WATER RESOURCES ANALYSIS
AND INFORMATION SECTION

Office Report No. 22

THE WATER RESOURCES OF THE CHELAN BASIN

By

Greg Sorlie and Robert T. Milhous

(For Use by the Water Resources Management Division)

June, 1975
Department of Ecology
Olympia, Washington

THE WATER RESOURCES OF

THE CHELAN BASIN

by Greg Sorlie and Robert T. Milhous

June, 1975

Open-File Technical Report 75-03

TABLE OF CONTENTS

INTRODUCTION

The purpose of this report is to review the water resources of the Chelan Basin with special regard to management of the level of Lake Chelan.

The basin contains 950 square miles. Most of this (97%) is drained by the Chelan River and its tributaries; the remaining portion drains the area bordering the Columbia River. Lake Chelan covers 52 square miles of the area. Figure 1 shows the location of the area, along with sub-areas (defined by the SCS) and major gaging stations.

Table 1 shows land use in the basin (as of 1966). As can be seen, about 85 percent of the basin is ungrazed forest land.

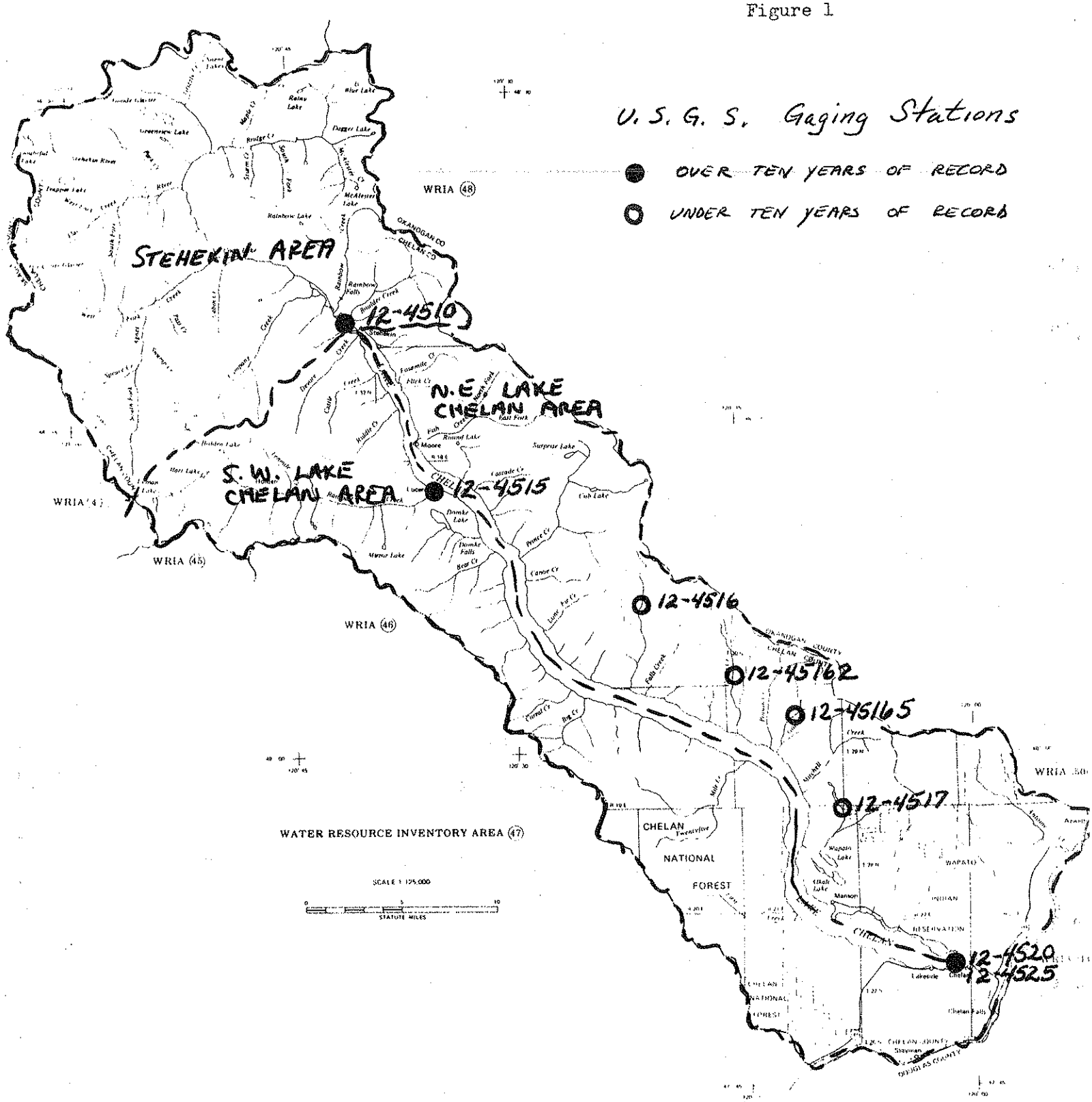
WATER USE

Based on the available information, the estimated water use in the Chelan Basin, for other than hydroelectric power purposes, is:

Use	Surface Water (acre ft/year)	Ground Water (acre ft/year)	Total Use (acre ft/year)
Irrigation	15,700	900	16,600
Industrial	650	0	650
Municipal	1,500	0	1,500
Domestic	300	50	350
Stock	100	0	100
TOTAL	18,250	950	19,200

About 8,000 acre-feet of water is used for irrigation of orchards bordering the Columbia River. This amount is not included in the table above because the water used is not part of the "Lake Chelan System".

Figure 1



Station name	Station number	Drainage area (sq mi)	Periods of record	
			Daily or monthly figures (calendar years)	Annual peaks (water years)
CHELAN RIVER BASIN				
Stehekin River (head of Chelan River) at Stehekin....	12451000	344	1910-15;1926-	
Lake Chelan:				
Railroad Creek at Lucerne, Wash.....	12451500	64.8	1910-13;1926-57.	
Safety Harbor Creek near Manson, Wash.....	12451600	7.85	1961-69.	
Grade Creek near Manson, Wash.....	12451620	8.45	1960-69.	
Cold Creek near Manson, Wash.....	12451650	6.30	1960-69.	
Antilon Lake feeder system (canal) near Manson.....	12451700	-	1958-69.	
Lake Chelan at Chelan, Wash.....	12452000	924	(1897-99;1905;1910)*;1911-	
Chelan River at Chelan (below Chelan Lake), Wash.....	12452500	924	1903-	

Table 1: Land Use in the Chelan Basin (1968)

(in acres)

Subbasin	Forest land		Range land	Crop land		Other	Total
	grazed	not grazed		irrigated	not irrigated		
Stehekin area	0	221,984	0	0	0	3,484	225,468
S.W. Lake Chelan area	20,000	137,395	6,000	700	1,700	18,226	184,021
N.E. Lake Chelan area	6,000	151,900	6,000	4,000	1,000	16,538	185,438
Total	26,000	511,279	12,000	4,700	2,700	38,248	594,927
Percent of basin area	4.3	85.9	2.0	0.7	0.4	6.4	100

Source: Soil Conservation Service

NOTE: The breakdown in the above table does not include Antoin Creek and the orchards bordering the Columbia River. The 18,000 acre area contains about 2,600 irrigated acres, and is not really considered part of the Lake Chelan system.

The amount of water used for power production is approximately 95 percent of the total flow of the Chelan River (1,490,000 acre-feet per year for the period 1904 to 1973). Lake Chelan is used for recreation, mostly boating and swimming, and is the largest natural lake in the state.

Table 2 gives a breakdown of water rights in the basin. The recorded rights are far in excess of actual water use. Table 3 shows water right claims in the basin.

Addition information on the water use in the Chelan Basin is given in the following paragraphs.

Hydroelectric Use

The Lake Chelan Hydro-Electric Project was granted an FPC (Federal Power Commission) operating license on May 8, 1926, and put into service the following year. The development utilizes Lake Chelan as a reservoir and regulates the lake outflow by means of a 35-foot high concrete dam at the lake outlet on the Chelan River some three miles upstream of the Columbia River. Lake Chelan is a narrow, deep body of water, some 55 miles in length, with a surface area of 32,800 acres and has a watershed of 924 square miles. The permissible reservoir fluctuation is from a maximum normal elevation of 1,100 to a minimum of 1,079. The layout of the hydroelectric system is shown on Figure 2.

The dam has eight gated spillway bays with a spillway crest elevation of 1,087 feet, and 20 foot by 14 foot tainter gates which raise the lake to a maximum level of 1,100 feet. The foundation of the dam is glacial till.

Table 2: Water Rights in the Chelan Basin (1967)

(in cfs)

Use	Surface	Ground	Total
Municipal	2.0	0	2.0
Irrigation	428.3*	29.4	457.7
Individual and Community Domestic	66.5	4.5	71.0
Industrial-Commercial	22.6	0.6	23.2
Fish Propagation	0	1.0	1.0
Stock	0.5	0	0.5
TOTAL	519.9	24.9**	544.8

*Nearly all of the quantities for irrigation, domestic supply, and stock use are common.

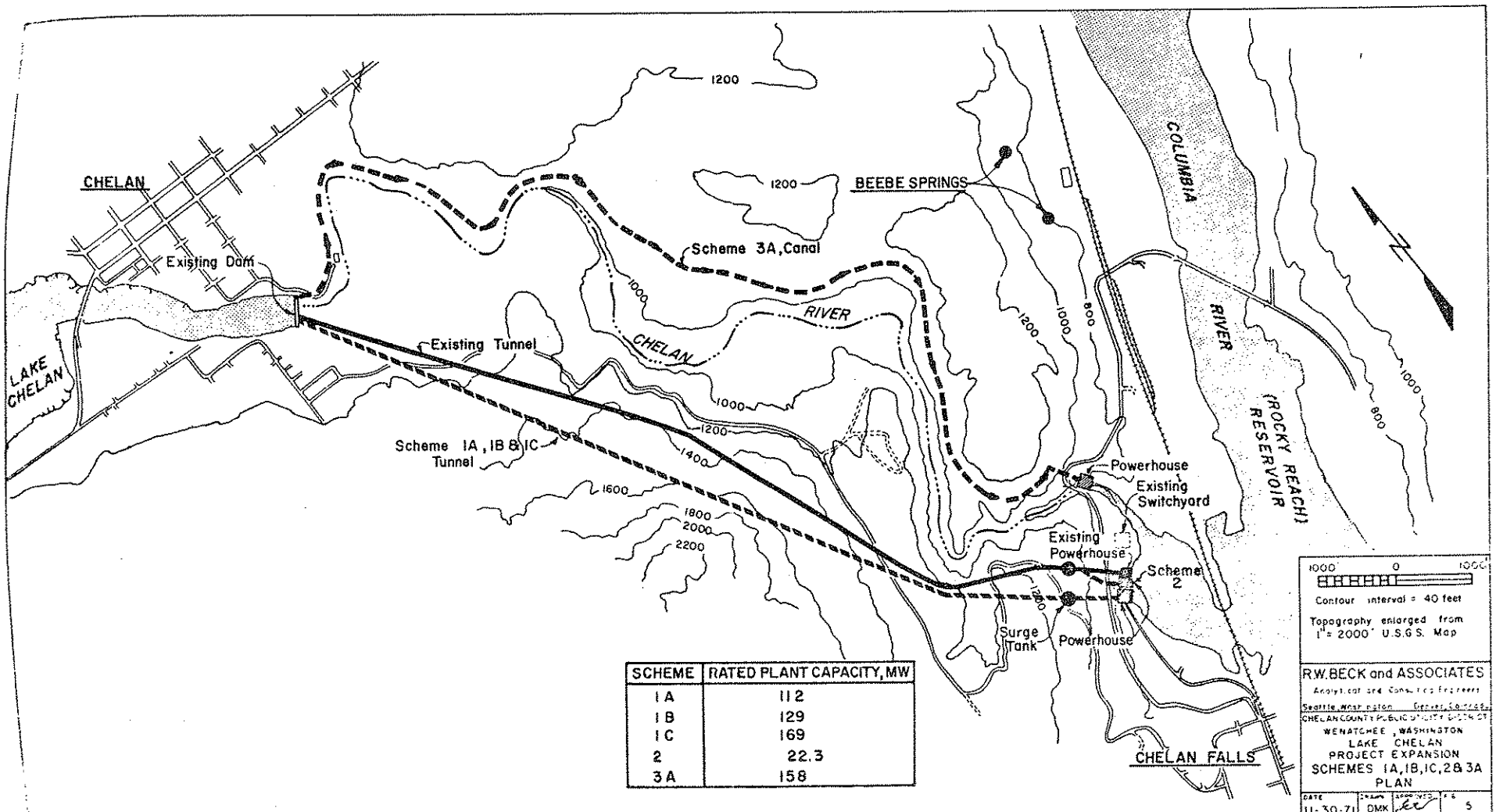
**Total prime right quantities do not agree with the sum of the uses because water right quantities that are common to two or more uses are listed under each appliable use category.

In addition to the rights listed above, there is 640,000 acre feet in reservoir storage rights and 4000 cfs for power generation.

Table 3: Water Right Claims, Chelan Basin, 1974

Source	Number of Water Right Claims					Irrigated Acres
	Domestic	Stock	Irrigation	Other	Total	
Surface Water	246	57	54	55	412	1335
Ground Water	67	13	15	2	97	149
Total	313	70	69	57	509	1484

NOTE: A high degree of reliability should not be placed on these figures; there is no accurate way to assess the human error involved when filing a claim.



SCHEME	RATED PLANT CAPACITY, MW
1A	112
1B	129
1C	169
2	22.3
3A	158

Figure 2

On the west abutment of the dam is the intake structure for a 14-foot and a 17-foot diameter tunnel. The 17-foot tunnel is stubbed off. A 14-foot butterfly valve controls the tunnel inlet while the downstream end connects to a steep, 35% grade steel lined section 1,002 feet in length. A vertical 14-foot riser pipe in this section leads to a surge tank 45 feet in diameter and 113 feet high. The steel lined conduit tapers to a diameter of 12.50 feet and splits into two 8.83-foot penstocks, 138 feet long. Each of the branches terminates in a hydraulically operated needle valve and a reducing section to the 6.50-foot diameter turbine scroll case.

The two identical reaction turbines have a 34,600 horsepower rating and discharge 1,100 cfs each when operating at full gate. Each generator has a nameplate rating of 24,000 kw at 0.80% power factor and 300 rpm. Maximum capability of the two units under the most favorable operating conditions is 52,000 kw. The plant discharges into the reservoir of the Rocky Reach Project on the Columbia River with an average elevation of 707 feet.

The total maximum hydraulic capacity of the hydroelectric system is 2,200 cfs.

Irrigation Use

The consumptive use (depletion) in the Chelan Basin has been estimated at 3.1 acre-feet per acre in the Irrigation Appendix of the CNP study. This figure may be a little high, but is considered accurate enough to use in computing water use. To date, the 118 water rights for irrigation

amounted to 16,308 irrigated acres. Most of this is under a few large rights held by the Bureau of Reclamation. These recorded rights are in excess of the number of acres actually irrigated; typically the ratio is in the order of 3 to 1. The Soil Conservation Service (in 1967) has estimated only 4,700 acres are actually irrigated in the basin, and all of this is by surface water. Approximately 7,800 acres have been classified as potentially irrigable land.

Presently the Department of Ecology is issuing water rights for domestic and irrigation purposes without condition. The Chelan P.U.D. has rights to 4,000 cfs in the Chelan River subject to a 33,000 acre-foot reservation for domestic and irrigation uses. All but about 1,000 acre-feet of this has been appropriated. When this reservation is fully appropriated, which will probably be in the near future, an immediate problem arises. Either additional rights issued will become subject to the P.U.D. right, or an additional reservation will have to become effective. This may take place if the 4,000 cfs right is reduced to the 2,200 cfs maximum hydraulic capacity for the dam.

Recreation Use

The recreation use of Lake Chelan is very large, with an estimated 600,000 visitor-days per year. The lake is long and narrow (55 miles x 1 mile) and is very scenic any time of the year. A commercial transport boat runs from Chelan to Stehekin year round. A number of boat launches facilities exist along the lake and commercial and public recreation facilities are numerous.

