APPENDIX E

DAILY SEQUENTIAL ROUTING

E-1. General. This appendix illustrates the daily sequential routing of a project that is operated primarily for flood control and non-power conservation storage. The project operates at minimum pool during the winter months for flood control and begins refill on February 1. The refill rule curve is based on providing flood control storage space consistent with the gradually diminishing flood risk while attempting to refill the conservation storage by June 1. Figure E-1 shows the annual rule curve for the project.

E-2. Basic Data. Following is a list of project characteristics:

Maximum pool elevation:	El. 1540.0
Minimum pool elevation:	El. 1450.0
Average pool elevation:	El. 1490.0
Minimum discharge:	100 cfs
Storage-elevation characteristics:	Figure E-2 (partial)
Tailwater characteristics:	Figure E-5
Head loss in penstock and trashracks:	3.0 feet
Rule curve elevations:	Table E-1 (partial)

TABLE E-1
Rule Curve Elevations for March

Day	Elevation	Day	Elevation	Day	Elevation
1	1499.0	11	1505.2	21	1511.2
2	1499.6	12	1505.8	22	1511.8
3	1500.2	13	1506.4	23	1512.4
4	1500.9	14	1507.0	24	1513.0
5	1501.5	15	1507.6	25	1513.6
6	1502.1	16	1508.2	26	1514.2
7	1502.7	17	1508.8	27	1514.8
8	1503.5	18	1509.4	28	1515.3
9	1504.0	19	1510.0	29	1515.9
10	1504.6	20	1510.6	30	1516.5
				31	1517.1

E-3. Powerplant Characteristics.

a. General. Assume that it is desired to have a two-unit powerplant with a total rated discharge of 1000 cfs. Assume further that the plant will operate in a "block-loading" mode, in that each day the plant will be operated at full load for as many hours as water permits and it will be shut down for the remainder of the day.

b. Head Range. For block-loaded operation, the tailwater elevation would normally correspond to a discharge of about 1000 cfs, or El. 1225.0 (see Figure E-5).

Head at full pool = El. 1540.0 - El. 1225.0 - 3.0 feet = 312 ft.
Head at min. pool = El. 1450.0 - El. 1225.0 - 3.0 feet = 222 ft.

With this head range, a Francis turbine would be most appropriate (see Figure 2-35). The ratio of minimum head to maximum head is (222 feet/ 312 feet) = 0.71, which is within the allowable head ratio for this type of unit (0.50, see Section 5-6i).

