APPENDIX H

FIRM ENERGY ESTIMATE FOR A STORAGE PROJECT

H-1. Introduction.

a. General. This appendix presents an example of how firm energy is estimated for a storage project having power storage. Section H-2 shows how a preliminary firm energy estimate is made. Section H-3 describes an initial hand routing using the sequential streamflow routing method, Section H-4 explains how the initial hand routing can be modified to obtain the final firm energy estimate, and Section H-5 summarizes the final firm energy estimate.

b. Project Characteristics. The example project used in this appendix (and in Appendices I and J) is Broken Bow Lake, a multiple-purpose storage project located on the Mountain Fork of the Red River in Oklahoma. Following are the major project characteristics:

Top of flood control pool:	El. 627.5 (1,368,800 AF)
Top of conservation pool:	El. 599.5 (918,800 AF)
Bottom of conservation pool:	El. 559.0 (448,700 AF)
Storage-elevation curve:	Figure 4-8
Area-elevation curve:	Figure 4-8
Tailwater curve:	Figure H-1
Reservoir withdrawals:	Table H-1
Evaporation losses:	Table H-1
Losses through dam (leakage):	Table H-1
Minimum flow requirements:	Table H-1
Monthly energy requirements:	Table H-1
Powerplant hydraulic capacity:	2000 cfs
Penstock and related head losses:	0.5 feet
Powerplant operation:	Block loading at full capacity

H-2. Computation of Preliminary Firm Energy Output.

a. Procedure. The preliminary firm energy estimate is made by assuming average head and streamflow conditions over the length of the critical period, as follows:

- identify critical period (see Section 5-10d)
- compute average streamflow (in cfs) over the length of the critical period

- estimate average evaporation and other losses and deduct from average critical period streamflow to obtain net streamflow available for generation
- estimate average reservoir pool elevation
- estimate average tailwater elevation
- compute average net head
- assume an average overall efficiency of 85 percent
- compute firm energy output using the water power equation