Other Uses

The other uses of water are for industrial, municipal, domestic, and stock purposes. These uses account for about 14 percent of the total consumptive water use.

WATER SUPPLY

The water supply of the Chelan Basin is extensive. The annual water balance for the basin is:

Precipitation	2,706,000 acre-feet
Runoff	1,490,000 acre-feet
Evapotranspiration	1,216,000 acre-feet

The water balances for subbasins of the Chelan Basin are given in Table 4. Data on the streamflows in the basin are given in Table 5.

The Chelan Basin has a mean elevation of 4,530 feet, hence much of the winter precipitation occurs as snow and is stored in the basin until the spring melt, usually beginning in April. The percent distribution of the precipitation and runoff are given in Figure 3.

Ground Water

Ground water use in the basin is relatively small and there are no extensive aquifers. Where stream valleys are large enough, high yields can be obtained from the narrow alluvial despoits. Near Manson, moderate supplies are

Table 4: Water Balance for the Chelan Basin

Gage Number	Name	Drainage Area (sq. mile)	Precipitation	Runoff	Evapotranspiration Lake	Evapotranspiration Other
			(1,000 acre-feet per year)			
12-4510	Stehekin at Stehekin	344	1,593	1,014	--	579
12-4515	Railroad Creek at Lucerne	65	190	148	--	42
--	Remainder of Basin	515	923	328	88	507
12-4525	Chelan at Chelan	924	2,706	1,490	88	1,128

Table 5: Streamflow Records and Characteristics

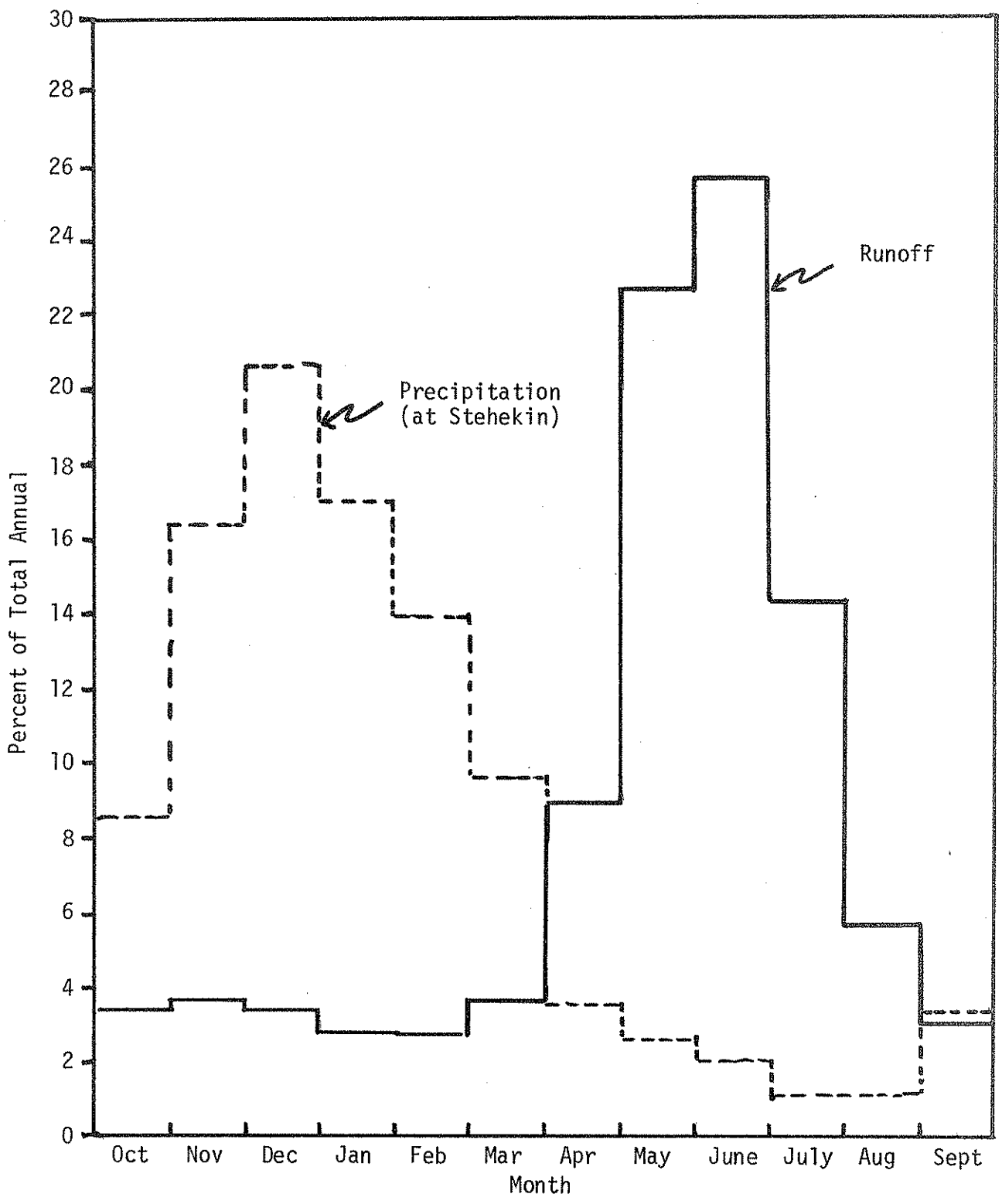
at gaging stations

- All Flows in cfs -

Stream	USGS Station No.	Drainage Area (sq. mi.)	Period of Record	Mean Annual Flow	Discharge maximum	Discharge minimum	20 Year 7-Day Mean Low Flow	2-Year Flood	50 Year Flood
Stehekin River	4510	344	1910-15 1926-73	1402	189,000	56	109	9,500	17,500
Railroad Cr.	4515	64.8	1910-13 1926-57	204	3,900	9.4	14	1,350	3,570*
Safety Harbor Cr.	4516	7.85	1961-69	13.9	410	0.6	-	-	-
Grade Cr.	4516.2	8.45	1960-69	6.47	78	0.2	-	-	-
Gold Cr.	4516.5	6.3	1960-69	0.87	18	0.1	-	-	-
Chelan River	4525	924	1904-73	2051	18,400	0	-	-	-

Source: A Proposed Streamflow - Data Program for Washington State - United States Department of Interior, U.S. Geological Survey

Figure 3: Monthly Distribution of Precipitation and Runoff in the Chelan Basin



pumped from the glacial drift material surrounding Wapato and Alkali Lakes. This is accentuated by the large amount of irrigation and percolation losses in the area which build up the water table. Below Chelan Dam, ground water is increased by seepage of the natural moraine dam as well as infiltration from the Columbia River. A rough sketch of ground water availability is given in Figure 4.

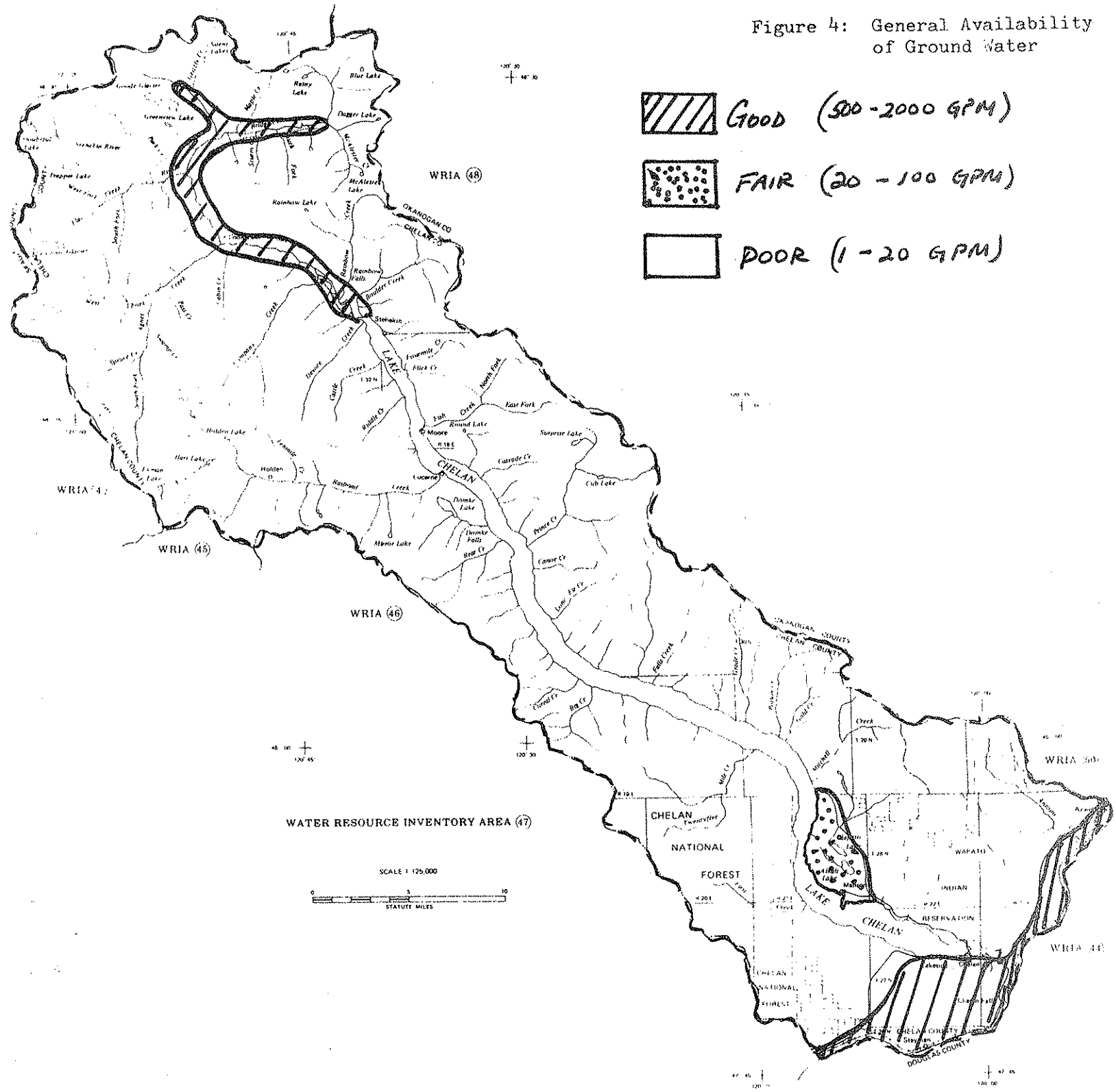
Lake Chelan

Lake Chelan is the largest natural fresh water lake in the state. The surface area is about 33,100 acres with a maximum depth of 1,605 feet. The original lake level was about 1,079 feet. In 1928 the maximum lake level was raised 21 feet to an elevation of 1,100 feet.

Prior to 1928 the lake level was controlled at low water in the interests of navigation by operation of a flash board dam at the outlet. Attempts to construct a dam were made in 1889, 1892, and 1893. Each of these dams was destroyed by the following year's spring flood.

The natural range in lake levels is between elevations 1,084.4 (June 8, 1921), and 1076.8 (January 27, 28, and December 2, 3, 1898); for a total change of 7.6 feet. The present allowable range is between 1,079 and 1,100 for a total change of 21 feet. The lowest elevation after construction of the dam was 1,079.67 in 1970. Prior to 1928 there were navigation hazards in the lake during low water periods; after 1928 the raised lake level eliminated the hazards.

Figure 4: General Availability of Ground Water



WATER RESOURCES MANAGEMENT PROBLEMS

The major water resources management problem in the Chelan Basin is the question of lake levels on Lake Chelan. Some questions exist as to whether the negative impacts of the present fluctuation of lake stage on other uses of the lake exceed the positive impacts of power production which results from the fluctuations. The current FPC license governing the Lake Chelan Hydroelectric Project is due to expire in 1976; hence, there is a need to review the present drawdown limits on the lake levels and the timing of drawdown.

Existing Situation

The Chelan County P.U.D. holds an appropriation permit for 4,000 cfs and a reservoir permit for 640,000 acre-feet. Both of these are for power production, although the maximum hydraulic capacity is only 2,200 cfs. Under the present operating permit (FPC License-Project No. 637) the lake may be drawn down from its full level elevation of 1,100 feet to a minimum elevation of 1,079 feet. This is a total drawdown of 21 feet. On April 15, the lake discharge must be restricted to 1,000 cfs until the water level has risen to elevation 1,096. On July 1, the lake must be full and from this date until September 15 the lake level must be maintained between elevations 1,100 and 1,092. The operation of the reservoirs is governed by a so-called energy content rule curve which permits the P.U.D. more flexibility than the customary rule curve based on the worst historical flow conditions. Figure 5 shows the allowable minimum level, and Figure 6 the results of applying the criteria from 1927-1974.

