CHAPTER 4

HYDROLOGIC DATA PREPARATION

4-1. Introduction.

a. This chapter identifies and briefly discusses the types and sources of hydrologic data required for hydropower studies. However, the details of hydrologic evaluation procedures used for developing this data are not described because they are already well documented in other EM's and standard hydrologic engineering references.

b. The most important type of hydrologic data required for a hydropower feasibility study is the long term streamflow record that represents the flow available for power production. Other important hydrologic data includes tailwater rating curves, reservoir storage-elevation tables, evaporation losses and other types of losses, sedimentation and water quality data, downstream flow requirements, streamflow routing criteria, and downstream channel constraints. The procedures used to develop this information are determined by the level of the study and the quality and quantity of data available. Detailed studies are not always necessary to develop reasonable estimates of this data, and sometimes, due to limitations in the type and amount of available information, detailed studies cannot be performed. Extrapolations of available data and simplified assumptions are sometimes necessary to compensate for lack of information.

4-2. Streamflow Records.

a. General. Streamflow records are the backbone of the hydropower study. Mean monthly discharges are sometimes adequate, but in other cases, weekly or daily values are necessary.

b. Data Collection. The U.S. Geological Survey (USGS) is the principal source of streamflow records. Currently, the USGS collects and disseminates the majority of the water data collected in the United States. Most data collected by the USGS is summarized in the Water Resources Data, an annual series of reports for each state or hydrologic region in the United States (75). Figure 4-1 is an example of data supplied by the USGS. Surface water records are also sometimes available from Federal, state, and local water management agencies and utilities.

c. <u>WATSTORE.</u> Surface water records collected by the USGS and others are stored in WATSTORE, the USGS's National Water Data Storage and Retrieval System. Access to the WATSTORE system is available to all Corps offices through an interagency agreement between the Corps of Engineers and the USGS. The WATSTORE data storage and retrieval system contains water resources data which includes surface runoff, ground water conditions, and water quality data for all 50 states, Puerto Rico, the Virgin Islands, and Canada. WATSTORE files contain daily, monthly, and yearly peak and mean flow data for gaging stations in the system. WATSTORE data can be displayed as standard-

PEND OREILLE RIVER BASIN

12323750 SILVER BOW CREEK AT WARM SPRINGS, MT

LOCATION.--Lat 46°11'07", long 112°46'04", in SE¼ sec.18, T.5 N., R.9 W., Deer Lodge County, on right bank 0.3 mi (0.5 km) upstream from county highway bridge, 0.2 mi (0.3 km) upstream from confluence with Warm Springs Creek, and 1.0 mi (1.6 km) northeast of Warm Springs.

DRAINAGE AREA.--483 mi² (1,251 km²).

PERIOD OF RECORD.--March 1972 to current year.

GAGE.--Water-stage recorder. Datum of gage is 4,787.05 ft (1,459.367 m) above sea level.

EXTREMES.--Current year: Maximum discharge, 1,320 ft³/s (37.4 m³/s) June 20, gage height, 7.47 ft (2.277 m); minimum daily, 24 ft³/s (0.680 m³/s) Jan. 3.

Period of record: Maximum discharge, 1,320 ft³/s (37.4 m³/s) June 20, 1975, gage height, 7.47 ft (2.277 m); maximum gage height, 8.64 ft (2.633 m) Jan. 16, 1974, (backwater from ice jam); minimum daily discharge, 15 ft³/s (0.43 m³/s) Sept. 12, 13, 1973.

REMARKS.--Records good. Flow can be regulated by dam on Anaconda Co. tailing ponds about 0.5 mi (0.8 km) upstream from gage. Diversions for irrigation of about 4,650 acres (18.8 km²) above station.

DISCHARGE, IN CUBIC FEET PER SECOND   WATER YEAR OCTOBER 1974 TO SEPTEMBER 1975
MEAN VALUES

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	52	111	98	69	81	131	122	208	643	403	438	177
2	56	120	93	65	81	176	115	226	748	514	332	161
3	49	120	96	24	87	244	111	240	872	569	230	161
4	53	114	99	37	91	262	115	274	896	569	214	172
5	104	108	107	38	89	232	114	298	861	531	210	168
6	84	66	112	51	85	156	114	297	934	502	188	163
7	81	37	112	54	85	160	111	322	903	502	194	150
8	77	130	109	60	85	154	110	332	907	471	216	147
9	74	89	102	64	85	150	102	339	874	568	208	140
10	66	38	105	45	85	150	102	357	749	463	188	130
11	65	105	108	50	84	140	104	461	639	378	170	130
12	47	55	101	50	88	131	114	692	623	341	160	123
13	73	140	101	49	92	130	140	547	660	306	145	117
14	83	152	102	44	102	122	196	616	639	343	168	123
15	81	187	96	55	106	117	246	696	685	334	160	122
16	88	163	96	72	106	120	259	720	680	314	150	123
17	81	120	96	83	102	122	319	605	550	298	170	122
18	81	120	102	102	96	122	319	696	704	406	168	137
19	80	111	101	109	91	140	274	740	1170	407	172	131
20	81	63	101	111	89	161	254	632	1240	264	198	147
21	118	52	102	106	91	147	264	534	1000	205	206	144
22	160	125	93	101	101	142	203	463	915	272	158	130
23	137	202	84	96	104	130	337	442	763	277	181	140
24	118	102	80	96	98	120	300	454	805	290	264	137
25	114	53	77	94	98	120	307	418	706	228	241	89
26	112	163	77	90	105	112	319	382	676	204	222	135
27	115	165	73	84	118	108	284	380	641	190	206	145
28	111	130	80	80	115	102	242	302	531	176	190	128
29	103	122	84	75	---	102	229	432	430	176	154	114
30	102	101	77	80	---	115	202	498	430	247	122	112
31	103	---	73	80	---	126	---	549	---	306	206	---
TOTAL	2751	3352	2937	2214	2632	4468	6099	14322	23113	11044	6237	4110
MEAN	88.7	112	94.7	71.4	94.0	144	203	462	770	356	201	137
MAX	160	202	112	111	115	262	337	740	1240	569	438	177
MIN	47	37	73	24	81	102	102	208	430	176	122	89
AC-FT	5460	6650	5830	4390	5220	8860	12100	28410	45840	21910	12370	8170

CAL YR 1974 TOTAL 53741 MEAN 147 MAX 908 MIN 27 AC-FT 106600
WTR YR 1975 TOTAL 83287 MEAN 228 MAX 1220 MIN 24 AC-FT 165200

Figure 4-1. Example of USGS daily streamflow data ized tables or graphs. An example of WATSTORE output used in hydropower studies are shown in Figure 4-2. This data can be analyzed and plotted. WATSTORE is also capable of producing a magnetic tape of selected data.

d. Data Accuracy and Reliability. Users of WATSTORE should review individual station records carefully. Retrieved data should be verified for its reliability because the USGS may have made subsequent revisions to this data as a result of a reanalysis. These revisions are most commonly made to correct errors found during historic high and low streamflow conditions or when ice is present, but may include the entire period of record if the accuracy of the gaging station is questionable.

