	51
Refused	2

16. Satisfaction with current visit to Mono Lake:

	Number
Very satisfied	217
Generally satisfied	68
Not satisfied	11
Refused	1
Total	297

17. Reasons for not being satisfied with current visit:

	Number
Lake too low	9
Other	2

18. Preferred lake level (feet above sea level):

Alternatives Compared	Prefer 6,372	Prefer 6,375	Prefer 6,390	Prefer 6,410	Doesn't Matter
6,372; 6,375; 6,390	2	26	111	N/A	2
6,372; 6,390; 6,410	5	N/A	82	58	4

19. Mean number of people in respondent's household: 2.42

20. Percent belonging to environmental or conservation group: 40

21. Respondent's year of birth:

	Number
Before 1926	33
1926-1935	29
1936-1945	55
1946-1956	67
1956-1965	81
1966-1975	29
After 1975	1
Refused	1
Total	297

22. Respondent's formal education level:

	Number
High school not completed	5
High school completed	37
Some college	73
College graduate	93
Graduate school	84
Refused	3
Total	297

23. Respondent's household income:

	Number
Under $10,000	18
$10,000-$20,000	24
$20,000-$30,000	31
$30,000-$40,000	39
$40,000-$50,000	46
$50,000-$60,000	43
$60,000-$80,000	28
$80,000-$100,000	30
$100,000-$200,000	24
More than $200,000	5
Refused	7

LOWER REACHES OF AFFECTED MONO LAKE TRIBUTARIES

Use Estimating Methodology

Recent use of the lower tributaries is low because fishing opportunities were not available until the early 1980s when continuous flows were resumed. Tributary recreation opportunities will increase gradually as the streams and riparian habitats become restored as a result of maintaining minimum streamflows. Over time, public awareness of these improved recreation opportunities will increase and more people will take advantage of them. The lower tributaries will eventually attract users in numbers comparable to similar streams in the eastern Sierra region.

Per-visitor use of the lower tributaries was estimated based on survey data collected from visitors to the study-area streams in August-October 1991. The tributary user survey contained questions relating users' preferences and anticipated use levels to streamflows. When presented with descriptions of recreation opportunities associated with streamflows of 20, 60, and 100 cubic feet per second (cfs), 51% of all respondents indicated that they preferred 100 cfs, 43% preferred 60 cfs, and 6% preferred 20 cfs.

The in-person survey of tributary users was administered on both Rush and Lee Vining Creeks; however, questions pertaining to how potential changes in flows would affect use focused on Rush Creek because of survey and data limitations. Most tributary use and better photographic documentation of streamflow variations occur for Rush Creek.

A similar distribution of preferences (48%, 43%, 9%) applies to those respondents who identified lure or bait fishing as their main reason for visiting the tributaries. Among those indicating that fly fishing was their main reason, however, 76% preferred streamflows of 60 cfs and 24% preferred 100 cfs. Survey results showed that 86% of the tributary users participated in lure or bait fishing, while 29% participated in fly fishing.

Survey results were used to regress the following use-estimating equation (R-squared is 0.14; t-values are shown beneath regression coefficients; all variables are significant at the 95% level of confidence):

$$\log(\text{DAYS}) = 0.456 + \underset{(4.92)}{0.0975[\log(\text{OTHR90})]} + \underset{(6.22)}{0.0715(\text{SQRTFLO})}$$

$$+ \underset{(4.06)}{0.0642(\text{FLYFISH})} - \underset{(6.44)}{0.198(\text{OTHFISH})} - \underset{(3.28)}{0.116[\log(\text{INCOME})]}$$

$$+ \underset{(3.12)}{0.1029(\text{UNRETIRED})} - \underset{(8.28)}{0.204(\text{FLXSTABL})}$$

where:

DAYS	=	per-visitor annual visitor days on the lower tributaries,
OTHR90	=	days spent recreating at other eastern Sierra recreation areas in 1990;
SQRTFLO	=	the square root of the mean May-October streamflow on lower Rush Creek;
FLYFISH	=	a dummy variable set to 1 if the respondent participated in fly fishing, and to 0 otherwise;
OTHFISH	=	a dummy variable set to 1 if the respondent participated in bait or lure fishing, and to 0 otherwise;
INCOME	=	respondent's household income;
UNRETIRED	=	a dummy variable set to 1 if the respondent was born after 1926, and to 0 if born before 1926; and
FLXSTABL	=	a dummy variable set to 1 if Rush Creek flows were relatively unstable over the recreation season, and to 0 if they were stable. Flows were considered stable if they fluctuated by less than 100% of the minimum flow over the recreation season.

The range of streamflows described in the user surveys was substantially narrower than the range subsequently resulting from the diversion alternatives using the Los Angeles Aqueduct Monthly Program (LAAMP) operations model. Survey respondents evaluated Rush Creek streamflows ranging from 20 cfs to 100 cfs, while LAAMP projections ranged from 0 to 165 cfs in normal runoff years and up to 490 cfs during extremely wet years. The projected high flows resulted largely from requirements for periodic channel flushing imposed on LAAMP simulations for the tributaries. These discrepancies limit the applicability of the use-estimating equation for assessing tributary use impacts for wet runoff years, and for the 6,390-Ft, 6,410-Ft, No-Restriction, and No-Diversion Alternatives.

The regression analysis showed that average annual per-visitor use increases with average streamflow and with the stability of flows over the season. The positive coefficient on FLYFISH and the negative coefficient on OTHFISH indicate that fly fishing anglers spend more days on the lower tributaries than average for all respondents, and bait and lure anglers spend fewer days than average. Overall, respondents spent an average of 1.5 days on the lower tributaries in 1991, when flows averaged roughly 50 cfs over the recreation season.

Survey results indicate that average annual per-visitor use of the lower tributaries would change by approximately 0.02 days (1.3%) per 1-cfs change in average streamflow for flows ranging from 20 to 100 cfs.

Summary of User Survey Results

Results from the user surveys conducted along Rush and Lee Vining Creeks between August and October 1991 are summarized below.

1. Location of interview:

	Number
Upper Rush Creek	97
Lower Rush Creek	1
Upper Lee Vining Creek	98
Lower Lee Vining Creek	4
Mill Creek	4
Convict Creek	46
Total	247

2. Place of residence:

	Number
Metropolitan Southern California	174
San Francisco Bay area	17
Mono Basin	5
Elsewhere in California	49
Out of state	1
Total	246

3. Mean number of people in vehicle of respondent: 2.44

4. Mean length of current trip (days): 20.1

5. Mean length of time visiting Inyo and Mono Counties this trip (days): 9.93

6. Other destinations on this trip:

Other Destinations on This Trip	Number
June Lake Loop	95
Mammoth Lakes	85
Bridgeport	74
Bishop	64
Saddlebag/Tioga/Ellery Lakes	37
Convict Lake/Convict Creek	28
Mono Lake	25
Lundy Lake	22
Owens River	20
Lee Vining Creek	18
Big Pine	15
Hot Creek	10
Bodie State Park	10
McGee Creek	7
Agnew Lake	6
Lake Crowley reservoir	6
Pleasant Valley reservoir	5
Devil's Postpile	5
Hawthorne, NV	4
Tremble Lake	3
Death Valley	3
Other	22

7. Mean expenditures in Mono and Inyo Counties on this trip ($/person/day):

Groceries and supplies	$2.32
Restaurants	1.61
Lodging	2.41
Camping	1.08
Auto expenses	2.22
Other	0.01
Total	$9.65

8. Mean number of days spent at tributary at which interview occurred this trip: 7.1

9. Mean number of hours spent at tributary today: 6.0

10. Activities participated in at tributary this trip:

Activity	Number Participating	Number for Whom Activity is Main Reason for Visiting
Bait/lure fishing	213	157
Fly fishing	71	20
Birdwatching/nature study	97	9
Swimming	8	0
Picnicking	80	4
Hiking	133	1
Camping	151	49
Photography	131	1
Enjoying the outdoors	11	1
Bicycling	4	4
Hunting	2	1
Off-road vehicle use	1	0

11. Percent who visited Mono/Inyo County region in 1990: 73

12. For 1990 visitors, mean number of separate visits to region in 1990: 2.92

13. For 1990 visitors, mean number of days spent on lower reaches of Mono Lake tributaries in 1990: 1.32

14. For 1990 visitors, mean total number of days spent on upper reaches of Mono Lake tributaries in 1990: 9.88

15. Number of respondents visiting other streams or lakes in the eastern Sierra Nevada in 1990: 76

16. Mean number of days spent on, or expected to be spent on, lower reaches of Mono Lake tributaries in 1991: 1.54

17. Preferred lower tributary streamflow (excludes 36 respondents interviewed at Mill or Convict Creek who did not visit lower tributaries in 1990-1991):

Prefer 20 cfs	Prefer 60 cfs	Prefer 100 cfs
13	90	107

18. Mean number of people in respondent's household: 2.56

19. Percent belonging to environmental or conservation group: 22

20. Respondent's year of birth:

	Number
Before 1926	33
1926-1935	35
1936-1945	47
1946-1956	68
1956-1965	53
1966-1975	9
After 1975	0
Refused	2
Total	247

21. Respondent's formal education level:

	Number
High school not completed	9
High school completed	53
Some college	93
College graduate	59
Graduate school	30
Refused	3
Total	247

22. Respondent's household income:

	Number
Under $10,000	8
$10,000-$20,000	14
$20,000-$30,000	34
$30,000-$40,000	38
$40,000-$50,000	29
$50,000-$60,000	31
$60,000-$80,000	35
$80,000-$100,000	23
$100,000-$200,000	17
More than $200,000	2
Refused	16
Total	247

GRANT LAKE RESERVOIR

Use-Estimating Methodology

Changes in per-visitor use of Grant Lake reservoir were estimated from survey results of responses to questions pertaining to how use would change if alternative hydrologic scenarios were adopted. Scenarios differed based on their average lake level and on the stability of the lake level over the recreation season. Three alternative scenarios are presented in Figure W-1.

