APPENDIX N

EXAMPLES OF HOURLY STUDIES

N-1. General. This appendix consists of sample calculations that illustrate sequential hand routings for three of the most commonly encountered short term power studies:

- determining the sustained peaking capacity and pondage requirements for a pondage project
- sizing a reregulating reservoir
- sizing an upper reservoir for a pumped-storage project

These examples are simplified, but they illustrate the approaches that can be applied to more complex hourly studies. These examples are referenced in Sections 6-8 and 6-9.

N-2. Case 1: Pondage Analysis.

a. General. The objective of this analysis is to estimate (a) the generating capacity that can be sustained, and (b) the amount of pondage required at a peaking project. In this study, a potential "worst case" scenario will be examined in order to help determine the minimum amount of capacity that can be sustained in the peak demand months and the corresponding pondage requirements. The peak demand month with the lowest average flow was selected for analysis in this example.

b. Project Data. Following are the physical characteristics of the proposed dam site:

- full pool elevation: El. 2306.0
- tailwater curve: see Figure N-1
- storage-elevation characteristics: 8000 AF of storage per foot of elevation
- head loss: 0.5 feet
- minimum average discharge for peak demand period: 6000 cfs
- minimum continuous discharge: 3000 cfs
- evaporation losses and withdrawals: assumed to be zero
- leakage losses: assumed to be zero
- powerplant efficiency: 85 percent
- available pondage: up to four feet of pondage (32,000 AF) can be drafted without affecting other project purposes