Figure 5: Allowable Minimum Level and Average Operating Level

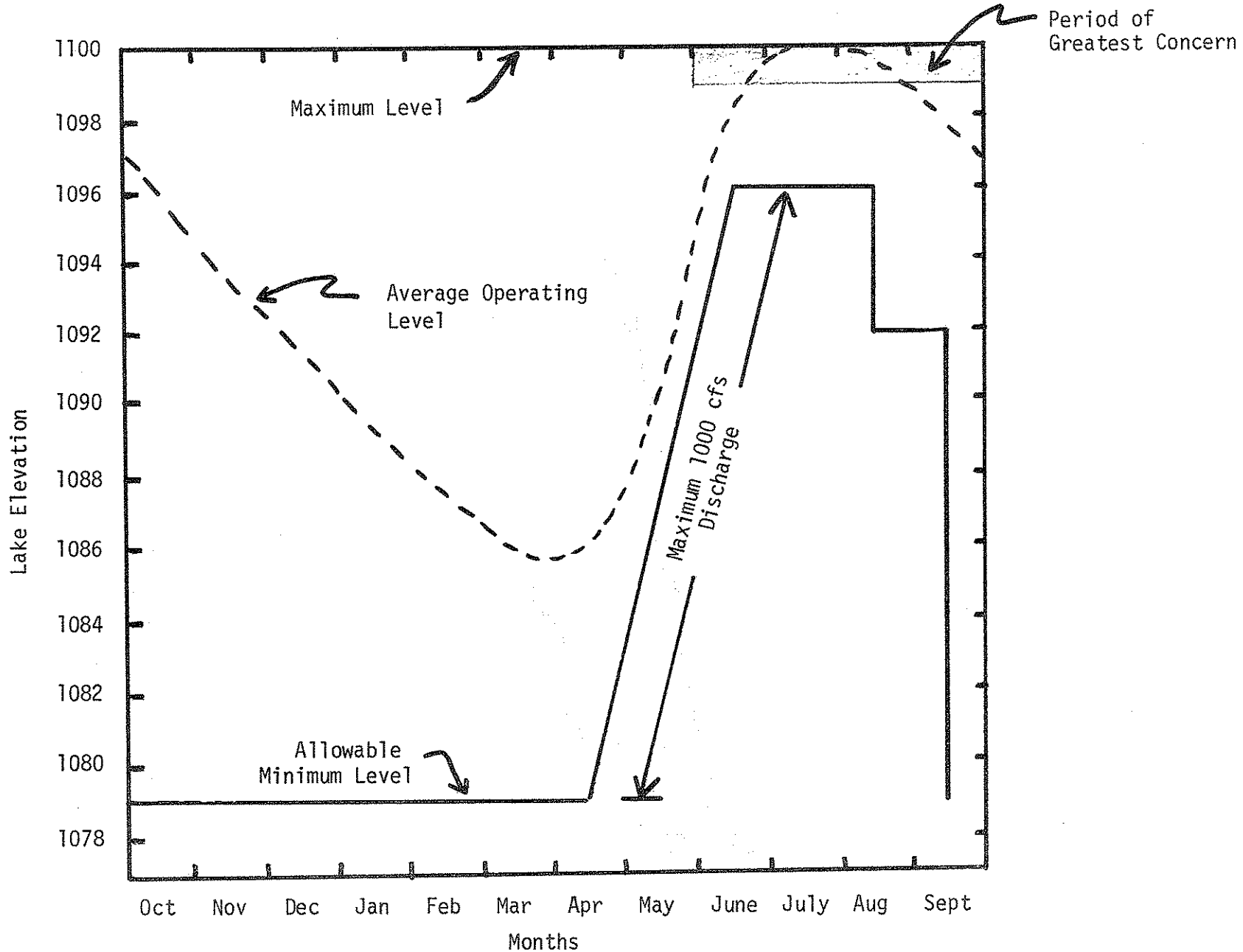
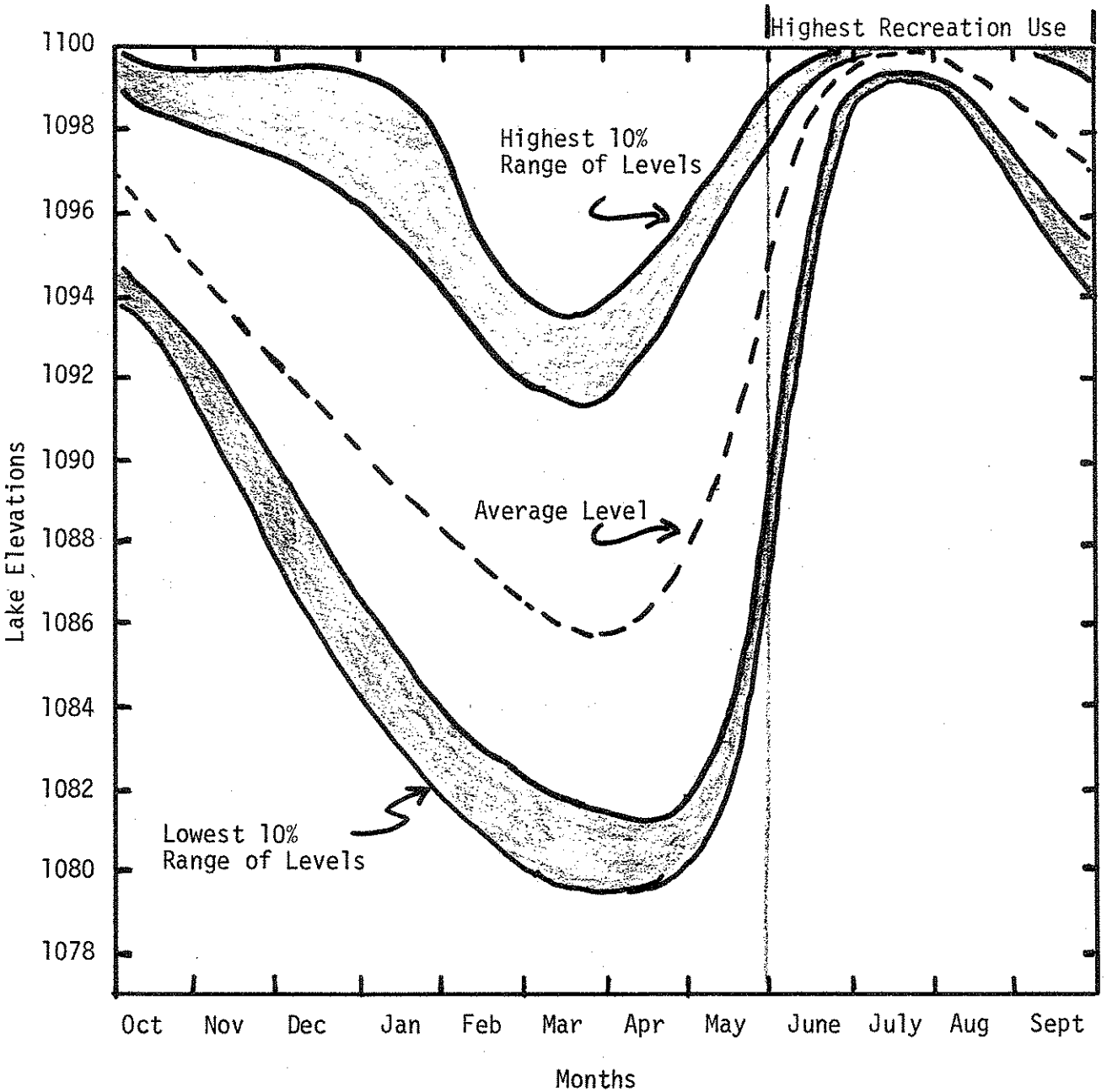


Figure 6: Lake Chelan Levels (47 year average)



Impact on Other Uses of the Lake

The impact of the existing range in lake levels is described below for each of the principal uses.

A. Navigation

The construction of the hydroelectric dam in 1928 eliminated the navigation hazards on the lake itself. The Chelan Boat Company operates from Chelan all year with regular stops at 25 Mile Creek, Lucern, and Stehekin as well as some private docks for mail stops. Boats can be lunched all year at the Chelan County P.U.D. ramp near the dam and at Manson although lunching at the lowest lake levels can be a bit of a problem. Many private docks cannot be used when the lake is at its lowest level.

The drawdown of the lake does not have a large impact on commercial navigation but use of most private docks is curtailed during low water.

B. Irrigation

At present the water of the lake is used for irrigation. The minimum level for pumps is as follows:

Lake Chelan Irrigation District	1,079 feet
Others	1,085 feet

The soil moisture reservoir is used to supply crop requirements until the lake level increases as a result of the spring runoff. In 90% of the years

the lake level is up to 1,085 feet by May 15 and in all past years by May 25.

C. Recreation

The major impact on recreation of low lake levels is through the impact on small boat use. There appears to be little problem with aesthetic and sport fishing resulting from the fluctuation in lake levels. The impact on water related recreation is of major concern to people in the basin as well as people outside the basin.

The Nature of the Conflict Between Recreation and Power

The area of greatest concern is not particularly the amount of drawdown on the lake, but rather the time of drawdown. The greatest period of recreation use on the lake is from May 30 (Memorial Day weekend) to September 1st (Labor Day weekend), when full lake level would be most desirable. The usual operating procedure of Chelan Dam for bringing the lake level up varies from year to year. Figure 6 shows this variance over a 47-year period. Usually the lake is full by mid-July and begins receding again in early August.

The conflict between recreation and power interests is related to whether the lake shall be full by June 1 and when should drawdown begin.

The Chelan County P.U.D. considers any change in timing of lake level as a constraint on drawdown. In a report to the P.U.D., R. W. Beck and Associates made the following statement:

"The hydraulic capacity of the existing power plant approximately matches the average annual flow and utilizes this discharge reasonably effectively with the present reservoir regulation. A decrease in the permitted 21-foot reservoir drawdown would reduce the energy output of the existing power plant. Preliminary calculations show the following approximate losses in average and critical period energy in the event that the reservoir minimum elevation is raised above the existing 1,079 level."

Minimum Reservoir Elevation	30-Year Average Energy Loss (Mw)	Percentage Loss	Critical Period Energy Loss (Mw)	Percentage Loss
1079	0	0	0	0
1087.5	3.22	7.4	0.54	1.5
1091.8	6.09	14.0	4.90	13.5

ANALYSIS OF THE PROBLEM

The management of the water resources of the Chelan is a function of the hydrologic system. The major factor is the timing of inflow into the lake. In general, the power demand is highest when the inflow is lowest and the water which could be used for power production approximates the supply. (At an efficiency of 0.9 and flow of 2,200 cfs, the annual use could be 1,432,000 acre-feet compared to an average supply of 1,490,000 acre-feet.)

A good way of looking at lake level fluctation vs. inflow is to look at a "wet" year and a "dry" year. These, of course, are not typical but can

serve as relative upper and lower bounds for a long period of record. Two very good and frequently used examples are 1972 (wet) and 1973 (dry). The runoff during the 1972 water year was 2,265,000 acre-feet and 985,100 acre-feet during the 1973 water year. The record flows and the flows adjusted for changes in lake storage are shown in Figures 7 and 8.

In the case of a dry year, outflow at the dam may have to be restricted in order to bring the lake level up. In 1973, there was an average 20 cfs outflow and no power production from March 25-June 22 in order to fill the lake. This was the most extreme case in 47 years. The relationship between inflow, outflow, power production, and lake levels is graphically shown in Figure 9.

In the case of a wet year, i.e. 1972, the opposite is true. Both inflow and outflow were very high as can be seen in Figure 10. During filling of the lake, more than 16,000 cfs was being discharged downstream, and from June 15 to June 30 the lake level was deliberately held at elevation 1,098. This was to reserve some storage for flood control, but it is not clear what the downstream flood control requirements are or how great the flood frequency is. Figure 11 demonstrates that during 1972, spillage actually began in the middle of May, long before the lake was at full level.

The water years 1972 and 1973 were the most extreme examples in the period of record.

The average measured and corrected flows for the period 1929-70 are given in Figure 12. A frequency analysis of the data has been made and the

Figure 7: Chelan River at Chelan (12-4525), 1973

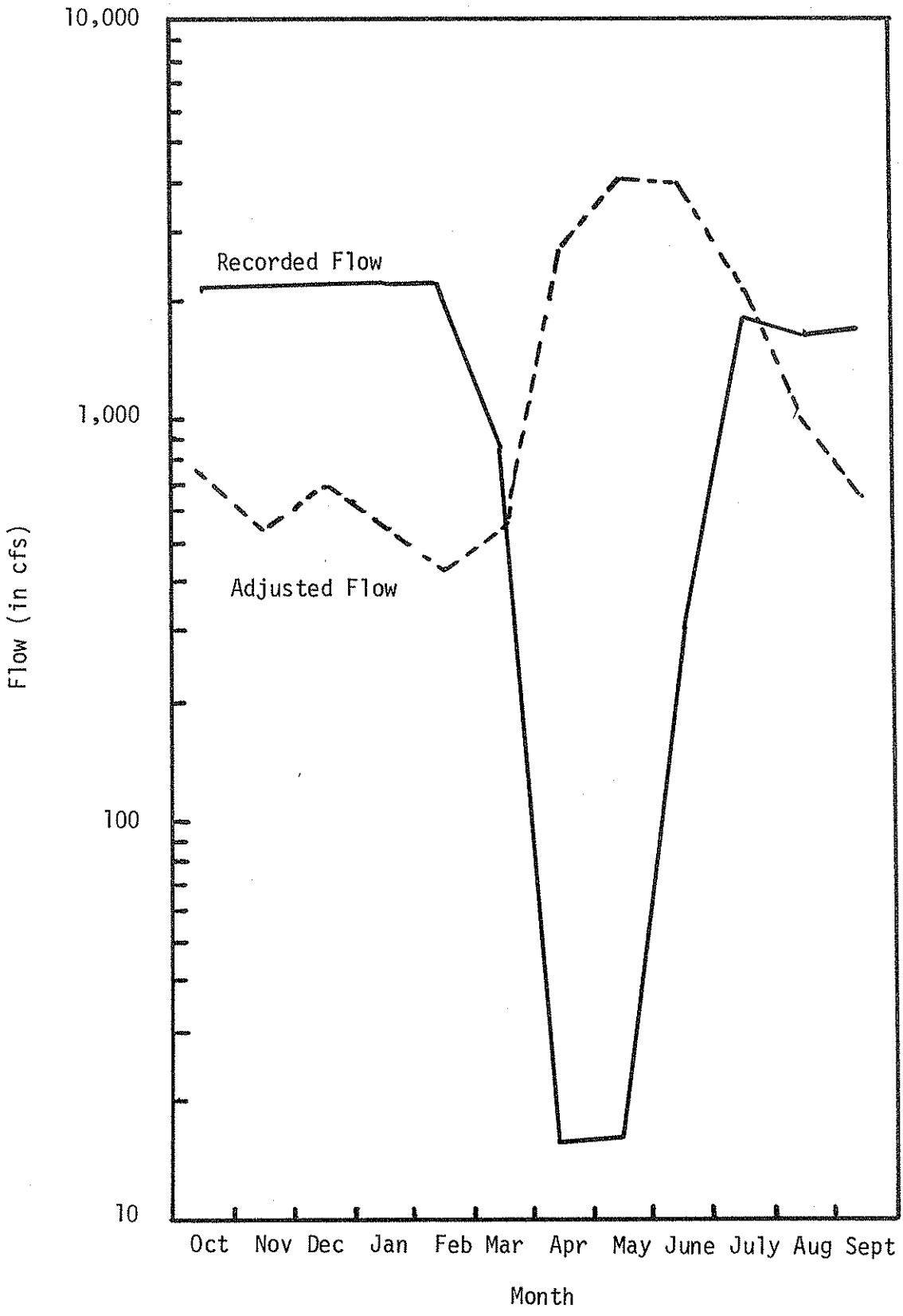


Figure 8: Chelan River at Chelan (12-4525), 1972

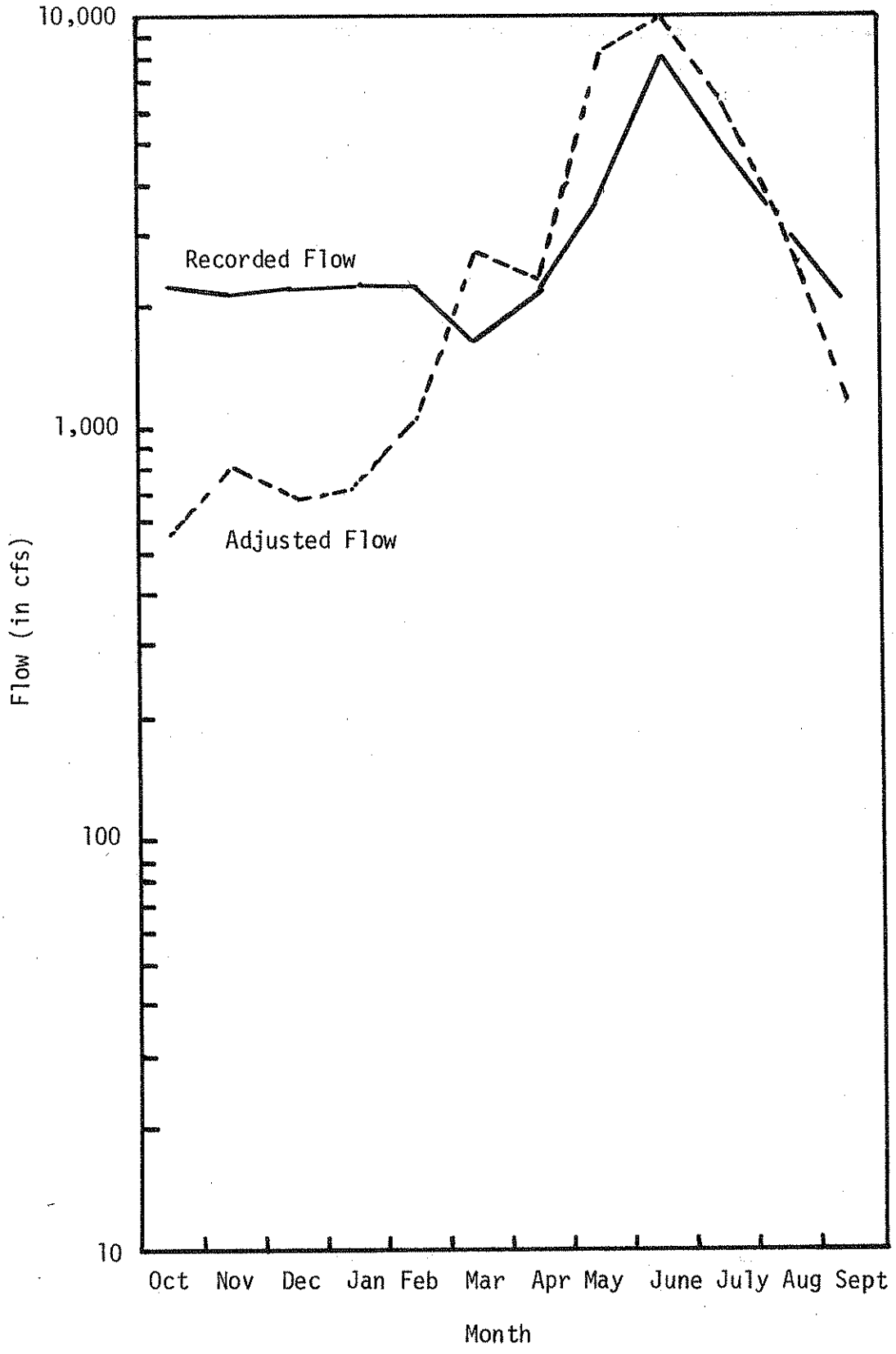


Figure 9 (1973)