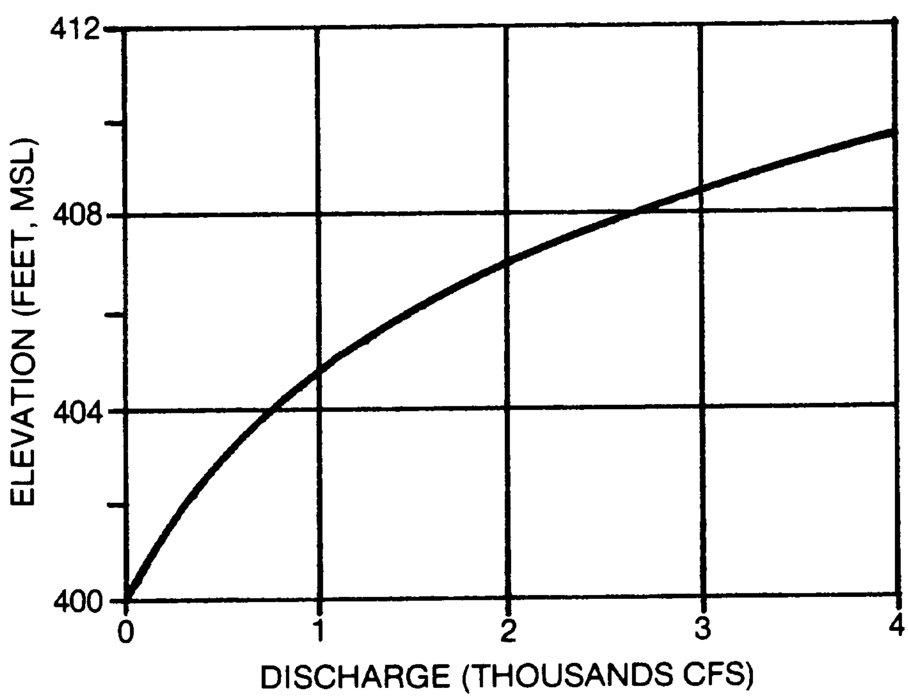

Figure H-1. Tailwater rating curve for Broken Bow Reservoir, Oklahoma

TABLE H-1
Monthly hydrologic and operations data,
Broken Bow Reservoir, Oklahoma

Month	Net Evaporation (inches)1/	Withdrawals (CFS)	Leakage Losses (CFS)	Minimum Flow Req. (CFS)	Percent Firm Energy Requirement
January	-2.42	24	10	118	8.33
February	-1.57	26	10	90	5.00
March	-1.10	27	10	86	5.00
April	-0.64	37	10	86	5.00
May	-1.53	55	10	88	8.33
June	1.87	95	10	90	8.33
July	3.10	94	10	120	16.67
August	3.15	94	10	173	16.67
September	1.41	66	10	314	8.33
October	0.15	33	10	320	5.00
November	-1.63	25	10	320	5.00
December	-2.41	24	10	235	8.33
22-mo. tot. 2/	-1.50	1136	220		190.00
22-mo. avg. 2/	-0.07	52 cfs	10 cfs		

1/ A negative number means that precipitation exceeds evaporation for the month.

2/ The 22-month period corresponding to the critical drawdown period (May of the first year through February of the third year). Totals shown in cfs-months.

b. Example.

(1) Identify Critical Period. Assume that the critical drawdown period has been determined to be the period May 1962 through February 1964 (see Figure F-2). The length of the critical drawdown period would be 22 months, or 670 days.

(2) Calculate Average Streamflow. From the flow records, the natural streamflow into Broken Bow Reservoir during the critical drawdown period was found to be 517,500 acre-feet. This amount, added to the total conservation storage volume of 470,100 acre-feet, shows

that 987,600 acre-feet of water is available for all purposes during the 670-day long critical drawdown period. This amount converts to an average available flow during the critical period of 744 cfs (which is slightly less than the 760 cfs firm yield estimated in Appendix F).

(3) Account for Consumptive Losses. The hydrologic data on Table H-1 shows that the total evaporation over the drawdown period is negative, which means that more water fell onto the reservoir surface as precipitation than evaporated from it. From Figure 4-8, the reservoir surface area at the average assumed average pool elevation of El. 581.4 (see Section H-2b(4)) is found to be 11,800 acres, so the total water gain in storage from the net negative evaporation is estimated to be

$$\frac{(1.50 \text{ inches})(11.800 \text{ acres})}{(12 \text{ in./foot})} = 1,475 \text{ AF}$$

which, over the critical drawdown period, is equivalent to 1.1 cfs. The total flow available for power generation is therefore:

	744 cfs	inflow
+	1 cfs	net evaporation
-	52 cfs	withdrawals/diversions
-	10 cfs	losses
	683 cfs	total

(4) Estimate Average Pool Elevation. The reservoir elevation over the critical drawdown period can be approximated by the elevation with 50 percent of the usable storage remaining. The storage at the top of conservation pool is 918,800 AF and the storage at the bottom of the conservation pool is 448,700 AF, so the total reservoir storage at 50 percent usable storage remaining would be

$$\frac{(918.800 \text{ AF} + 448,700 \text{ AF})}{2} = 683,800 \text{ AF.}$$

Referring to the storage-elevation curve (Figure 4-8), the pool elevation at 50 percent usable storage remaining is found to be El. 581.4.

(5) Estimate Average Tailwater Elevation. If the powerplant were operated at a constant output, the average tailwater elevation could be approximated as the tailwater elevation at the average flow during the critical drawdown period. However, the project will be operated for peaking and will be block-loaded at full capacity.

Hence, the average tailwater elevation would be equal to the tailwater elevation at the powerplant hydraulic capacity (2000 cfs), or El. 407.4 (see Figure H-1).

(6) Compute Average Head. The average head for the critical period would be the average pool elevation minus the average tailwater elevation minus the estimated average head loss or

Average Head = El. 581.4 - El. 407.4 - 0.5 feet = 173.5 feet.

