4.0 HYDROLOGICAL AND POWER STUDIES

4.1 Introduction

River flow records from a gaging station are usually accepted as the best indicator of future runoff from a drainage basin. The longer the period of record is, the more reliable it is assumed to be in forecasting future runoff. For Chakachamna Lake, the records of a gage located near the lake outlet cover only a relatively short period of time, May 1959 to September 1972. During that time some periods occurred during which flow rates were not obtained, reducing the continuous record to a period dating from June 1959 to August 1971.

There are no records of inflow to Chakachamna Lake, and since that information is needed to perform reservoir operation and power studies, inflows were calculated for the continuous period of record by reverse routing of outflows and making appropriate adjustments for changes in water levels. Calculated inflows for the 11 calendar years 1960 through 1970 were used in the power studies conducted during 1981 for Alternates A, B, C and D.

In order to develop a longer series of inflows to Chakachamna Lake, the lake inflows were statistically correlated with hydrometeorological records from other stations. Using the resulting correlation, inflows were calculated to produce a total period of 31 years of recorded and synthesized records. That 31-year sequence was used to determine the energy-generating potential for the recommended project, Alternative E, during the studies conducted during fiscal year 1982.

4.2 Historical Data

Hydrometeorological data from several stations in the Cook Inlet Basin were used for the derivation and extension of estimated lake inflow records. Streamflow records included the following furnished by U. S. Geological Survey:

Station No.	Description
15294500	Chakachatna River near Tyonek (the lake outlet gage)
15284000	Matanuska River near Palmer
15284300	Skwentna River near Skwentna
15292000	Susitna River at Gold Creek

Gaging Station No. 15294500 is located on the right bank of the Chakachatna River close to the outlet of Chakachamna Lake. The gage records include 13 years and 5 months from May 21, 1959 to September 30, 1972. The gage however, was destroyed by a lake outbreak flood on August 12, 1971 and the records between that date and June 20, 1972 are estimated rather than recorded flows. Thus, the period of actual record extends only from May 21, 1959 to August 12, 1971 and from June 20, 1972 to September 30, 1972. Furthermore, during that period, several of the winter-month flows were estimated because of icing conditions and instrument failure. Inaccurate winter records are not a serious engineering concern, because only 11% of the average annual flow normally occurs during the seven months from November through May.

In addition to the streamflow data, records of the water surface elevation at Station No. 15294500 were also obtained from the U. S. Geological Survey in Anchorage.

Available meteorological data consist of daily temperature and precipitation data obtained from the U. S. National Oceanic and Atmospheric Administration, National Climatic Center, Ashville, N.C. for stations at Kenai, Anchorage, and Sparrevohn.

The locations of these three meteorological stations are shown on Figure 4-1. A bar chart showing the periods of record for these stations is plotted on Figure 4-2.

4.3 Derived Lake Inflows

Chakachamna Lake with its surface area of about 26-square miles stores runoff and provides natural regulation of flow to the Chakachatna River. In order to derive a record of inflows to the lake, the regulating effects of the lake were removed from the outflow records using a reverse routing procedure which uses the basic continuity equation