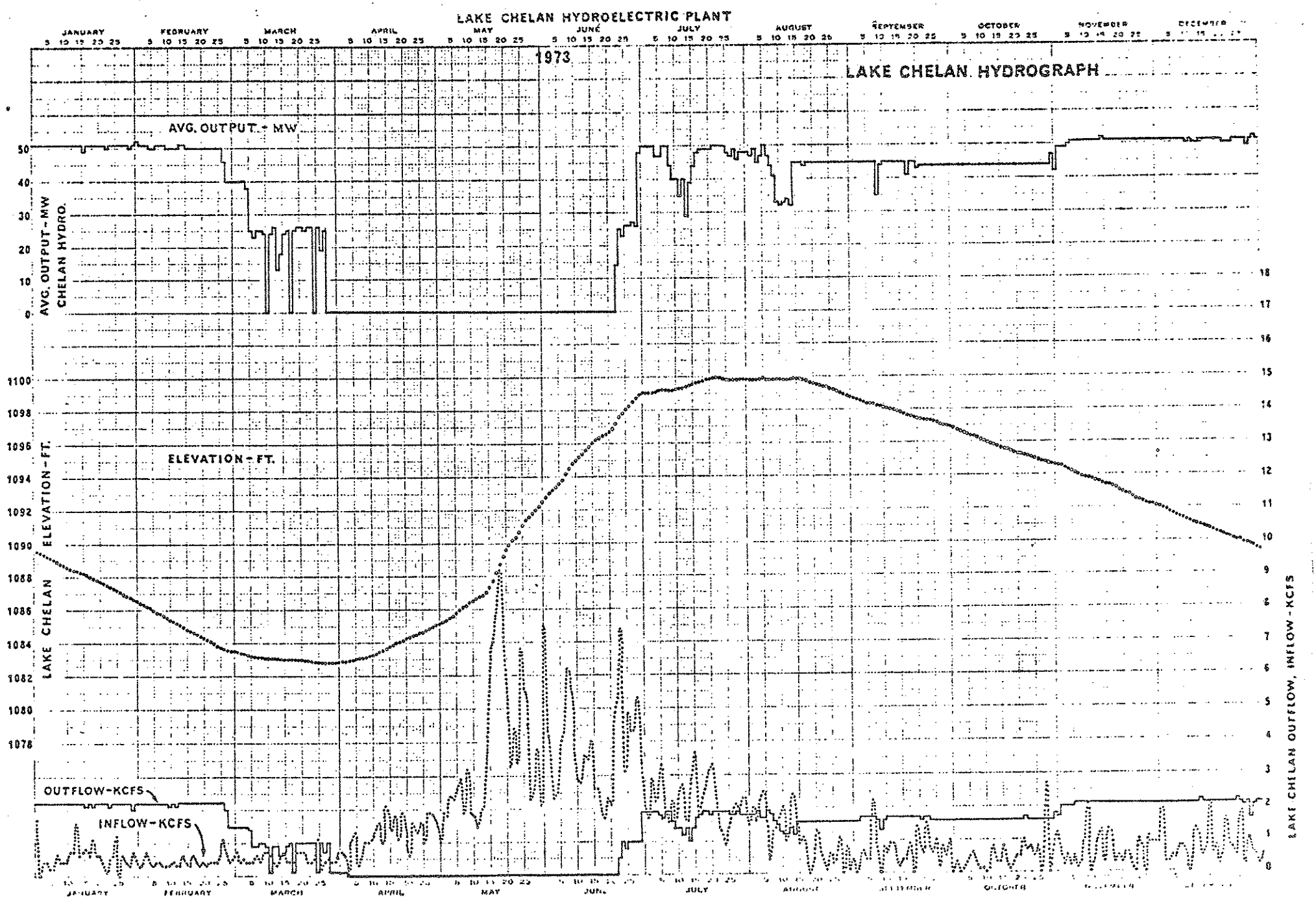


Figure 20 (1972)

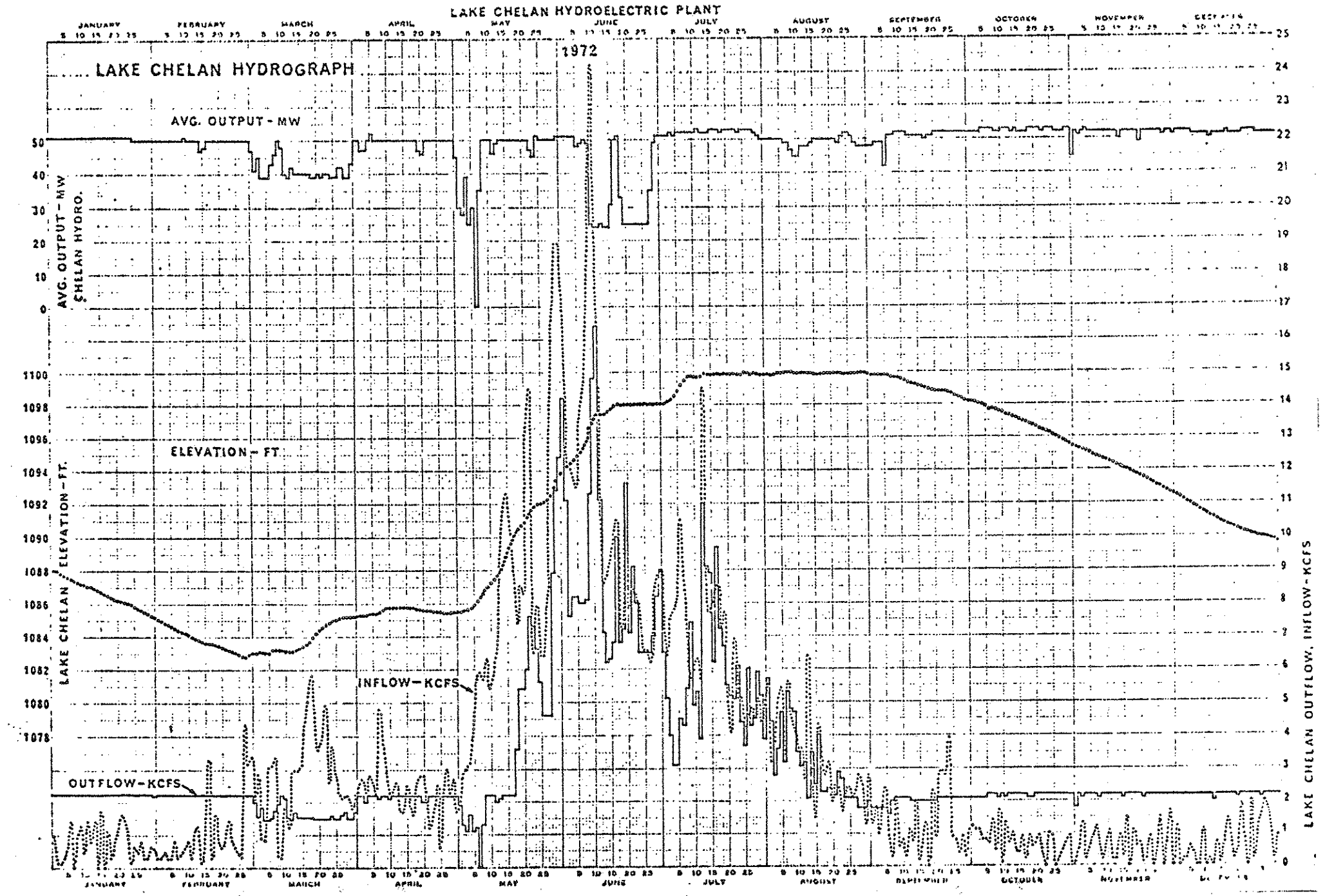


Figure 11

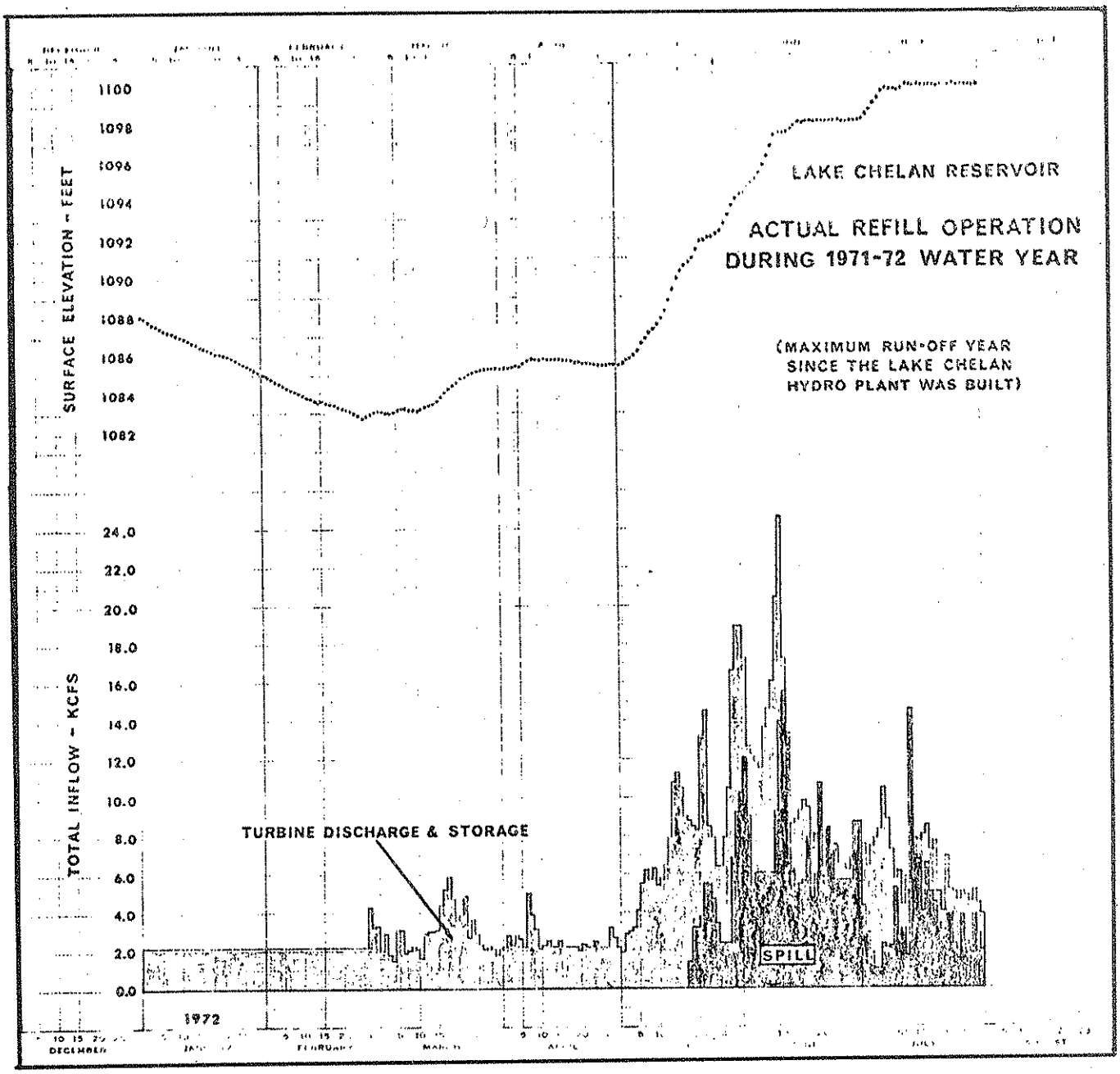
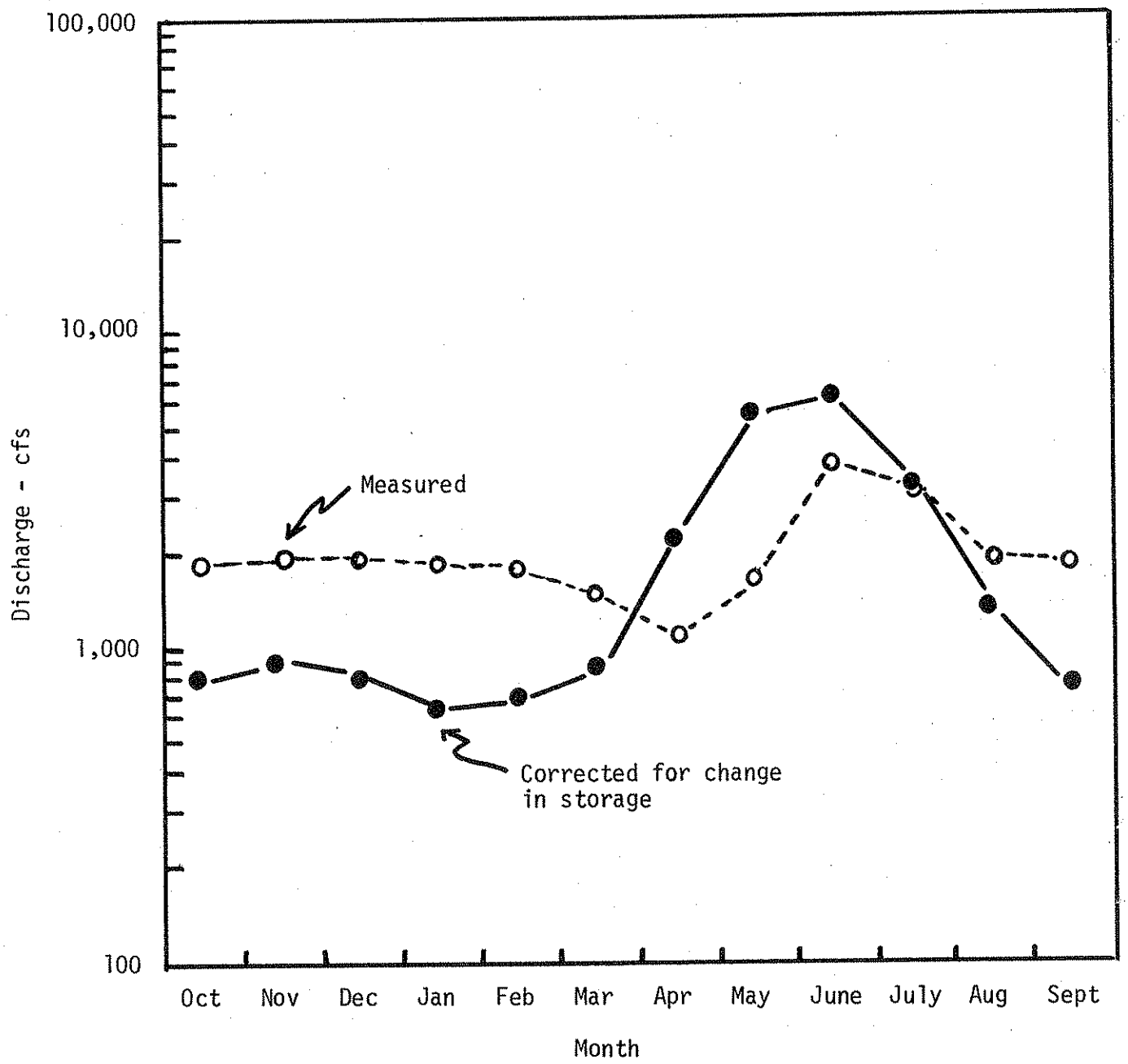

LAKE CHELAN RESERVOIR
ACTUAL REFILL OPERATION
DURING 1971-72 WATER YEAR
(MAXIMUM RUN-OFF YEAR
SINCE THE LAKE CHELAN
HYDRO PLANT WAS BUILT)
SURFACE ELEVATION - FEET
1100
1098
1096
1094
1092
1090
1088
1086
1084
1082
TOTAL INFLOW - KCFS
24.0
22.0
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
TURBINE DISCHARGE & STORAGE
SPILL
1972
DECEMBER
FEBRUARY

Figure 12: Average Monthly Flows of the Chelan River at Chelan (1929-1970)



results presented in Tables 6 and 7. The storage contents of Lake Chelan at the end of the month have been analysed and are presented in Table 8. The curve relating lake elevation to content is given as Figure 13.