FILE TYPE	STATE CODE	AGENCY CODE	STATION IDENTIFICATION NUMBER	CROSS SECTION	SAMPLING DEPTH	PARAMETER CODE	YEAR	STAT CODE	NO VALUE INDICATOR	DIST CODE	COUNTY CODE	DRAINAGE AREA	CONTRIB. DRAINAGE AREA
R	42	USGS	01474500	999999.000	999999.000	00060	1974	00003	999999.0000	42	101	1893.00	0.00

STATION NAME OR LOCAL WELL NUMBER	WELL DEPTH	DATUM	HYDROLOGIC UNIT CODE	RIV SEQ NO	BEG NO	SITE CODE	STATION LOCATOR LATITUDE	STATION LOCATOR LONGITUDE	STATION LOCATOR SEQ NO	GEOLOGIC UNIT CODE
SCHUYLKILL RIVER AT PHILADELPHIA, PA.	-99999.00	5.74	000000000	01	10	SW	395942	0751140	00	

DAY	10	11	12	01	02	03	04	05	06	07	08	09
1	1570.00	2250.00	1260.00	5830.00	4080.00	3110.00	11000	2060.00	1700.00	1650.00	965.000	1120.00
2	1610.00	1910.00	1030.00	5180.00	3580.00	3210.00	8310.00	1920.00	2120.00	2280.00	777.000	1360.00
3	1980.00	1660.00	929.000	4460.00	3370.00	2900.00	7320.00	2090.00	2050.00	1890.00	1030.00	2700.00
4	1530.00	1420.00	862.000	6170.00	3010.00	2760.00	8130.00	2410.00	1680.00	1500.00	1810.00	5530.00
5	1310.00	1280.00	1750.00	5380.00	2570.00	2610.00	12500	2060.00	1450.00	1480.00	3950.00	3400.00
6	1160.00	1240.00	6610.00	4260.00	2240.00	2470.00	12200	1870.00	1300.00	1320.00	1920.00	2150.00
7	1050.00	1130.00	4520.00	3910.00	2290.00	2330.00	9150.00	1950.00	1200.00	1250.00	1220.00	3260.00
8	997.000	1080.00	3220.00	3630.00	2290.00	2200.00	7530.00	1900.00	1180.00	1100.00	981.000	3650.00
9	1010.00	1060.00	5290.00	3210.00	2030.00	3110.00	13700	1860.00	1200.00	954.000	917.000	2410.00
10	968.000	972.000	9620.00	3260.00	1810.00	5370.00	9870.00	2990.00	1140.00	858.000	1390.00	1890.00
11	949.000	963.000	6630.00	5260.00	1770.00	5130.00	7080.00	2930.00	1090.00	790.000	1070.00	1610.00
12	996.000	909.000	4970.00	6380.00	1730.00	4330.00	5990.00	2780.00	996.000	812.000	927.000	1550.00
13	916.000	915.000	3970.00	4300.00	1650.00	3860.00	7690.00	11500	965.000	777.000	763.000	1410.00
14	907.000	904.000	6080.00	3160.00	1690.00	3370.00	8540.00	7040.00	933.000	729.000	651.000	2270.00
15	858.000	845.000	5610.00	3010.00	1620.00	3000.00	8660.00	4780.00	983.000	615.000	632.000	2570.00
16	806.000	840.000	4210.00	3150.00	1880.00	3230.00	7850.00	3860.00	2010.00	586.000	557.000	2060.00
17	783.000	764.000	3850.00	3100.00	1760.00	6290.00	5970.00	3200.00	2990.00	554.000	547.000	1670.00
18	740.000	789.000	3400.00	3050.00	1760.00	4640.00	5120.00	2810.00	1640.00	507.000	2460.00	1440.00
19	738.000	785.000	2820.00	3000.00	1800.00	3550.00	4630.00	2610.00	1230.00	553.000	1560.00	1280.00
20	739.000	791.000	2050.00	3000.00	2500.00	3250.00	4460.00	2320.00	1010.00	523.000	1000.00	1170.00
21	728.000	763.000	37400	4000.00	3120.00	5170.00	4000.00	2100.00	1150.00	540.000	743.000	1160.00
22	723.000	734.000	26400	5700.00	2510.00	9370.00	3640.00	1960.00	1520.00	503.000	626.000	1310.00
23	726.000	708.000	13600	9000.00	4060.00	5890.00	3640.00	2630.00	2260.00	461.000	2980.00	1280.00
24	742.000	713.000	9190.00	8100.00	4760.00	5010.00	3330.00	2560.00	2650.00	787.000	1160.00	1390.00
25	708.000	756.000	6800.00	7200.00	3950.00	4400.00	2920.00	2380.00	2470.00	936.000	870.000	957.000
26	684.000	831.000	10800	6000.00	3600.00	3760.00	2650.00	1820.00	1850.00	822.000	663.000	859.000
27	668.000	897.000	22000	6200.00	3110.00	3410.00	2490.00	1700.00	1540.00	687.000	974.000	793.000
28	630.000	1130.00	12000	6000.00	3010.00	3060.00	2330.00	1670.00	1480.00	610.000	777.000	1200.00
29	1730.00	1920.00	9190.00	6500.00	999999	2940.00	2270.00	1640.00	1880.00	550.000	701.000	8540.00
30	3760.00	1940.00	7530.00	5900.00	999999	5000.00	2200.00	1700.00	1770.00	1030.00	961.000	2610.00
31	3760.00	999999	6220.00	5300.00	999999	18600	999999	1680.00	999999	1080.00	1110.00	999999

Figure 4-2. Example WATSTORE output: daily streamflow data for a surface water gage

c. WATSTORE. Surface water records collected by the USGS and others are stored in WATSTORE, the USGS's National Water Data Storage and Retrieval System. Access to the WATSTORE system is available to all Corps offices through an interagency agreement between the Corps of Engineers and the USGS. The WATSTORE data storage and retrieval system contains water resources data which includes surface runoff, ground water conditions, and water quality data for all 50 states, Puerto Rico, the Virgin Islands, and Canada. WATSTORE files contain daily, monthly, and yearly peak and mean flow data for gaging stations in the system. WATSTORE data can be displayed as standardized tables or graphs. An example of WATSTORE output used in hydropower studies is shown in Figure 4-2. This data can be analyzed and plotted. WATSTORE is also capable of producing a magnetic tape of selected data.

d. Data Accuracy and Reliability. Users of WATSTORE should review individual station records carefully. Retrieved data should be verified for its reliability because the USGS may have made subsequent revisions to this data as a result of a reanalysis. These revisions are most commonly made to correct errors found during historic high and low streamflow conditions or when ice is present, but may include the entire period of record if the accuracy of the gaging station is questionable.

e. Data From Other Sources. There are some areas within the country where USGS streamflow information is not available or is insufficient. Local irrigation districts, public utility districts, private utility companies, state water resources agencies and Federal agencies, such as the Corps of Engineers, Bureau of Reclamation, and Tennessee Valley Authority may possess streamflow or reservoir storage data that is not in the USGS files. These potential sources should be investigated when adequate data is not available from the USGS.