$$I_t - O_t = \Delta s$$

Where

I_t is the inflow volume during month t

O_t is the outflow volume during month t

Δs is the change in lake storage during month t

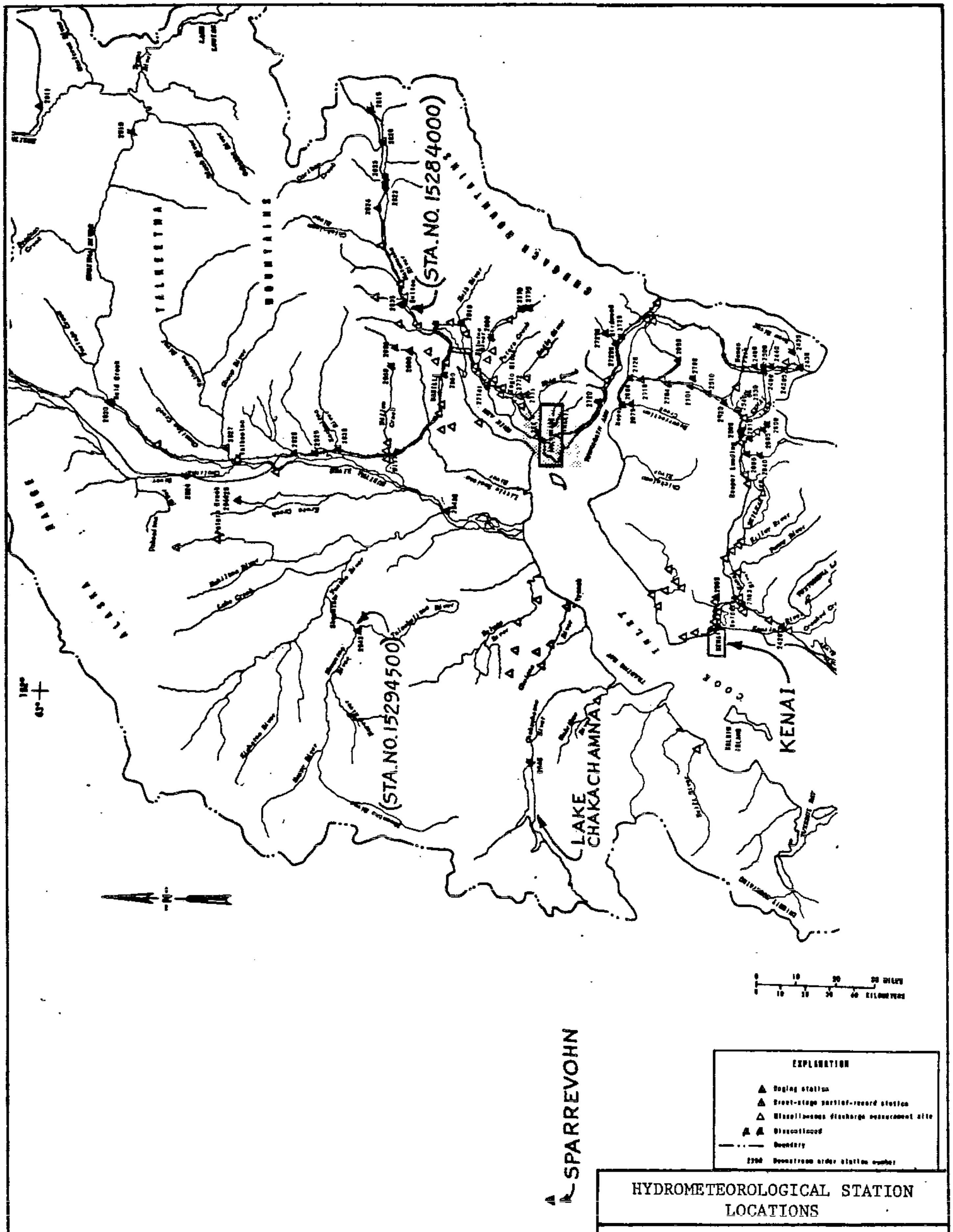
For all practical considerations, the Chakachatna River near Tyonek gage is, in effect, located at the lake outlet and field observations confirmed that gage readings closely represent the lake water-surface elevation. Hence, it was assumed for the reverse routing computations that the two were the same. Evaporation, seepage and other losses of water from the lake were assumed to be small and effectively compensated for by direct precipitation onto the lake surface.

The lake stage-storage curve used in the computations is shown on Figure 4-3. This is based on data measured by the USGS and recorded on the USGS maps Chakachatna River and Chakachamna Lake Sheets 1 and 2, dated 1960.

Average monthly inflows were calculated for the period June 1, 1959 through August 31, 1971, and are presented in Table 4-1. The calculated inflows for the 11 calendar years January 1, 1960 through December 31, 1970 were used in the power studies for Alternates A, B, C and D of the project layouts during 1981.