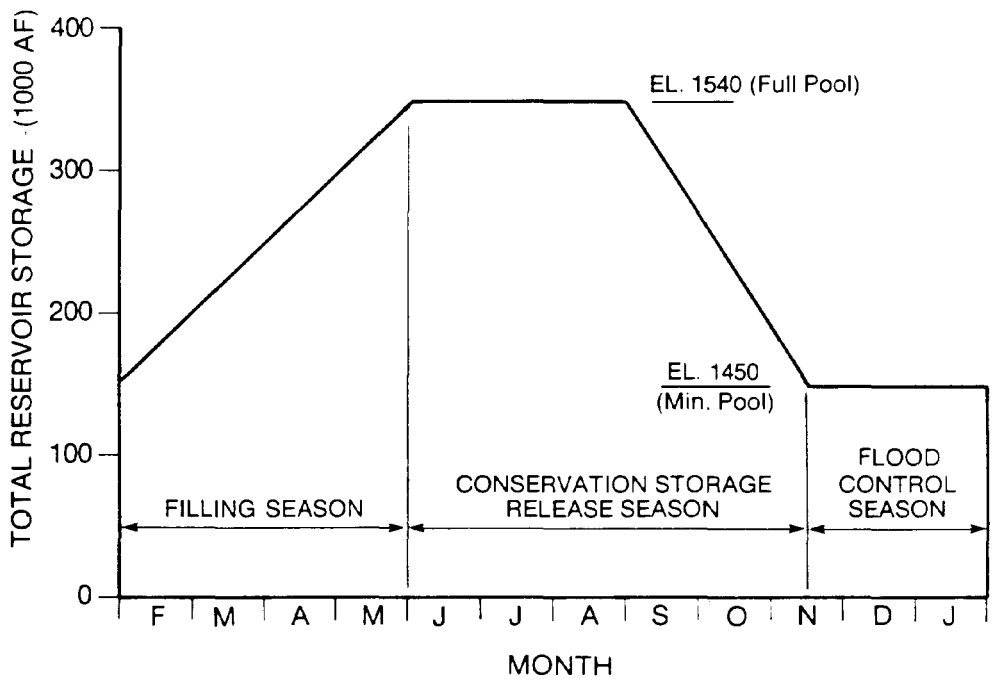

Figure E-1. Reservoir rule curve for example project

c. Rated Capacity. As noted above, the powerplant rated discharge or hydraulic capacity will be 1000 cfs. The unit will be rated at average head, which is the head corresponding to the average pool elevation of 1490.0 feet.

Rated head = El. 1490.0 - El 1225.0 - 3.0 feet = 262.0 feet.

Assuming an overall efficiency of 88 percent at rated output and using the water power equation (Eq. 5-2),

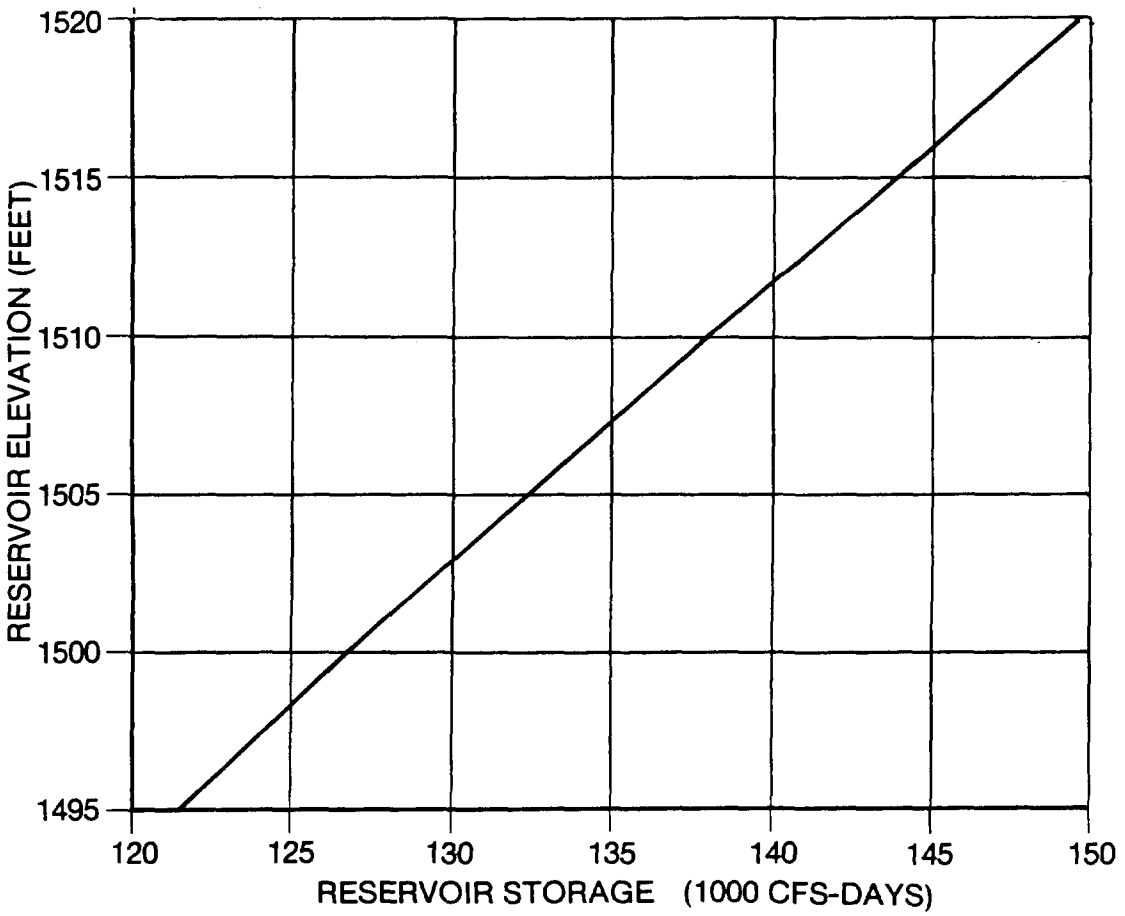

Figure E-2. Partial reservoir storage-elevation curve

$$\text{Rated capacity} = \frac{Q_R H_R e}{11.81} = \frac{(1000 \text{ cfs})(262.0 \text{ ft})(0.88)}{11.81} = 19{,}500 \text{ kW.}$$