4-3. Historical Records Adjustment.

a. General. Streamflow data obtained from the USGS or another agency may not be immediately usable for hydropower site analysis. Historical streamflow records, especially if they span a long period of time, may have to be adjusted to account for diversions, reservoir regulation, and upstream land use changes. This is done so that the streamflow record is consistent throughout the period of record and properly reflects conditions at some base level. This base level could represent present conditions or expected streamflow conditions at some future date. When analyzing a hydropower project on a stream where diversions or factors influencing streamflow are expected to change substantially with time, it may be necessary to develop modified flows for one or more future levels to insure that accurate long-term estimates of energy potential are developed. Adjustments may also be necessary to account for the differences in runoff between the gaging station and the study site.

b. Natural and Modified Streamflow Conditions.

(1) Natural Streamflows. When regional streamflow studies are performed, it is often necessary to modify observed streamflow data to represent an unregulated or "natural" basin condition. Streamflow data is developed to generate a set of hydrologically consistent data that reflects a base condition where the effects of diversions and withdrawals that have occurred at different times during the period of record are removed. This discharge data is obtained by adding back flow diversions or withdrawals of water that bypassed the gaging station. Reservoir storage-release records are also corrected for evaporation and percolation losses. It is also necessary in some cases to adjust discharge data for changes in long-term watershed conditions due to changes in land use.

(2) Modified Streamflows. It is not necessary to develop a set of natural streamflows if existing uses of water, such as irrigation withdrawals, are expected to continue in the future. In the latter case, a uniform basin condition is established for a specific point in time, where the effects of upstream regulation are accounted for during the entire period of record. In order to obtain uniform flow data, streamflows prior to the date that any diversion was initiated must be adjusted to reflect the selected base condition. The discharge record that is developed for this situation is called a modified flow record, which represents a basin condition at some point in time.

c. Estimating Flow at a Damsite. Correction to streamflow data is required if a gaging station is not located in the immediate vicinity of the study site. Standard hydrologic methods should be used to adjust the streamflow information of the gage to represent flow at each project site. Hydrologic characteristics of the watershed such as drainage area, topography, soil, and precipitation patterns should be considered. Streamflow evaluation at existing dams is often easier than at undeveloped sites because existing streamflow records and other hydrologic data can be used.

d. Extension of Historical Records.

(1) Although short-term records may be considered acceptable for reconnaissance studies, more detailed studies require longer periods of record. The decision to extend a short historical record should be based on the level of study and the type of analysis for which the record is to be used. Generally, streamflow records should be

extended if the available record is less than 20 to 30 years. Correlation and regression techniques can be used to extend a period of record if one or more sites with similar flow variations can be found. If good correlation does not exist, other techniques such as examination of precipitation records should be used to test the existing record to determine if it is representative of the long-term record.

(2) Streamflow extension can be accomplished by regression analysis. This method finds regression coefficients for simultaneous flows between a gage with a short term record and one or more gages with a long period of record. These coefficients are applied to the long record values to extend the short record. This technique requires that the station records have sufficient concurrent record to obtain satisfactory correlation.

(3) Stochastic techniques can also be used to generate a long synthetic record as a substitute for a short length of actual record. Stochastic techniques are also used to fill in missing periods of record. The program HEC-4, "Monthly Streamflow Simulation," is capable of generating monthly flows.

(4) Basin rainfall-runoff models are used when streamflow records are either too short, unreliable, or unavailable. These models use precipitation information and basin characteristics to generate additional streamflow information. A continuous simulation model, such as North Pacific Division's SSARR Model (Streamflow Synthesis and Reservoir Regulation), generates hourly or daily flows and is suitable for more detailed studies (56).

e. Future Flow Depletions. Future levels of consumptive uses must be evaluated when studying total water availability during the life of a project. Future demands for irrigation, municipal and industrial consumptive use, and population levels are quantities that should be determined and incorporated in the streamflow data used for making the power studies.

4-4. Types of Streamflow Data Used in Power Studies.

a. General. Streamflow data is used to develop estimates of water available for power generation. The most common types of streamflow data used for this process are mean daily, mean weekly and mean monthly flows. This data is often summarized in flow duration curves.

b. Mean Daily Data. This is the basic increment of hydrologic data available from the streamflow records. Daily flow data can be used directly to develop flow duration curves for estimating the power potential of small hydro projects. It is also used to help evaluate projects where little or no seasonal storage is available for power generation either at-site or upstream. Daily flows may also be required as supplemental information in studies based on monthly flows. An example would be a flood control project where flood flows are flashy and of short duration. Monthly average flows may be suitable for evaluating most of the year, but they could mask out the wide variations of discharge and reservoir elevation that would occur during the flood season. This type of operation may occur during only a small portion of the year, and monthly average flows may be suitable for evaluating the remainder of the year.

c. Mean Weekly and Monthly Data. Mean weekly and monthly data are obtained from mean daily flow records. These values are sometimes used in place of daily data in power calculations in order to reduce computation time. Because the mean value represents a series of flow values, care should be taken to verify that this value represents the useable flows available to the powerplant units. Where flows vary widely within the week or month, an average weekly or monthly value may overestimate the amount of streamflow available for generation. For example, a given monthly average flow may be well within a hydro plant's hydraulic capacity, but there may be many days during that month when the flow exceeds the hydraulic capacity, and water is spilled. On the other hand, where streamflows are relatively constant within the week or month, as is sometimes the case when flows are highly regulated, the use of weekly or monthly flows can save considerable computation time. Section 5-6b discusses this topic in more detail.

d. Flow-Duration Curves. Flow-duration curves are used to summarize streamflow characteristics and can be constructed from daily, weekly, or monthly streamflow data. Duration curves can be constructed with historical data from WATSTORE or with regulated flows from HEC-5, SUPER, or one of the other sequential routing models described in Appendix C. These curves show the percentage of time that flow equals or exceeds various values during the period of record. The disadvantages of the flow-duration curve is that it does not present flow in chronological sequence, does not describe the seasonal distribution of streamflow, and does not account for variations of head independent of streamflow. However, these curves are useful for evaluating the power output of run-of-river projects and for other power projects where head varies directly with flow. The procedures for constructing a flow-duration curve is presented in most standard hydrology texts. An example of a flow duration curve is shown as Figure 4-3.

e. Seasonal Flow Distribution. Regardless of the type of streamflow data used in making the power study, information should be presented showing seasonal distribution of runoff. This information, which could be presented in tabular or graphical form, is useful for evaluating the usability of the power from the project. Figure 4-4 shows an example of a graph showing period-of-record average streamflow by month.

4-5. Other Hydrologic Data.

a. Introduction. In addition to determining the annual and seasonal distribution of water available for power generation, hydrologic analysis can include other related studies. Common types of data required are tailwater rating curves, reservoir elevation-area-capacity tables, sedimentation data, water quality data, downstream flow information, water surface fluctuation data, and evaporation and seepage loss analyses.

