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)

$$
\begin{aligned}
= \; & + \; (74{,}324 \text{ af}) \times (\text{release factor}) \\
& + \; (0.228) \times (74{,}324 \text{ af}) \\
& + \; (0.57 \text{ ft}) \times (\text{lake surface acreage}) \\
& - \; (4.00 \text{ ft}) \times (\text{lake surface acreage}) \\
& + \; (23{,}421 \text{ af})
\end{aligned}
$$

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.