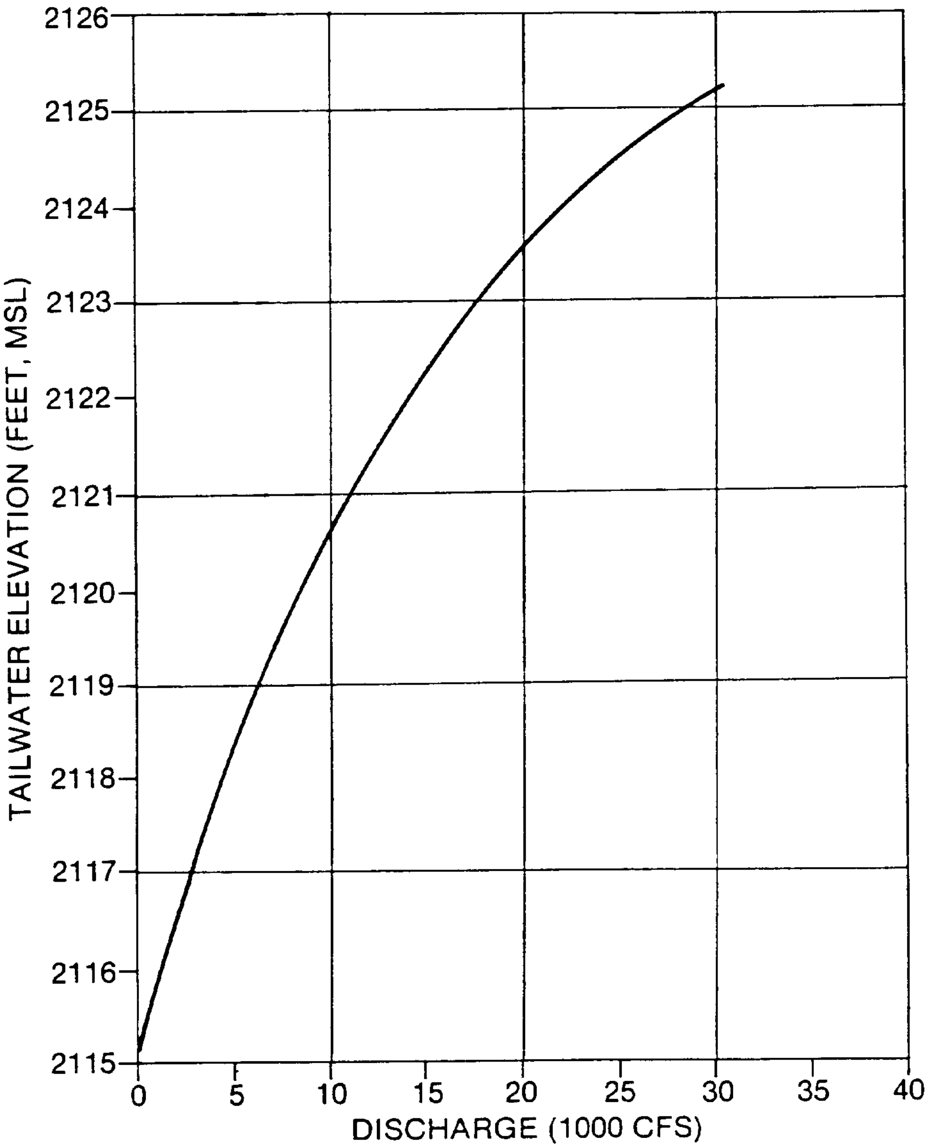

Figure N-1. Tailwater curve for peaking project

Assume that the regional Power Marketing Administration has indicated that on-peak power is required between 8 am and 6 pm, five days a week.

c. Preliminary Estimate of Sustained Peaking Capacity.

(1) A preliminary estimate of the installed capacity can be obtained by making a simple streamflow routing and assuming an average head. The average weekly discharge is 6000 cfs, and the minimum required discharge is 3000 cfs. This leaves

$$(6000 - 3000 \text{ cfs}) \times (168 \text{ hours})$$

to be used for peaking between 8 am and 6 pm (10 hours) on the five weekdays. Hence, the peak discharge will be approximately:

$$3000 \text{ cfs} + \frac{(168 \text{ hrs})(6000 - 3000 \text{ cfs})}{(5 \text{ days})(10 \text{ hrs})} = 13{,}080 \text{ cfs}$$

(2) Figure N-1 shows that the tailwater elevation at a discharge of 13,080 cfs is about El. 2121.5. Assume an average drawdown of 1.0 feet, which gives an average pool elevation of El. 2305.0. Thus, the average head is assumed to be (El. 2305.0 - El. 2121.5 - 0.5 ft (loss)) = 183.0 ft. Using the water power equation, the preliminary estimate of the sustained peaking capacity is:

$$\text{kW} = \frac{Qhe}{11.81} = \frac{(13{,}080 \text{ cfs})(183 \text{ ft})(0.85)}{11.81} = 172{,}300 \text{ kW}.$$

d. Hand Routing.

(1) A hand routing was then made to verify the sustained peaking capacity and to determine the pondage requirements. Since inflow is assumed to be constant throughout the week and the project is operating at only two levels (at the full 172,300 kW peak output or at the 3,000 cfs minimum discharge), it is possible to simplify the routing by using multi-hour blocks instead of hourly increments. The weekdays were divided into three blocks: (a) midnight to 8 am at 3,000 cfs, (b) 8 am to 6 pm at 172,300 kW peak output, and (c) 6 pm to midnight at 3,000 cfs. Saturday and Sunday were each treated as 24-hour blocks at 3,000 cfs. The routing was started at 8 am on Monday morning, when the reservoir was assumed to be full.

(2) The hand routing is summarized on Table N-1. A simplified version of Table 5-6 was used. The routing procedure follows the same general approach outlined in Appendix H, Section H-3b. The 172.3 MW

peaking requirement establishes the required discharge during the peak demand hours and the 3000 cfs minimum discharge controls during the remainder of the time. Since the net head used in each period is based on an estimated average head, more than one iteration was required in some hours to achieve convergence with the end-of-period elevation. However, only the final iterations are shown in the table.

(3) In examining Table N-1, it can be seen that the reservoir exactly refills to the starting elevation at 8 am Monday morning, so the routing is in balance. In addition, the full 172,300 kW was delivered in all of the specified hours. Therefore, the preliminary estimate for sustained peaking capacity is correct. Note also that the discharges during the peaking hours (13,000 to 13,100 cfs) are very close to the required average of 13,080 cfs and the average pool elevation (El. 2305.1) is very close to the assumed El. 2305.0. The required pondage (as measured at the point of maximum drawdown, at 6 pm on Friday) is 15,300 AF.

(4) The routing on Table N-1 is graphically displayed as Figure N-2.

N-3. Case 2: Reregulating Reservoir Analysis.

a. General. Assume the same peaking project as described in the previous example, except that a reregulating reservoir will be constructed to maintain a constant discharge downstream, thus permitting the peaking project to concentrate all of its generation in the peak demand hours of the day. The purpose of this analysis is to determine the amount of reregulating reservoir pondage required to meet this objective. In order to simplify the analysis, tailwater fluctuation due to encroachment of the reregulating reservoir on the peaking project will be ignored.

b. Regulation of the Peaking Project.