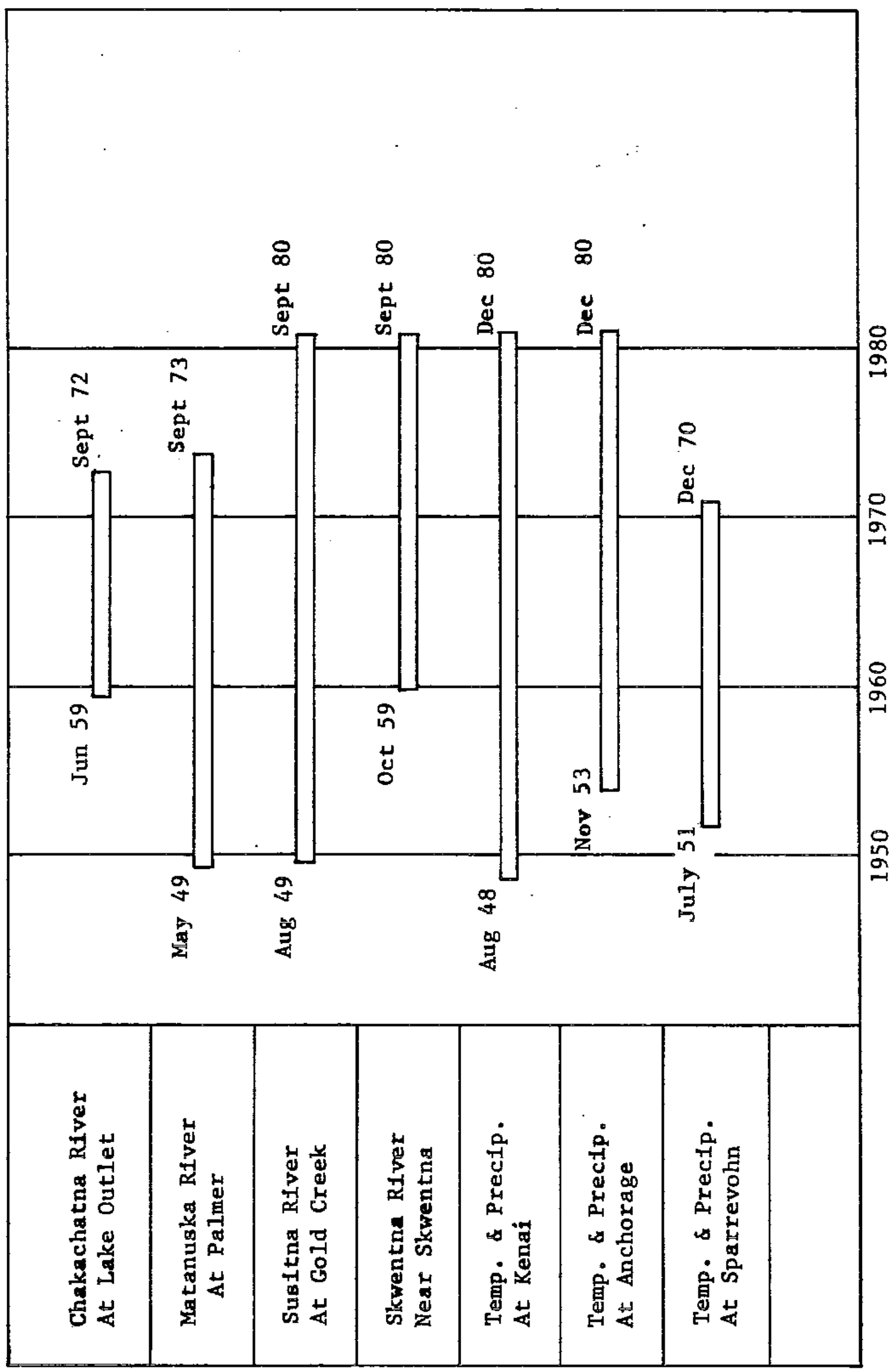
4.4 Synthesis of Long-Term Lake Inflows

In order to develop a long-term estimate of energy-production, methods for extending the inflow record were investigated. Transposition of records from other rivers in the region, correlation with meteorological data from nearby long-term stations, and combinations of both, were studied using regression analysis.