Survey results indicate preferences for higher and more stable lake levels. For example, in comparing Scenarios 2 and 3, 54% of the respondents preferred Scenario 2, 40% were indifferent, and 5% preferred Scenario 3. In comparing Scenarios 1 and 2, which have roughly equal average lake levels, 48% preferred the more stable scenario (Scenario 1), 42% were indifferent, and 9% preferred the fluctuating scenario (Scenario 2).

Respondents were also asked whether their use of Grant Lake reservoir under the scenarios would change from their anticipated use under the planned schedule of operations. Depending on the scenario, between 54% and 73% of the respondents indicated that their use would not change from their anticipated use. Among scenarios considered, per-visitor use would change the most under Scenario 1, an increase of 2.8 days per year. This change represents a 30% increase over the average 1991 Grant Lake reservoir use level of 9.6 days for survey respondents. Per-visitor use would increase by 1.7 days (18%) under Scenario 2 and would decrease by 0.7 days (8%) under Scenario 3.

The median lake level under Scenario 2 reservoir operations was 22 feet lower than the median level under Scenario 3 (Figure W-1). Assuming that per-visitor use changes at a rate constant with changes in median lake level between these two scenarios, use would change by an average of 0.1 days (1.0%) per 1-foot change in median lake level. Survey results also indicate that changing from an operating schedule characterized by approximately 10 feet of lake-level fluctuation over the recreation season (Scenario 2) to a schedule with the same average level but only 2 feet of vertical fluctuation (Scenario 1) would result in an average use increase of 1.1 days (11%).

Summary of User Survey Results

Results from the user surveys conducted at Grant Lake reservoir between August and October 1991 are summarized below.

1. Location of interview:

	Number
Grant Lake marina	91
Uncontrolled area	8
Total	99

2. Place of residence:

	Number
Metropolitan Southern California	71
San Francisco Bay area	1
Mono Basin	3
Elsewhere in California	23
Out of state	1
Total	99

3. Mean number of people in vehicle of respondent: 2.59

4. Mean length of current trip (days): 15.7

5. Mean length of time visiting Inyo and Mono Counties this trip (days): 12.4

6. Other destinations on this trip:

Other Destinations on This Trip	Number
June Lake Loop (other than Grant Lake reservoir)	65
Mammoth Lakes	28
Bishop	17
Saddlebag/Tioga/Ellery Lakes	15
Lundy Lake	14
Bridgeport	14
Convict Lake/Convict Creek	9
Lee Vining/Lee Vining Creek	8
Owens River	8
Mono Lake	7
Pleasant Valley reservoir	6
Lake Crowley reservoir	4
Big Pine	3
Topaz Lake	3
Yosemite National Park	3
Other	12

7. Percent of respondents for whom Grant Lake reservoir is the principal destination for current trip: 66

8. Mean expenditures in Mono and Inyo Counties on this trip ($/person/day):

Groceries and supplies	$2.03
Restaurants	1.86
Lodging	2.97
Camping	0.87
Auto expenses	1.95
Other	0.04
Total	$9.72

9. Mean number of days spent at Grant Lake reservoir this trip: 5.3

10. Mean number of hours spent at Grant Lake reservoir today: 4.3

11. Activities participated in at Grant Lake reservoir this trip:

Activity	Number Participating	Number for Whom Activity is Main Reason for Visiting
Boating	9	1
Waterskiing	1	1
Windsurfing	3	1
Trolling for trout	12	1
Float-tubing for trout	2	1
Shore fishing for trout	93	85
Fishing for other species	1	1
Wading	7	0
Birdwatching/nature study	26	0
Picnicking	21	0
Camping	29	4
Enjoying the outdoors	1	0

12. Percent who visited Mono/Inyo County region in 1990: 74

13. For 1990 visitors, mean number of separate visits to region in 1990: 3.34

14. For 1990 visitors, mean number of days spent on lower reaches of Grant Lake reservoir in 1990: 11.7

15. Number of respondents visiting other eastern Sierra Lakes in 1990: 58

16. Mean number of days spent at, or expected to be spent at, Grant Lake reservoir in 1991: 9.61

17. Percent of respondents who visited Grant Lake reservoir before June 1 this year: 17

18. Respondent satisfaction with Grant Lake reservoir recreation opportunities this year:

	Number
Very satisfied	21
Generally satisfied	68
Not satisfied	7
Refused	3
Total	99

19. Preferred reservoir level management alternative (see Figure W-1 for scenario description):

	Scenarios			
Scenarios Compared	1	2	3	Doesn't Matter
(2,3)	NA	20	2	15
(1,3)	0	NA	21	8
(1,2)	16	3	NA	14

20. Mean number of people in respondent's household: 2.78

21. Percent belonging to environmental or conservation group: 16

22. Respondent's year of birth:

	Number
Before 1926	28
1926-1935	19
1936-1945	17
1946-1956	16
1956-1965	17
1966-1975	2
After 1975	0

21. Respondent's formal education level:

	Number
High school not completed	8
High school completed	23
Some college	36
College graduate	26
Graduate school	6

22. Respondent's household income:

	Number
Under $10,000	5
$10,000-$20,000	7
$20,000-$30,000	15
$30,000-$40,000	19
$40,000-$50,000	12
$50,000-$60,000	11
$60,000-$80,000	15
$80,000-$100,000	4
$100,000-$200,000	5
More than $200,000	1
Refused	5

LAKE CROWLEY RESERVOIR

Use-Estimating Methods

Survey respondents at Lake Crowley were presented with information on planned reservoir water operations in 1992 and on four alternative scenarios. Scenarios 1 and 2 maintained stable water levels, and Scenarios 3 and 4 were characterized by fluctuating water levels. The median water level under Scenario 1 exceeded that under Scenario 2 by 18 feet, the same amount that the median level under Scenario 3 exceeded that under Scenario 4. Planned 1992 operations were moderately stable at a median level between that of Scenarios 1 and 2. The four alternative scenarios are presented in Figure W-2.

Almost all respondents ranked Scenarios 1 and 3 over Scenario 2, and Scenario 2 over Scenario 4. Scenarios 1 and 3 were not directly compared. These results indicate that users prefer higher water levels over lower levels and, at least at lower levels, prefer relatively stable water levels over fluctuating levels.

Respondents were asked how their use would change if various scenarios were substituted for planned 1992 operations, under which the lake level would average 6,767 feet. Under this scenario, use of Lake Crowley reservoir by all respondents would average 13.0 days. Relative to anticipated use, Scenario 4 elicited the largest use response, an average decrease of 5.1 days per visitor. Under Scenario 3, average annual use would decrease by an average of 3.7 days. Annual per-visitor use would increase by an average of 3.1 days under Scenario 2 and by 4.4 days under Scenario 1.

These results indicate that, on average, per-visitor use would increase by approximately 0.46 days for each 1-foot increase in the reservoir's median water level, a substantially greater rate of change than was estimated for Grant Lake reservoir (0.1 day per foot).

Summary of User Survey Results

Results from the user surveys conducted at Lake Crowley reservoir between August and October 1991 and during April 1992 are summarized below.

1. Location of interview:

	Number
South Landing	184
North Landing	87
Pleasant Valley reservoir	52
Total	323

2. Place of residence:

	Number
Metropolitan Southern California	196
San Francisco Bay area	4
Mono Basin	32
Elsewhere in California	88
Out of state	3
Total	323

3. Mean number of people in vehicle of respondent: 2.60

4. Mean length of current trip (days): 8.31

5. Mean length of time visiting Inyo and Mono Counties this trip (days): 6.95

6. Other destinations on this trip:

Other Destinations on This Trip	Number
Bishop	86
Convict Lake/Convict Creek	57
Mammoth Lakes	47
June Lake Loop	20
Owens River	17
Twin Lakes	13
Lone Pine	7
Hot Creek	6
Pleasant Valley Reservoir	5
McGee Creek	4
Big Pine	4
Saddlebag/Tioga/Ellery Lakes	4
Mono Lake	3
Mt. Whitney	3
Other	26

7. Percent of respondents for whom Lake Crowley reservoir is the principal destination for current trip: 61

8. Mean expenditures in Mono and Inyo Counties on this trip ($/person/day):

Groceries and supplies	$3.60
Restaurants	2.84
Lodging	4.05
Camping	0.49
Auto expenses	3.31
Other	0.19
Total	$14.48

9. Mean number of days spent at Lake Crowley reservoir this trip: 3.79

10. Mean number of hours spent at Lake Crowley reservoir today: 6.22

11. Activities participated in at Lake Crowley reservoir this trip (for respondents interviewed at Lake Crowley reservoir only:

Activity	Number Participating	Number for Whom Activity is Main Reason for Visiting
Boating	107	26
Waterskiing	39	21
Windsurfing	7	0
Trolling for trout	96	66
Float-tubing for trout	46	30
Shore fishing for trout	209	110
Fishing for other species	65	7
Wading	41	1
Birdwatching/nature study	56	1
Picnicking	68	2
Camping	90	3
Hiking	44	2
Bicycling	5	0
Hunting	1	0