(1) The sustained peaking capacity was computed in the same way as for the previous example. The average on-peak discharge would be (6,000 cfs)x(168 hrs/50 hrs) = 20,160 cfs, and the corresponding tailwater elevation would be El. 2123.5. Assuming an average pool elevation of El. 2304.0, the head at full output would be

$$(\text{El. } 2123.5 - \text{El. } 2304.0 - 0.5) = 181.0 \text{ feet},$$

and the preliminary estimate of the sustained peaking capacity would be

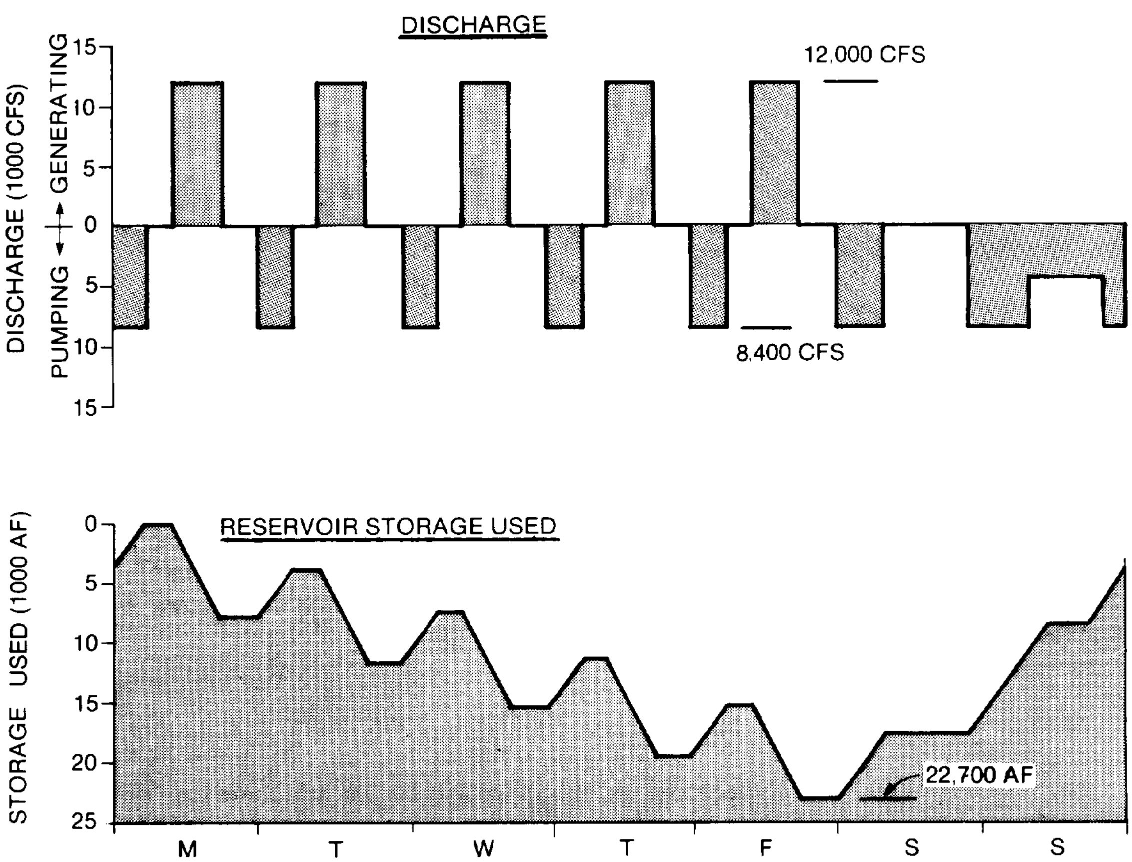

Figure N-2. Graphical illustration of pondage analysis for peaking project

$$KW = \frac{Qhe}{11.81} = \frac{(20{,}160 \text{ cfs})(181 \text{ ft})(0.85)}{11.81} = 263{,}000 \text{ kW.}$$

(2) A routing similar to that described in Section N-2 was made (not shown), and the following average peaking discharges were computed:

Monday - 20,000 cfs
Tuesday - 20,100 cfs
Wednesday - 20,200 cfs
Thursday - 20,200 cfs
Friday - 20,300 cfs

The pondage requirement was determined to be 30,700 AF, which is within the allowable maximum of 32,000 AF (see Section N-2b).