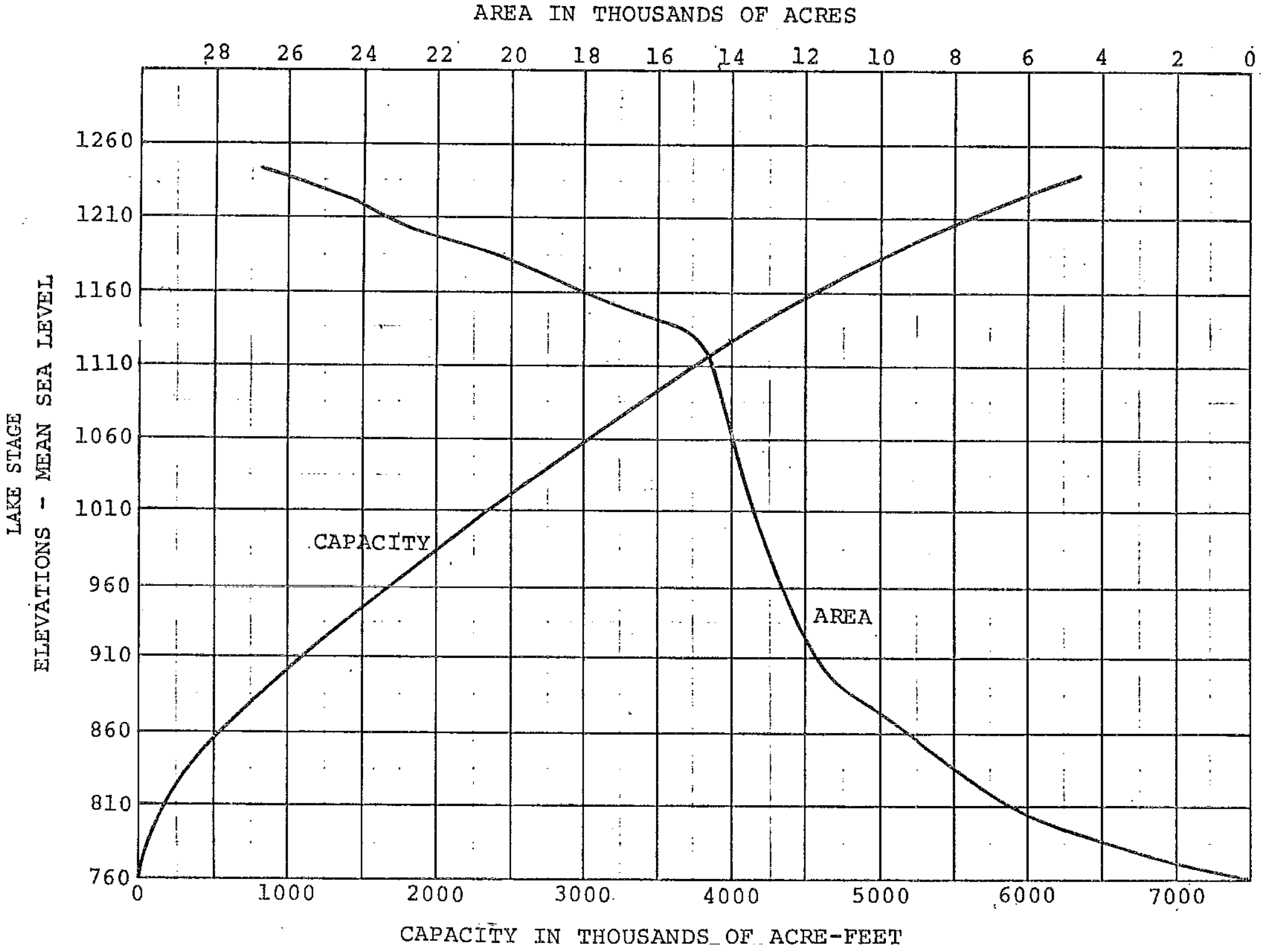
HYDROMETEOROLOGICAL STATION LOCATIONS

FIGURE 4-1



HYDROMETEOROLOGICAL STATIONS
PERIODS OF RECORD

FIGURE 4-2



CHAKACHAMNA
LAKE
AREA & CAPACITY DATA

ELEV. M.S.L.	AREA IN ACRES	CAPACITY ACRE FEET
760	0	0
765	810	2,025
770	1,300	7,300
780	2,690	27,200
800	5,670	111,000
20	7,320	241,000
40	8,270	397,000
60	9,280	572,000
80	10,400	769,000
900	11,590	988,000
20	11,960	1,224,000
40	12,320	1,467,000
60	12,650	1,717,000
80	12,980	1,973,000
1000	13,280	2,236,000
20	13,520	2,504,000
40	13,740	2,776,000
60	13,960	3,053,000
80	14,170	3,335,000
1100	14,390	3,620,000
20	14,620	3,910,000
40	16,100	4,218,000
42	16,780	4,250,000
60	18,250	4,572,000
80	19,900	4,953,000
1200	22,956	5,382,000
20	24,104	5,852,000
40	26,038	6,354,000

CHAKACHAMNA LAKE
LAKE STAGE-AREA AND CAPACITY

FIGURE 4-3

TABLE 4-1

LAKE CHAKACHAMNA INFLOWS (cfs)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JLY	AUG	SEP	OCT	NOV	DEC	MEAN
1959						9459.	10388.	11731.	3662.	1370.	654.	508.	
1960	400.	307.	267.	393.	3637.	6837.	11209.	9337.	3145.	1439.	799.	870.	3220.
1961	877.	589.	470.	346.	1881.	7983.	12808.	10899.	6225.	1586.	843.	696.	3767.
1962	633.	541.	471.	470.	1265.	7925.	13149.	10411.	5542.	1197.	863.	613.	3590.
1963	498.	357.	315.	337.	1801.	4735.	13249.	12208.	5847.	2056.	930.	710.	3587.
1964	364.	435.	332.	477.	1830.	8093.	10700.	11798.	4246.	1245.	909.	662.	3424.
1965	419.	219.	337.	398.	1286.	3490.	13046.	10516.	10802.	2114.	597.	466.	3641.
1966	388.	336.	350.	410.	1893.	8072.	10303.	9974.	6608.	1953.	910.	313.	3459.