where: Q_R = rated discharge, cfs
H_R = rated head, feet

d. Hydraulic Capacity and Efficiency vs. Head. For preliminary studies, the variation of hydraulic capacity (full gate discharge) and overall unit efficiency with head can be ignored. However, in this example, these variables will be accounted for. Where this is done, calculation of energy for a large number of time increments can be expedited by using hydraulic capacity versus head and efficiency versus head curves. Turbine characteristics will be based on the generalized performance curve for a Francis turbine, Figure 2-39. Because the unit will be block-loaded, the unit performance is defined by the full gate discharge line at heads up to rated head and by the generator rated capacity line at heads greater than rated head. Table E-2 was compiled by assuming a series of heads (expressed as ratios of head to rated head) and reading corresponding values of percent of rated discharge (Q_R) and percent of rated capacity (P_R) from the full gate discharge and rated capacity lines on Figure 2-39. The actual values of head, discharge, and capacity shown on the table are based on the percent values from Figure 2-39 and the rated discharge of 1000

TABLE E-2
Computation of Powerplant Characteristics

H_R	Head (feet)	Percent of Q_R	Hydraulic Capacity (cfs)	Percent of P_R	Capacity (kW)	Efficiency (percent)
0.65	170.3	92	920	55	10,725	0.81
0.75	196.5	94	940	67	13,065	0.84
0.85	222.7	97	970	83	16,185	0.89
1.00	262.0	100	1000	100	19,500	0.88
1.15	301.3	88	880	100	19,500	0.87
1.30	340.6	77	770	100	19,500	0.88
1.40	366.8	70	700	100	19,500	0.90