12. Percent who visited Mono/Inyo County region in 1990: 80

13. For 1990 visitors, mean number of separate visits to region in previous year: 4.04

14. For 1990 visitors, mean number of days spent at Lake Crowley reservoir in previous year: 12.96

15. Number of respondents visiting other eastern Sierra Lakes in previous year: 152

16. Mean number of days spent at, or expected to be spent at, Lake Crowley reservoir in 1991:

Fall 1991 survey respondents	20.3
Spring 1992 survey respondents	5.6
All respondents	13.0

17. Percent of 1991 respondents who visited Lake Crowley reservoir before June 1: 48

18. Respondent satisfaction with Lake Crowley reservoir recreation opportunities in 1991 (for respondents who visited Lake Crowley reservoir in 1991):

	Number
Very satisfied	51
Generally satisfied	137
Not satisfied	55
Total	243

19. Preferred reservoir level management alternative (see Figure W-2 for scenario description):

	Scenarios				
Scenarios Compared	1	2	3	4	Doesn't Matter
(4,3)	NA	NA	63	6	18
(4,1)	49	NA	NA	2	7
(3,2)	NA	20	31	NA	19
(2,1)	50	1	NA	NA	11
(4,2)	NA	22	NA	5	14

20. Mean number of people in respondent's household: 2.84

21. Percent belonging to environmental or conservation group: 25

22. Respondent's year of birth:

	Number
Before 1926	31
1926-1935	42
1936-1945	76
1946-1956	100
1956-1965	58
1966-1975	15
After 1985	0
Total	322

21. Respondent's formal education level:

	Number
High school not completed	24
High school completed	61
Some college	105
College graduate	92
Graduate school	38
Refused	2
Total	322

22. Respondent's household income:

	Number
Under $10,000	4
$10,000-$20,000	24
$20,000-$30,000	33
$30,000-$40,000	45
$40,000-$50,000	46
$50,000-$60,000	24
$60,000-$80,000	58
$80,000-$100,000	32
$100,000-$200,000	34
More than $200,000	12
Refused	10
Total	322

Figure W-1.
Reservoir Levels for Survey Scenarios
Grant Lake Reservoir

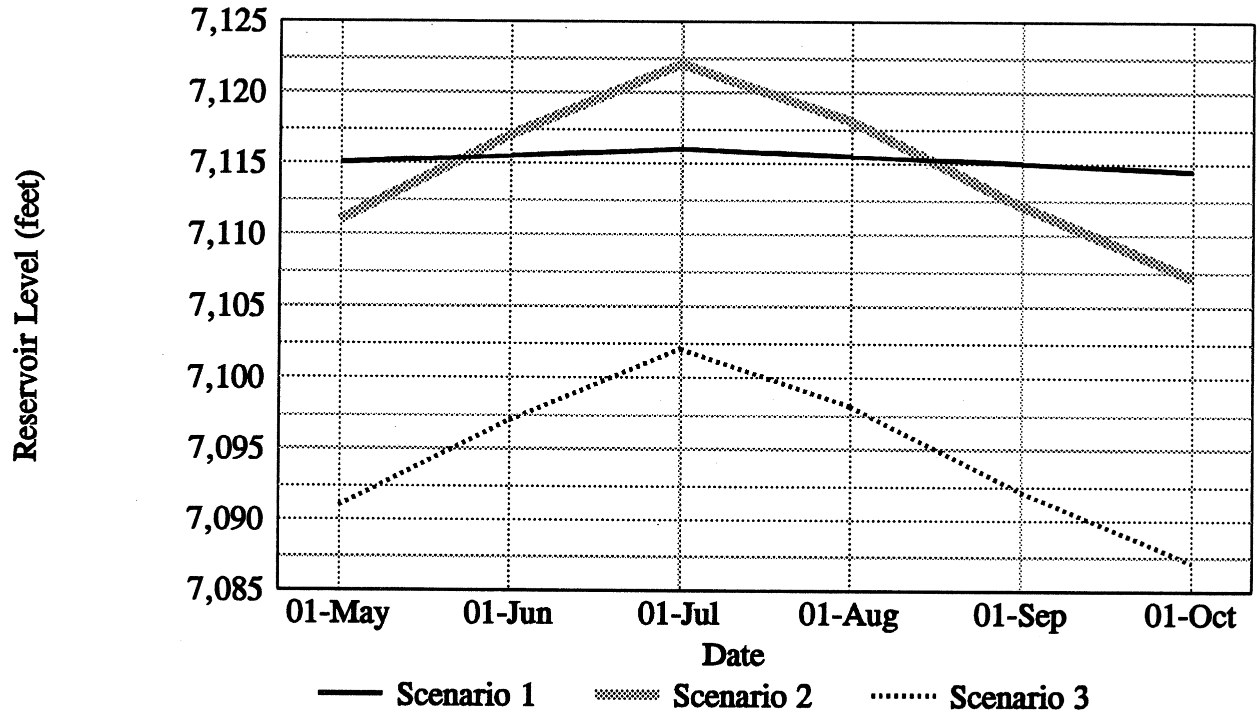
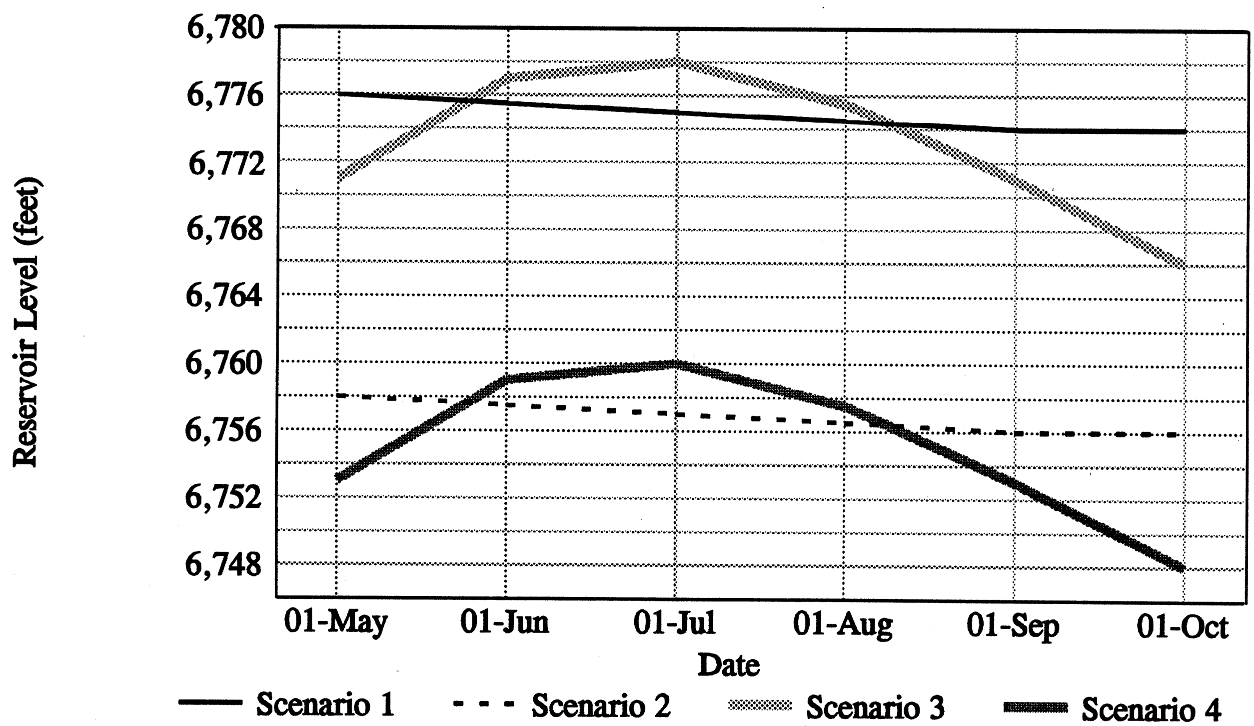
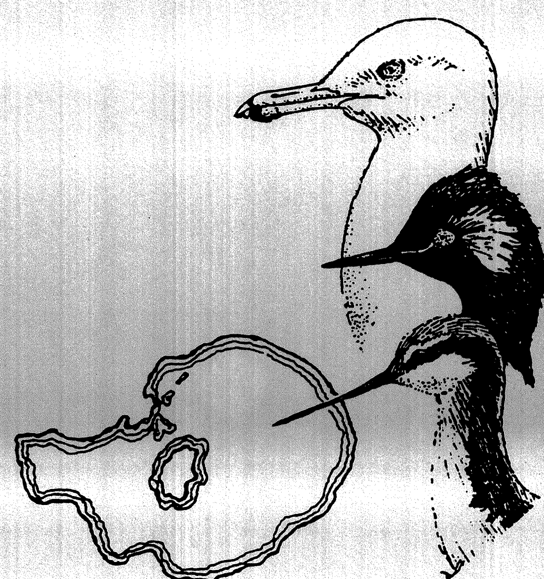


Figure W-2.
Reservoir Levels for Survey Scenarios
Lake Crowley Reservoir



Appendix X. Economics



MONO BASIN EIR

Prepared by Jones & Stokes Associates

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Programs A and B

The new correlated response model is applied to the data on Programs A and B. The starting point for the correlated response model, as for the conventional discrete response model, is an underlying (indirect) utility function associated with each of those outcomes, which we index with the subscript t: the default, no-action label level ($t = 0$), the improvement associated with Program A ($t = 1$), and the improvement associated with Program B ($t = 2$). We employ the following Box-Cox formulation for the indirect utility function:

(1) $$u_t = \alpha_t + \beta_t \left(\frac{y^\lambda - 1}{\lambda}\right) + \epsilon_t \qquad t = 0,1,2.$$

where y is the respondent's income, α_t β_t and λ are parameters to be estimated, and the ϵ_ts are stochastic terms reflecting the random component of the respondents' preferences for outcome $t = 0, 1, 2$. This formulation nests the two specific models that have been used most frequently in the existing literature: the linear model (corresponding to $\lambda = 1$), where

(2) $$u_t = \alpha_t + \beta_t y + \epsilon_t \, .$$

and the log model (corresponding to $\lambda = 0$), where

(3) $$u_t = \alpha_t + \beta_t \ln y + \epsilon_t$$

The Box-Cox model can also be regarded as a form of CES utility function in income and the environmental commodity. For the time being, we will assume that $\alpha_t > \alpha_0$ $t = 1, 2$ and $\beta_t > \beta_0$, $t = 1, 2$ but below we will consider the possibility that $\beta_t = \beta_0$, $t = 1, 2$.