The June 1 Proposal

The present operation criteria for the lake levels requires that the lake be as near to 1,100 feet elevation as possible on July 1. A proposal has been made to change the criteria to require an elevation of 1,100 (or 1,098) by June 1. In the period 1929-1968, the July 1 and June 1 lake levels have been in the range shown below:

	June 1	July 1
Low	1,087.07 (1937)	1,098.48 (1953)
High	1,099.19 (1968)	1,099.94 (1941)

A problem with requiring higher lake levels on June 1 is that in some years much of the spring runoff (April-June) occurs in June. Data for 1958 through 1974 are given in Table 9. The range in percentage is 64 to 30 with an average of 48. The data have been plotted in Figure 14 with the percent of spring runoff in June as a function of the total runoff. The data suggest that the percentage of runoff occurring in June decreases with a decrease in the total spring runoff.

The Chelan County P.U.D. considers that changing the time when the lake has to be at a high state would have the same effect as restricting minimum lake level; hence a reduction in power generation. Data given in a report by R. W. Beck and Associates have been used to determine the probability

Table 6

FREQUENCY AND WATER USE DATA

FOR Chelan at Chelan. U.S.G.S. Gage 12-4525.

	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
Mean Discharge	1896	1882	1875	1837	1745	1465	1073	1632	3824	3279	1868	1857
One in Two Year Discharge (Q_2)	1826	1805	1816	1734	1420	1173	757	932	2953	3048	1819	1795
One in Ten Year Discharge (Q_{10})	1235	1206	1287	1066	526	391	196	197	956	1861	1337	1241
$Q_2 - Q_{10}$												
Water Use												

Period of Record: 1929-70. Remarks: Measured flow, includes flow in channel and in penstocks.

Table 7 FREQUENCY AND WATER USE DATA

FOR Chelan at Chelan . U.S.G.S. Gage 12-4525 .

	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
Mean Discharge	809	905	805	648	692	861	2206	5418	6319	3425	1359	743
One in Two Year Discharge (Q_2)	709	699	687	564	596	779	1987	5184	6022	3157	1280	703
One in Ten Year Discharge (Q_{10})	365	263	334	269	291	448	1104	3532	4016	1868	820	446
$Q_2 - Q_{10}$												
Water Use												

Period of Record: 1929-70 . Remarks: Adjusted for change in storage in Lake Chelan.

Table 8: Frequency and Water Use Data for Lake Chelan

(In Acre-feet and Stage ht.)

Month	Mean End of Month Contents	One in Two Year	One in Ten Year
October	502,000 (1094.8)	497,000 (1094.6)	409,000 (1091.9)
November	444,000 (1093.0)	432,000 (1092.7)	316,000 (1089.0)
December	378,000 (1090.9)	358,000 (1090.3)	231,000 (1086.4)
January	305,000 (1088.8)	279,000 (1087.9)	157,000 (1084.0)
February	246,000 (1086.9)	219,000 (1086.0)	111,000 (1082.7)
March	209,000 (1085.8)	172,000 (1086.0)	70,000 (1081.3)
April	277,000 (1087.8	235,000 (1086.5)	102,000 (1082.2)
May	509,000 (1095.0)	496,000 (1094.5)	363,000 (1090.4)
June	657,000 (1099.7)	657,000 (1099.7)	641,000 (1099.0)
July	666,000 (1099.9)	666,000 (1099.9)	657,000 (1099.7)
August	635,000 (1098.8)	634,000 (1098.7)	592,000 (1097.5)
September	569,000 (1096.8)	566,000 (1096.7)	501,000 (1094.8)

Period of Record: 1929-70

Figure 13: Lake Elevation and Contents, Lake Chelan

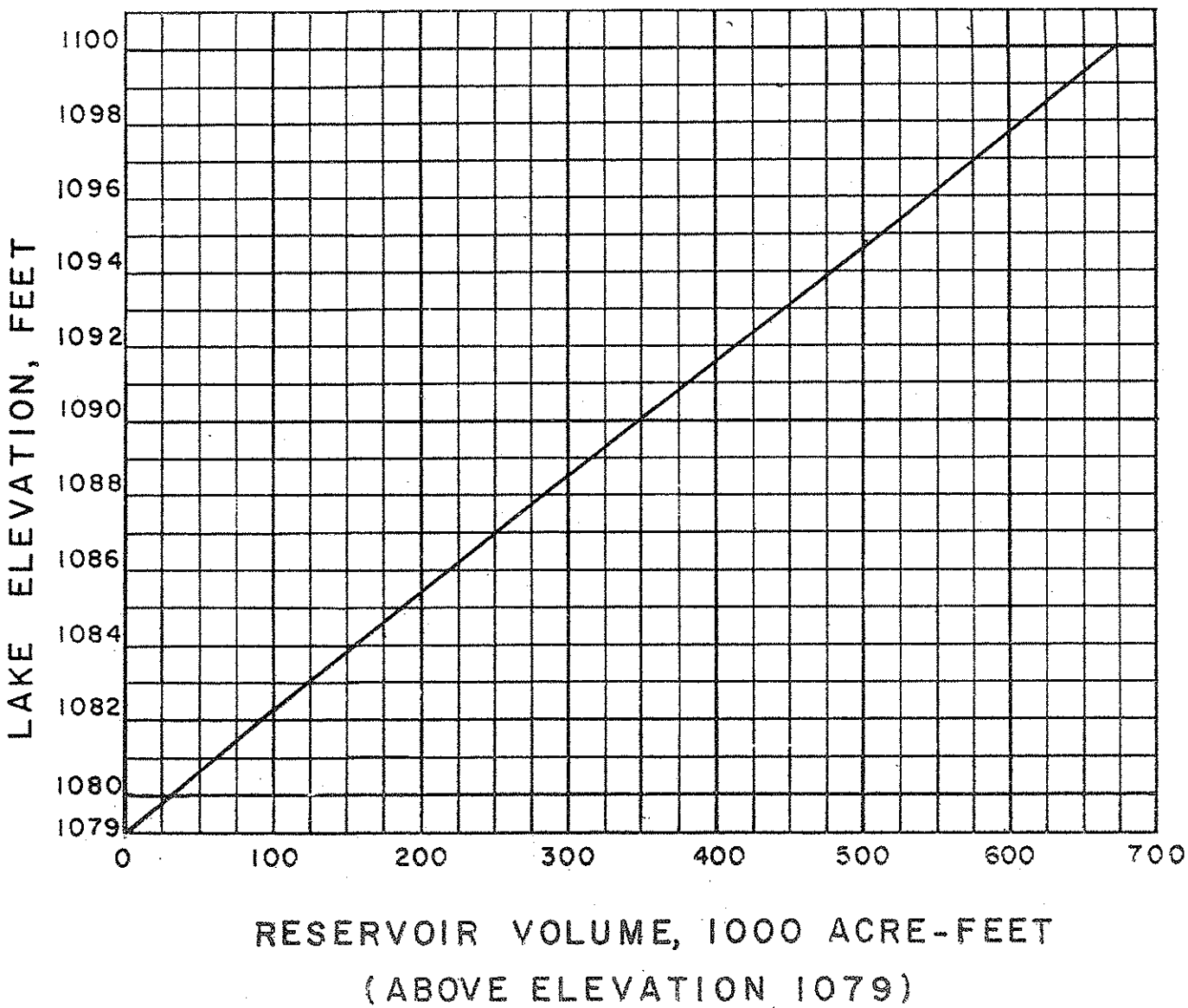
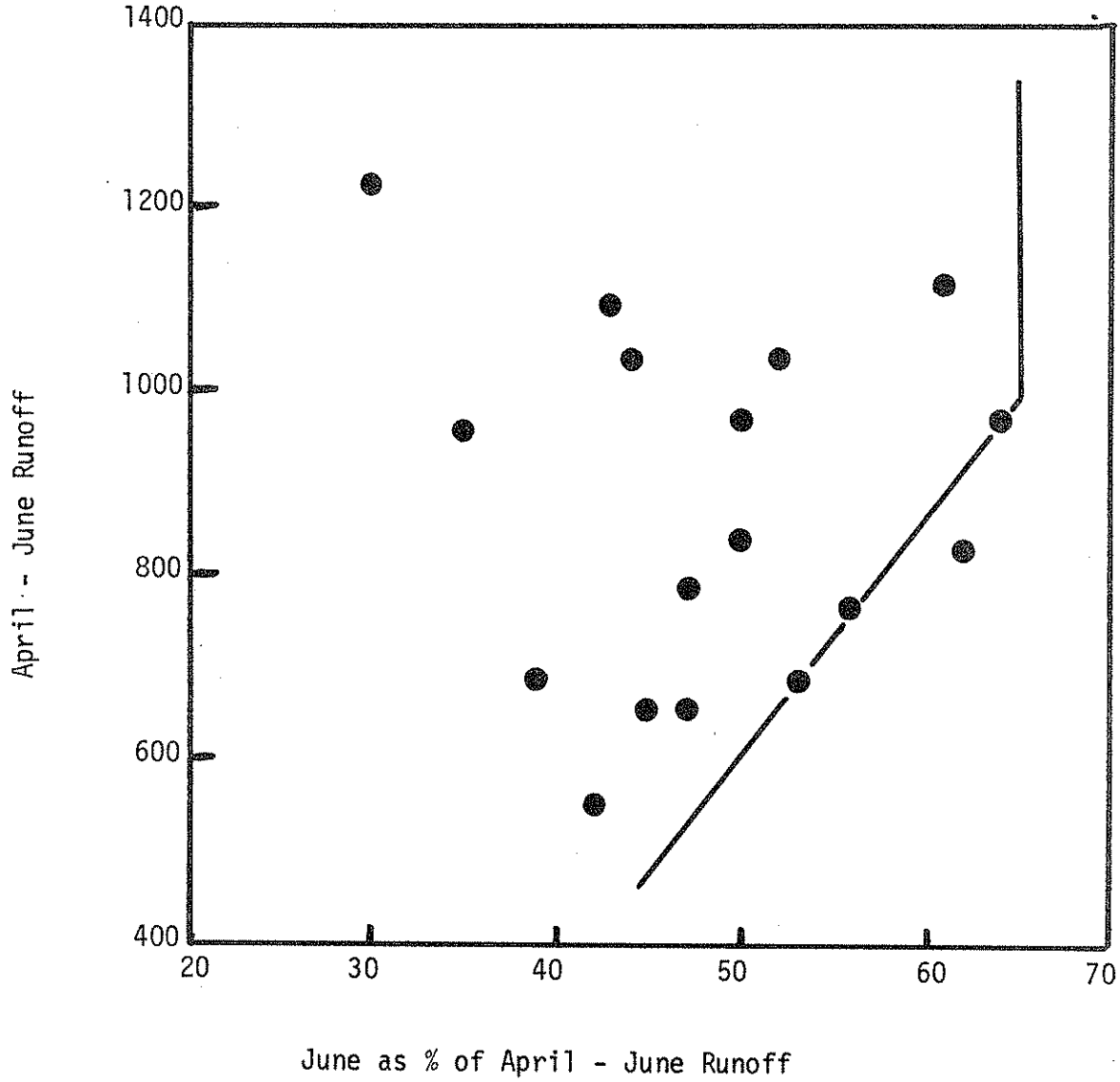


Table 9: Spring Runoff and the Percentage of Spring Runoff in June -- Chelan River at Chelan

Year	Runoff in 1,000 Acre-feet June	Runoff in 1,000 Acre-feet April-June	June as Percent of April-June
1974	690	1,127	61
1973	227	544	42
1972	369	1,250	30
1971	450	1,019	44
1970	381	683	56
1969	468	1,093	43
1968	422	798	53
1967	618	966	64
1966	268	686	39
1965	374	792	47
1964	509	821	62
1963	293	655	45
1962	309	651	47
1961	538	1,032	52
1960	419	839	50
1959	484	974	50
1958	333	954	35

Figure 14: Percent of Spring Runoff in June as a Percent of Total Runoff (1958-74)



of equaling or exceeding a specific lake level as a function of the minimum lake level. The results are given in Figure 15 for June 1 and in Figure 16 for July 1. These figures can then be used to determine the required minimum lake level, given any probability. As an example, if you assumed a 90 percent probability of equaling or exceeding 1,098 feet on July 1 or June 1, the resulting minimum lake levels would be:

July 1	1,081.3 feet
June 1	1,089.3 feet.

The energy loss from these restrictions would be:

Minimum Elevation	Average Annual Energy Loss	Percentage Loss
	(Mw)	
1,081.3	0	0
1,089.3	4.6	10.6

The rule curves used in the R. W. Beck and Associates study are given in Figure 17. The Chelan County P.U.D. has estimated, in terms of MWH and dollars, the energy losses they feel would result from changing the minimum lake level. This is shown in Figures 18 and 19.

Chelan Basin Inflow & Outflow

In order to obtain some idea of the inflow to Lake Chelan, the streamflow data for Railroad Creek, Stehekin Creek, and the Chelan River at Chelan were used. The annual runoff into the lake was calculated using the equation

Figure 15: Probability of Reaching Required Lake Level as a Function of the Minimum Lake Level - June 1