1/ Ratio of head to rated head

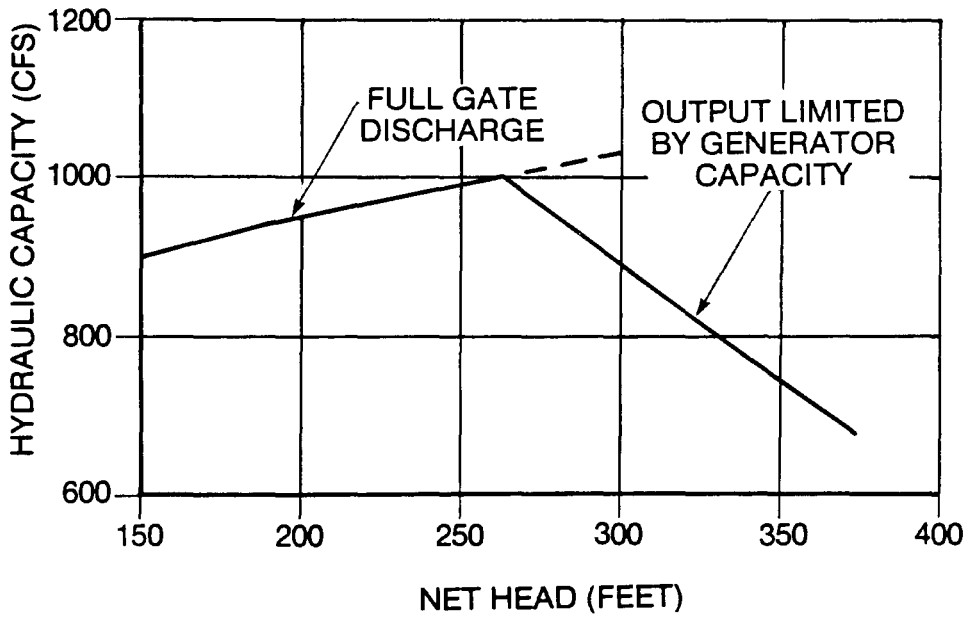

Figure E-3. Hydraulic capacity vs. head

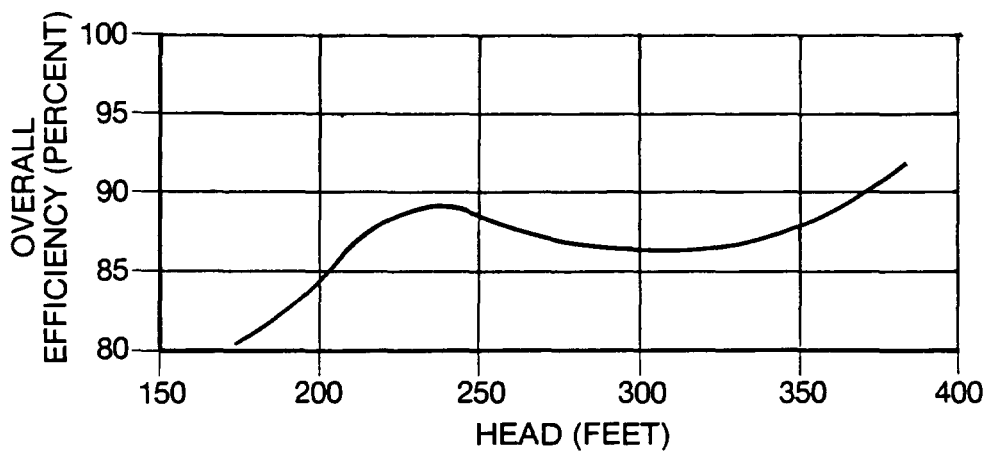

Figure E-4. Efficiency vs. head

cfs, the rated head of 262 feet, and the rated output of 19,500 kW. Efficiency was computed for each head using the water power equation,

$$\text{Efficiency} = \frac{11.81(\text{kW})}{QH} \qquad \text{(Eq. E-1)}$$

Figure E-3 shows the resulting plot of hydraulic capacity versus head, and Figure E-4 shows the plot of efficiency versus head.

E-4. Computation of Energy Output.

a. General. Table E-3 summarizes the computation of energy for each day using regulated flows for the month of March 1982. Table E-4 shows how each value was determined, by column. Figure E-6 shows a plot of actual reservoir elevation by day compared to the rule curve elevations.

b. Rules for Selection of Daily Discharge.

(1) During flood control operation, project discharge is reduced to zero when flood flows are being stored. During evacuation of flood storage, the objective is to empty the flood control space as rapidly as possible, but project discharge is limited to 4000 cfs in order to avoid exceeding bankfull conditions downstream.

(2) During the filling of conservation storage (1 February to 1 June), the daily discharge is generally equal to inflow minus water required to be added to storage to reach the end-of-day rule curve elevation. However, a minimum daily discharge of 100 cfs must be maintained at all times for downstream uses. Some deviation from the rule curve elevation is permissible to avoid spilling energy (days 5 and 6, for example).

(3) During the conservation season (1 June to 15 November), discharge is generally based on downstream requirements. However, larger releases may be scheduled to keep the reservoir from exceeding the rule curve elevation. Small deviations above the rule curve may be permitted here also in order to avoid spill.

c. Routing for March 1982. The daily routing shown on Table E-3 and Figure E-6 is for the month of March, which is midway through the refill phase. This routing is based upon actual regulation of a similar project during calendar year 1982. Flood regulation occured

during the last few days of February. During the first five days of March, the reservoir was being drawn back down to the rule curve elevation. During these five days, the required draft rate caused the powerplant hydraulic capacity to be exceeded, and some water was spilled.