(7) Compute Energy for Critical Drawdown Period. Using the water power equation (Eq. 5-4) and the average streamflow (683 cfs), the average head (173.5 feet), and an assumed average overall efficiency of 85 percent, the preliminary energy estimate for the critical drawdown period is

$$\text{Energy} = \frac{(683\ \text{cfs})(173.5\ \text{feet})(0.85)(670\ \text{days})(24\ \text{hours/day})}{(11.81)}$$

$$= 137{,}000{,}000\ \text{kWh}.$$

(8) Calculate Annual Firm Energy Requirement. The next step is to calculate how much of this power is generated during a 12-month span of time during the period of critical drawdown. By adding up the 22 monthly firm energy values for the critical drawdown period (May 1962 to February 1964. inclusive -- see Table H-1 for monthly percentages), it can be seen that the generation requirements during the entire critical drawdown period are equal to 190 percent of the annual generation requirements. Therefore, the generation for a 12-month period would be:

$$(137.000.000\ \text{kWh}) \times \frac{100\%}{190\%} = 72{,}000{,}000\ \text{kWh}.$$

(9) Find Monthly Firm Energy Requirements. The final step is to allocate this annual firm energy figure among the twelve months of the year. Table H-2 shows the resulting monthly generation allocation.

H-3. Initial Critical Period Hand Routing.

a. General.

(1) This section describes an initial hand routing of the Broken Bow project over the critical drawdown period. The project is regulated to meet the preliminary monthly firm energy requirements

TABLE H-2
Preliminary Allocation of Firm Energy by Month

Month	Percent of Annual Firm Energy Requirement	Firm Energy Allocation (kWh)
January	8.33	6,000,000
February	5.00	3,600,000
March	5.00	3,600,000
April	5.00	3,600,000
May	8.33	6,000,000
June	8.33	6,000,000
July	16.67	12,000,000
August	16.67	12,000,000
September	8.33	6,000,000
October	5.00	3,600,000
November	5.00	3,600,000
December	8.33	6,000,000
Total	100.00	72,000,000

developed in Section H-2. using the procedures described in Section 5-10f. Minimum discharge requirements must also be maintained for water quality. The only other factors that must be accounted for in the analysis other than power requirements are reservoir withdrawals, reservoir evaporation, and leakage through the dam.

(2) The computations are summarized in Table H-3. Section H-3b illustrates sample calculations for the first month in the critical period. As described in Section H-3b(3), at least two iterations are required in order to accurately solve the continuity equation for most months. Both iterations are shown on Table H-3 for the first four months, but only the final iteration is shown for subsequent months.

(3) It will be noted that the reservoir does not draft to the bottom of the conservation pool (El. 559.0) at the end of the drawdown period, but reaches only El. 561.9. To fully utilize the storage, the firm energy requirements must be adjusted and the regulation must be redone. Section H-4 describes this procedure.

b. Example Calculation.

(1) Following is an example calculation illustrating how the values shown on Table H-3 for May, 1962 were derived.

(2) Determine Net Inflow. Given are reservoir inflow (I, Column 3), evaporation rate (Table H-1), and reservoir withdrawals (W, Column 5). Reservoir evaporation is in inches per month and can be converted to average cfs over the month as follows:

$$E = \frac{(0.042)(EVAP)(A)}{(t)}$$

where: EVAP = evaporation rate, inches/month
A = reservoir surface area, acres
t = number of days in month

For preliminary studies, the surface area at average pool elevation (see Section H-2b(4)) and 30 days per month can be used for all months. For more detailed studies, the approximate reservoir surface area for a given period can be obtained from an area-elevation curve or table, using the reservoir elevation at the end of the previous period. The more detailed calculation is used in this example. The end-of-month reservoir elevation is obtained from Figure 4-8 and is entered in Column 17. For May, 1962, the evaporation is -1.53 inches and the surface area of the reservoir at the end of April 1962 (El. 599.5) is 14,200 acres. The evaporation in cfs would be:

$$E = \frac{(0.042)(-1.53 \text{ in./mo.})(14{,}200 \text{ acres})}{(31 \text{ days/month})} = -29 \text{ cfs.}$$

The net reservoir inflow for the same period is

$$\text{Net inflow} = I - E - W$$

$$= 389 \text{ cfs} - (-29 \text{ cfs}) - 55 \text{ cfs} = 363 \text{ cfs.}$$

This value would be inserted in Column 6.