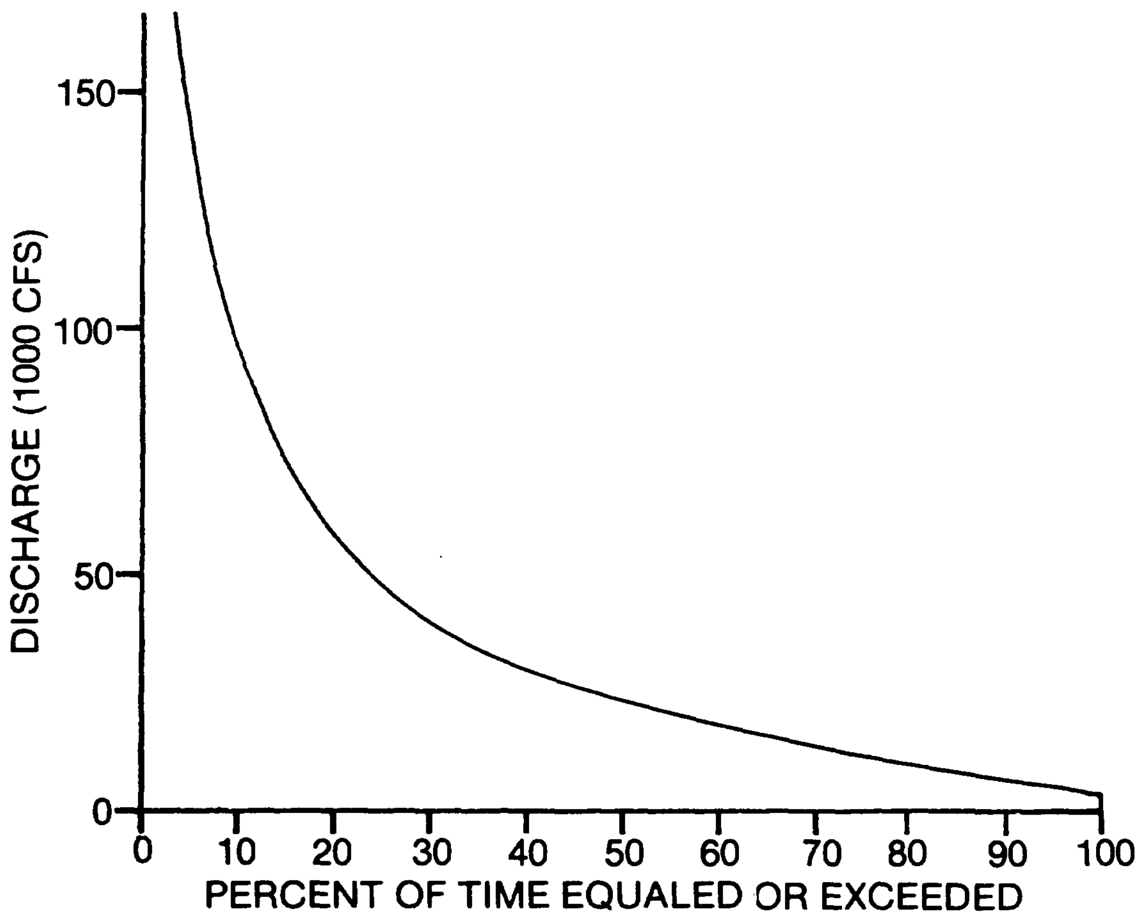

Figure 4-3. Flow-duration curve

b. Tailwater Rating Curves.

(1) General. Tailwater rating studies are made to define the variation of tailwater elevation with project flow discharge. This data is used to compute the generating head available at each discharge level. Tailwater elevation is a function of downstream channel geometry, project discharge, and downstream backwater effects. Tailwater restrictions can also limit the gross hydraulic capacity of the proposed powerhouse. Figure 4-5 is a typical example of a tailwater rating curve. For new projects, tailwater curves can be developed using the standard step method, with computer models such as HEC-2, "Water Surface Profiles".

(2) Run-of-River Projects. For pure run-of-river projects, such as lock and dam structures, the tailwater rating curve and the forebay elevation can often be used to develop a head vs. discharge curve.

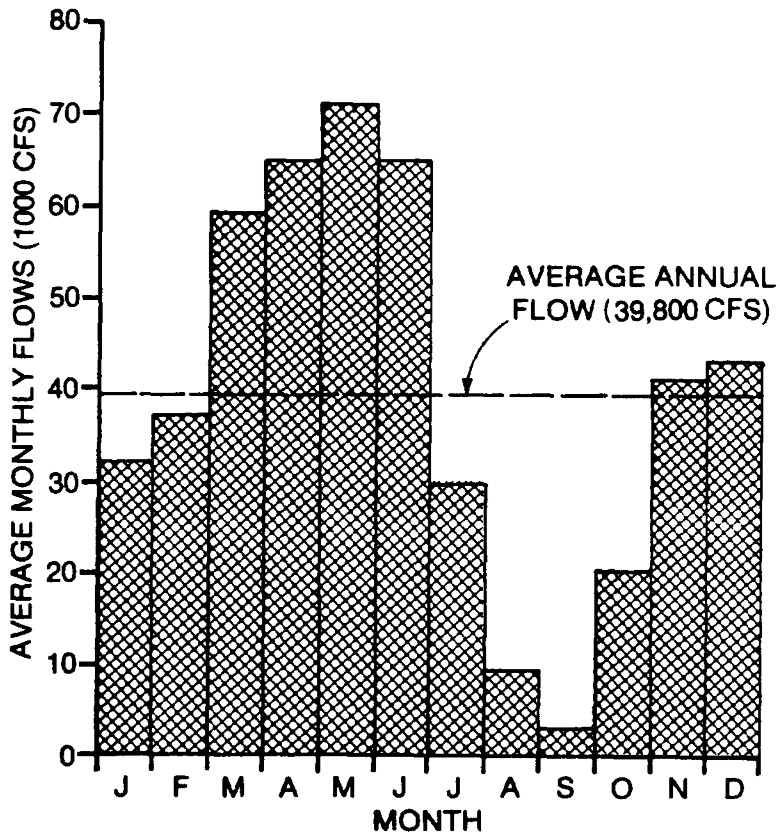

Figure 4-4. Monthly flow distribution

Data from this curve and the flow-duration curve can be combined to develop a generation-duration curve. Figure 4-6 shows an example of a head vs. discharge curve. For pure run-of-river projects, the forebay elevation can usually be assumed to be constant over a substantial flow range, but in many cases it begins to increase at high inflows.

(3) Peaking Projects. A peaking plant may typically operate at or near full output for part of the day and at zero or some minimum output during the remainder of the day. In these cases, the tailwater elevation during generation may be virtually independent of the average streamflow for the day, except perhaps during periods of high runoff. For projects of this type, a single tailwater elevation based upon the peaking discharge could be specified. This value could be a weighted average tailwater elevation, developed from hourly operation