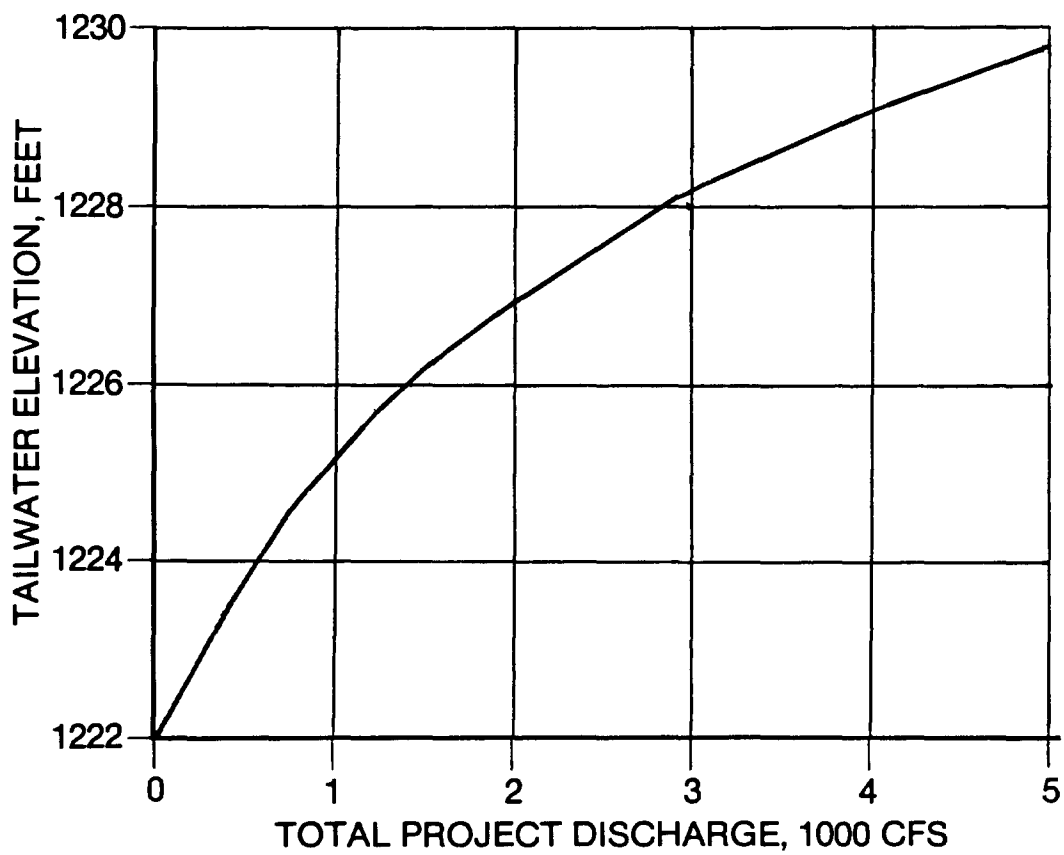

Figure E-5. Tailwater rating curve

TABLE E-3. Energy Calculation for Project Without Power

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Day of Month	Reservoir Inflow (CFS)	Starting Reservoir Elevation (Ft., MSL)	Starting Reservoir Storage (KSFD)	Rule Curve Elevation (ft., MSL)	Rule Curve Storage (KSFD)	Target Storage Change (CFS)	Discharge Required to Meet Target (CFS)	Maximum Flood Control Discharge (CFS)	Approx. Hydraulic Capacity (CFS)	Average Actual Discharge (CFS)
1	2670	1506.5	134.1	1499.0	125.8	-8300	10970	4000	1000	4000
2	2580	1505.3	132.8	1499.6	126.5	-6300	8880	4000	965	4000
3	2260	1504.0	131.3	1500.2	127.2	-4100	6360	4000	970	4000
4	2180	1502.4	129.6	1500.9	127.9	-1800	3980	4000	970	3980
5	1940	1500.8	127.8	1501.5	128.6	800	1140	4000	980	980
6	1730	1501.7	128.8	1502.1	129.2	400	1330	4000	970	970
7	1580	1503.2	129.6	1502.7	129.9	300	1280	4000	970	970
8	1480	1502.9	120.2	1503.5	130.8	600	880	4000	960	880
9	1570	1503.5	130.8	1504.0	131.3	500	1070	4000	960	960
10	1600	1504.1	131.4	1504.6	132.0	600	1000	4000	960	960
11	2070	1504.7	132.1	1505.2	132.7	600	1470	4000	955	955
12	1860	1505.7	133.2	1505.8	133.4	200	1660	4000	960	960
13	1660	1506.5	134.1	1506.4	134.0	-100	1760	4000	955	955
14	1560	1507.1	134.8	1507.0	134.7	-100	1660	4000	950	950
15	1430	1507.6	135.4	1507.6	135.4	0	1430	4000	950	950
16	1280	1508.1	135.9	1508.2	136.1	200	1080	4000	945	945
17	1180	1508.3	136.2	1508.8	136.7	500	680	4000	945	680
18	1150	1508.8	136.7	1509.4	137.4	700	450	4000	940	450
19	1050	1509.4	137.4	1510.0	138.1	700	350	4000	940	350
20	1000	1510.0	138.1	1510.6	138.8	700	300	4000	940	300
21	940	1510.6	138.8	1511.2	139.5	700	240	4000	935	240
22	900	1511.2	139.5	1511.8	140.2	700	200	4000	935	200
23	880	1511.8	140.2	1512.4	140.9	700	180	4000	935	180
24	920	1512.4	140.9	1513.0	141.6	700	220	4000	930	220
25	1010	1513.0	141.6	1513.6	142.3	700	310	4000	925	310
26	1150	1513.6	142.3	1514.2	143.0	700	450	4000	925	450
27	1190	1514.2	143.0	1514.8	143.7	700	490	4000	925	490
28	1270	1514.8	143.7	1515.3	144.2	500	770	4000	920	770
29	1070	1515.3	144.2	1515.9	144.9	700	370	4000	920	370
30	1010	1515.9	144.9	1516.5	145.6	700	310	4000	920	310
31	1090	1516.5	145.6	1517.1	146.4	800	290	4000	915	290