(3) Determine Required Power Discharge. From Table H-2, the firm energy requirement for May, 1962 was found to be 6,000,000 kWh. A previously prepared kW/cfs curve will be used to account for the efficiency and net head calculations (see Appendix G). The kW/cfs value used for a given month should be based on the average reservoir elevation for that month. However, since the average elevation is a

function of the end-of-month elevation and this elevation is not known initially, two or more iterations must be made for some periods in order to achieve a correct solution (see Section 5-10f(7)). For the first iteration, the initial kW/cfs value can be based on the start-of-month reservoir elevation. For May, 1962, the start-of-month elevation is El. 599.5 and from Figure G-2, the kW/cfs would be 14.0. The required power discharge would be computed as follows;

$$Q_P = \frac{(6{,}000{,}000 \text{ kWh/month})}{(744 \text{ hours/month})(14.0 \text{ kW/cfs})} = 576 \text{ cfs.}$$

This value would be inserted in Column 10.

(4) Compute Required Total Discharge. The total required discharge would be the sum of the power discharge needed to meet firm energy requirements (Q, Column 11) plus estimated leakage losses (Q_L), Table H-1), and non-power discharge requirements (Table H-1). Column 10 lists the minimum discharge required for water quality. If this value exceeds the required power discharge plus losses, it would serve as the total discharge requirement. For this month, the minimum discharge requirement is 88 cfs, which is less than ($Q + Q_L$) = (576 cfs + 10 cfs) = 586 cfs, so the power discharge requirement establishes the total discharge requirement (Column 12).

(5) Compute Change in Storage. The change in reservoir storage would be a function of net inflow (Column 6), total discharge requirements (Column 12), and the start-of-month reaservoir elevation (Column 16 for the previous month). The difference between the net reservoir inflow and the total discharge requirement would establish whether the reservoir would draft, fill, or maintain the same elevation. This computation represents the solution of the continuity equation (Eq. 5-13), which, when rearranged, would be as follows;

$$\Delta S = (I - E - W) - (Q_P + Q_L)$$

For May, 1962,

$$\Delta S = (363 \text{ cfs}) - (586 \text{ cfs}) = (-223 \text{ cfs}).$$

The ΔS value would be converted to acre-feet using the discharge-to-storage conversion factor (C_S) for a 31-day month, from Table 5-5. Thus,

$$\Delta S = (-223 \text{ cfs})(61.49 \text{ AF/cfs-month}) = (-13{,}700 \text{ AF}).$$

These values would be inserted in Columns 13 and 14. For those months where net inflow exceeds total discharge requirements, the reservoir would store the difference unless it is already at the top of conservation pool. If the reservoir is full, the full net inflow (minus losses) would be discharged through the powerhouse, if possible. Any generation above the firm energy requirement (Column 7) would be classified as secondary energy.

(6) Compute End-of-Month Reservoir Status. The change in storage, ΔS, can also be expressed as follows:

$$\Delta S = S_2 - S_1$$

where: S_1 = start-of-period storage volume
S_2 = end-of-period storage volume

The change in reservoir storage computed in step (5) would be applied to the start-of-month storage volume (Column 15 of preceding month) to determine the end-of-month storage volume. The end-of-month reservoir elevation would then be obtained from the storage-elevation curve or tables. For May, 1962;

$$S_2 = S_1 + \Delta S = 918{,}800 \text{ AF} + (-13{,}700 \text{ AF}) = 905{,}100 \text{ AF.}$$

From Figure 4-8, the end-of-month reservoir elevation is found to be El. 598.5.

(7) Adjust Power Discharge Requirement. In step (3), it was noted that a second iteration may be required in order to account for the change in reservoir elevation (head) during the month. For the second iteration, a new kW/cfs factor is obtained from Figure G-1, based on the average of the start-of-month elevation (El. 599.5) and the end-of-month elevation from the first iteration (El. 598.5). The average pool elevation would be (El. 599.5 + El. 598.5)/2 = El. 599.0. In this case, the actual average pool elevation is very close to the El. 599.5 value assumed in the first iteration, so the kW/cfs value of 14.0 still applies. As a result, the values computed for Columns 10 through 16 remain the same as for the first iteration. However, for some of the subsequent months, the second iteration produces a substantially different end-of-month storage. In Table H-3, both iterations are shown for the first four months. For subsequent months, only the second iteration is listed.