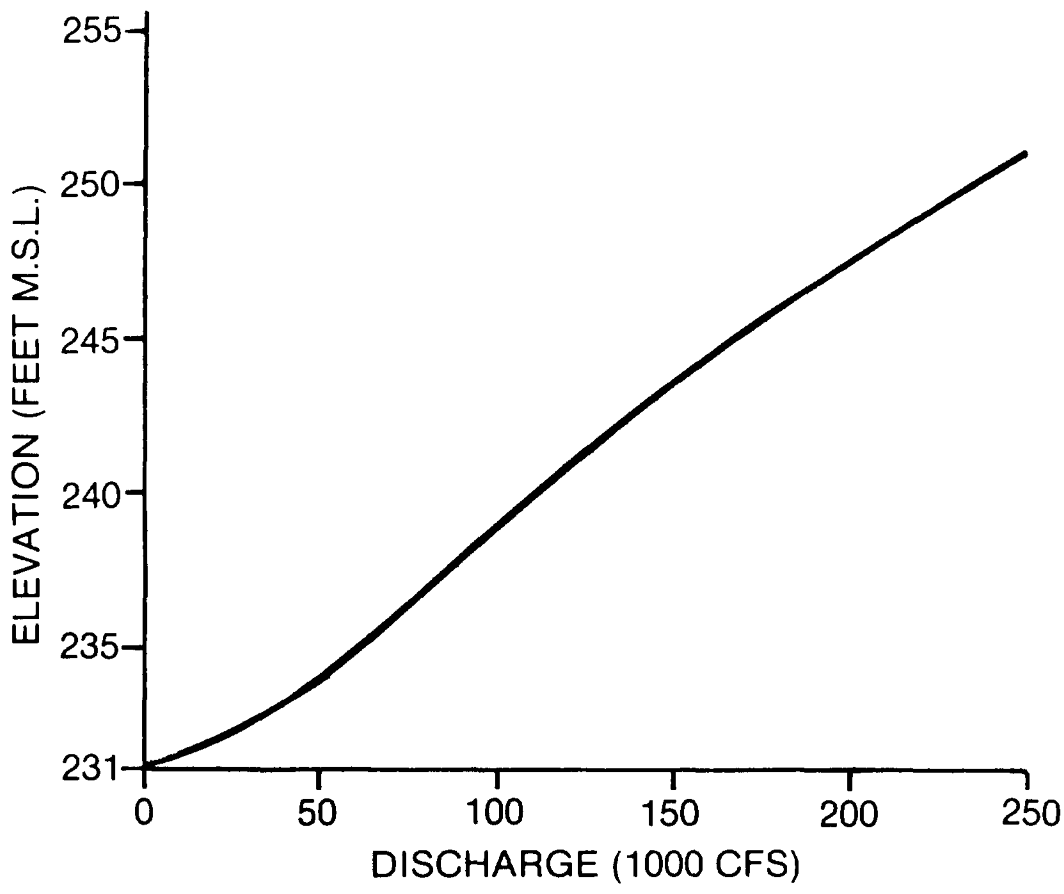

Figure 4-5. Tailwater rating curve

studies and weighted proportionally to the amount of generation produced in each hour of the period examined. Alternatively, it could be a "block-loaded" tailwater elevation, based on an assumed typical output level. The specific output level used for a "block-loaded" tailwater elevation could be based on (a) operation at full rated output, (b) output at best efficiency (typically 75 to 80 percent of full rated output for Francis turbines, for example), or (c) an output value developed in coordination with the agency which will be

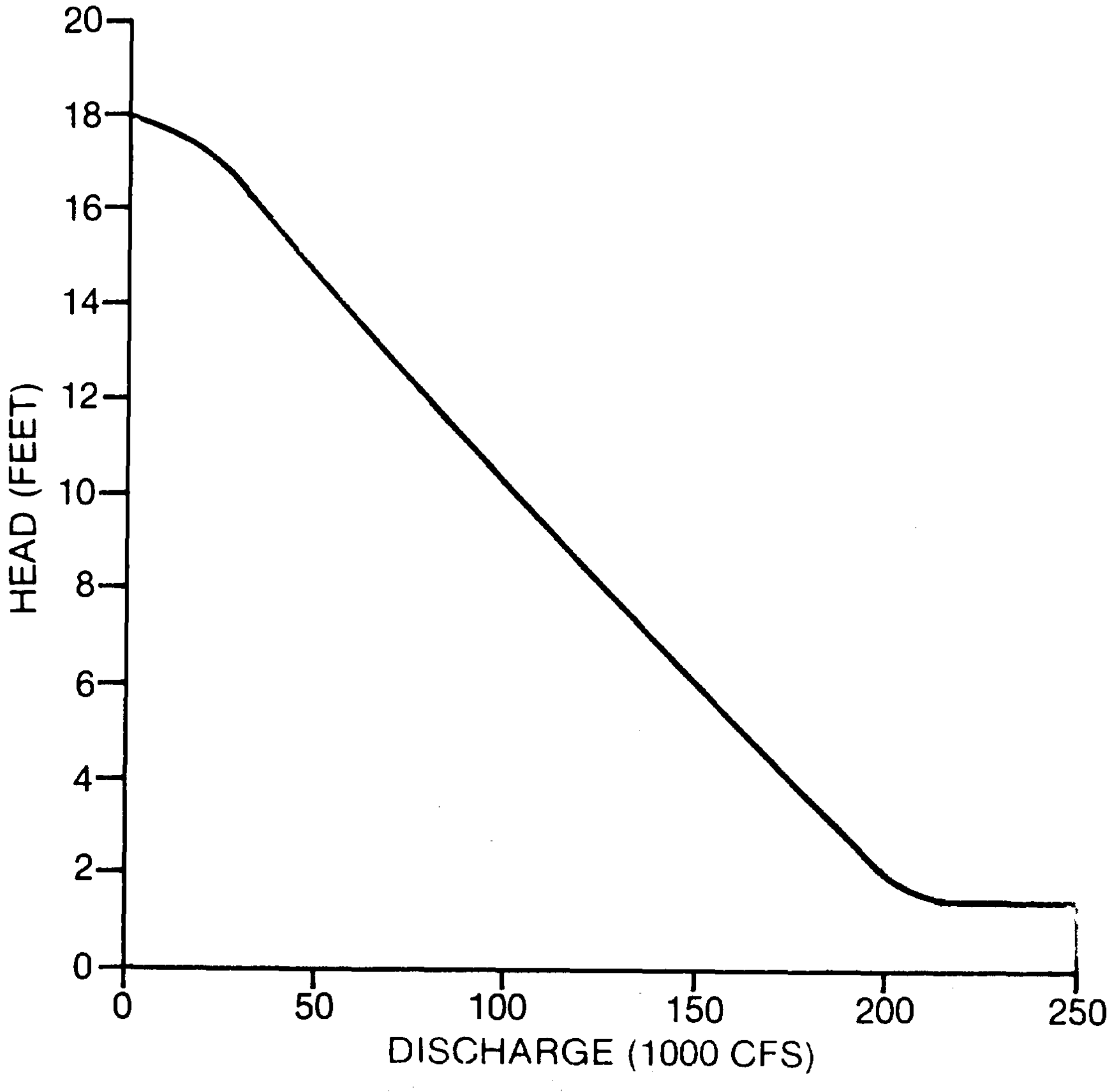

Figure 4-6. Head-discharge curve

marketing the project's power output. Figure 4-7 shows a tailwater curve modified to reflect "block-loading" in the low flow range. The loading would be generally similar to the loading shown on shown on Figure 5-23, except that it is assumed that the minimum discharge is zero instead of 150 cfs and the minimum number of hours on peak is five instead of eight).

(4) Existing Projects. A record of tailwater discharge-elevation relationships may be available to aid analysis of the addition of power to existing projects. A tailwater rating curve can be developed directly from this data.