c. Reregulating Reservoir Storage Requirement. Using the peaking discharge above as inflow, a routing was made to determine the amount of reregulating storage required to maintain the 6,000 cfs continuous discharge. Since it is assumed that there will be no power installation at the reregulating dam, the analysis, which is summarized on Table N-2, was a simple streamflow routing. The maximum storage requirement is 30,700 AF, which also occurs at 6 pm on Friday. This routing is shown on Figure N-3.

d. Additional Storage Required for a Three-Day Weekend. The above analysis is based on a normal week with five working days. When three-day weekends occur, holiday loads are frequently at low levels, so it may be necessary for the reregulating reservoir to maintain minimum flows for three full days instead of two. This requires additional storage. The supplemental routing at the bottom of Table N-2 shows that 11,900 AF of additional storage would be required to handle this demand, resulting in a total storage requirement of (30,700 AF + 11,900 AF) = 42,600 AF. This additional "reserve" storage would be refilled in subsequent weeks, as surplus flows become available.

N-4. Pumped-Storage Reservoir.

a. General. The objective of this example is to develop make a preliminary estimate of the upper reservoir storage requirements for an off-stream pumped-storage project. The project will be operated on a weekly cycle.

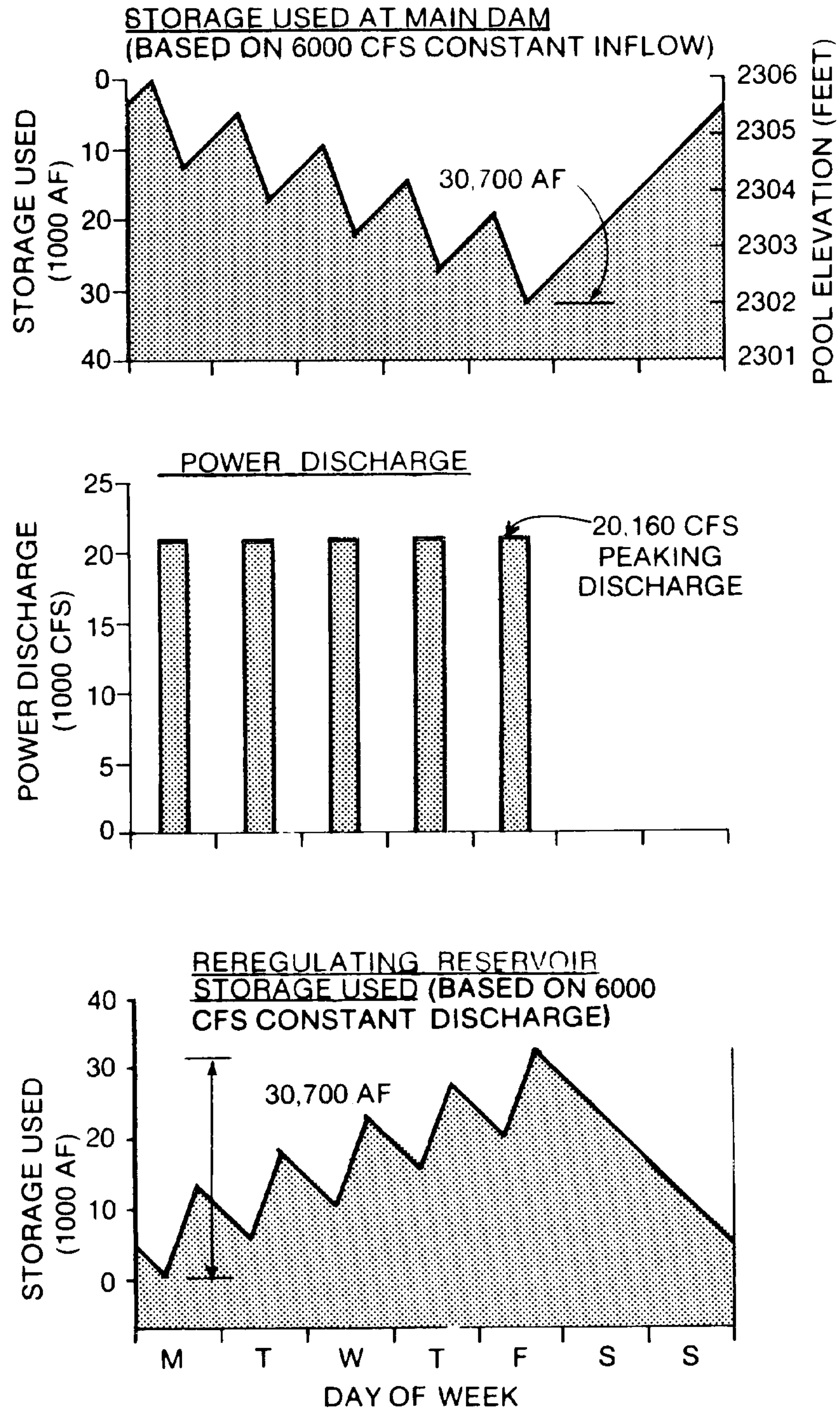

Figure N-3. Graphical illustration of reregulating reservoir analysis

b. Project Data. Following are the project characteristics:

- average net head: 1,200 feet
- generating capacity: 1,000 MW
- pumping capacity: same as generating capacity
- generating efficiency: 82 percent
- pumping efficiency: 85 percent
- required generating hours: 10 am - 6 pm, Monday-Friday
- available pumping hours:
  - Monday-Friday: 12 midnight - 6 am
  - Saturday: 12 midnight - 8 am, 8 pm - 12 midnight
  - Sunday: 12 midnight - 10 am, 6 pm - 12 midnight

