APPENDIX J

CONSTRUCTION OF A RULE CURVE FOR SINGLE-PLANT POWER OPERATION

J-1. General. As discussed in Section 5-11a, a rule curve describes how much storage must be maintained in a reservoir at different times in the year to insure that firm discharge requirements can always be met. The rule curve is usually defined by the reservoir operation during the critical period, but it is also necessary to test other adverse streamflow periods to make sure that they do not control during certain periods of the year. To illustrate the development of rule curves, two examples will be described: (a) a simple single-year rule curve describing the storage required to meet the water quality discharges listed in Table H-1, and (b) a multi-year hydropower rule curve that will be used as the basis for Case 2 in Appendix I.

J-2. Single-Year Rule Curve.

a. This rule curve will be based on meeting the water quality requirements for the Broken Bow Reservoir, as listed in Table H-1, and it will be used as a possible constraint in the solution of Case 5 in Appendix I. An examination of the mass curve (Figure F-2) shows that the 1963-64 operating year is the most adverse single year, and the critical drawdown period could extend from the first of May through the end of February. However, since the water quality requirements for May and February (88 cfs and 90 cfs, respectively) are considerably less than the inflow for those months (396 cfs and 338 cfs), the critical drawdown period would not include May and February in this case.

b. The rule curve will be developed by doing a reverse routing, beginning with the reservoir empty at the end of the critical drawdown period (end of January, 1964). The routing continues through the point when the maximum pool elevation is reached (the start of the critical drawdown period, the end of May, 1963), and on until the reservoir is empty once more. The same basic procedures are followed as for a normal sequential power routing, except that the routing is done in reverse chronological order, starting with the reservoir empty. In addition, since the objective in this example is simply to meet monthly flow requirements, power calculations do not have to be made.

c. Table J-1 summarizes the calculations, and Figure J-1 shows the resulting rule curve. As long as the reservoir elevation stays above this rule curve and a flow sequence drier than 1963-64 does not occur, the water quality discharge requirements will always be met. In Case 5 in Appendix I, the objective is to maximize generation in the summer months, when energy has its highest value. There are no firm energy requirements to be met during the remainder of the year. Therefore, to insure that water quality requirements will be met in all months, summer drafts for power generation will not be permitted to fall below the water quality rule curve.

d. In this example, a reverse routing was done only for the 1963-64 operating year, because an examination of available streamflow records showed that it was the driest year on record. No other years approached that year in severity. However, if the records showed other comparably dry water years, reverse routings would be done for those years as well, and the rule curve would be constructed as an envelope curve, enclosing all of these curves. An example of how this would be accomplished is described in the next section.

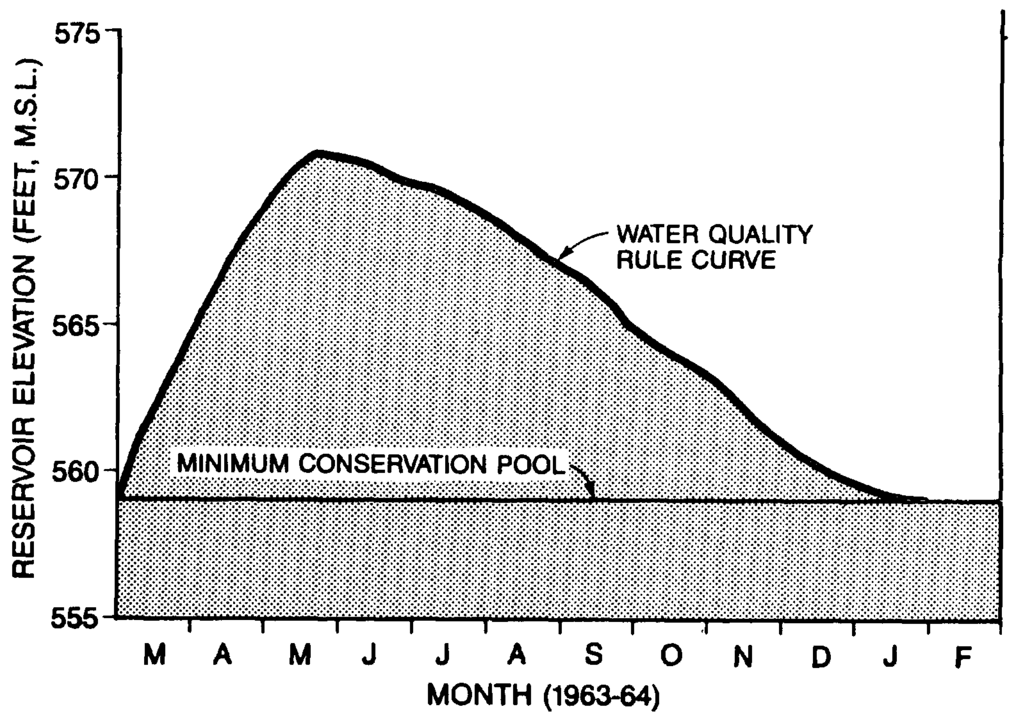

Figure J-1. Single-year water quality rule curve

J-3. Rule Curve Based on Multi-Year Critical Period.