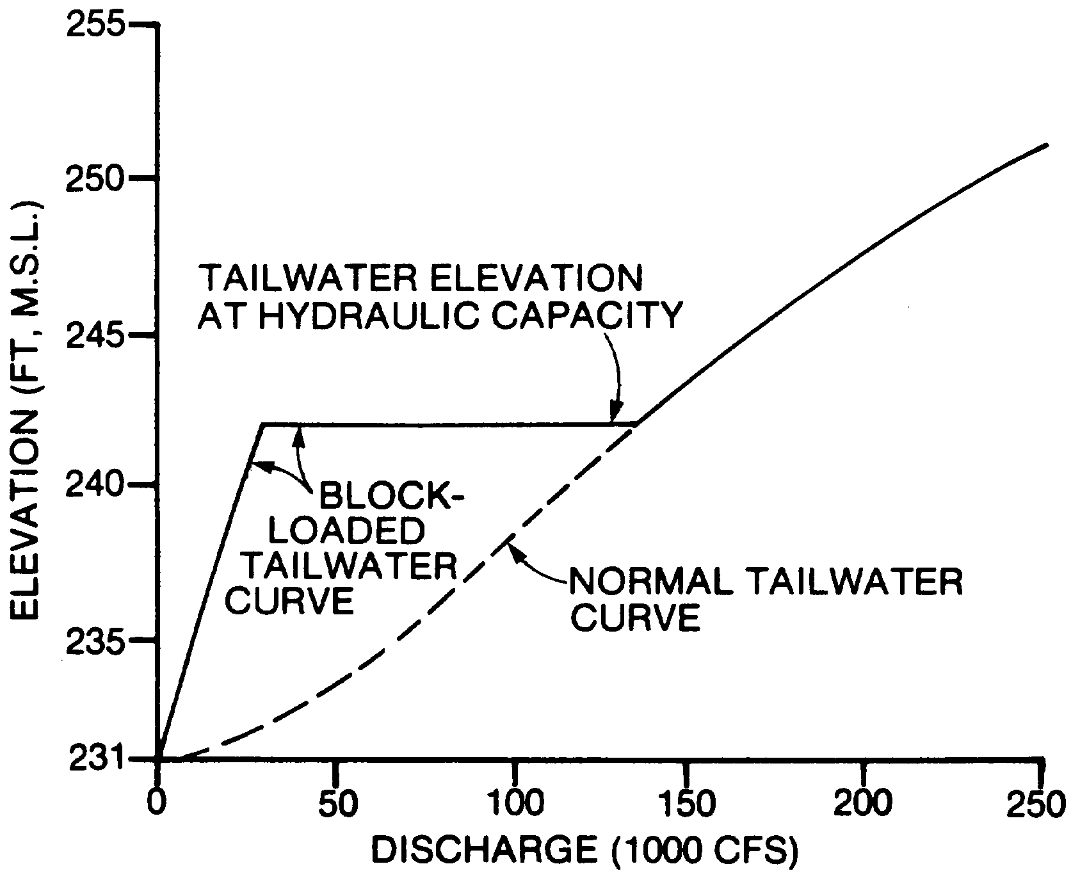

Figure 4-7. Block-loaded tailwater curve

(5) <u>Hourly Studies.</u> When evaluating peaking hydro projects, hourly streamflow routing studies are often made to estimate peaking capability and pondage requirements and to evaluate the impact of discharge fluctuation downstream from the project. In this type of study, it may be necessary to incorporate an hourly routing subroutine in the power generation model in order to accurately measure tailwater elevation and head. The actual tailwater elevation during hourly operation tends to "lag" the tailwater elevation obtained from the usual steady-state tailwater rating curve.

c. <u>Reservoir Storage-Elevation and Area-Elevation Data.</u>

(1) For storage projects, it is necessary to determine the storage-elevation and area-elevation characteristics of the reservoir. This information is used in reservoir regulation and evaporation studies. Figure 4-8 is an example of a typical reservoir elevation-area-capacity curve. This data can also be developed in tabular form for direct input to sequential streamflow routing programs.

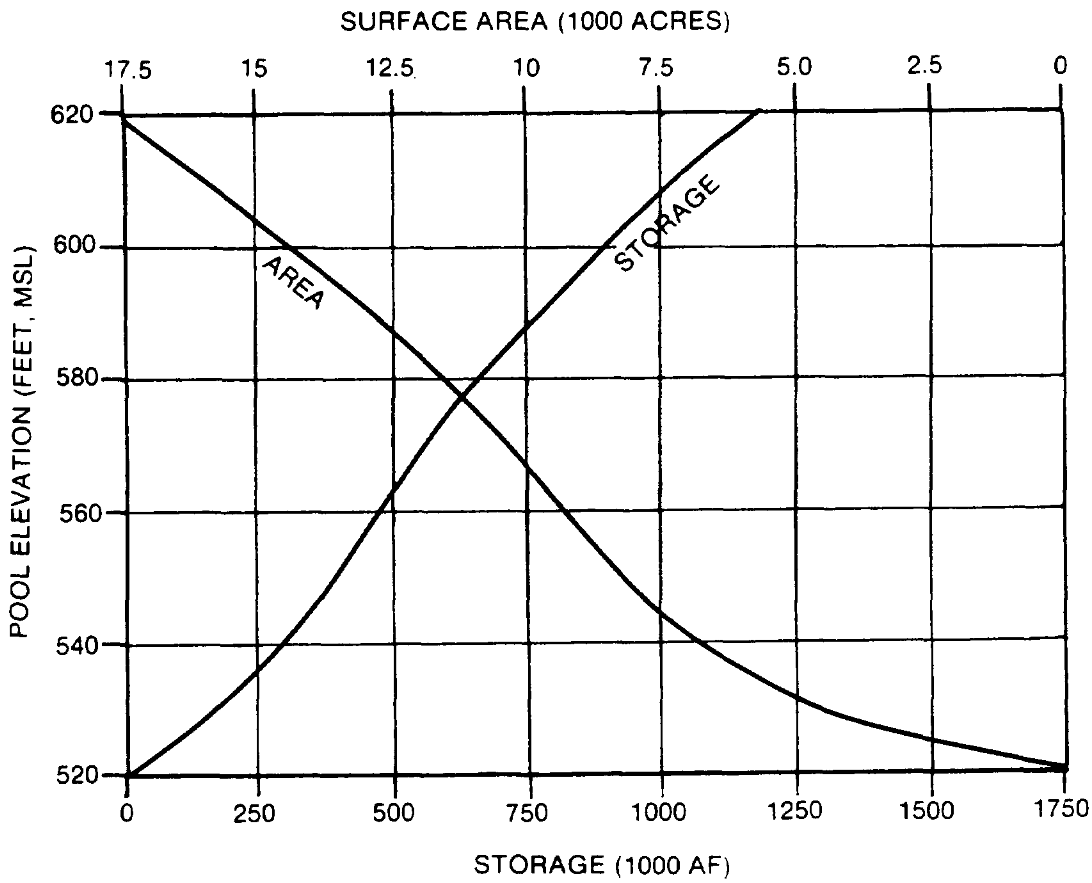

Figure 4-8. Storage-elevation and area-elevation curves

(2) Storage-elevation and area-elevation curves are generally developed from topographic maps by planimetering elevation contours upstream from the damsite. The "average end area" method is used to compute the volume between elevation curves. Increased accuracy is obtained by using large-scale, high resolution mapping and small elevation increments. HEC's computer program #723-G1-L233A, "Reservoir Area Capacity Tables by Conic Method", is a useful tool for developing this type of data.