Define $a_t \equiv (\alpha_t - \alpha_0)$, $b \equiv (\beta_t / \lambda)$, and $\eta_t \equiv (\epsilon_t - \epsilon_0)$. Let W_t denote the respondent's WTP for raising the level of Mono Lake from the no-action level (i.e., lake elevation 6,372 feet) to level $t = 1$ or 2. It follows from (1) that the formula for W_t is

(4) $$W_t = y - \left[\frac{\beta_0}{\beta_t} y^\lambda + \left(\frac{\beta_t - \beta_0}{\beta_t}\right) - \frac{a_t}{b_t} - \frac{\eta_t}{b_t}\right]^{\frac{1}{\lambda}} .$$

Since it depends on an η_t, which is a random variable, WTP is itself a random variable. If the median of η_t is zero, then

(5) $$\text{Median}(W_t) = y - \left[\frac{\beta_0}{\beta_t} y^\lambda + \left(\frac{\beta_t - \beta_0}{\beta_t}\right) - \frac{a_t}{b_t}\right]^{\frac{1}{\lambda}} .$$

We assume that the random variables (η_1, η_2) are jointly distributed with mean zero, variances σ_1^2 and σ_2^2, and correlation ρ. More specifically, we assume that (η_1, η_2) are - bivariable normal, with correlation ρ. The parameters σ_1, σ_2 and ρ are to be estimated from the data, subject to restrictions on their identifiability. It is the presence of the (potentially nonzero) correlation coefficient, ρ, that distinguishes this correlated response model from the conventional discrete-response models that already exist in the literature. The Mono Lake CV survey employed a bid design that involved sometimes single-bounded responses and sometimes double-bounded responses. Starting with the former, the probability that an individual responds "Yes" to the question, "If Program A costs \$x per household per year, would you be willing to vote in favor of it?" is given by

(6)
$$\begin{aligned} \Pr\{\text{YES to \$}x \text{ for Program A}\} &= \Pr\{W_1 \geq x\} \\ &= \Pr\{\eta_1 \geq g_1(x)\} \\ &= \text{Pj}\{\upsilon_1 \geq \bar{g}_1(x)\} \end{aligned}$$

where

$$\upsilon_1 \equiv \eta_1 / \sigma_1, \qquad \bar{g}_1(x) \equiv g_1(x)/\sigma_1,$$

and

(7)
$$\bar{g}_1(x) = -\frac{a_1}{\sigma_1} + \frac{b_0}{\sigma_1}\left(\frac{y^{\lambda} - 1}{\lambda}\right) - \frac{b_1}{\sigma_1}\left(\frac{(y - x)^{\lambda} - 1}{\lambda}\right).$$

Similarly, if the individual responds "Yes" to the question, "If Program B costs \$z per household per year, would you be willing to vote in favor of it?" the probability of this response is given by

(8)
$$\begin{aligned} \Pr\{\text{YES to \$}z \text{ for Program B}\} &= \Pr\{W_2 \geq z\} \\ &= \Pr\{\upsilon_2 \geq \bar{g}_2(x)\} \end{aligned}$$

where $\upsilon_2 \equiv \eta_2 / \sigma_2$ and

(9)
$$\bar{g}_2(z) = \frac{-a_2}{\sigma_2} + \frac{b_0}{\sigma_2}\left(\frac{y^{\lambda} - 1}{\lambda}\right) - \frac{b_2}{\sigma_2}\left(\frac{(y - z)^{\lambda} - 1}{\lambda}\right).$$

The probability that an individual responds "Yes" to a bid of \$x for Program A but "No" to a bid of $z > x$ for that same Program is given by

(10)
$$\begin{aligned} &P_1\{\text{YES to \$}x \text{ and NO to \$}z \text{ for Program A}\} \\ &= P_1\{z \geq W_1 \geq x\} \\ &= P_1\{\bar{g}_1(z) \geq \upsilon_1 \geq \bar{g}_1(x)\}. \end{aligned}$$

An analogous formula, involving $\bar{g}_2(z)$ and $\bar{g}_2(x)$, would describe the double-bounded response probability for Program B. The random variables υ_1 and υ_2 have means of zero, variances of unity, and a correlation coefficient ρ.

Appendix X. Economics

This appendix provides details of the methods used to estimate recreation benefits, Mono Lake preservation values, and water and power supply costs.

RECREATION BENEFITS

Recreation benefits associated with changes in streamflows and lake levels were estimated for directly affected recreation areas. Statistical analyses were performed on survey data obtained from onsite interviews at Mono Lake, the lower tributaries, Grant Lake reservoir, and Lake Crowley reservoir. Survival analysis was performed using logistic models on the discrete choice responses to willingness-to-pay questions. Estimates of the mean and median willingness-to-pay values were calculated and used to estimate the recreation benefits of hydrologic conditions associated with the project alternatives.

The steps followed to estimate recreation benefits and the statistical results of the willingness-to-pay analysis for each directly affected recreation areas (excluding Upper Owens River where no survey was conducted) are identified in Tables X-1 through X-9.

MONO LAKE PRESERVATION VALUES

Social benefits of maintaining resource conditions associated with alternative lake levels at Mono Lake were analyzed based on a survey of California households. The data collected in the survey were analyzed using statistical models and the results were then expanded to the statewide population. The details of the survey design and data analysis are described below.

Survey Design

The contingent valuation methods (CVM) was selected as the technique best able to measure WTP for resource conditions. CVM is a widely accepted method for valuing both recreation and other nonmarketed benefits of environmental resources. CVM has been recommended by the U.S. Water Resources Council as one of two preferred methods for valuing outdoor recreation in federal benefit-cost analysis. CVM is capable of measuring the value of outdoor recreation under alternative levels of resource conditions and is the only method currently available to measure other components of total economic value, such as option, existence, and bequest values.

The basin notion of CVM is that a realistic but hypothetical market for "buying" use or preservation of a nonmarketed natural resource is described to an individual. The individual is then asked to use the market to express his or her valuation of the resource. Key features of the market include a description of the resource being preserved, a means of payment (often called payment vehicle), and the value elicitation procedure.

For the Mono Lake study, three resource conditions were described to survey participants. These conditions corresponded to lake levels of 6,375 feet, 6,390 feet, and 6,410 feet and were based on available information about wildlife conditions, tufa towers, lake access, visibility, and lake surface area. Respondents were then asked if they would be willing to pay different amounts to see programs implemented to maintain these lake levels and associated resource conditions. A referendum-type survey format was used in which payment would be made for state-sponsored bonds to buy additional water supplies for Mono Lake.

The goal for survey completion was 600 California households. The survey included an initial telephone contact, a mailing of survey materials that visually depicted and described the resource conditions associated with the programs, and a followup in-depth interview by telephone that lasted about 15 minutes, on average. Copies of the survey scripts, summary statistics from the survey, and details about the sampling procedures are available on request.

Statistical Model and Results

Following the methodology described in Hanemann (1984) and Hanemann, Kanninen, and Loomis (1991), we analyzed the responses to the discrete choice contingent valuation (CV) data using a statistical model that is derived from an underlying utility maximization (Figure X-1). In the present application to the Mono Lake CV, where we are valuing several programs (i.e., several lake levels), we have extended the standard discrete-response model to allow for the possibility of a nonzero correlation in the values that respondents place on the various programs. We refer to this as the Correlated Discrete-Response CV Model.

A preliminary analysis of the responses to the CV survey shows that most of the respondents regarded Program C (lake elevation 6,410 feet) as inferior to either Program A (lake elevation 6,375 feet) or Program B (lake elevation 6,390 feet). Because of this, we decided to analyze Program C separately from the two other programs.

It follows from (7) and (9) that not all of the model parameters are separately identifiable. While ρ and λ are identified, not all of parameters a_1, a_2, b_0, b_1, b_2, σ_1, σ_2 are identified. Thus, for example, from (7) one obtains estimates of a_1/σ_1, b_0/σ_1, and b_1/σ_1, while, from (9), one obtains estimates of a_2/σ_2, b_0/σ_2, and b_2/σ_2; in addition, one can estimate the ratio $\sigma_1/\sigma_2 = [(b_0/\sigma_1) / (b_0/\sigma_2)]$. Similarly, for the purpose of computing the median WTP in (5), one can estimate the ratios $\beta_0/\beta_1 = [(b_0/\sigma_1) / (b_1/\sigma_1)]$ and $a_1/b_1 = [(a_1/\sigma_1) / (b_1/\sigma_1)]$.