(8) Compute Total Generation. During the critical period, generation will be limited to meeting firm energy requirements. The generation would be computed by applying the kW/cfs factor (Column 9) to the greater of the required power discharge or the water quality

requirement (Column 11) minus 10 cfs losses. For May, 1962, the generation would be

(576 cfs)(14.0 kW/cfs)(744 hours/month) = 6,000,000 kWh,

which is, of course, equal to the firm energy requirement. In many months,

surplus water may be available for producing secondary energy (see step (5)). The second routing (Table H-4) extends beyond the end of the critical period, and secondary energy is produced in June of 1965. In this month, the net inflow is 1,643 cfs. 242 cfs is required to fill the reservoir (Column 13), which leaves a total of 1,643 cfs minus the 242 cfs placed in storage, or 1,401 cfs available for power generation. This exceeds the 615 cfs firm energy requirement (Column 10) (plus the 10 cfs leakage loss) by 776 cfs. The 1,401 cfs is entered in Column 12, instead of the greater of (a) the required power discharge plus losses or (b) the minimum discharge requirement from Column 10. The total generation for the month can be computed by deducting the 10 cfs losses and applying the kW/cfs factor. Thus, the generation for June, 1965 would be

(1,401-10 cfs)(14.0 kW/cfs)(720 hours/month) = 14,020,000 kWh.

The power discharge must not exceed the powerplant hydraulic capacity, which in this case is 2,000 cfs. Note that hydraulic capacity varies with head (see Section E-3d), and in some studies it may be desirable to account for this variation.

H-4. Adjustment of Firm Energy Output.

a. Introduction. In the initial routing (Table H-3), the storage remaining at the end of the critical period was 475,800 AF, which means that (475,800 AF - 448,700 AF) = 27,100 AF of power storage remained unused. As described in Section 5-10g, the firm energy estimate must be adjusted and the routing must be done again if the project fails to utilize all of the storage in the critical drawdown period. Following is a summary of the procedure used to make this adjustment and an example showing the adjustment of the firm energy estimate used in Table H-3.

b. Procedure. The following steps are required to develop a revised firm energy estimate where a reservoir fails to completely use its power storage during the critical drawdown period.

- convert the storage remaining at the end of the critical drawdown period to average cfs in order to determine the additional average flow that could be used during the critical drawdown period.

- divide the initial energy output for the critical drawdown period by the number of hours to determine the average power in kilowatts.

- determine the average power discharge for the critical drawdown period from the routing data.

- divide the average power output by the average power discharge to determine the average kW/cfs for the critical drawdown period.

- multiply the additional average flow from the first step by the average kW/cfs and the number of hours in the critical drawdown period to determine the approximate amount of additional energy that could be produced during the critical drawdown period.

- convert the additional energy to a monthly distribution as described in Section H-2b(9) and add to the monthly power requirements.

c. Example of Firm Energy Output Recalculation.

(1) The 27,100 acre-feet of storage remaining at the end of the critical drawdown period corresponds to:

$$\frac{(27{,}100\ \text{AF})(43{,}560\ \text{ft}^3/\text{AF})}{(670\ \text{days})(24\ \text{hrs/day})(3600\ \text{sec/hr})} = 20.4\ \text{cfs.}$$

(2) The total output for the critical drawdown period is the sum of the values in Column 18, or 136,800,000 kWh. The average power output during the initial hand regulation was:

$$\frac{(136{,}800{,}000\ \text{kWh})}{(670\ \text{days})(24\ \text{hrs/day})} = 8{,}510\ \text{kW.}$$

(3) The average power discharge, obtained from Column 10 of Table H-3, was 654 cfs. Therefore, average kW/cfs was:

$$\frac{8510\ \text{kW}}{654\ \text{cfs}} = 13.0\ \text{kW/cfs.}$$

TABLE H-3. Initial Critical period SSR routing

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Routing Period Month	Year	Inflow 'I' (CFS)	Evapo-ration 'E' (CFS)	With-drawals 'W' (CFS)	Net Inflow (CFS)	Energy Required (MWh)	Average Pool Elev. (Feet)	kW Per CFS	Required Power Discharge $'Q_p'$ (CFS)
Apr	1962	-	-	-	-	-	-	-	-
- - -									Start of
May	1962	389	-29	55	363	6,000	599.5	14.0	576
		"	"	"	"	"	599.0	14.0	576
Jun	1962	230	37	95	98	6,000	598.5	13.9	600
		"	"	"	"	"	597.4	13.8	604
Jul	1962	21	58	94	-131	12,000	596.3	13.8	1,169
		"	"	"	"	"	593.4	13.6	1,186
Aug	1962	46	55	94	-103	12,000	590.2	13.3	1,213
		"	"	"	"	"	586.9	13.1	1,231
Sep	1962	182	24	66	92	6,000	582.2	12.7	656
Oct	1962	1,731	2	33	1,696	3,600	584.1	12.8	378
Nov	1962	697	-29	25	701	3,600	588.1	13.1	382
Dec	1962	465	-42	24	483	6,000	588.5	13.2	611
Jan	1963	633	-42	24	651	6,000	588.1	13.1	616
Feb	1963	182	-30	26	186	3,600	587.7	13.1	409
Mar	1963	2,109	-19	27	2,101	3,600	591.2	13.4	361
Apr	1963	913	-12	37	888	3,600	596.4	13.8	362
May	1963	396	-29	55	370	6,000	597.0	13.8	584
Jun	1963	36	36	95	-95	6,000	595.0	13.7	608
Jul	1963	65	56	94	-85	12,000	590.3	13.3	1,213
Aug	1963	43	54	94	-105	12,000	583.8	12.8	1,260
Sep	1963	19	23	66	-70	6,000	578.4	12.4	672
Oct	1963	0	2	33	-35	3,600	575.2	12.2	397
Nov	1963	0	-25	25	0	3,600	572.8	12.0	417
Dec	1963	15	-35	24	26	6,000	569.5	11.8	684
Jan	1964	15	-33	24	24	6,000	565.0	11.4	707
Feb	1964	338	-22	26	334	3,600	562.3	11.2	462
- - -								End of	Critical

for Broken Bow Reservoir, Oklahoma

(11) Required Minimum Discharge (CFS)	(12) Required Total Discharge (CFS)	(13) Change in Storage, Δ S (CFS)	(14) (AF)	(15) End of Period Reservoir Status (AF)	(16) (Elev.)	(17) Reservoir Surface Area (Acres)	(18) Total Power Generation (MWh)
-	-	-	-	918,800	599.5	14,200	-
Critical Period - - -							
88	586	-223	-13.700	905,100	598.5	-	-
88	586	-223	-13,700	905,100	598.5	14,100	6,000
90	610	-512	-30,500	874,600	596.3	-	-
90	614	-516	-30,700	874,400	596.3	13,800	6,000
120	1,179	-1,310	-80.600	793.800	590.4	-	-
120	1,196	-1,327	-81,600	792,800	590.2	13,000	12,000
175	1.223	-1,326	-81,500	711,300	583.7	-	-
175	1,241	-1,343	-82,600	710,200	583.6	12,200	12,000
314	666	-574	-34,200	676,000	580.8	11,800	6,000
320	388	1,308	80,400	756,400	587.5	12,600	3,600
320	392	309	18,400	774,800	588.8	12,800	3,600
235	621	-138	-8,500	766,300	588.1	12,700	6,000
118	626	25	1,500	767,800	588.2	12,700	6,000
90	419	-233	-12,900	754,900	587.2	12,600	3,600
86	371	1,730	106,400	861,300	595.3	13,600	3,600
86	372	516	30,700	892,000	597.5	13,900	3,600
88	594	-224	-13.800	878,200	596.6	13,800	6,000
90	618	-713	-42,400	835,800	593.4	13,400	6,000
120	1,223	-1,308	-80.400	755,400	587.2	12,600	12,000
173	1.270	-1,375	-84,500	670,900	580.3	11,700	12,000
314	682	-752	-44,700	626,200	576.4	11,200	6,000
320	407	-442	-27.200	599,000	574.0	10,900	3,600
320	427	-427	-25,400	573,600	571.6	10,600	3,600
235	694	-720	-44,300	529,300	567.4	10,100	6,000
118	717	-741	-45,600	483,700	562.7	9,600	6,000
90	472	-138	-7,900	475,800	561.9	9,500	3,600
Drawdown Period - - -							