d. Sedimentation Data. Sedimentation studies may be conducted for an existing or proposed reservoir in order to determine the rate reservoir storage capacity is being lost to deposited sediment. Sediment studies can also identify sediment source areas and may be used to develop sediment management programs. The results of these studies can also be used for updating storage-elevation curves and projecting future capacity losses at older reservoirs situated in high-sediment river basins. In addition to examining impacts within reservoirs, studies may also be made to investigate downstream channel capacity and other characteristics. Studies at project sites usually involve the laboratory analysis of suspended sediment samples and computer simulation to predict future sediment deposition in the reservoir. Three HEC computer progams may be of value in preliminary sedimentation studies: "Suspended Sediment Yield" (HEC #723-G2-L2240), "Deposition of Suspended Sediment" (HEC #723-G2-L2250), and "Scour and Deposition in Rivers and Reservoirs" (HEC-6).

e. Water Quality Data. Studies may be required to define the current status of water quality conditions at and below the hydropower site and to predict how these conditions would be altered by project operation. Requirements for water quality studies are established in ER 1110-2-1402, Hydrologic Investigation Requirements for Water Quality Control. Information on the downstream water quality effects of hydropower development is contained in the technical report, Effects of Reservoir Releases on Water Quality, Macroinvertebrates, and Fish In Tailwaters; Field Study Results (80). Availability of water quality data is often critical to the completion of the required studies. Water quality data needs must be defined early in the feasibility study in order to provide enough time to collect the needed data so that water quality problems can be assessed adequately.

f. Downstream Flow Requirements.

(1) Downstream flow requirements are sometimes established to ensure that the range of project discharges produced by power operations does not adversely impact the utilization of the stream. Streamflow uses which might be considered when establishing flow requirements include the following:

- navigation
- water quality
- municipal and industrial water supply
- irrigation
- fish and wildlife habitat
- migratory fish passage
- instream fishing
- recreational uses (boating and beaches)
- flood control discharge limitations

(2) Flow requirements can be expressed either as instantaneous or average flow values either at-site or at some downstream point. Limits may also be placed on the daily minimum or maximum discharge permitted and on daily or hourly rates of change in discharge. Flow requirements may originate in different ways. They may be based on an international treaty, an interstate river basin management compact, or on downstream water rights. Others may arise from court decisions or enabling legislation aimed at preventing a project from adversely impacting non-power uses of streamflow. In most cases, flow requirements result directly from project environmental and operations studies, which are often made in conjunction with other agencies and river use interests.

(3) The impact of proposed downstream flow requirements on power operation should be carefully evaluated. Maximum discharge limits may restrict the use of a project for peaking operations. Similarly, the imposition of high discharge requirements for downstream uses may limit the use of reservoir storage for power generation. The objective of the downstream flow requirement study should be to achieve a reasonable balance to insure that downstream river uses are protected without unnecessarily limiting the site's power potential.

g. Water Surface Fluctuation Studies. Advanced feasibility and GDM studies may require evaluation of the effect of power operations on the shoreline of the reservoir and riparian land downstream from the project site. Areas of concern may include safety of and access to shoreline areas for commercial and recreational activities; damage to waterfowl nesting areas; fish migration and spawning; and habitat areas of rare or endangered species. Fluctuation studies may be conducted using either conventional hydrologic routing techniques or more advanced hydraulic modeling techniques based on unsteady flow theory. Computer programs such as HEC-5 (40) and SSARR (56) are capable of performing hydrologic routings for these purposes.

h. Losses.

(1) General. Not all of the streamflow entering a reservoir may be available for power generation. Some flow may be lost due to

reservoir evaporation, transpiration, and to diversions from the reservoir for irrigation and water supply. Water may also be required at the dam for operation of a navigation lock, fish passage facilities, powerplant cooling, or other project operating purposes. There also may be losses due to leakage through or around the dam or other embankment structures and around gates. If these losses are not accounted for, a hydro project's power output may be substantially overestimated. Following are discussions of some of the major categories of losses.

(2) Evaporation. The purpose of the evaporation loss computation is to determine the net loss to evaporation resulting from the larger surface area of the reservoir compared to the river, prior to construction of the project. A rigorous analysis of this type would also account for the effects of infiltration, transpiration, and precipitation. Section 3.02 of Reservoir Yield (44c) describes several techniques for analyzing evaporation and related losses. Although accounting for net evaporation is very important for large reservoir projects, it can sometimes be neglected at small reservoirs and run-of-river projects.

(3) Irrigation and Water Supply Diversions. Reservoirs often serve as the source of water for adjacent irrigation projects or communities. Water may be pumped directly from the reservoir or diverted through a pipeline at the dam. Because irrigation or water supply is often included as a project purpose, data on these diversions is usually developed in the planning process, and this data can be used in the hydropower analysis. At existing projects, historical data may be available, although consideration should be given to the possibility of future increases in the level of diversion.

(4) Seepage and Leakage. There is usually some seepage under or around dams and other embankment structures, and there is sometimes leakage through the dam structure itself. In a few cases there may even be seepage losses to underground aquifers or other strata adjacent to the reservoir. As a rule, seepage or leakage is relatively small, and in most cases it is difficult to estimate before a project is actually constructed. However, this type of loss should be considered where significant leakage is a possibility. The amount of leakage is a function of the type and size of dam, the geologic conditions, and the pressure caused by water in the reservoir. The measured leakage at a similar type of dam in a similar geologic area may be used as a basis for estimating losses at a proposed project. The best source of data in this area would be the District foundation and materials branch.

(5) <u>Gate Leakage.</u> Leakage from spillway gates is a function of gate perimeter, type of seal, and the head on the gate. Leakage may be measured at existing projects with similar seals, and a leakage rate may then be computed per foot of perimeter for a given head. This leakage rate may then be used to compute estimated leakage for a proposed project.

(6) <u>Navigation Lock Operation.</u> The inclusion of a navigation lock at a dam requires that locking operations and leakage through the lock be considered. The leakage is dependent upon the lift, the type and size of lock, and the type of gates and seals. Again, estimates can be made from observed leakage at similar structures. Water required for locking operations should also be deducted from water available at the dam site. These demands can be computed by multiplying the volume of water required for a single locking operation times the number of operations anticipated in a given time period and converting the product to a flow rate over the given period.

(7) <u>Fish Facilities.</u> Some projects have facilities for passing migratory fish upstream or downstream, and others have fish hatcheries or spawning beds that are an integral part of project operation. Fish ladders or locks may be required for upstream passage, and water is often required for attracting fish to the fish passage facility entrances as well as for operation of the facilities themselves. In some case, streamflow may also be required for downstream migrant fish facilities, and in other cases spill may be required during the downstream migration season. Where fish hatcheries are constructed adjacent to the dam, water may be diverted directly from the reservoir to the hatchery and this must be accounted for also. Information on fish passage facility and fish hatchery water requirements can be obtained from fishery agencies, design personnel, or from operating experience at similar projects.