All of the above applies to the general model in which $\beta_0 \neq \beta_1 \neq \beta_2$. A special case is the restricted model in which it is assumed that $\beta_0 = \beta_1 = \beta_2 \equiv \beta$. In that case, the formula for WTP in (4) simplifies to

(4') $$W_t = y - \left[y^\lambda - \frac{a_t}{b} + \frac{\eta_t}{b}\right]^{\frac{1}{\lambda}} \qquad t = 1,2,$$

where b $\equiv \beta/\lambda$, with

(5') $$\text{Median}(W_t) = y - \left[y^\lambda - \frac{a_t}{b}\right]^{\frac{1}{\lambda}} \qquad t = 1,2.$$

The single and double-bounded response probabilities are given by (6), (8), and (10), where the functions $\bar{g}_t(x)$ simplify to

(7') $$\bar{g}_1(x) = \frac{-a_1}{\sigma_1} + \frac{b}{\sigma_1}\left(\frac{y^\lambda - 1}{\lambda}\right) - \frac{b}{\sigma_1}\left(\frac{(y - x)^\lambda - 1}{\lambda}\right)$$

(9') $$\bar{g}_2(z) = \frac{-a_2}{\sigma_2} + \frac{b}{\sigma_2}\left(\frac{y^\lambda - 1}{\lambda}\right) - \frac{b}{\sigma_2}\left(\frac{(y - z)^\lambda - 1}{\lambda}\right).$$

Again, not all of the model parameters are separately identifiable. From (7') one obtains estimates of (a_1/σ_1) and (b/σ_1), while from (9') one obtains estimates of (a_2/σ_2) and (b/σ_2).

With the double-bounded format there are three bids: an initial bid (x_S) and two followup bids, one higher (x_U) than the initial bid and the other lower (x_L). If the respondent answers "Yes" to the first bid, the higher followup bid is used; if he answers "No", the lower followup bid is used. Thus, for a given program, four outcomes are possible: Yes-Yes, No-No, Yes-No, and No-Yes. With two programs - A and B - 16 (= 4 x 4) possible sets of response outcome are possible. For example, there is a response of Yes-Yes for A and Yes-No for B if the following inequalities are satisfied:

(11) $$\upsilon_1 \geq \bar{g}_1(x_U) \quad \text{and} \quad \bar{g}_2(z_U) > \upsilon_2 \geq \bar{g}_2(z_S)$$

where z denotes a bid used for Program B, and x a bid for Program A. Under the stochastic specifications adopted here, $(\upsilon_1\ \upsilon_2)$ are standard bivariate normal with correlation coefficient ρ. Let $\phi\ (\upsilon_1\ \upsilon_2)$ be the standard bivariate normal density. Then, the probability that the inequalities in (11) hold is given by

(12) $$\int_{g_1(x_U)}^{\infty} \int_{g_2(z_S)}^{\bar{s}_2(z_U)} \phi(\upsilon_1, \upsilon_2) d\upsilon_1 d\upsilon_2 .$$

This and the other response probabilities can be expressed in terms of the standardized bivariate normal cumulative distribution function $\Phi(\cdot\ ,\cdot)$ using the conclusion that

(13) $$\int_a^b \int_c^d \Phi(x,y)dxdy = \Phi(b,d) + \Phi(a,c) - \Phi(a,c) - \Phi(a,d) - \Phi(b,c).$$

The likelihood function for the responses for Programs A and B is built up from (11) - (13) for each of the 16 possible response outcomes.

The correlated response model was estimated by maximum likelihood using the GAUSS Program on a PC applied to the responses for Programs A and B. Two features stand out from the results. First, the linear (and logarithmic) models can be rejected in favor of the general, Box-Cox model: the parameter λ consistently took a value of around 0.8 - 0.9, which is quite close to the value $\lambda = 1$, which implies a linear model, but it was always significantly different from unity (and zero). Second, we could not reject the hypothesis that $\beta_2 = \beta_1 = \beta_0$ (i.e., the data support the restricted model). The maximum likelihood coefficient estimates (and asymptotic standard errors and t-statistics) for the restricted, Box-Cox model are shown in Table X-10; these are the estimated values for the parameters in equations (7') and (9'). Using the formula in (5') together with an income level of y = \$35,000, which is the median for the sample of respondents to the statewide survey (and close to the 1990 Census), the median WTP is estimated to be \$96.38 for Program A and \$110.68 for Program B.

Table X-10. Correlated Response Model Coefficient Estimates
(Programs A and B)

Parameters	Estimates	Standard Error	Estimated Standard Error
C	0.8533	0.0233	36.654
a_1/σ_1	0.9647	0.1127	8.561
b/σ_1	0.3286	0.0477	6.889
a/σ_2	0.8407	0.0661	12.713
b/σ_2	0.2494	0.0251	9.956
λ	0.8712	0.0105	83.150

Program C

For Program C, we employed the conventional, double-bounded (univariate) discrete-response model outlined in Hanemann, Kanninen, and Loomis (1991). However, instead of the linear-logistic model employed there, we use the Box-Cox formulation in (1) combined with normal distribution (i.e., a double-bounded probit model). As with Programs A and B, we found that the model with $\beta_0 = \beta_1$ fits best. The estimation procedure is equivalent to fitting the $g_1(x)$ function in (7'). Using maximum likelihood, the coefficient estimates are shown in Table X-11.

Table X-11. Coefficient Estimates for Program C

Parameters	Estimates	Standard Error	Estimated Standard Error
a/σ	0.1373	0.0826	1.663
b/σ	0.1347	0.0704	1.913
λ	0.8975	0.0632	14.200

The median WTP for the sample, estimated using the formula in (5') and the sample median income of $35,000 is $26.21. The *population* median WTP, calculated using the formula in (20) and a population median income of $36,000, is zero.

Extrapolation to the Statewide Population

The estimates of median WTP developed above need to be extrapolated from the sample of California households covered by the survey to the set of *all* California households to derive a statewide estimate of WTP for the programs. Two important issues need to be considered in making this extrapolation: households with a language barrier and non-responding households. Because the survey was conducted entirely in English, households in which nobody over 18 could speak English were unable and thus ineligible to participate. Out of 1,158 households contacted during the telephone survey, 125 households (10.8%) were in this category. The survey cannot be considered representative of such non-English-speaking households; they may or may not place the same value on protecting wildlife resources and habitat at Mono Lake as the English-speaking households, but we cannot tell from the survey. To be conservative, we will assume that non-English-speaking households place *no* value on Mono Lake, and we will exclude them from the statewide population to which the WTP values are extrapolated.

According to the 1990 census, there were 10,399,700 households in California in 1990. Although this number will have increased since 1990, we will use the 1990 figure as the basis for our statewide estimate because we do not have a comparably accurate estimate for 1992. We will assume that the percentage of non-English-speaking households in the statewide population is approximately the same as in our survey (to the extent that such households are less likely to have telephones, this may be an underestimate). Accordingly, we will extrapolate the survey results to an estimated 9,276,530 English-speaking households statewide (= 0.892 * 10,399,700).

The households that refused to participate in the survey may reasonably be supposed to value Mono Lake less than those that did participate. A very conservative approach would be to assume that the nonresponding households have a value of zero. The issue, however, is to determine the fraction of households in our survey.

As noted above, the survey involved *two* interviews, both by telephone. The initial interview was based on random digit dialing (RDD), and the respondent was asked to participate in a survey being conducted on behalf of the SWRCB. If the respondent agreed to participate and was willing to provide a mailing address, an information booklet was mailed and a second interview was scheduled for a time after the booklet had arrived. The substance of the survey was conducted during this second interview.

In the first phase of the interview, 1,158 households were contacted, but 185 were considered ineligible to participate either because of language barriers, because the household members were going to be away for the duration of the survey, or because household members were otherwise incapable of being interviewed. Of the 973 eligible households, 725 scheduled an interview, 182 refused to participate in the survey or provide a mailing address, and 66 were still in callback status when the completion goal was reached. Of the 725 households that agreed to schedule a second interview, 54 were subsequently deemed ineligible to participate for various reasons (language barriers, respondent was under 18 years or was not known, all household members were away, nobody in the household was capable of doing an interview, or the telephone was never answered). Thus, for the second interview there were 671 eligible households. Of these, 600 completed interviews (the target completion number), 27 refused to participate and, at the time the survey ended, eight had conducted partial interviews and 36 were still in callback status.

Of all these households, the 27 that refused to participate in the second interview can clearly be presumed to have a lower value for Mono Lake than the others. At that point in the survey process, they had seen the information booklet and they knew that the survey dealt with Mono Lake. Their refusal to participate can be viewed as an indication that they were not very concerned about the lake. A more difficult question concerns the households that were in callback status for the second interview or had only partially completed it. It can be argued that these households should not be seen as having different feelings toward Mono Lake merely because the survey company did not make contact with them before the target number of interviews was completed. The counter-argument is that some of these households were among those that required many more callbacks than average and this could be a indication not only of a busy lifestyle but also, at least in some cases, of a diminished interest in Mono Lake. The truth, probably, lies somewhere in between; however, to be conservative we will treat this group as nonrespondents.

The third group consisted of the 248 households that refused to participate or were still in callback status for the first interview. Unlike the other two groups, this group did not know the true nature of the survey. During the first interview, the interviewer emphasized water costs but did not mention Mono Lake or environmental issues: "We need your help with an important study concerning the cost of water in California. SWRCB wants your input to help them establish a balance among our diverse needs for water in the state. By getting your views we can help ensure that government actions will be in the best interest of those who live and pay taxes here." It is harder, therefore, to argue that these households should be presumed to place a lower value on protecting aquatic ecosystems by virtue of their refusing to participate on the basis of this description of the survey.