TABLE H-4. Second Critical period SSR routing

(1) Routing Period Month	(2) Year	(3) Inflow 'I' (CFS)	(4) Evapo-ration 'E' (CFS)	(5) With-drawals 'W' (CFS)	(6) Net Inflow (CFS)	(7) Energy Required (MWh)	(8) Avg. Pool Elevation (Ft., MSL)	(9) kW Per CFS	(10) Required Power Discharge (CFS)
Apr	1962								
									Start
May	1962	389	-29	55	363	6,200	599.5	14.0	595
		"	"	"	"	"	599.0	14.0	595
Jun	1962	230	37	95	98	6,200	598.4	13.9	620
		"	"	"	"	"	597.3	13.8	624
Jul	1962	21	58	94	-131	12,350	596.1	13.8	1,212
		"	"	"	"	"	593.0	13.6	1.230
Aug	1962	46	55	94	-103	12,350	589.8	13.3	1,248
		"	"	"	"	"	586.5	13.1	1,277
Sep	1962	182	24	66	92	6,200	581.5	12.7	684
Oct	1962	1,731	2	33	1,696	3,700	583.2	12.8	389
Nov	1962	697	-29	25	701	3,700	587.3	13.1	392
Dec	1962	465	-41	24	482	6,200	587.6	13.2	636
Jan	1963	633	-41	24	650	6,200	587.2	13.1	636
Feb	1963	182	-30	26	186	3,700	586.7	13.1	424
Mar	1963	2,109	-18	27	2,100	3,700	590.1	13.4	374
Apr	1963	913	-12	37	888	3,700	595.3	13.8	375
May	1963	396	-29	55	370	6,200	595.8	13.8	608
Jun	1963	36	36	95	-95	6,200	593.7	13.7	633
Jul	1963	65	55	94	-84	12,350	588.8	13.3	1,258
Aug	1963	43	52	94	-103	12,350	581.9	12.8	1,307
Sep	1963	19	22	66	-69	6,200	576.1	12.4	700
Oct	1963	0	2	33	-35	3,700	572.8	12.2	414
Nov	1963	0	-24	25	-1	3,700	570.1	12.0	436
Dec	1963	15	-34	24	25	6,200	566.7	11.8	725
Jan	1964	15	-32	24	23	6,200	562.2	11.4	744
Feb	1964	338	-21	26	333	3,700	559.3	11.2	483
									End of
Mar	1964	2,438	-14	27	2,424	3,700	559.3	11.27	436
Apr	1964	2,851	-9	37	2,823	3,700	577.6	12.36	414
May	1964	457	-25	55	427	6,200	583.4	12.77	651
Jun	1964	46	31	95	-80	6,200	580.9	12.67	683
Jul	1964	2	48	94	-140	12,350	574.7	12.17	1,372
Aug	1964	501	45	94	362	12,350	567.1	11.72	1,431
Sep	1964	796	19	66	711	6,200	563.6	11.31	762
Oct	1964	316	2	33	281	3,700	562.8	11.26	444
Nov	1964	1.225	-22	25	1,222	3,700	564.6	11.31	451
Dec	1964	589	-33	24	598	6,200	566.5	11.50	725
Jan	1965	1.200	-33	24	1.199	6,200	567.5	11.57	718
Feb	1965	3.579	-24	26	3,577	3,700	576.6	12.17	448
Mar	1965	1,208	-18	27	1,199	3,700	586.3	13.03	383
Apr	1965	774	-11	37	748	3,700	589.1	13.21	389
May	1965	2,567	-27	55	2,539	6,200	594.3	13.51	613
Jun	1965	1.775	37	95	1,643	6,200	599.0	13.97	615
								End of Critical	