a. The first step in developing a rule curve for the Broken Bow project is to do a reverse routing for the multi-year critical drawdown period, May 1962 through February 1964. Sinoe only firm energy requirements are to be met, this routing would be identical to the critical drawdown period routing described in Appendix H. The reverse routing is then extended from May 1962, meeting only firm energy requirements, until the reservoir is once again empty (the first of November, 1961). This routing defines the lowest reservoir elevations that could be maintained month by month during the winter and spring of 1961-62, while still insuring that the reservoir fills by the first of May.

b. Note that this leg of the reverse routing does not necessarily define the actual routing that would be followed during the period November 1961 through April 1962, because the historical streamflow sequence prior to November 1961 would have probably left the reservoir well above the bottom of the power pool on the first of November. It only serves as a possible adverse combination of streamflows and reservoir elevations, which will help define the refill leg of the power rule curve. The reverse routing for the entire period, November 1961 through February 1964, is shown on Figure J-2.

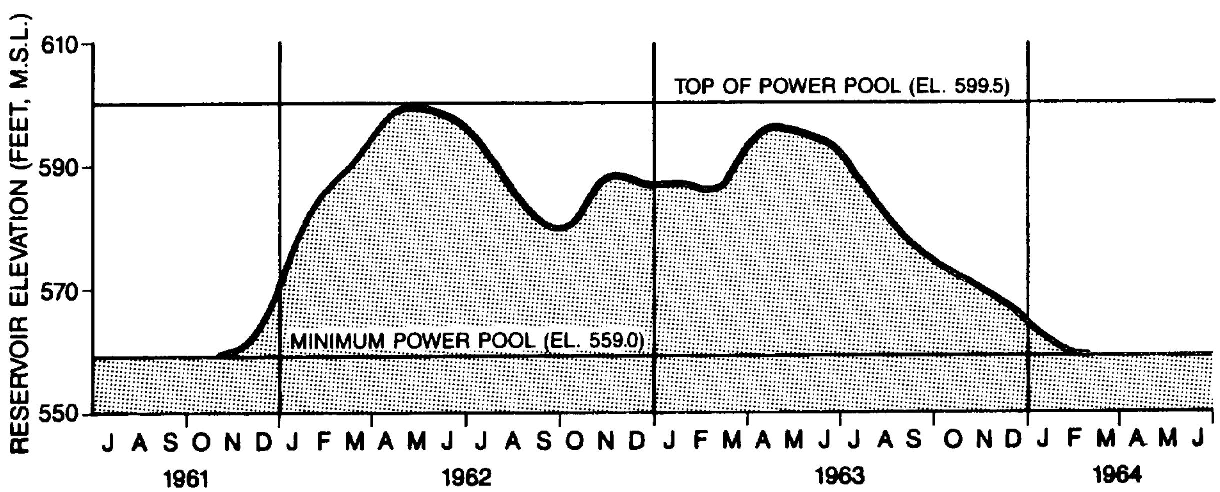

Figure J-2. Reverse routing for 1962-64 critical drawdown period

c. In addition to the most severe drought of record, several other periods of low inflow should be analyzed in order to determine whether combinations of demand and hydrologic conditions other than those experienced in the critical period might affect the location of the rule curve. Reverse routings would be made for each of these sequences, starting with the reservoir empty at the end of the period. Power discharges would be limited to firm energy requirements and the routing would continue forward in time until the reservoir is once again empty. Figure J-3 shows reverse routings for three additional low flow periods.

d. The final step is to plot the routings for all of the significant low-flow periods on a single-year time base, as shown in Figure J-4. Since an envelope of these hydrographs represents the pool levels required to provide adequate storage at the beginning of the four significant low-flow periods of record, a curve which envelops all hydrograph plots represents the pool elevations required at all times of the year to assure firm energy generation through all droughts of the period of record. The power operating rule curve (the enveloping curve) is also shown on Figure J-4. The rule curve insures that firm energy demands will always be met, providing no drought more severe than the critical period drought occurs during the project life.

e. However, if a more severe drought should occur, the reservoir power storage would be completely drafted and a firm energy shortfall would occur. In order to minimize the probability of such an event taking place, the period of record used for analyzing the project should be as long as possible (Section 5-6d). If there is some question about the adequacy of the record, streamflow data for adjacent basins and rainfall records should be examined in order to determine if there have been other periods that might have been more severe than the most adverse sequence in the existing period of record.