Storage Using Sequential Streamflow Routing Method.

(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)
Change in Storage (CFS)	End of Period Storage (KSFD)	End of Period Elevation (Ft., MSL)	Tailwater Elevation (Ft., MSL)	Average Head (Feet)	Efficiency (Percent)	Actual Hydraulic Capacity (CFS)	Power Discharge (CFS)	Spill (CFS)	Energy (MWh)
-1330	132.8	1505.3	1229.1	273.8	87.4	965	965	3035	469
-1420	131.3	1504.0	1229.1	272.6	87.4	970	970	3030	470
-1740	129.6	1502.4	1229.1	271.1	87.5	970	970	3030	468
-1800	127.8	1500.8	1229.0	269.6	87.5	980	980	3000	470
960	128.8	1501.7	1225.0	273.3	87.4	970	980	0	476
770	129.6	1503.2	1225.0	274.5	87.3	965	970	0	472
610	120.2	1502.9	1225.0	275.0	87.2	960	970	0	473
600	130.8	1503.5	1224.9	275.2	87.2	960	880	0	429
610	131.4	1504.1	1225.0	275.8	87.2	960	960	0	469
660	132.1	1504.7	1225.0	276.4	87.2	955	960	0	470
1115	133.2	1505.7	1225.0	277.2	87.2	960	955	0	469
900	134.1	1506.5	1225.0	278.1	87.2	955	960	0	473
705	134.8	1507.1	1225.0	278.8	87.1	950	955	0	471
610	135.4	1507.6	1225.0	279.4	87.1	950	950	0	470
480	135.9	1508.1	1225.0	279.9	87.0	945	950	0	470
335	136.2	1508.3	1225.0	270.2	87.0	945	945	0	468
500	136.7	1508.8	1224.3	281.2	86.9	940	680	0	289
700	137.4	1509.4	1223.7	282.4	86.9	940	450	0	223
700	138.1	1510.0	1223.6	283.1	86.9	940	350	0	175
700	138.8	1510.6	1223.5	283.8	86.8	935	300	0	150
700	139.5	1511.2	1223.0	284.9	86.7	935	240	0	120
700	140.2	1511.8	1222.9	285.6	86.7	935	200	0	101
700	140.9	1512.4	1222.9	286.2	86.7	930	180	0	91
700	141.6	1513.0	1223.0	286.7	86.6	930	220	0	110
700	142.3	1513.6	1223.5	286.8	86.6	925	310	0	157
700	143.0	1514.2	1223.7	287.2	86.6	925	450	0	227
700	143.7	1514.8	1223.8	287.7	86.6	925	490	0	247
500	144.2	1515.3	1224.7	290.3	86.5	920	770	0	389
700	144.9	1515.9	1223.6	289.1	86.5	920	370	0	188
700	145.6	1516.5	1223.5	289.7	86.4	920	310	0	158
800	146.4	1517.1	1223.4	290.4	86.4	915	290	0	148