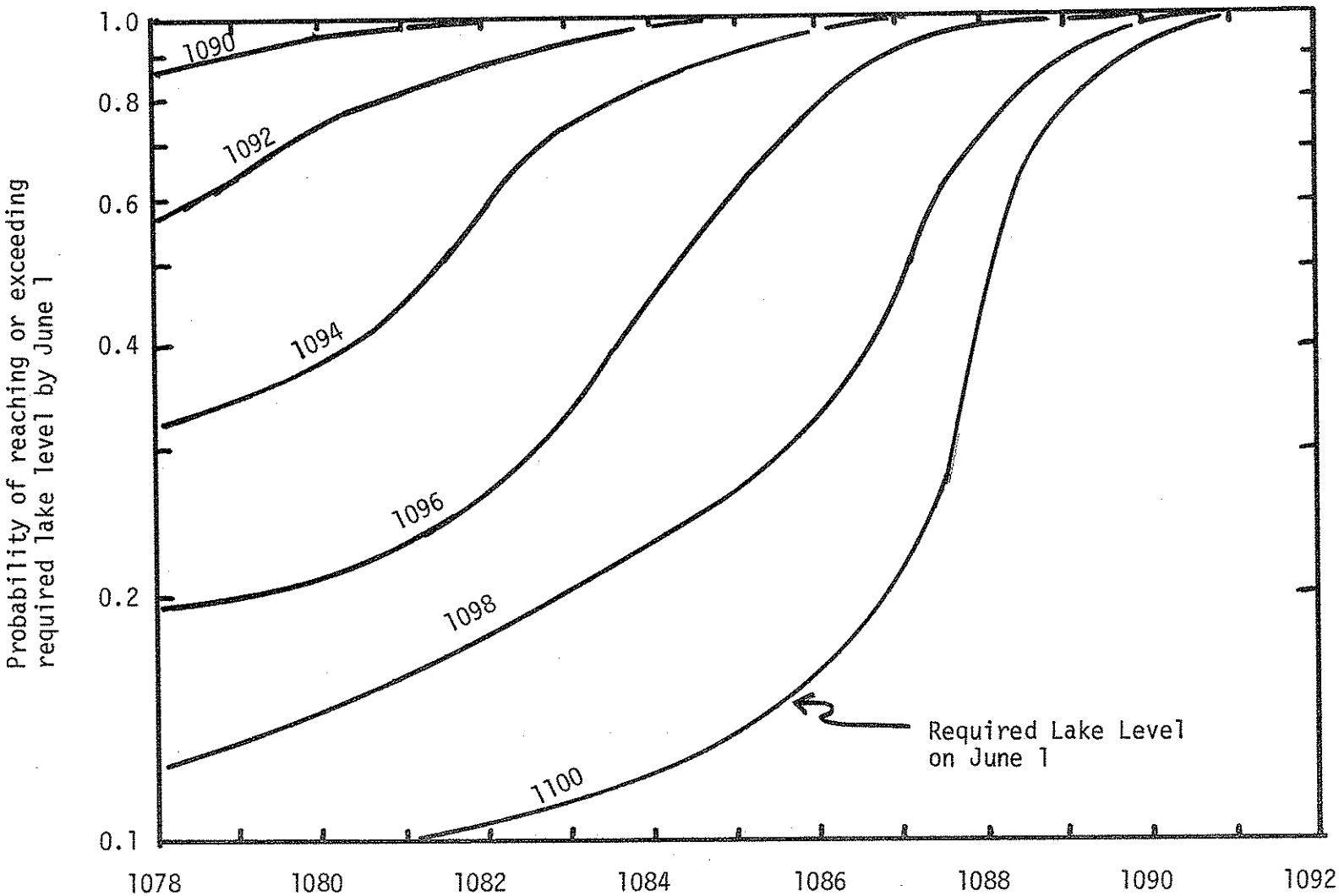
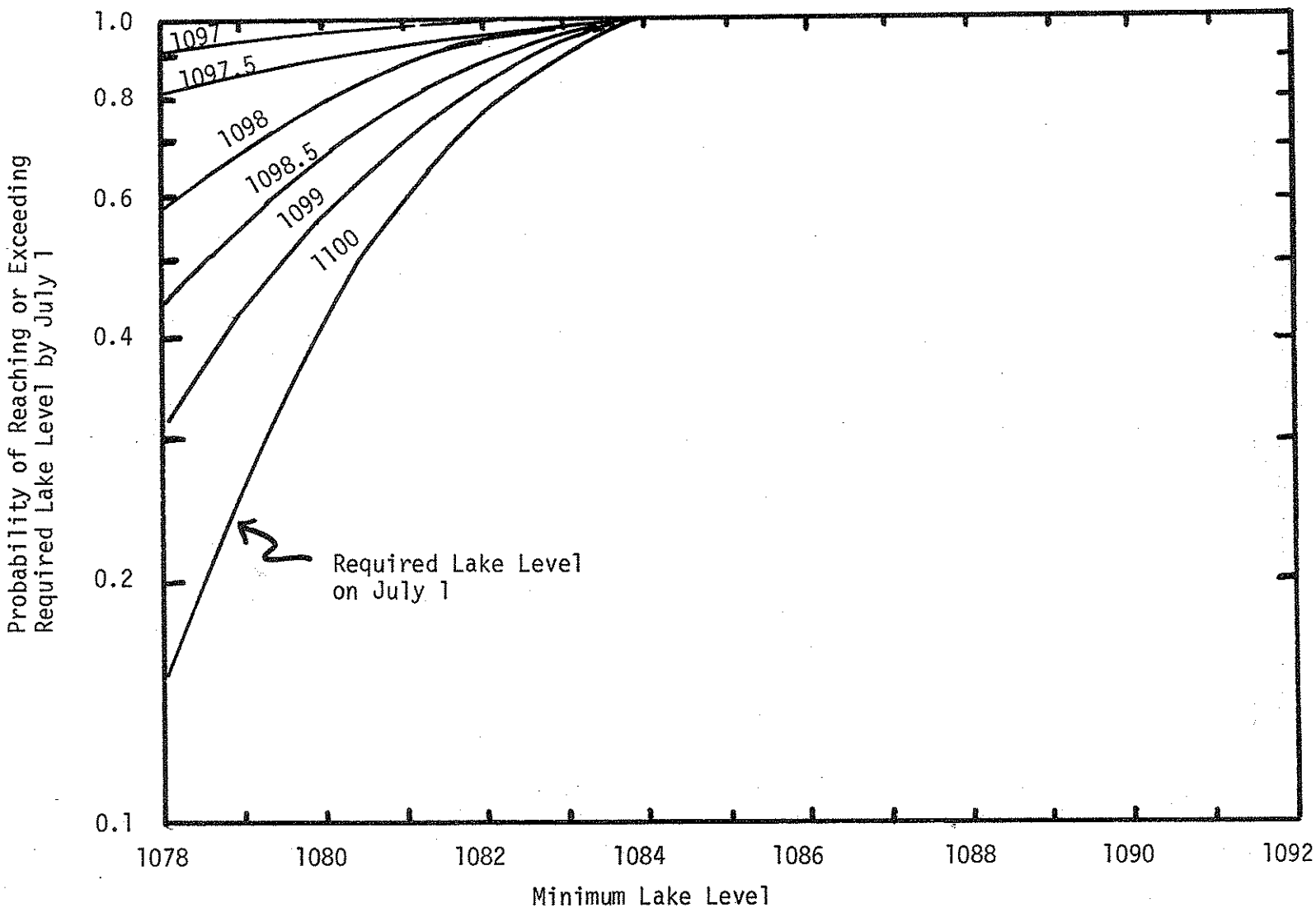


Figure 16: Probability of Reaching Required Lake Level as a Function of the Minimum Lake Level - July 1



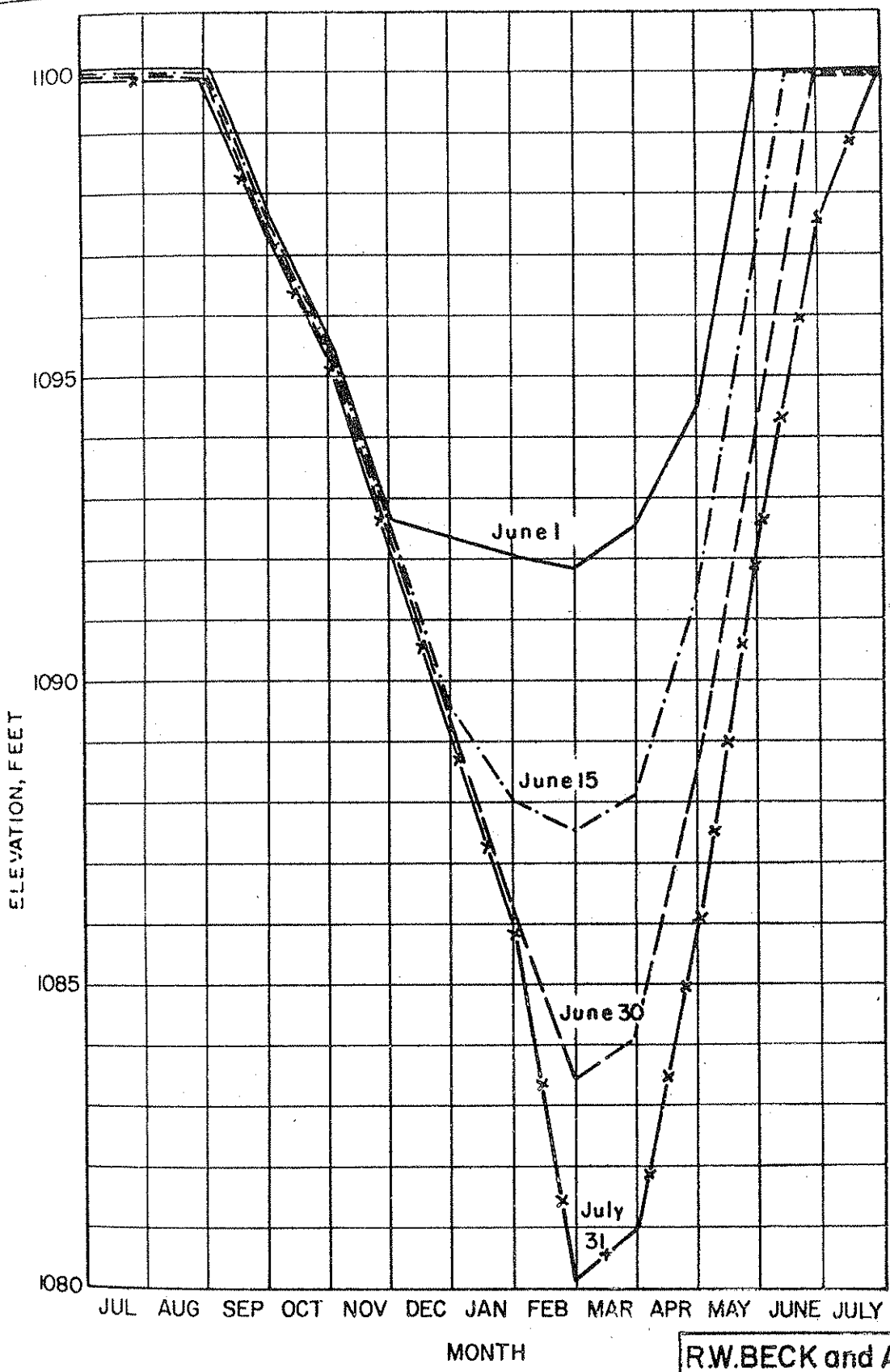


Figure 17

LEGEND

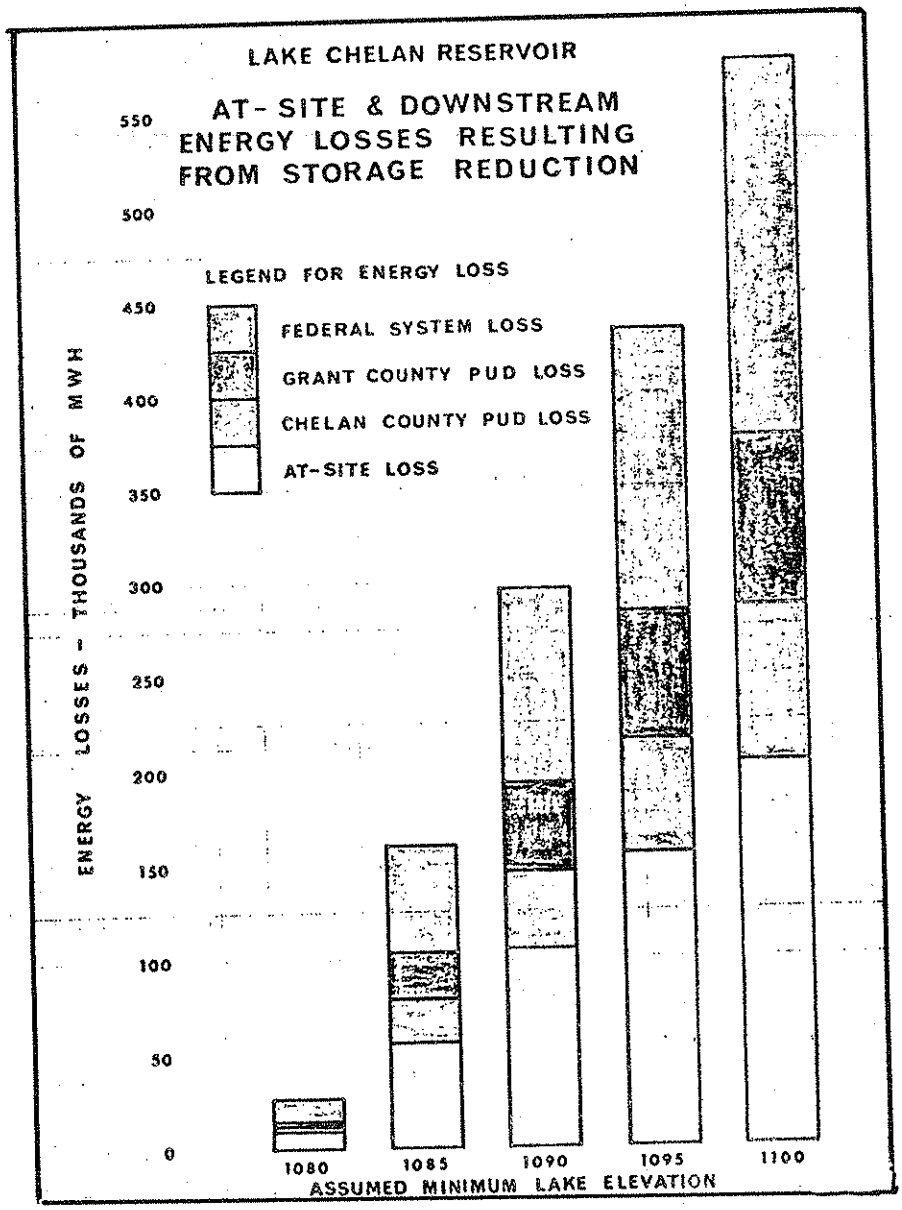
- June 1 filling date
- June 15 filling date
- June 30 filling date
- July 31 filling date

R.W. BECK and ASSOCIATES
Analytical and Consulting Engineers
Seattle, Washington Denver, Colorado

CHELAN COUNTY PUBLIC UTILITY DISTRICT
WENATCHEE, WASHINGTON
LAKE CHELAN
PROJECT EXPANSION
RESERVOIR RULE CURVE
BASED ON WORST FLOW

DATE:	DRAWN:	APPROVED:	FIG:
11-30-71	RY		

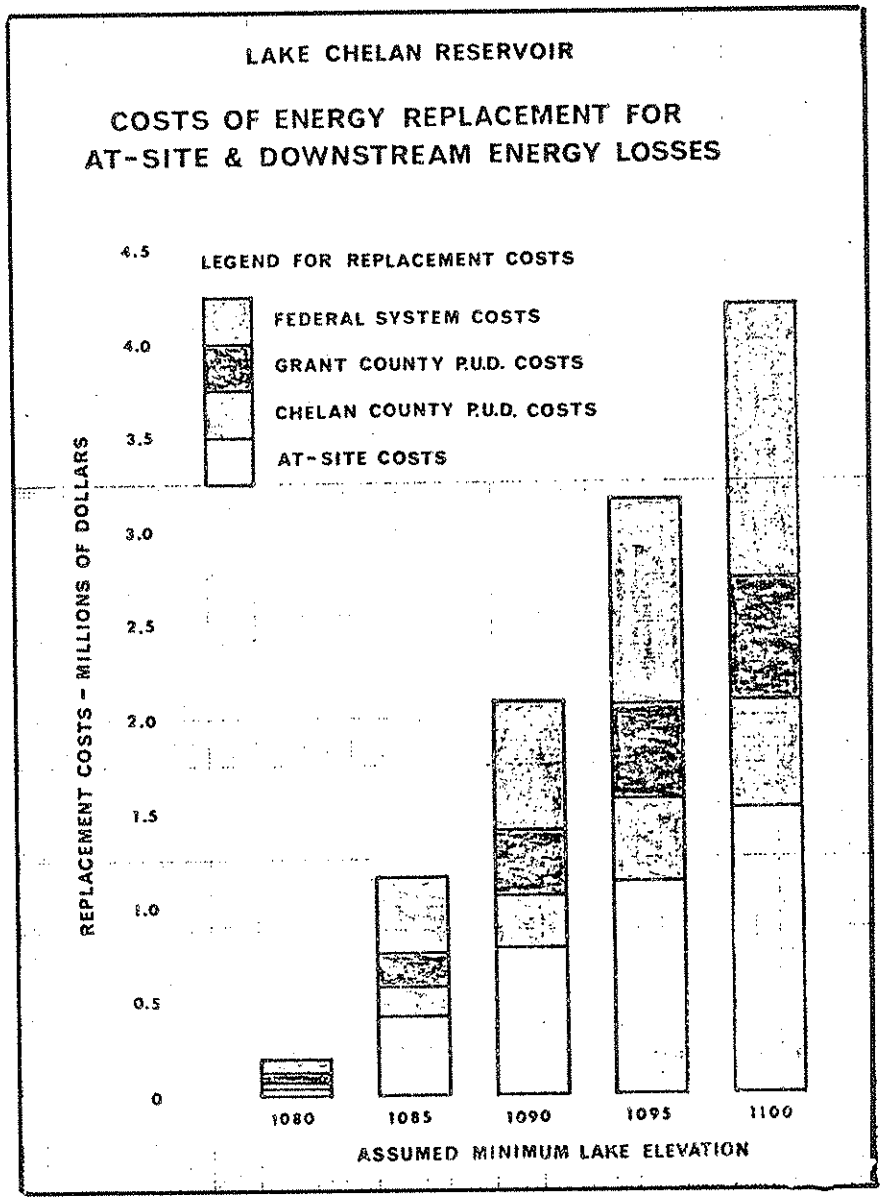
Figure 18



At-Site & Downstream Energy Loss Resulting from Storage Reduction (MWH)

Assumed Min. Elev.	1080	1085	1090	1095	1100
At-Site	9,284	56,494	105,153	155,260	206,656
Chelan P.U.D.	3,721	22,441	41,395	60,559	79,911
Grant P.U.D.	4,198	25,318	46,702	68,323	90,156
Federal Sys.	9,254	55,814	102,956	150,621	198,753
Total Downstream	17,173	103,573	191,053	279,503	368,820
Total Loss	26,457	160,067	296,206	434,763	575,476

Figure 19



Costs of Energy Replacement for At-Site & Downstream Energy Loss (Costs based on Alternate Source at 7.27 mills/KWH)

Assumed Min. Elev.	1080	1085	1090	1095	1100
At-Site	$ 67,000	411,000	764,000	1,129,000	1,502,000
Chelan P.U.D.	27,000	163,000	301,000	440,000	581,000
Grant P.U.D.	31,000	184,000	340,000	497,000	655,000
Federal Sys.	67,000	406,000	748,000	1,095,000	1,445,000
Total Downstream	$ 125,000	756,000	1,389,000	2,032,000	2,681,000
Total	$ 192,000	1,164,000	2,153,000	3,161,000	4,183,000

$$Q_{in} = Q_c + S + E$$

where Q_{in} is the inflow into the lake, Q_c is the measured flow of the Chelan River at Chelan, S is the change in storage in the lake, and E is the estimated evaporation from the lake (88,000 acre-feet per year). A schematic diagram of the concept is shown in Figure 20.