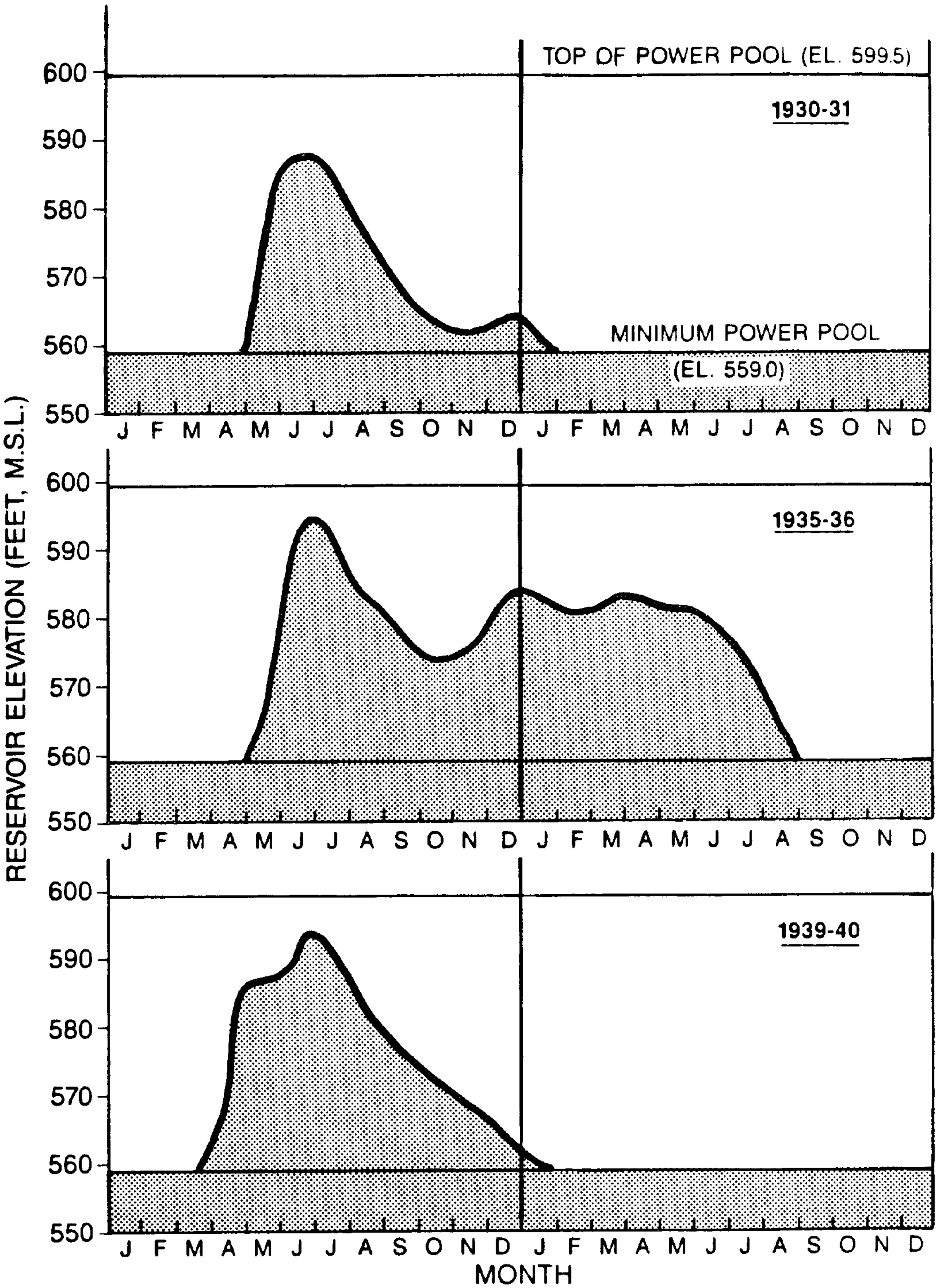

Figure J-3. Reverse routings for three additional historical low flow periods

TABLE J-1. Reverse Routing

Routing Interval Month	Year	Inflow 'I' (CFS)	Evapo-ration 'E' (CFS)	With-drawals 'W' (CFS)	Net Inflow (CFS)	Water Quality Discharge (CFS)
Feb	1964					
Jan	1964	15	-30	24	21	118
Dec	1963	15	-30	24	21	235
Nov	1963	0	-21	25	-3	320
Oct	1963	0	2	33	-31	320
Sep	1963	19	19	66	-66	314
Aug	1963	43	43	94	-94	173
Jul	1963	65	43	94	-72	120
Jun	1963	36	27	95	-86	90
May	1963	396	-22	55	363	88
Apr	1963	913	-9	37	885	86
Mar	1963	2,109	-15	27	2,097	86