1967	531.	449.	384.	880.	2030.	8761.	14931.	15695.	6191.	2040.	1215.	571.	4473.
1968	534.	510.	467.	630.	2996.	7808.	13117.	11257.	2793.	976.	689.	612.	3532.
1969	485.	486.	500.	652.	1948.	9271.	12510.	7297.	2793.	3057.	1215.	541.	3396.
1970	497.	504.	550.	899.	2265.	6789.	10360.	7986.	2734.	1359.	742.	460.	2929.
1971	394.	441.	513.	1275.	4063.	12672.	13695.	16680.					
MEAN	502.	431.	413.	597.	2241.	7838.	12261.	11215.	5049.	1699.	864.	585.	3606.

Examination of the inflows to Chakachamna Lake in Table 4-1, indicated that, for this watershed, the hydrological year (water year) should be defined as the period from May to April to minimize the overall basin-storage effects. The majority of the lake inflow, 93% of the annual runoff volume, occurs during May through October, while flow recession starts in November. Flows recorded at the lake outlet from November to May were, in general, estimated by USGS personnel using personal judgment because ice cover prevented proper functioning of the stage recorder during that period. The accuracy of the recorded winter streamflow is, therefore, questionable, but estimated total outflow volume during the low-flow winter months is thought to be reasonable. Because of their different hydrologic characteristics, it was decided that regression analyses should be performed separately for the periods, May to October, and November to April. In so doing, the less-accurate monthly-flow estimates for the winter period would not unduly influence calculations for flows during the remainder of each year.