Tailwater and reservoir elevation fluctuations are assumed to be small in comparison to the project's high head and can be ignored in a preliminary analysis of this type. Evaporation, local inflow, and leakage losses are assumed to be negligible.

c. Hand Routing.

(1) Because the objective is only to determine the storage requirement and because tailwater and forebay fluctuations are considered negligible, a simplified analysis is possible (i.e., it is not necessary to compute the head for each time increment). As with the previous examples, the week is divided into a series of multi-hour blocks. Except for Monday, computations are shown only for those time periods when pumping or generating is taking place. The generating discharge is computed as follows:

$$Q_g = \frac{11.81\text{kW}}{he_g} = \frac{(11.81)(1{,}000{,}000\ \text{kW})}{(1{,}200\ \text{ft})(0.82)} = 12{,}000\ \text{cfs}$$

The pumping discharge is computed as follows:

$$Q_p = \frac{11.81\text{kW}e_p}{h} = \frac{(11.81)(1{,}000{,}000\ \text{kW})(0.85)}{(1{,}200\ \text{ft})} = 8{,}400\ \text{cfs}$$

(2) Using the generating and pumping discharges computed above and the pumping and generating schedule shown in paragraph N-4b, a routing was made for the week (Table N-3). The maximum storage requirement (which occurred at 6 pm on Friday) is 22,700 AF.

(3) Note that the table shows the plant pumping at full capacity for all of the available weekend pumping hours, and the reservoir over-filling by 1000 AF as on 6 am Monday. Rather than over-filling the reservoir, the pumping would actually have stopped at full

reservoir capacity at some time prior to 6 am on Monday. One thousand acre-feet, converted to hours of pumping at full capacity, would be:

$$\frac{(1{,}000\ \text{AF})(43{,}560\ \text{ft}^3/\text{AF})}{(8{,}400\ \text{cfs})(3{,}600\ \text{sec/hr})} = 1.5\ \text{hours.}$$

Thus, the pumping would have stopped at 4:30 am instead of at 6 am. The routing for the week is shown on Figure N-4.