for Water Quality Rule Curve

Required Total Discharge (CFS)	Change in Storage, $S_2 - S_1$ (CFS)	Change in Storage, $S_2 - S_1$ (AF)	Start of Period Reservoir Status (AF)	Start of Period Reservoir Status (Elev.)	Start of Period Reservoir Status (Acres)
			448,700	559.0	9,170
118	-97	-6,000	454,700	559.6	9,240
235	-214	-13,200	467,900	561.0	9,400
320	-323	-14,300	482,200	563.2	9,650
320	-351	-21,600	503,800	564.8	9,840
314	-380	-22,600	526,400	567.1	10,090
173	-267	-16,400	542,800	568.7	10,270
120	-192	-11,800	554,600	569.8	10,400
90	-176	-10,500	565,100	570.8	10,530
88	275	16,900	548,200	569.2	10,330
86	799	47,500	500,600	564.5	9,810
1,253	844	51,900	448,700	559.0	9,170

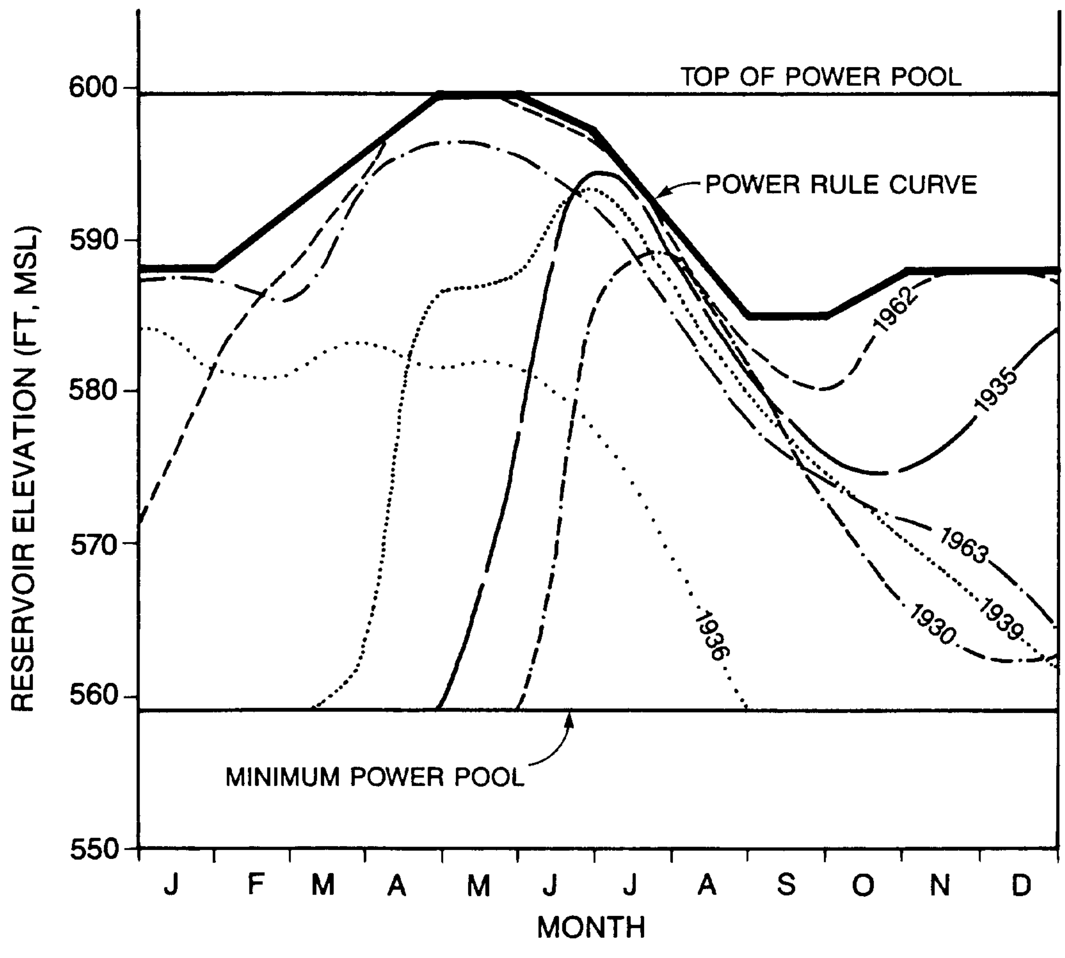

Figure J-4. Power operating rule curve (enveloping rule curve)