The initial selection of independent variables to be used in the regression analyses was based on the lengths of the available hydrometeorologic records in the region, as well as the potential physical relationship with the inflow regime of Lake Chakachamna. Since Chakachamna Lake is glacially-fed, a heat-input index, such as monthly degree-days above 32°F recorded at Kenai and Anchorage, could be an important independent variable. Monthly streamflow records from nearby watersheds which are considered to have hydrologic characteristics similar to that of the

Chakachamna basin were also incorporated in the study. These include the streamflows of Matanuska River at Palmer, Susitna River at Gold Creek and Skwentna River near Skwentna. In addition, monthly precipitation at Kenai and Anchorage were also considered. The final selection of the independent variables used for the lake-inflow synthesis was based on the results of the preliminary analyses.

The final regression analyses were performed systematically using different combinations of the pre-selected independent variables in a step-wise regression-analysis program (Bechtel TM 750). The regression equations obtained were evaluated on the basis of probable physical relationships to topographic, meteorological and hydrologic conditions as well as the computed level of statistical significance of the correlation. It was found that for both the high and low-flow periods, May to October and November to April respectively, the monthly streamflow records for the Matanuska River at Palmer correlate well with the historical monthly Chakachamna lake inflows. The regression equations obtained were:

May - October: $Q_{Lake} = 595.0 + 0.8967\ Q_{Palmer}$
November - April: $Q_{Lake} = 265.3 + 0.4597\ Q_{Palmer}$

Correlation coefficients for these two regression equations were found to be 0.89 and 0.40 respectively and are well within the 95 percent significance level. However, the Matanuska gage was discontinued in September of 1973. Another set of regression equations was therefore required for the flow synthesis for the period after September 1973. New correlation studies were performed. It was found that recorded streamflows for Skwentna River near Skwentna were a good substitute for those at the Matanuska gage. The regression equations obtained were:

$$\text{May - October:} \quad Q_{Lake} = 674.67 + 0.5233\ Q_{SK}$$
$$\text{November - April:} \quad Q_{Lake} = 283.27 + 0.2690\ Q_{SK}$$

The correlation coefficients for these two regression equations were found to be 0.73 and 0.45 respectively and are well within the 95 percent significance level.

The correlation coefficients for the regression equations for the low-flow season are relatively low. This was to be expected, because, as discussed earlier, streamflow values for this period were known to be inaccurate since they had to be estimated by personnel from the U.S. Geological Survey on the basis of regional streamflow data and/or personal judgment because of frequent malfunctioning of gages during winter. However, the streamflow volume in this period represents only about 7 percent of the total annual runoff volume. Because the operation study used monthly flow volumes, inaccuracies inherent in the flow synthesis for the winter months do not significantly affect the overall accuracy of the study and the respective regression equations are therefore regarded as acceptable for use in the derivation of the long-term streamflow record. Table 4-2 presents the lake inflows synthesized by using these equations and the reverse-routing procedure. The 31 year sequence of inflows includes the June 1959 through August 1971 inflows calculated by reverse-routing of outflows plus the May 1949 through May 1959 and the