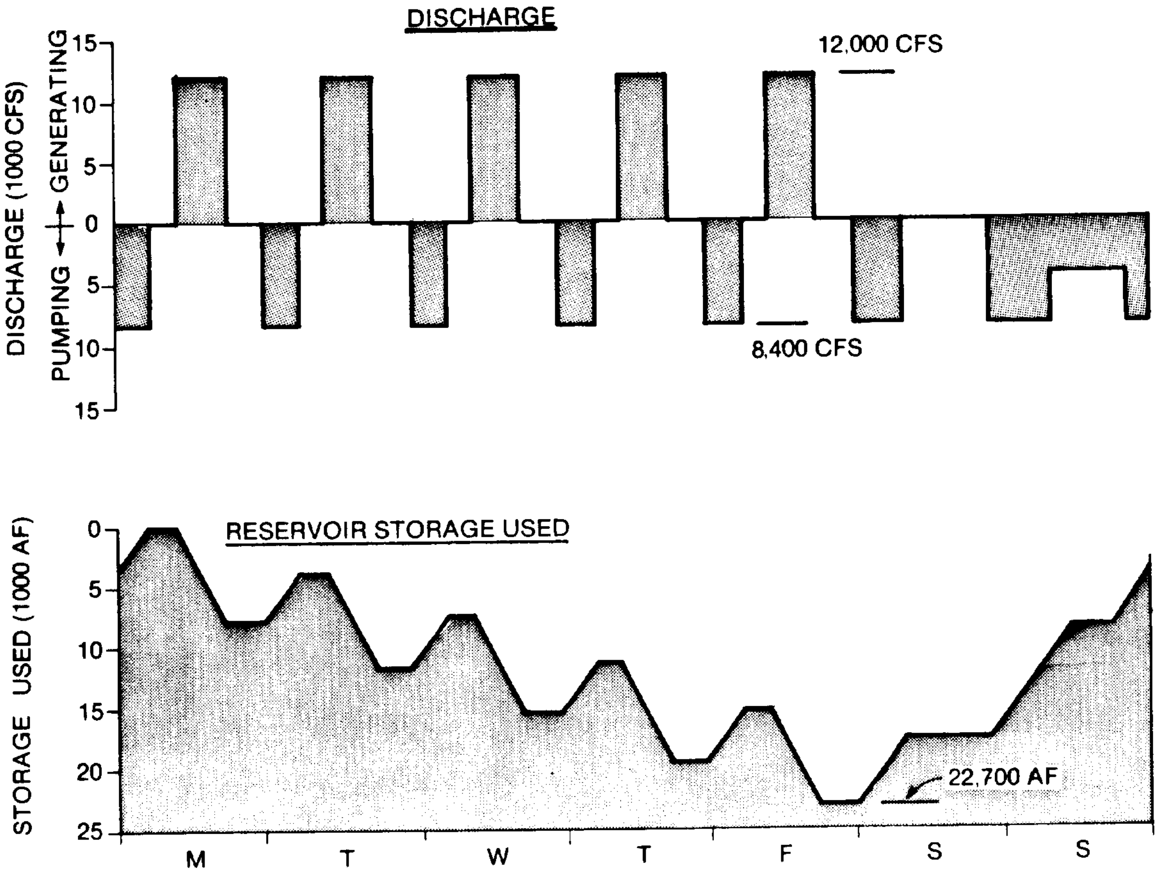

Figure N-4. Graphical illustration of off-stream pumped-storage project analysis

TABLE N-1. Regulation

	Interval	Hours	Inflow (cfs)	Generating Requirement (MW)	Average Res. Elev. (feet)	Net Head (feet)	Power Discharge (cfs)
M	0000-0800	8	-	-	-	-	-
M	0800-1800	10	6,000	172.3	2305.7	183.7	13,000
M	1800-2400	6	6,000	0.0	2305.4	183.4	0
T	0000-0800	8	6,000	0.0	2305.6	183.6	0
T	0800-1800	10	6,000	172.3	2305.3	183.3	13,000
T	1800-2400	6	6,000	0.0	2305.1	183.1	0
W	0000-0800	8	6,000	0.0	2305.3	183.3	0
W	0800-1800	10	6,000	172.3	2305.0	183.0	13,100
W	1800-2400	6	6,000	0.0	2304.8	182.8	0
Th	0000-0800	8	6,000	0.0	2305.0	183.0	0
Th	0800-1800	10	6,000	172.3	2304.8	182.8	13,100
Th	1800-2400	6	6,000	0.0	2304.5	182.5	0
F	0000-0800	8	6,000	0.0	2304.7	182.7	0
F	0800-1800	10	6,000	172.3	2304.4	182.4	13,100
F	1800-2400	6	6,000	0.0	2304.2	182.2	0
Sa	0000-2400	24	6,000	0.0	2304.6	182.6	0
Su	0000-2400	24	6,000	0.0	2305.4	183.4	0
M	0000-0800	8	6,000	0.0	2305.9	183.9	0