The annual flow from the Chelan Basin below gages on the Stehekin River and Railroad Creek was then calculated using the equation

$$DQ = Q_{in} - Q_S - Q_{RR}$$

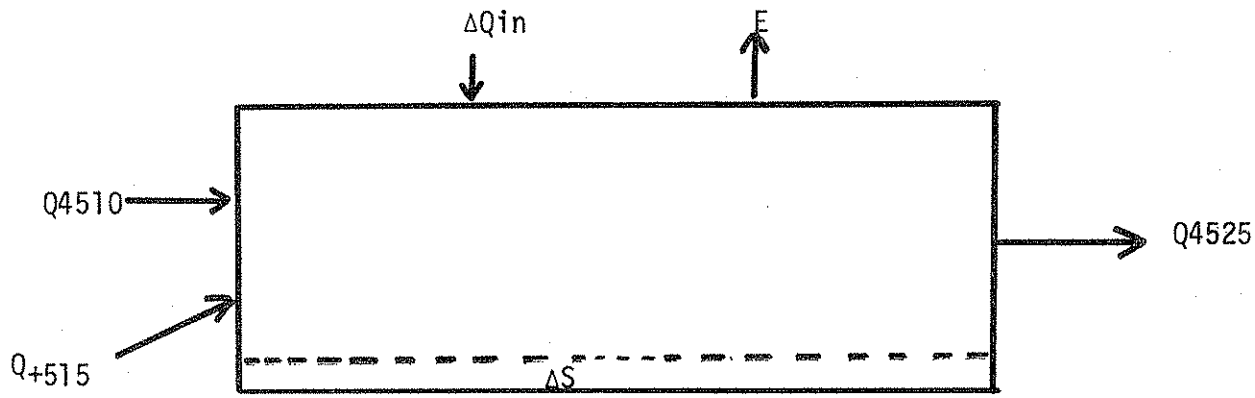
where DQ is the flow from the basin above the Chelan River at Chelan and the gages on the Stehekin and Railroad Creek; Q_{in} is the inflow into the lake; Q_S is the flow of the Stehekin; and Q_{RR} the flow of Railroad Creek.

The monthly distribution of the flows from the Lower Chelan Basin were estimated using streamflow data for short term gages. The following distribution numbers represent the ratio of the mean monthly discharge (in cfs) to the mean annual discharge (in cfs).

October	0.134	April	0.473
November	0.134	May	3.309
December	0.093	June	6.064
January	0.113	July	0.986
February	0.134	August	0.237
March	0.165	September	0.154

The resulting monthly inflows, during the period 1927-57, are presented in Table 10.

Figure 20: Annual Inflow - Outflow Diagram for Lake Chelan.



Where:

Q4525 = mean annual discharge of "Chelan River at Chelan"

Q4510 = mean annual discharge of "Stehekin River at Stehekin"

Q4515 = mean annual discharge of "Railroad Creek at Lucerne"

ΔQ = The difference between Q4525 and Q4510. This, with other data, is the amount of H_2O entering the system from tributary streams.

ΔS = The change in lake storage, using gage 4520 Lake Chelan"

E = Lake evaporation, using annual average (32 in) X lake area (33104 acre)

Qin = amount of H_2O in basin; E + ΔS + Q4525 + others

ΔQin = Difference between the amount coming in at Stehekin and the amount in basin; Qin =ΔQin - Q4510

Table 10 FREQUENCY AND WATER USE DATA

FOR Lake Chelan Inflows . U.S.G.S. Gage -- .

	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
Mean Discharge	814	818	628	476	467	609	1940	5980	7870	3507	1467	862
One in Two Year Discharge (Q_2)	740	664	534	420	408	549	1780	5790	7576	3288	1399	840
One in Ten Year Discharge (Q_{10})	421	287	254	220	217	317	1048	4152	5277	2069	946	627
$Q_2 - Q_{10}$	319	377	280	200	191	232	732	1638	2299	1219	453	213
Water Use												

Period of Record: 1927-57 . Remarks: Calculated - see text (in cfs)

The inflow into Lake Chelan, over the period prior to July 1, was calculated using the data developed from the above concepts. The equation used was:

$$Q(\text{inflow over period}) = \sum_{i}^{\text{June}} Q_i$$

where Q_i is the average monthly flow during the i^{th} month. An example is, the flow from October 1 to July 1 is the sum of the flows of the months October through June. The flows remaining for periods up to June 1, May 1, and April 1 were also made. After the data for each year were compiled, a frequency analysis of the compiled data was made. The results for the case where the volume exceeds the shown volume nine in ten years are given in Figure 21. The amount of inflow for the average, the one in two year, and the nine in ten year cases are given in Table 11.

The inflow volumes are not the same as possible outflow volumes because of evaporation. Estimated evaporation volumes for the various months are shown in Table 12.

Using the information in Tables 11 and 12, the amount of water needed to fill the lake by a certain date can be calculated. With a 90% probability of reaching elevation 1,098 (610,700 acre-feet) by June 1, the volume required in Lake Chelan and the amount of inflow needed are:

Figure 21 Lake Chelan Inflow Volumes Remaining
For the Nine in Ten Year Exceedence Interval

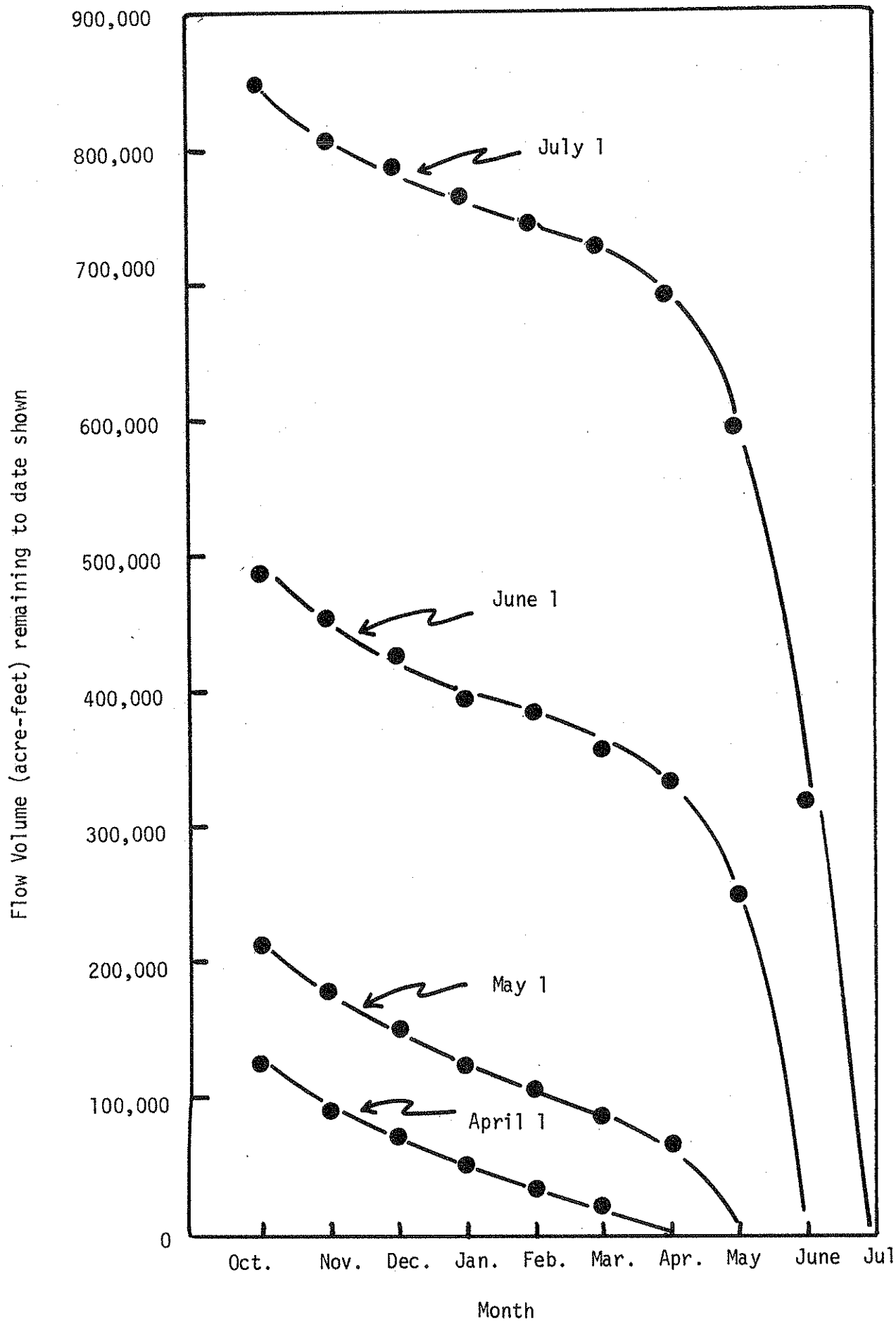


Table 11: Lake Chelan Inflow Volumes

Period	Average	Exceeded 1 in 2 years	Exceeded 9 in 10 years
		(acre-feet)	
Oct - June	1,182,000	1,150,000	848,000
Nov - June	1,133,000	1,102,000	812,000
Dec - June	1,084,000	1,057,000	789,000
Jan - June	1,046,000	1,021,000	765,000
Feb - June	1,017,000	993,000	746,000
Mar - June	989,000	966,000	727,000
Apr - June	952,000	929,000	697,000
May - June	835,000	812,000	595,000
June - June	475,000	457,000	318,000
Oct - May	707,000	683,000	488,000
Nov - May	658,000	636,000	455,000
Dec - May	609,000	590,000	427,000
Jan - May	571,000	554,000	400,000
Feb - May	542,000	526,000	380,000
Mar - May	514,000	499,000	361,000
Apr - May	478,000	463,000	336,000
May - May	361,000	349,000	250,000
Oct - Apr	347,000	327,000	212,000
Nov - Apr	298,000	280,000	177,000
Dec - Apr	248,000	234,000	150,000
Jan - Apr	211,000	197,000	125,000
Feb - Apr	182,000	169,000	105,000
Mar - Apr	154,000	142,000	87,000
Apr - Apr	117,000	107,000	63,000

Table 12: Estimated Evaporation from Lake Chelan

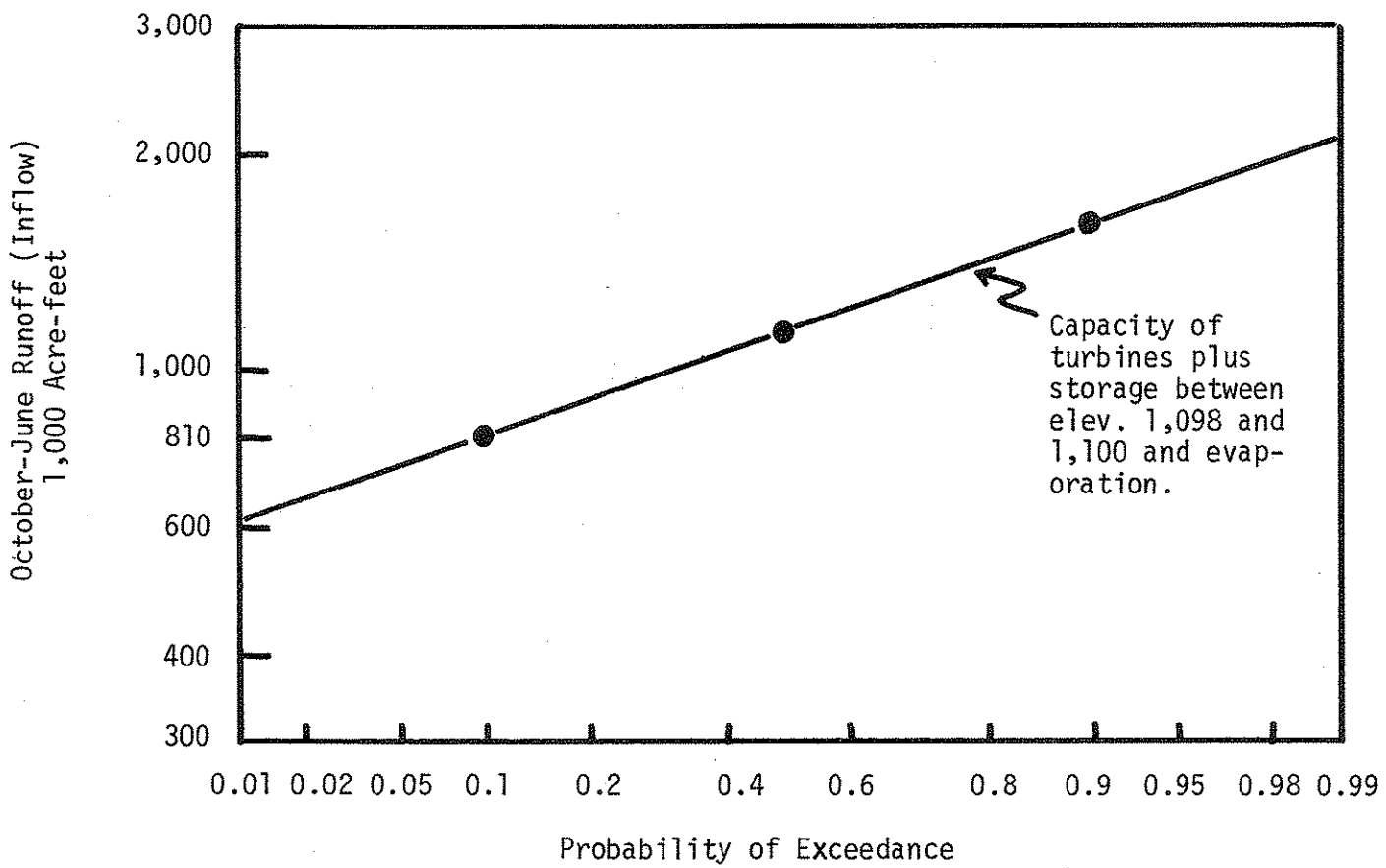
Month	Monthly Evaporation	Evaporation from 1st of Month to June 1
	(in acre-feet)	
October	5,400	46,300
November	3,400	40,900
December	2,500	37,400
January	3,000	34,900
February	4,600	32,000
March	6,800	27,400
April	9,300	20,500
May	11,200	11,200
June	12,000	--
July	11,600	--
August	10,200	--
September	7,800	--

Month	Inflow Value to June 1 (90% prob. of exceeding	Lake Value required for 90% probability	Lake Elevation on 1st of Month
	(acre-feet)	(acre-feet)	(feet)
October	486,000	171,000	1,084.4
November	452,800	198,800	1.085.2
December	424,800	223,300	1,086.0
January	398,400	247,200	1,086.9
February	378,500	264,200	1,087.0
March	359,600	278,500	1,088.0
April	334,000	297,200	1,088.4
May	249,100	372,800	1,090.8

The information above is helpful in developing a rule curve for the filling of the lake. Another part of the lake level problem is the drawdown of the lake in the fall and winter. The present criteria allows the lake to be drawn down to elevation 1,092 during the summer and 1,079 beginning in mid-September. A suggested criteria is that the lake not be drawn down below elevation 1,098 until after October 1. The only problem here is predicting the inflow for spring. Spills could be larger in spring in order to anticipate the amount of water to be used for power or storage. Figure 22 shows the probability of October-June inflows, and suggests that the capacity to use the inflow is exceeded one out of four years. Over the period 1927 through 1970 the actual spill volumes have exceeded 50,000 acre-feet 22 out of 43 years (incomplete data for 1955) and exceeds 100,000 acre-feet during 11 of the 43 years. Hence, the maintenance of a lake level of 1,098 feet until October 1 would not result in a significant loss of energy.