(8) <u>Turbine Leakage.</u> If a proposed project is to include power, and if the area demand is such that the turbines will sometimes be idle, it is advisable to estimate leakage through the turbines when closed. This leakage is a function of the type of penstock, type of turbine wicket gate, number of turbines, and head on the turbine. The measurement of turbine leakage at similar existing projects may be used to estimate leakage for a proposed project. Hydraulic machinery specialists at the Hydropower Design Centers would be another source of information on estimated turbine leakage. An estimate of the percent of time that a unit will be closed may be obtained from actual operation records for similar units in the same demand area. The measured or estimated leakage rate is then reduced by multiplying by the proportion of time the unit will be closed. For example, if leakage through a turbine has been measured at 1.0 cubic feet per

second (cfs), and the operation records indicate that the unit is closed 60% of the time. The average leakage rate for the turbine would be (0.6 x 1.0 cfs) = 0.6 cfs.

(9) Station Water Requirements. The use of water for purposes related to operation of a project is often treated as a loss. Station use for sanitary and drinking purposes, cooling water for generators, and water for condensing operations are typical station water requirements at hydro projects. Examination of operation records for comparable projects in a given study area may be useful in estimating these losses, and the Hydroelectric Design Centers would be additional sources of information. If a station service unit is included in a project to supply the project's power needs, data should be obtained from the designer in order to estimate water used by the house unit or units.

(10) Other Considerations. Some of the losses described above vary considerably by season, while others are relatively constant the year around. Irrigation diversions and evaporation losses vary widely with season, while seepage and leakage and station water requirements may be essentially constant the year around. Others, such as navigation lock requirements and fish facility requirements, may or may not vary, depending on the project. When the sum of the losses varies substantially by season, the data should be developed by month. In other cases, a single average annual value may be satisfactory. Where the data is to be used in a model which routes streamflow to downstream projects or control points, the total losses should be divided into consumptive and non-consumptive losses. Table 4-1 shows a typical summary of monthly streamflow losses.

TABLE 4-1.
Example Monthly Streamflow Loss Table

LOSS (cfs)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Avg
Nonconsumptive													
Fish facilities 1/	50	100	100	100	100	100	100	100	100	100	100	100	100
Closed turbines 2/	30	30	25	16	12	10	10	10	12	15	25	30	19
Navigation locks 3/	22	22	22	22	36	50	50	50	50	36	22	22	29
Seepage 4/	15	15	15	15	15	15	15	15	15	15	15	15	15
Station use	8	8	8	8	8	8	8	8	8	8	8	8	8
Leakage 5/	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	125	175	170	161	171	183	183	183	185	174	170	175	172
Consumptive													
Net evaporation 6/	-44	-33	-20	-13	-30	-37	60	50	18	2	-23	-37	-3
Irrigation 7/	0	0	15	45	65	75	85	85	40	15	0	0	47
Water supply 7/	18	18	18	22	25	28	31	31	28	25	20	18	23
Total	-26	-15	13	55	60	140	176	166	86	42	-3	-19	56

1/ Shut down two weeks for maintenance in January.
2/ Average leakage through closed turbines is 40 cfs.
3/ Includes 8 cfs continuous leakage.
4/ Seepage through dam and reservoir (estimated).
5/ Leakage through spillway gates and conduits (projected).
6/ Net result of evaporation and precipitation on the surface of the reservoir. A net gain in water is shown as a negative loss.
7/ Water withdrawn from reservoir. Any water withdrawn below the dam is a loss to downstream projects only.

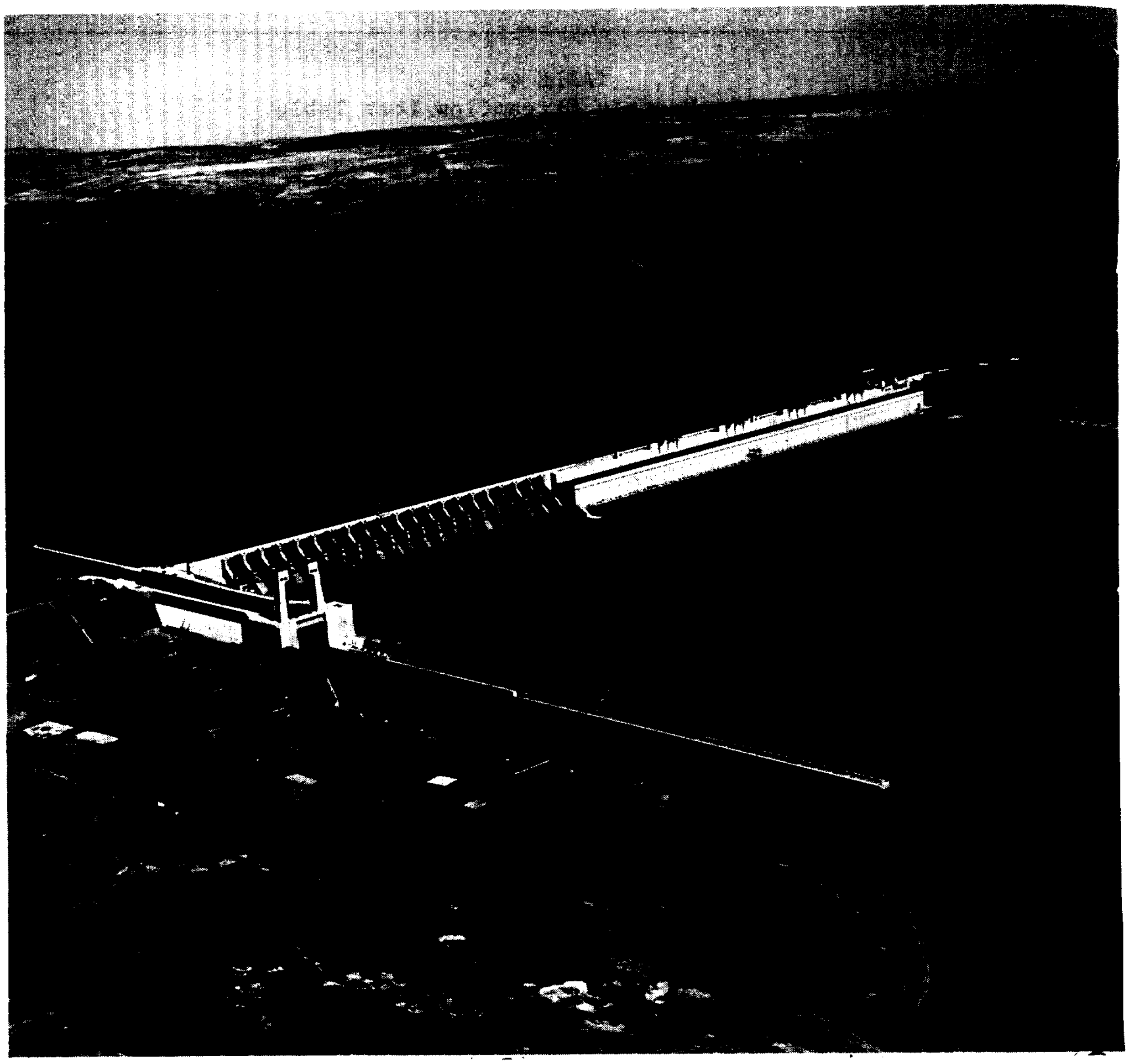

Figure 4-9. John Day Lock and Dam. With a peaking capacity of 2,484 MW, this is the largest hydroelectric project constructed by the Corps of Engineers (Portland and Walla Walla Districts)