of Pondage Project

Minimum Discharge (cfs)	Required Discharge (cfs)	Change in Storage (cfs)	Change in Storage (AF)	End of Period Storage (AF)	End of Period Elev. (ft.)	Hourly Generation (MW)
-	-	-	-	0	2306.0	-
3,000	13,000	-7,000	-5,800	-5,800	2305.3	172.3
3,000	3,000	3,000	1,500	-4,300	2305.5	39.6
3,000	3,000	3,000	2,000	-2,300	2305.7	39.6
3,000	13,000	-7,000	-5,800	-8,100	2305.0	172.3
3,000	3,000	-7,000	1,500	-6,600	2305.2	39.5
3,000	3,000	3,000	2,000	-4,600	2305.4	39.6
3,000	13,100	-7,100	-5,900	-10,500	2304.7	172.3
3,000	3,000	3,000	1,500	-9,000	2304.9	39.5
3,000	3,000	3,000	2,000	-7,000	2305.1	39.5
3,000	13,100	-7,100	-5,900	-12,900	2304.4	172.3
3,000	3,000	3,000	1,500	-11,400	2304.6	39.4
3,000	3,000	3,000	2,000	-9,400	2304.8	39.4
3,000	13,100	-7,100	-5,900	-15,300	2304.1	172.3
3,000	3,000	3,000	1,500	-13,800	2304.3	39.3
3,000	3,000	3,000	5,900	-7,900	2305.0	39.4
3,000	3,000	3,000	5,900	-2,000	2305.8	39.6
3,000	3,000	3,000	2,000	0	2306.0	39.7

TABLE N-2
Regulation of Reregulating Reservoir

Interval		Hours	Inflow (cfs)	Required Discharge (cfs)	Change in Storage (cfs)	Change in Storage (AF)	End of Period Storage (AF)
M	0000-0800	8	-	-	-	-	0
M	0800-1800	10	20,000	6,000	14,000	11,500	11,500
M	1800-2400	6	0	6,000	-6,000	-3,000	8,500
T	0000-0800	8	0	6,000	-6,000	-3,900	4,600
T	0800-1800	10	20,100	6,000	14,100	11,600	16,200
T	1800-2400	6	0	6,000	-6,000	-3,000	13,200
W	0000-0800	8	0	6,000	-6,000	-3,900	9,300
W	0800-1800	10	20,200	6,000	14,200	11,700	21,000
W	1800-2400	6	0	6,000	-6,000	-3,000	18,000
Th	0000-0800	8	0	6,000	-6,000	-3,900	14,100
Th	0800-1800	10	20,200	6,000	14,200	11,700	25,800
Th	1800-2400	6	0	6,000	-6,000	-3,000	22,800
F	0000-0800	8	0	6,000	-6,000	-3,900	18,900
F	0800-1800	10	20,300	6,000	14,300	11,800	30,700
F	1800-2400	6	0	6,000	-6,000	-3,000	27,700
Sa	0000-2400	24	0	6,000	-6,000	-11,900	15,800
Su	0000-2400	24	0	6,000	-6,000	-11,900	3,900
M	0000-0800	8	0	6,000	-6,000	-3,900	0

Supplemental Regulation to Determine Additional
Storage Required for Three-Day Weekend

Su	0000-2400	24	-	-	-	-	3,900
M	0000-2400	24	0	6,000	-6,000	-11,900	-8,000
T	0000-0800	8	0	6,000	-6,000	- 3,900	-11,900

TABLE N-3
Regulation of Off-Stream Pumped-Storage Reservoir

	Interval	Hours	Generating Requirement (MW)	Pumping Capacity (MW)	Dis-charge (cfs)	Change in Storage (AF)	End of Period Storage (AF)
M	0000-0600	6	-	-	-	-	0
M	0600-1000	4	0	0	0	0	0
M	1000-1800	8	1,000	0	-12,000	-7,900	-7,900
M	1800-2400	6	0	0	0	0	-7,900
T	0000-0600	6	0	1,000	8,400	4,200	-3,700
T	1000-1800	8	1,000	0	-12,000	-7,900	-11,600
W	0000-0600	6	0	1,000	8,400	4,200	-7,400
W	1000-1800	8	1,000	0	-12,000	-7,900	-15,300
Th	0000-0600	6	0	1,000	8,400	4,200	-11,100
Th	1000-1800	8	1,000	0	-12,000	-7,900	-19,000
F	0000-0600	6	0	1,000	8,400	4,200	-14,800
F	1000-1800	8	1,000	0	-12,000	-7,900	-22,700
Sa	0000-0800	8	0	1,000	8,400	5,600	-17,100
Sa	2000-2400	4	0	1,000	8,400	2,800	-14,300
Su	0000-1000	10	0	1,000	8,400	6,900	-7,400
Su	1800-2400	6	0	1,000	8,400	4,200	-3,200
M	0000-0600	6	0	1,000	8,400	4,200	1,000 1/

1/ see paragraph N-4c(3)