Accordingly, the sample for computing the response rate is the 600 respondents plus the 71 refusals/callback status households from the second interview. The nonresponse rate is estimated to be 10.6% (= 71/671). We do not assume that these households necessarily have a *zero* value for Mono Lake, merely that their value is well below the median. We take this into account when we calculate the *population* median WTP, which is to be distinguished from the median for the sample of respondents that was reported above. The population median is the dollar amount that at least 50% of the population, including the nonrespondents, would be willing to vote to pay for the Mono Lake program. To calculate it, we proceed as follows. Let $G(x) \equiv Pr\{WTP \leq x)$ denote the cumulative distribution function for WTP induced by (4) or (4'), and let θ denote the proportion of non-respondents. The median for the sample of respondents is the quantity $x\sim$ which satisfies

(14) $$G(x\sim) = 0.5,$$

while the population median is the quantity x^* satisfying

(15) $$\theta + (1-\theta)G(x^*) = 0.5.$$

Hence,

(16) $$G(x^*) = [0.5 - \theta] / [1 - \theta] \equiv \gamma.$$

Thus, x^* corresponds to the γ-percentile of the distribution of WTP. With $\theta = 0.106$, we have $\gamma = .441$ (i.e., the quantity x^* corresponds to the 44.1-percentile of WTP). For the model corresponding to (4'), x^* is calculated for Program t = A or B as the solution to

(17) $$\gamma = Pr\left(y - \left[y^{\lambda} - \frac{a_t}{b} + \frac{\eta_t}{b}\right]^{\frac{1}{\lambda}} \leq x*\right).$$

Equivalently, we can write

(18) $$\gamma = Pr \left(b(y - x*)^{\lambda} - by^{\lambda} + a_t \leq \eta_t \right)$$

or

$$\gamma = Pr \left[\frac{b}{\sigma_t} (y - x*)^{\lambda} - \frac{b}{\sigma_t} y^{\lambda} + \frac{a_t}{\sigma_t} \leq \upsilon_t \right].$$

where υ_t is a standard univariate normal random variable. Now, with $\gamma = 0.441$, the standard normal distribution yields

(19) $$\Pr (\upsilon_t \geq 0.148) = 0.441.$$

Hence,

$$\frac{b}{\sigma_t} (y - x*)^{\lambda} - \frac{b}{\sigma_t} y^{\lambda} + \frac{a_t}{\sigma_t} = 0.148.$$

It follows that

(20) $$x* = y - \left[y^{\lambda} - \frac{a_t}{b} + 0.148 * \frac{\sigma_t}{b} \right]^{\frac{1}{\lambda}}.$$

We evaluate this using the coefficient estimates in Table X-10 and a value of y = \$36,000 for income. This corresponds approximately to the statewide median income: according to the 1990 census, the median household income in 1989 in California was \$35,789. The result is an estimate of \$81.90 for population median WTP Program A and \$91.16 for Program B. These population median WTPs are then applied to the estimated 9,276,530 English-speaking households; this yields aggregate statewide estimates of \$759.7 million for Program A and \$845.6 million for Program B.

In principle, these are *annual* values. The survey was framed in terms of willingness to pay an increase in state taxes for all residents of California over the next 20 years. On this basis, these values for Programs A and B could be extrapolated over any planning period. However, there are strong grounds for questioning whether these annual payments should be extended over a long time period. Everyone can state with some confidence what they would be willing to pay *now* for something, but they cannot say with certainty what they would be willing to pay in the future. Individuals cannot know now how they will feel about public programs in the future (i.e., 5 years from now) nor what demands on their budget will subsequently arise. A conservative approach would be to take the CV responses as expressions of a commitment for the *near future* and to discount the WTP values in later years in some way that reflects the increased uncertainty associated with future preferences. This approach would significantly reduce the average annual WTP values over the 20-year analysis period. Rather than actually perform this discounting, we show in Chapter 3N, "Economics", that the overall economic optimum (i.e., the lake level alternative up to which the marginal benefit curve exceeds the marginal cost curve) is not sensitive to substantial discounting of marginal benefits, even to the point of reducing them by as much as 80%.

Application to the Mono Lake Alternatives

The estimates of willingness to pay by California households described above need to be applied to the alternatives that were evaluated in the EIR. The survey asked about WTP for three programs: to maintain the lake at 6,375 feet, to increase the lake level to 6,390 feet, and to increase the lake level to 6,410 feet. In all cases, the default lake level was 6,372 feet.

The alternatives for the EIR are actually target lake levels below which the lake would not drop. Consequently, lake levels would be maintained above the target in almost all years and would exceed the target by several feet in most years. Because these conditions were not known at the time that the survey was conducted and therefore were not explained to survey respondents, a conservative approach to applying the estimates of willingness to pay for different lake levels is taken.

It is assumed that the base condition that households would want to maintain is that associated with the 6,372-Ft Alternative. The median lake level associated with this alternative is 6,375 feet (Table 3J-13), which is 1 foot below the median for the point of reference. With this level as a baseline, it is assumed that the estimated WTP for Program A would apply to avoiding conditions associated with the No-Restriction Alternative, which would allow the lake to decline to a median of 6,354 feet over the long term. For the 6,377-Ft to 6,390-Ft Alternatives, the marginal WTP to go from Program A ($81.90) to Program B ($91.16) is used. This value of $9.26 is divided by the change in lake elevation (15 feet) between the two programs to obtain a WTP per 1-foot change in lake elevation ($0.62). This value is then multiplied by the change in elevation between the EIR alternatives and the estimated number of English-speaking households (9,276,530) in the state to obtain an estimate of total WTP for the 6,377-Ft, 6,383-Ft, and the 6,390-Ft Alternatives.

After the adjustment for nonrespondents, the median WTP to obtain Program C (6,410 feet) was $0. Consequently, no value could be assigned to the 6,410-Ft Alternative. Also, no value was assigned to the No-Diversion Alternative because no survey data were collected for this alternative, which is higher than the 6,410-Ft Alternative.

The results of applying these procedures are reflected in the benefit-cost summary table (Table 3N-14) in Chapter 3N, "Economics".

WATER SUPPLY AND POWER GENERATION COSTS

The methods used to estimate water supply and power generation costs are described in Chapters 3L and 3M, respectively. The worksheets that show the annual and total changes in water supply and power generation costs for the point of reference and alternatives are included in Table X-12.

CITATIONS

Printed References

Hanemann, W. M. 1984. Welfare evaluations in contingent valuation experiments with discreet responses. American Journal of Agricultural Economics 66(3):332-341.

Hanemann, W. M., Loomis, J. L., and Kanninen, B. J. 1991. Estimation efficiency of double bounded dichotomous choice contingent valuation. American Journal of Agricultural Economics.

Table X-3. Worksheet for Estimating Recreation Benefits for Lower Tributaries Visitors

1.	Number of annual visitor days (in 1990, from Table 3J-1)	350
2.	Average number of annual visitor days per visitor (from user survey, Appendix W)	1.54
3.	Estimated number of visitors	227
4.	Average visitor benefits per change in cfs (estimated median benefits [$17.64] from statistical analysis divided by change in cfs [20] described in survey)	$0.88
5.	Estimated benefits at 50% rate for changes between 60 cfs and 100 cfs	$0.44
6.	Calculate benefits per visitor and total annual benefits for a change in median cfs from point-of-reference conditions (52 cfs) (Table 3J-13)	

- No restriction: cfs = 36
  16 x 0.88 = $14.08 x 227 = -$3,196

- 6,372-Ft: cfs = 49
  3 x 0.88 = 2.64 x 227 = -$599

- 6,377-Ft: cfs = 76
  8 x 0.88 = 7.04 x 227 = $1,598
  16 x 0.44 = 7.04 x 227 = 1,598 + 1,598 = $3,196

- 6,383.5-Ft: cfs = 95
  8 x 0.88 = 7.04 x 227 = $1,598
  35 x 0.44 = 15.40 x 227 = 3,496 + 1,598 = $5,094

- 6,390-Ft: cfs = 115
  8 x 0.88 = 7.04 x 227 = $1,598
  40* x 0.44 = 17.60 x 227 = 3,995 + 1,598 = $5,593

- 6,410-Ft: cfs = 126
  8 x 0.88 = 7.04 x 227 = $1,598
  40* x 0.44 = 17.60 x 227 = 3,995 + 1,598 = $5,593

- No diversion: cfs = 110
  8 x 0.88 = 7.04 x 227 = $1,598
  40* x 0.44 = 17.60 x 227 = 3,995 + 1,598 = $5,593

* Values were not assigned for flows above 100 cfs.