A method of improving water management is to use forecasted inflow volumes. Inflow volumes have been forecasted by the Soil Conservation Service using snow survey data. Their March forecasts for April-June runoff are given

Figure 22: Probability of October through June Inflows into Lake Chelan



in Table 13 and in Figure 23. Using the March forecasts for 1971 through 1974 and the information in Figures 14 and 23, the April 1 lake levels that would virtually insure filling are:

1974	1,087.2
1973	1,089.5
1972	1,086.8
1971	1,087.2

An option to a fixed rule curve is to include the snow survey forecasts in the operating criteria for the lake. If a fixed rule curve is used for Lake Chelan, the results for filling the lake are shown in Figure 24A (assuming a 90 percent chance of filling by June 1, and limiting the drawdown to 1,098 until October 1).

The elevations of 1,098 for the summer recreation period appears to be a desirable level from the standpoint of shoreline owners. This is only two feet below maximum lake level, which arrives sometine in July anyway. Elevation 1,098 also has traditionally been a "holding" level for flood control. According to Washington Water Power Company figures, this elevation would provide 610,700 acre-feet of useable storage. There is a 65,400 acre-foot capacity from elevation 1,098 to 1,100 (full lake). Extension of this elevation through the month of September seems quite possible from the information available as well as from the Chelan County P.U.D.

Another possible set of lake level criteria is for the lake to be at 1,095 by June 1, 1,098 by July 1, then held at or above 1,098 until October 1. The results of applying this criteria are given in Figure 24B.

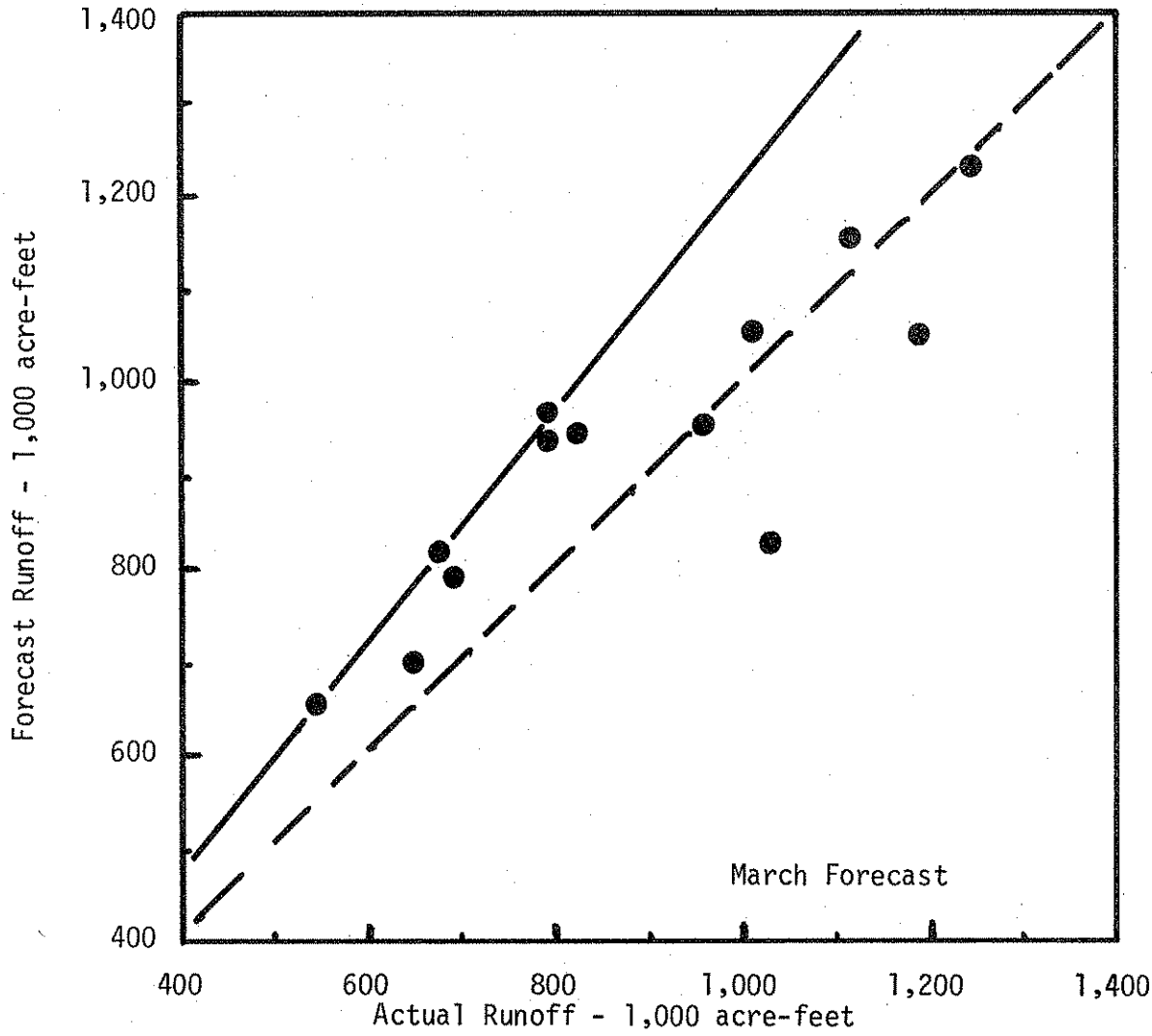
Table 13: Forecasted and Actual Runoff Volumes in the Chelan Basin for April-June Runoff

Year	March Forecast	Actual	Ratio
	(1,000 acre-feet)		
1974	1,145	1,127	1.02
1973	660	544	1.21
1972	1,230	1,250	0.98
1971	1,050	1,019	1.03
1970	820	683	1.20
1969	1,050	1,093	0.96
1968	940	798	1.18
1967	950	966	0.98
1968	790	686	1.15
1965	970	792	1.22
1964	940	821	1.14
1963	700	655	1.07
1962	(NF)	651	--
1961	825	1,032	0.80

NF = no forecast

Source: Water Supply Outlook for Washington for March of years shown.

Figure 23: Forecasted versus Actual Runoff in the Chelan Basin



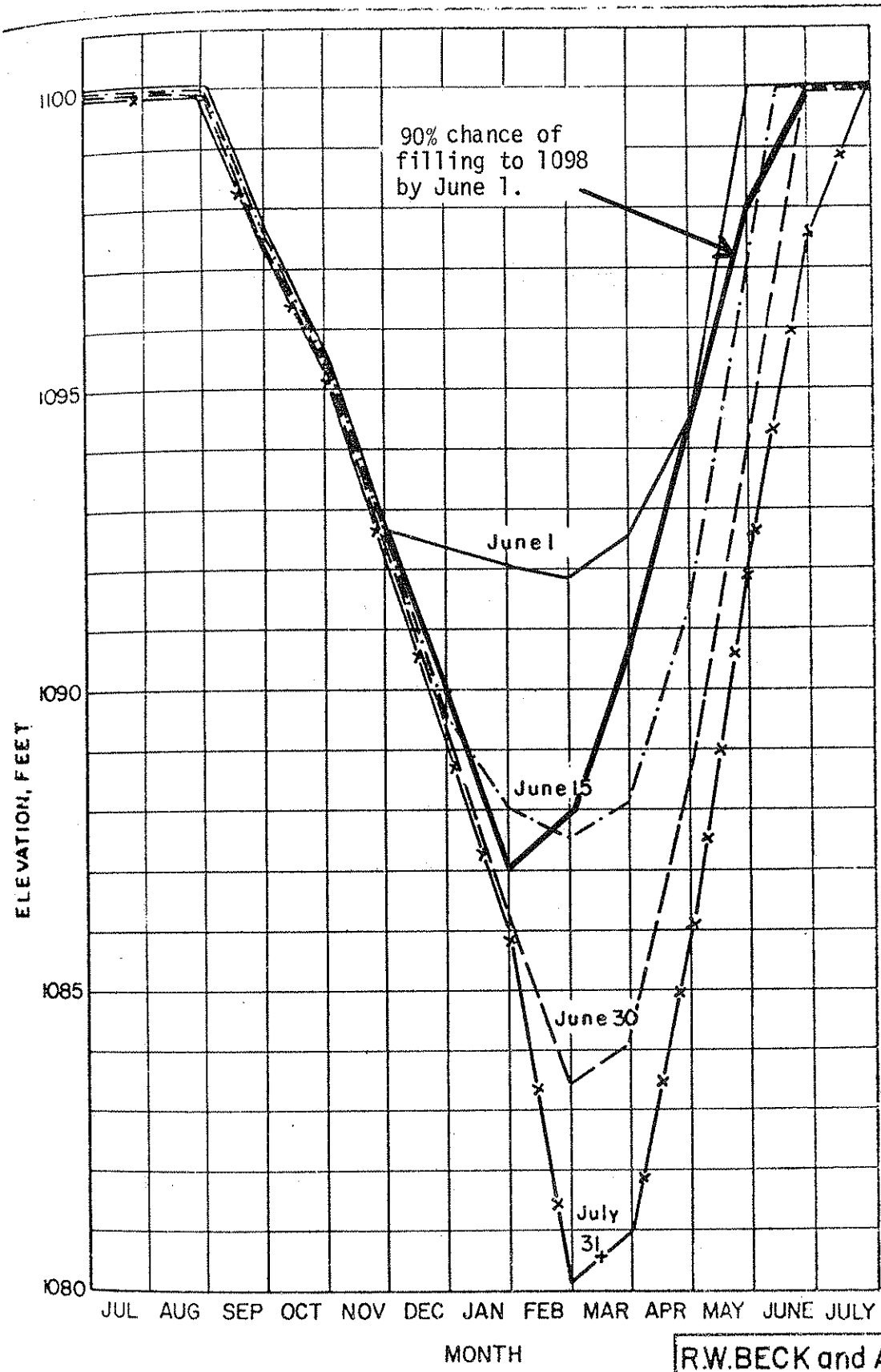


Figure 24-A
Fixed Rule Curve
(Case 1)

R.W. BECK and ASSOCIATES
Analytical and Consulting Engineers
Seattle, Washington Denver, Colorado

CHELAN COUNTY PUBLIC UTILITY DISTRICT
WENATCHEE, WASHINGTON
LAKE CHELAN
PROJECT EXPANSION
RESERVOIR RULE CURVE
BASED ON WORST FLOW

DATE:	DRAWN:	APPROVED:	FIG:
11-30-71	RY		

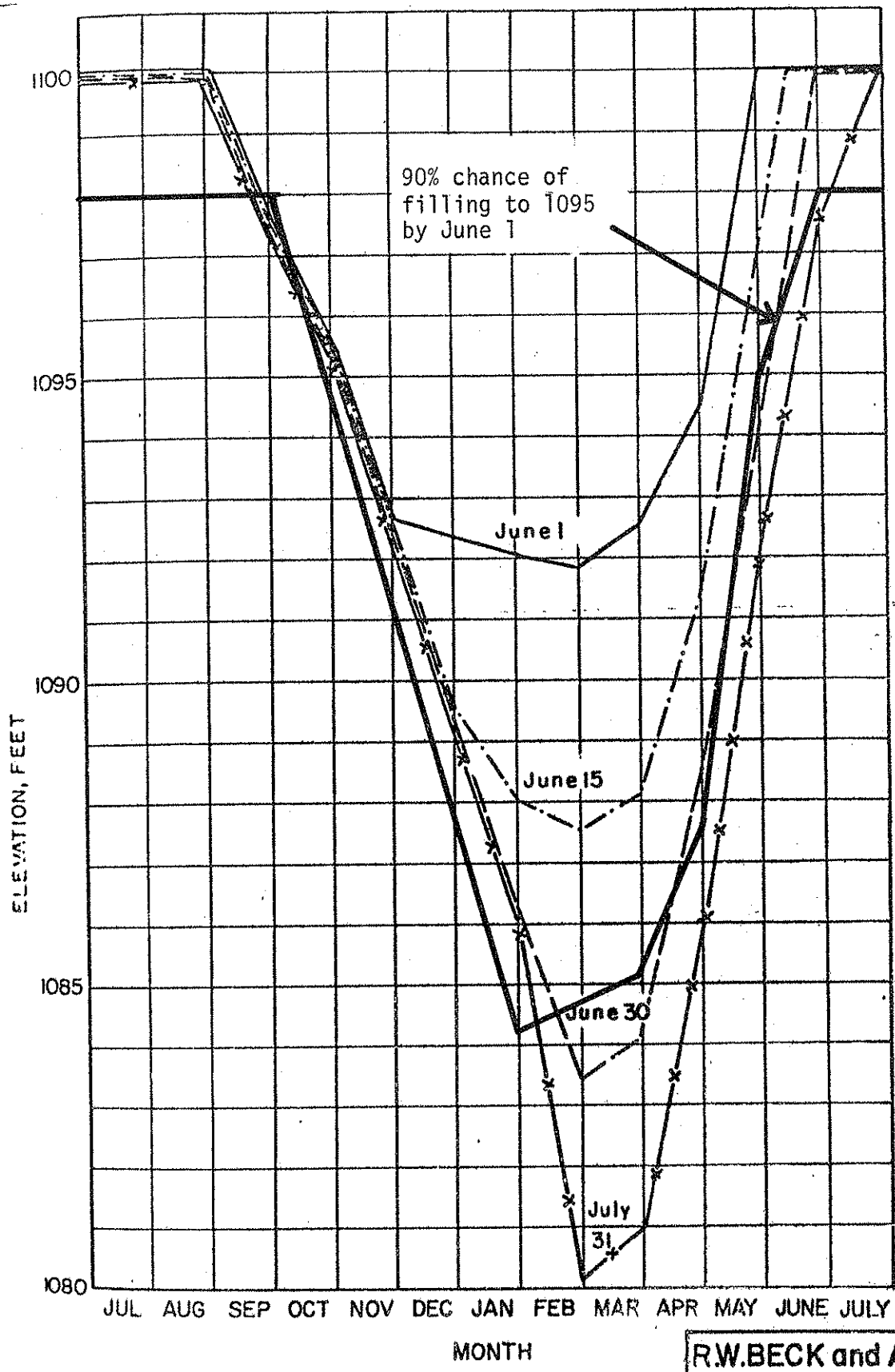


Figure 24-B
Fixed Rule
Curve
(Case 2)

LEGEND

- June 1 filling date
- June 15 filling date
- June 30 filling date
- July 31 filling date

R.W.BECK and ASSOCIATES
Analytical and Consulting Engineers
Seattle, Washington Denver, Colorado

CHELAN COUNTY PUBLIC UTILITY DISTRICT
WENATCHEE, WASHINGTON
LAKE CHELAN
PROJECT EXPANSION
RESERVOIR RULE CURVE
BASED ON WORST FLOW

DATE:	DRAWN:	APPROVED:	FIG:
11-30-71	RY		

DISCUSSION

Only one alternative lake level and date of filling has been presented in this report. The data presented are adequate to produce alternative levels, dates, and probabilities of filling as required in developing alternative management policies.

There appears to be a difference between the R. W. Beck results and the results of the analysis presented in this report. The cause of this difference has not been determined.