TABLE 4-2

CHAKACHAMNA PROJECT OPERATION STUDY
H/H,H&CF,BECHTEL CIVIL&MINERALS INC.,SF.
ALASKA POWER AUTHORITY

PROJECT 14879001 DATE 11783 PAGE 3

ALTERNATIVE E: MCARTHUR SHORT TUNNEL, WITH FISH RELEASES

INFLOWS TO THE LAKE IN CFS

YEAR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	JAN	FEB	MAR	APR	AVEYR	CALYR
1	4513.	10728.	15220.	11615.	6305.	2689.	802.	636.	542.	488.	493.	541.	4548.	1950
2	2055.	8572.	13194.	10548.	4521.	1761.	569.	532.	495.	472.	450.	631.	3650.	1951
3	3801.	10719.	13095.	8831.	8635.	3216.	842.	699.	630.	495.	467.	510.	4328.	1952
4	2027.	8204.	12575.	9431.	3562.	2712.	865.	642.	523.	477.	477.	641.	3511.	1953
5	3992.	13247.	13355.	10808.	4505.	2002.	629.	550.	527.	472.	458.	541.	4257.	1954
6	3434.	9002.	12091.	12046.	6075.	2787.	755.	619.	578.	507.	466.	487.	4071.	1955
7	2193.	6826.	12996.	9983.	5068.	1988.	595.	532.	504.	475.	449.	496.	3509.	1956
8	2936.	7475.	14601.	10235.	5940.	2053.	583.	565.	569.	536.	505.	598.	3883.	1957
9	4393.	14817.	13149.	10405.	6910.	2707.	793.	562.	569.	510.	489.	675.	4665.	1958
10	2496.	9930.	10163.	8691.	3452.	1896.	526.	483.	426.	468.	449.	526.	3292.	1959
11	3120.	9459.	10388.	11731.	3662.	1370.	654.	508.	400.	307.	267.	393.	3522.	1960
12	3637.	6837.	11209.	9337.	3145.	1439.	799.	870.	877.	589.	470.	346.	3296.	1961
13	1881.	7983.	12808.	10899.	6225.	1586.	843.	696.	633.	541.	471.	470.	3753.	1962
14	1265.	7925.	13149.	10411.	5542.	1197.	863.	613.	498.	357.	315.	337.	3539.	1963
15	1801.	4735.	13249.	12208.	5847.	2086.	930.	710.	364.	435.	332.	477.	3598.	1964
16	1830.	8093.	10700.	11798.	4246.	1245.	909.	662.	419.	219.	337.	398.	3405.	1965
17	1286.	3490.	11633.	11929.	10802.	2114.	597.	466.	388.	336.	350.	410.	3650.	1966
18	1893.	8072.	10303.	9974.	6608.	1953.	910.	313.	531.	449.	384.	880.	3523.	1967
19	2030.	8761.	14931.	15695.	6191.	2040.	1215.	571.	534.	510.	467.	630.	4465.	1968
20	2996.	7808.	13117.	11257.	2793.	976.	689.	612.	485.	486.	500.	652.	3531.	1969
21	1948.	9271.	12478.	7297.	2793.	3057.	1215.	601.	497.	504.	550.	899.	3426.	1970
22	2265.	6789.	10360.	7986.	2734.	1359.	742.	460.	394.	441.	513.	1275.	2943.	1971
23	4063.	12672.	13695.	16680.	5075.	3181.	1090.	736.	581.	531.	492.	479.	4940.	1972
24	3468.	8228.	13490.	9263.	5012.	2396.	679.	514.	495.	492.	480.	586.	3759.	1973
25	2131.	7457.	8850.	7809.	2794.	2527.	740.	623.	558.	526.	501.	554.	2923.	1974
26	4215.	6248.	6781.	6159.	6850.	3059.	909.	530.	498.	485.	485.	489.	3059.	1975
27	4784.	10649.	10889.	6802.	5107.	3136.	814.	622.	544.	524.	498.	625.	3750.	1976
28	5283.	8587.	8304.	6494.	4947.	3917.	1058.	1055.	1044.	773.	606.	606.	3556.	1977
29	5335.	19864.	13898.	11224.	6059.	3709.	922.	700.	609.	537.	509.	558.	5327.	1978
30	5387.	7917.	10146.	7865.	4513.	3258.	708.	701.	597.	562.	547.	713.	3576.	1979
31	6776.	8514.	8958.	9157.	4572.	4471.	1412.	882.	762.	718.	647.	810.	3973.	1980
MEAN	3201.	8996.	11928.	10147.	5177.	2383.	828.	621.	551.	491.	465.	588.	3781.	
MAX	6776.	19864.	15220.	16680.	10802.	4471.	1412.	1055.	1044.	773.	647.	1275.	5327.	
MIN	1265.	3490.	6781.	6159.	2734.	976.	526.	313.	364.	219.	267.	337.	2923.	

September 1971 through April 1979 inflows calculated from the regression equations.