Table X-3. Continued

7. Estimate benefits for visitors who do not currently use the lower tributaries (assume that the number of visitors is 50% of the existing number and that their willingness to pay for flows is 75% of the amount for existing users)	
- No restriction	-$1,199
- 6,372-Ft Alternative	- 244
- 6,377-Ft Alternative	1,199
- 6,383.5-Ft Alternative	1,910
- 6,390-Ft Alternative	2,097
- 6,410-Ft Alternative	2,097
- No diversion	2,097
8. Estimate annual benefits	
- No restriction	-$4,395
- 6,372-Ft Alternative	- 823
- 6,377-Ft Alternative	4,395
- 6,383.5-Ft Alternative	7,004
- 6,390-Ft Alternative	7,690
- 6,410-Ft Alternative	7,690
- No diversion	7,690

Table X-1. Worksheet for Estimating Recreation Benefits for Mono Lake Visitors

1.	Number of annual visitor days (in 1992, from Table 3J-3)	162,000
2.	Average number of annual visitor days per visitor (from user survey, Appendix W)	3.14
3.	Estimated number of visitors	51,592
4.	Average visitor benefits per change in lake elevation (estimated WTP benefits from statistical analysis)	

5. Calculate benefits per visitor and total annual benefits for a change in median lake level from point-of-reference conditions (6,372): \$3.47 per foot for changes between 6,375 feet and 6,390 feet and \$0.99 per foot for changes between 6,391 feet and 6,411 feet

   - No restriction: median long-term lake level = 6,354 feet
     Used WTP (\$61.30) to maintain 6,375 feet to approximate the value to avoid dropping to this lake level (\$61.30 x 51,592 = \$3,162,590)
   - 6,372-Ft: median long-term lake level = 6,375 feet
     (3 x 3.47 = \$10.41 x 51,592 = \$537,072)
   - 6,377-Ft: median long-term lake level = 6,379 feet
     (7 x \$3.47 = \$24.29 x 51,592 = \$1,253,169)
   - 6,383.5-Ft: median long-term lake level = 6,386 feet
     (14 x \$3.47 = \$48.58 x 51,592 = \$2,506,339)
   - 6,390-Ft: median long-term lake level = 6,392 feet
     (18 x 3.47 = \$62.46 x 51,592 = \$3,222,436)
     (2 x \$0.99 = \$1.98 x 51,592 = 102,152 + 3,222,436 = \$3,324,588)
   - 6,410-Ft: median long-term lake level = 6,411 feet
     (39 x \$0.99 = \$38.61 x 51,592 = \$1,991,967)
   - No diversion: median long-term lake level = 6,427 feet
     No estimate; outside estimatable range

Note: Median lake level for point of reference differs from that shown in Table 3J-13 because the economic analysis requires the actual median of hydrologic conditions as opposed to the assumed lake level (i.e., 6,376 feet).

Table X-2. Willingness to Pay: Mono Lake

Lake Level (Feet)	Distribution	Intercept	Slope	Median WTP	Mean WTP
6,375	Logistic	1.36106	0.02108	64.5719	75.400
6,375	Loglogistic	4.38079	1.07482	58.8994	793.523
6,390	Logistic	1.46590	0.02108	69.5460	79.401
6,390	Loglogistic	4.48519	1.07482	64.9079	874.472
6,410	Logistic	0.83442	0.02108	39.5868	56.692
6,410	Loglogistic	3.87691	1.07482	36.8566	496.550

Note: Lake level is treated as a covariate in the model.

Table X-4. Willingness to Pay: Tributary Survey

Program	Distribution	Intercept	Slope	Median WTP	Mean WTP
Flow = 43.3	Logistic	0.59855	0.03392	17.6468	30.560
Flow = 43.3	Loglogistic	3.73454	1.28304	18.3697	70.404
Flow = 60	Logistic	0.73602	0.04468	16.4720	25.231
Flow = 60	Loglogistic	2.71070	1.03616	13.6823	379.119

Note: There were no coviariates in the model.

Table X-5. Worksheet for Estimating Recreation Benefits at Grant Lake Reservoir

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1. Average number of annual visitor days over 20-year period, by alternative (Table 3N-17)

2. Average visitor benefits per change in lake elevation (estimated median WTP per visitor day from statistical analysis divided by change in lake level [21 feet] described in survey) — $0.22

3. Calculate benefits per visitor and total annual benefits for a change in median lake level from point-of-reference conditions (7,112 feet) (Table 3J-13)

   - No restriction: median lake level = 7,119 feet
     7 x $0.22 = $1.54 x 69,800 = $107,492
   - 6,372-Ft: median lake level = 7,106 feet
     -7 x $0.22 = $1.32 x 64,600 = $-85,272
   - 6,377-Ft: median lake level = 7,105 feet
     -7 x $0.22 = $1.54 x 64,400 = $-99,176
   - 6,383.5-Ft: median lake level = 7,104 feet
     -8 x $0.22 = $1.76 x 63,500 = $-111,760
   - 6,390-Ft: median lake level = 7,103 feet
     -9 x $0.22 = $1.98 x 62,800 = $-124,344
   - 6,410-Ft: median lake level = 7,102 feet
     -10 x $0.22 = $2.20 x 62,000 = $-136,400
   - No diversion: median lake level = 7,132 feet
     20 x $0.22 = $4.40 x 81,000 = $365,400

Table X-6. Willingness to Pay: Grant Lake Reservoir

Distribution	Intercept	Slope	Median WTP	Mean WTP
Logistic	1.55539	0.33296	4.67137	5.24661
Loglogistic	2.55963	1.76997	4.24669	7.69744

Note: Only survey versions 2 and 3 and lake-level alternative 2 included in the analysis.

Table X-7. Worksheet for Estimating Recreation Benefits at Lake Crowley Reservoir

1.	Number of annual visitor days (in 1991, from Table 3J-1)	142,000
2.	Average number of annual visitor days per visitor (from user survey, Appendix W)	13.0
3.	Estimated number of visitors	10,923
4.	Average visitor benefits per change in lake elevation (estimated median WTP per year from statistical analysis divided by change in lake level [8 feet] described in survey)	
5.	Calculate benefits per visitor and total annual benefits for a change in median lake level from point-of-reference conditions (6,773) (Table 3J-13)	

- No restriction: median lake level = 6,774 feet
  1 x $8.12 = $8.12 x 10,923 = $88,694
- 6,372-Ft: median lake level = 6,772 feet
  -1 x $8.12 = $8.12 x 10,923 = $-88,694
- 6,377-Ft: median lake level = 6,773 feet
  No change
- 6,383.5-Ft: median lake level = 6,770 feet
  -3 x $8.12 = $24.36 x 10,923 = $-266,084
- 6,390-Ft: median lake level = 6,770 feet
  -3 x $8.12 = $24.36 x 10,923 = $-266,084
- 6,410-Ft: median lake level = 6,769 feet
  -4 x $8.12 = $32.48 x 10,923 = $-354,779
- No diversion: median lake level = 6,769 feet
  -4 x $8.12 = $32.48 x 10,923 = -$354,779

Table X-8. Willingness to Pay: Lake Crowley Reservoir

Distribution	Intercept	Slope	Median WTP	Mean WTP
Logistic	2.10436	0.03239	64.9640	68.516
Loglogistic	5.68689	1.37483	62.5797	189.262

Note: 1991 and 1992 data combined; only survey versions 2 and 6 and lake-level alternative 2 included in the analysis; only annual pass holders included in the analysis.

Table X-9. Worksheet for Estimating Recreation Benefits for Upper Owens River

1.	Number of annual visitor days (in 1987, from Table 3J-1)	18,300
2.	Average number of annual visitor days per visitor (approximated from user survey for Mono Lake tributaries)	9.9
3.	Estimated number of visitors	1,848
4.	Average visitor benefits per change in cfs (estimated benefits from statistical analysis for lower tributaries divided by change in cfs described in the user survey)	$1.70
5.	Calculate benefits per visitor and total annual benefits for a change in median cfs from point-of-reference conditions (190 cfs) (Table 3J-13)	

- No restriction: cfs = 204
  14 x $1.70 = $23,80 x 1,848 = $43,982
- 6,372-Ft: cfs = 200
  10 x $1.70 = $17.00 x 1,848 = $31,416
- 6,377-Ft: cfs = 164
  -26 x $1.70 = $44.20 x 1,848 = -$81,681
- 6,383.5-Ft: cfs = 125
  -65 x $1.70 = $110.50 x 1,848 = -$204,204
- 6,390-Ft: cfs = 110
  -80 x $1.70 = $136 x 1,848 = -$251,328
- 6,410-Ft: cfs = 82
  -108 x $1.70 = $183.60 x 1,848 = -$339,292
- No diversion: cfs = 81
  -109 x 1.70 = $185.30 x 1,848 = -$342,434