for Broken Bow Reservoir. Oklahoma

(11) Required Minimum Discharge (CFS)	(12) Required Total Discharge (CFS)	(13) Change in Storage, ΔS (CFS)	(14) Change in Storage, ΔS (AF)	(15) End of Period Reservoir Status (AF)	(16) End of Period Reservoir Status (Elev.)	(17) Reservoir Surface Area (Acres)	(18) Total Power Generation (MWh)
				918,800	599.5	14,200	
Critical Period							
88	605	-242	-14,900	903,900	598.4		
	605	-242	-14,900	903,900	598.4	14,000	6,200
90	630	-532	-31,700	872,200	596.2		
	634	-536	-31,900	872,000	596.1	13,700	6,200
120	1,222	-1,353	-83,200	788,800	588.9		
	1,240	-1,371	-84,300	787,700	589.8	12,900	12,350
173	1,258	-1,361	-83,700	704,000	583.1		
	1,287	-1,390	-85,500	702,200	583.0	12,000	12,350
314	694	-602	-35,800	666,400	579.9	11,600	6,200
320	399	1,297	79,800	746,200	586.6	12,500	3,700
320	402	299	17,800	764,000	588.0	12,700	3,700
235	646	-164	-10,100	753,900	587.2	12,600	6,200
118	646	4	200	754,100	587.2	12,600	6,200
90	434	-248	-13,800	740,300	586.1	12,400	3,700
86	384	1,716	105,500	845,800	594.2	13,500	3,700
86	385	503	29,900	875,700	596.4	13,800	3,700
88	618	-248	-15,200	860,500	595.3	13,600	6,200
90	643	-738	-43,900	816,600	592.0	13,200	6,200
120	1,268	-1,352	-83,100	733,500	585.5	12,300	12,350
173	1,317	-1,420	-87,300	646,200	578.2	11,400	12,350
314	710	-779	-46,300	599,900	574.1	10,900	6,200
320	424	-459	-28,200	571,700	571.4	10,600	3,700
320	446	-447	-26,600	545,100	568.9	10,300	3,700
235	735	-710	-43,700	501,400	564.5	9,800	6,200
118	754	-731	-44,900	456,500	559.8	9,300	6,200
90	493	-160	-9,200	447,300	558.8	9,200	3,700
Critical Drawdown Period							
86	446	1,978	121,600	568,900	571.2	10,600	3,700
86	424	2,399	142,700	711,600	583.8	12,200	3,700
88	661	-234	-14,400	697,200	582.6	12,000	6,200
90	693	-773	-46,000	651,200	578.7	11,500	6,200
120	1,382	-1,522	-93,600	557,600	570.1	10,500	12,350
173	1,441	-1,079	-66,300	491,300	563.6	9,700	12,350
314	772	-61	-3,600	487,700	563.3	9,700	6,200
320	454	-173	-10,600	477,100	562.2	9,500	3,700
320	461	761	45,300	522,400	566.7	10,100	3,700
235	735	-137	-8,400	514,000	565.9	10,000	6,200
118	728	471	29,000	543,000	568.7	10,300	6,200
90	458	3,119	173,200	716,200	584.1	12,200	3,700
86	393	806	49,600	765,800	588.1	12,700	3,700
86	399	349	20,800	786,600	589.7	12,900	3,700
88	623	1,916	117,800	904,400	598.5	14,100	6,200
90	1,401	242	14,400	918,800	599.5	14,200	14,020
Period							

(4) The additional energy that could be generated during the critical drawdown period from the 19.9 cfs of "unused" flow calculated in Step (1) would be approximately equal to

(20.4 cfs)x(13.0 kW/cfs)x(670 days)x(24 hours/day) = 4,300,000 kWh.

(5) The new firm energy estimate for the critical drawdown period at Broken Bow Reservoir would be

(136,800,000 kWh + 4,300.000 kWh) = 141,100.000 kWh.

Using the procedure described in Section H-2b(8), the annual firm energy generation would be:

$$(141,100,000 \text{ kWh}) \times \frac{(100\%)}{(190\%)} = 74,200,000 \text{ kWh.}$$

(6) Each month's firm energy requirement must now be recalculated using the monthly percentages shown in Table H-1. The resulting firm energy requirements are as follows;

January	6,200.000 kWh	July	12,350,000 kWh
February	3.700.000 kWh	August	12,350,000 kWh
March	3,700,000 kWh	September	6,200.000 kWh
April	3,700.000 kWh	October	3,700,000 kWh
May	6,200.000 kWh	November	3,700,000 kWh
June	6,200.000 kWh	December	6,200,000 kWh

H-5. Final Firm Energy Estimate. The second hand routing for Broken Bow Reservoir. using the recalculated monthly firm energy requirements, is shown on Table H-4. In this routing, Broken Bow Reservoir is drafted to 1,400 acre-feet below the bottom of its power pool in February 1964. This means that firm energy was slightly overestimated (by 0.16%). A further regulation could be made to eliminate this error, but 0.16 percent is well within the accuracy required for planning studies.