TABLE E-4
Key to Calculations Shown on Table E-3

Column	Explanation
1	Given.
2	Given.
3	Given for day 1; for all other days, obtain from Column 14 of previous day.
4	On first day, value from storage-elevation curve (Figure E-2) corresponding to elevation in Column 3; for all other days, obtain from Column 13 of previous day.
5	From rule curve (Table E-1).
6	Value from storage-elevation curve (Figure E-2) corresponding to elevation in Column 5.
7	Change in storage required to reach rule curve elevation by end of day, expressed in average cfs: (Column 6 - Column 4)x(1000)
8	(Column 2) - (Column 7).
9	Given (see Section E-4b(1)).
10	Approximate value only. For day 1, use rated discharge; for other days, use Column 18 value for previous day.
11	See Section E-4b.
12	(Column 2) - (Column 11).
13	(Column 4) + (Column 12/1000)
14	Value from storage-elevation curve (Figure E-2) corresponding to value in Column 13.
15	Value from tailwater curve (Figure E-5) corresponding to discharge in Column 11.
16	(0.5)(Column 3 + Column 14) - (Column 15) - (3.0 foot head loss).
17	Value from Figure E-4 corresponding to head in Column 16.
18	Value from Figure E-3 corresponding to head in Column 16.
19	The smaller of Column 11 or Column 18. Note that for those days, where the actual discharge (Column 11) is based on the powerplant hydraulic capacity, Column 11 would actually be based on Column 18 instead of Column 10. Hence, Columns 18, 19 and 11 would all be equal.
20	Column 11 - Column 18.
21	$MWh = \frac{QHe}{11,810} \times 24 \text{ hours} = \frac{(\text{Col. } 19)(\text{Col. } 16)(\text{Col. } 17)}{11,810} \times 24 \text{ hours}$

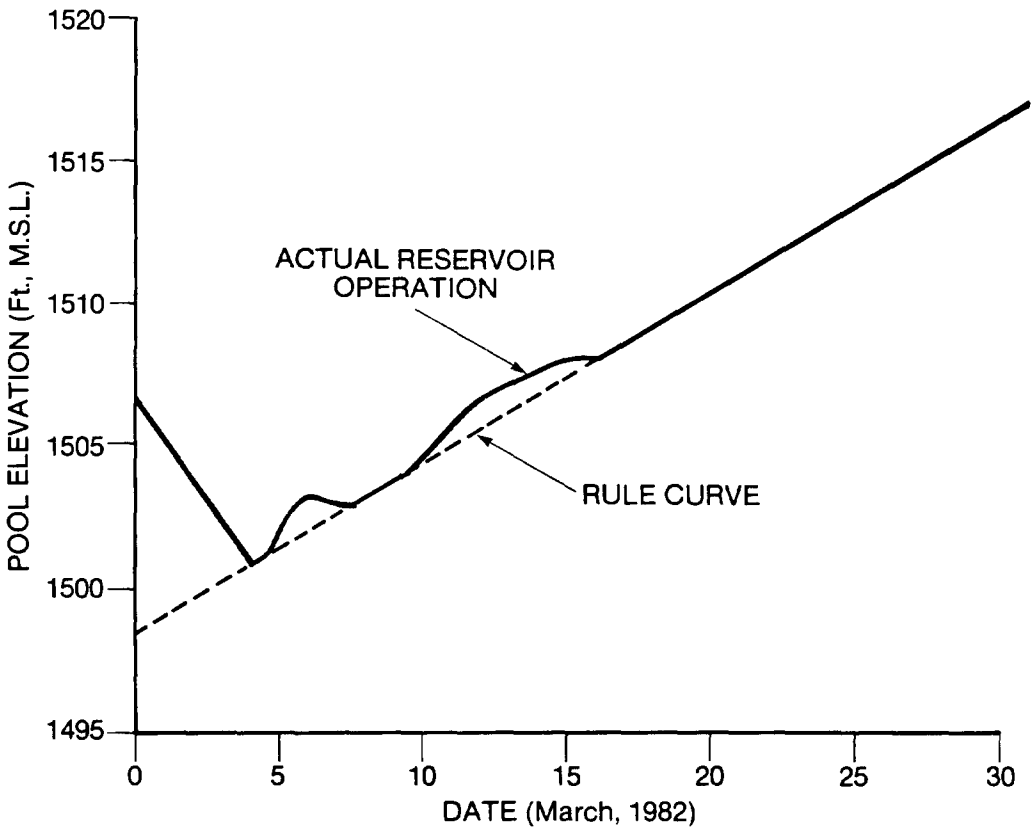

Figure E-6. Rule curve vs. March 1982 daily reservoir routing