Table X-12. Water and Power Supply Costs over the 20-Year Period

	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	Average	Total
Point of Reference:																						
L.A. Water Supp$ million	80.527	91.805	118.328	142.204	101.708	162.365	150.881	144.195	283.598	158.749	117.033	194.237	122.756	173.837	127.298	182.365	212.192	317.457	307.244	308.397	174.859	3,497.177
AF	480,169	467,753	466,309	432,253	530,937	432,579	464,890	485,643	283,722	471,870	538,500	423,470	538,500	463,629	538,500	457,682	428,720	298,926	315,958	319,890	441,995	8,839,900
L.A. Power Supp$ million	427.200	435.949	435.222	467.626	484.621	507.760	531.290	538.729	599.878	614.951	656.942	725.617	751.860	805.568	830.017	872.655	914.004	930.154	971.646	1,009.838	675.580	13,511.609
GWH	1,151	1,166	1,157	1,010	1,192	961	1,125	1,065	587	1,198	1,221	960	1,278	1,041	1,232	1,155	1,048	722	728	757	1,038	20,754
Difference from Point-of-Reference Conditions																						
No-Restriction Alternative:																						
L.A. Water Supp$ million	0.057	(1.173)	(1.914)	(9.883)	1.929	(10.803)	(1.627)	3.113	(11.306)	(8.709)	3.194	(9.139)	(0.003)	(6.730)	(0.003)	12.732	(19.765)	(13.677)	(13.567)	(14.614)	(5.094)	(101.888)
AF	(1,287)	3,690	4,668	22,059	(3,414)	19,633	3,329	(4,917)	16,825	12,294	(5,211)	16,235	0	9,082	0	(16,656)	25,655	17,268	16,821	17,985	7,703	154,059
L.A. Power Supp$ million	(1.956)	(0.171)	0.000	(1.442)	(0.603)	(1.519)	1.672	(1.078)	(1.138)	(0.608)	(1.049)	(2.987)	(1.195)	(3.948)	(1.192)	0.802	(1.162)	(0.383)	(2.983)	(3.597)	(1.227)	(24.536)
GWH	45	5	6	68	(2)	51	(17)	35	50	12	32	73	25	78	27	(4)	50	40	46	62	34	682
6,372-Ft Alternative:																						
L.A. Water Supp$ million	(0.609)	(0.089)	(1.937)	23.736	10.891	15.249	19.005	5.711	23.067	0.985	9.641	25.143	(11.425)	10.381	(1.786)	2.961	33.182	10.138	21.214	20.831	10.815	216.291
AF	2,975	(2,082)	4,742	(52,284)	(21,546)	(27,613)	(31,850)	(8,882)	(33,904)	(1,676)	(15,804)	(31,392)	19,079	(26,218)	3,490	(6,311)	(43,008)	(12,984)	(26,490)	(25,697)	(16,873)	(337,455)
L.A. Power Supp$ million	(0.732)	0.639	0.486	2.981	0.386	3.959	4.869	(1.289)	4.711	2.562	(1.089)	2.237	(4.543)	2.141	(3.332)	3.912	6.535	3.463	5.924	4.196	1.901	38.017
GWH	30	(9)	(10)	(90)	20	(119)	(115)	62	(111)	(56)	68	(65)	123	(42)	101	(66)	(136)	(66)	(95)	(87)	(33)	(663)
6,377-Ft Alternative:																						
L.A. Water Supp$ million	7.942	20.248	7.207	26.295	26.510	25.418	28.221	(0.088)	27.853	6.651	9.634	26.956	(11.425)	19.754	(1.786)	12.820	40.205	9.880	22.652	25.866	16.541	330.815
AF	(56,608)	(22,385)	(17,517)	(57,767)	(52,874)	(46,910)	(47,573)	158	(40,723)	(9,712)	(15,789)	(33,801)	19,079	(39,074)	3,490	(19,295)	(52,047)	(12,568)	(28,305)	(31,679)	(28,095)	(561,900)
L.A. Power Supp$ million	(0.259)	1.685	0.830	3.404	1.264	3.592	4.169	0.540	5.259	2.667	0.708	3.268	(4.611)	3.715	(1.554)	5.361	5.831	5.772	6.512	5.395	2.678	53.550
GWH	22	(28)	(49)	(111)	4	(103)	(152)	15	(137)	(57)	11	(82)	128	(93)	69	(109)	(125)	(80)	(98)	(106)	(54)	(1,081)
6,383.5-Ft Alternative:																						
L.A. Water Supp$ million	5.684	30.422	26.813	33.590	9.763	39.342	40.296	10.405	30.856	41.761	23.723	44.462	(8.561)	13.628	5.924	16.812	45.641	15.399	36.823	30.636	24.671	493.422
AF	(40,020)	(59,612)	(64,680)	(73,444)	(18,774)	(72,222)	(67,938)	(16,794)	(74,596)	(60,325)	(36,690)	(53,619)	14,583	(28,040)	(9,528)	(16,049)	(58,712)	(19,667)	(46,001)	(37,762)	(41,995)	(839,890)
L.A. Power Supp$ million	1.987	4.761	5.512	6.126	1.498	3.694	7.102	1.603	5.875	6.858	0.708	3.268	(3.594)	8.046	(0.575)	8.119	4.669	5.772	6.512	5.395	4.167	83.336
GWH	(111)	(218)	(202)	(188)	(27)	(147)	(256)	(36)	(158)	(155)	11	(82)	88	(163)	12	(135)	(103)	(80)	(98)	(106)	(108)	(2,154)
6,390-Ft Alternative:																						
L.A. Water Supp$ million	5.684	30.422	26.813	33.590	9.763	39.342	40.296	10.405	30.856	41.761	23.723	44.462	(3.918)	35.141	9.043	49.374	55.353	15.601	36.823	38.544	28.654	573.080
AF	(40,020)	(59,612)	(64,680)	(73,444)	(18,774)	(72,222)	(67,938)	(16,794)	(74,596)	(60,325)	(36,690)	(53,619)	6,596	(51,690)	(14,626)	(62,030)	(71,535)	(19,996)	(46,001)	(47,534)	(47,277)	(945,530)
L.A. Power Supp$ million	1.807	4.094	5.693	7.742	1.498	5.110	7.167	0.853	6.356	8.495	2.393	8.774	(2.468)	8.830	0.769	8.723	7.072	4.041	7.772	6.034	5.038	100.754
GWH	(102)	(179)	(206)	(236)	(28)	(176)	(259)	(55)	(162)	(221)	(38)	(177)	46	(211)	(4)	(186)	(156)	(59)	(134)	(126)	(133)	(2,669)
6,410-Ft Alternative:																						
L.A. Water Supp$ million	7.942	30.147	29.650	35.818	23.604	38.873	41.864	12.371	30.713	45.303	48.345	50.174	7.303	65.879	15.200	71.965	52.635	21.895	36.823	42.124	35.431	708.627
AF	(56,608)	(49,293)	(71,692)	(78,166)	(46,834)	(71,086)	(70,433)	(19,607)	(83,297)	(65,778)	(71,814)	(61,513)	(12,236)	(87,771)	(24,554)	(87,610)	(67,864)	(28,014)	(46,001)	(51,898)	(57,603)	(1,152,069)
L.A. Power Supp$ million	5.217	3.399	4.924	7.742	3.871	5.110	8.455	0.924	6.356	9.010	3.054	10.894	3.363	10.966	3.525	10.968	12.062	6.927	8.360	7.912	6.652	133.039
GWH	(236)	(177)	(232)	(257)	(153)	(176)	(312)	(57)	(162)	(244)	(78)	(251)	(76)	(259)	(94)	(235)	(259)	(99)	(146)	(169)	(184)	(3,672)
No-Diversion Alternative:																						
L.A. Water Supp$ million	8.446	45.583	34.197	36.416	20.609	39.340	48.581	25.988	30.696	57.753	33.389	65.204	20.209	76.763	13.329	84.658	72.124	20.676	36.823	44.787	41.178	823.570
AF	(59,378)	(90,217)	(83,411)	(80,033)	(56,925)	(72,215)	(82,308)	(41,025)	(78,056)	(83,407)	(50,985)	(82,616)	(30,993)	(97,371)	(21,715)	(104,286)	(92,951)	(26,465)	(46,001)	(55,270)	(66,781)	(1,335,628)
L.A. Power Supp$ million	5.102	7.160	6.905	8.165	5.132	5.556	9.827	3.999	6.356	11.576	5.740	10.835	4.581	12.201	4.071	12.512	14.940	12.122	8.319	8.511	8.181	163.611
GWH	(263)	(307)	(268)	(259)	(184)	(194)	(346)	(122)	(162)	(302)	(140)	(244)	(118)	(298)	(91)	(280)	(298)	(199)	(146)	(184)	(220)	(4,405)

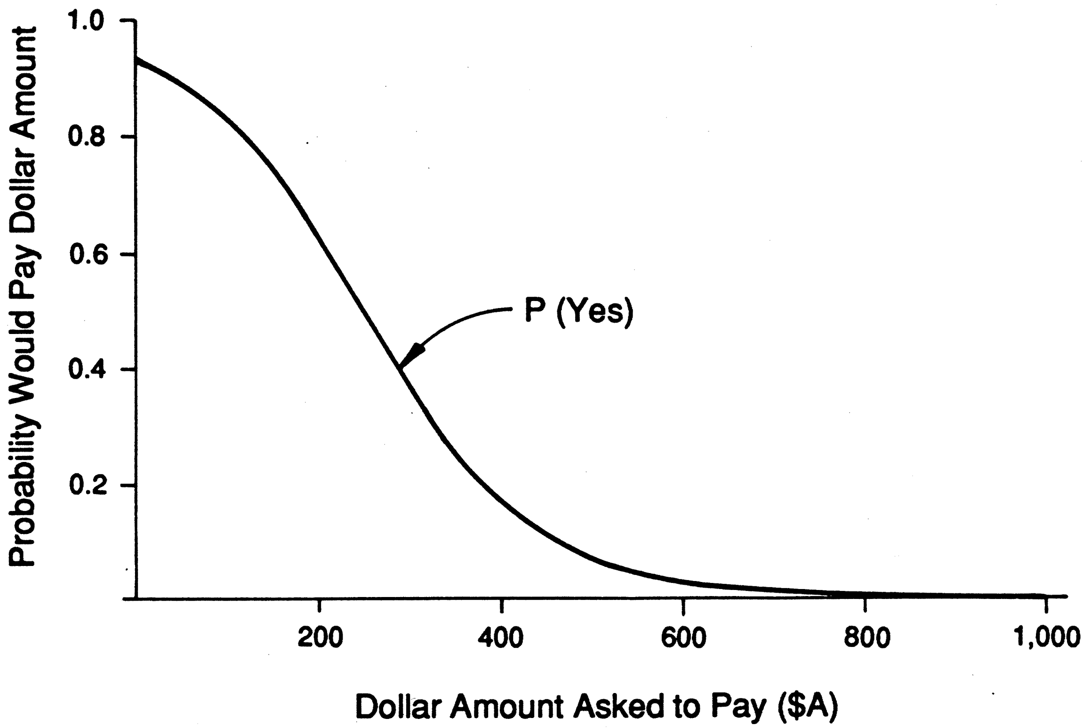

Figure X-1.
Discrete Response Willingness-to-Pay Model