4.5 Power Studies

During the 1981 project studies four basic alternative project layouts were developed and designated Alternatives A, B, C and D as described in Section 3.3 of this report. Power studies also performed during 1981 for these four alternates were based on the 11 complete calendar years (January 1, 1960 through December 31, 1970) of Chakachamna Lake inflow set forth in Table 4-1. During the 1982 studies, the recommended Alternative E, also described in Section 3.3, was developed, as was the 31 year sequence of inflow to Chakachamna Lake which was used during the 1982 power studies for each of the alternatives A through E. The power operation studies were performed to determine generated firm and secondary energy, flow releases, and the fluctuations in the water surface elevation of Chakachamna Lake for a range of installed capacities for each of the five project alternatives. The studies were made using a computer program that performs sequential routing of the derived monthly inflows while satisfying power demands, projected in-stream flow requirements, and physical system constraints. Power demands were in accordance with a plant load factor of 0.5, and the monthly variations in peak demand listed in Table 4-3. As advised by APA, these demands are those being used in the evaluation of sources of power alternative to that of the Chakachamna Hydroelectric Project.

The in-stream flow requirements, listed in Table 4-4, represent provisional minimum monthly flows to be

TABLE 4-3

MONTHLY PEAK POWER DEMANDS USED IN POWER STUDIES

MONTH	MONTHLY PEAK DEMAND (Percent of Annual Peak Demand)
January	92
February	87
March	78
April	70
May	64
June	62
July	61
August	64
September	70
October	80
November	92
December	100

Source: Susitna Hydroelectric Project Development Selection Report Appendix D, Table D.1 (Second Draft, July 1981)

TABLE 4-4

PROVISIONAL MINIMUM RELEASES FOR INSTREAM FLOW IN CHAKACHATNA RIVER DOWNSTEEAM FROM CHAKACHAMNA LAKE OUTLET FOR USE IN POWER STUDIES

MONTH	MC ARTHUR TUNNEL DEVELOPMENT ALTERNATIVE B (CFS)*	CHAKACHATNA TUNNEL DEVELOPMENT ALTERNATIVE D (CFS)	MCARTHUR TUNNEL DEVELOPMENT ALTERNATIVE E (CFS)*
January	365	30	365
February	343	30	357
March	345	30	358
April	536	30	582
May	1,094	30	1,094
June	1,094	30	1,094
July	1,094	30	1,094
August	1,094	30	1,094
September	1,094	30	1,094
October	365	30	365
November	365	30	365
December	360	30	363

* Criteria used to determine fish instream flow release:

April through September - 1094 cfs or inflow to lake whichever is less

October through March - 365 cfs or inflow to lake whichever is less released into the Chakachatna River near the lake outlet as further discussed in Sections 7.3.2 and 7.3.3 of this report.

The physical system constraints, set forth in Table 4-5, are the overall plant efficiency, tailwater elevation, and head loss for the hydraulic conduits.

In the power studies water was drafted from lake storage whenever the monthly inflows were insufficient to meet the power demand. It was assumed that spill, or discharge of water from the lake into the Chakachatna River in excess of the tentative instream requirements would occur whenever the lake water level exceeded elevation 1,128 feet, for alternatives A through D, and 1155 for alternative E. The secondary energy is that which can be generated by plant capacity in excess of that needed to meet the load carrying capability, using water which otherwise would have spilled.

For each of the alternatives considered for development of the project, a range of installed powerplant capacities was tested in order to establish the installed capacity that would make the most use of all water available for power generation without drawing the lake level below a given minimum elevation. This minimum was taken as elevation 1,014 feet for alternatives A through D and elevation 1,085 for alternative E respectively. The lake was assumed to be full at the beginning of each run.

4.6 Results

The results of the power studies listed in Table 4-6 show that, on the basis of the 11 calendar years of

TABLE 4-5

POWERPLANT SYSTEM CONSTRAINTS FOR ALTERNATIVE PROJECT DEVELOPMENTS

ALTERNATIVE	PLANT EFFICIENCY (%)	PLANT FACTOR	AVERAGE TAILWATER ELEVATION (FT.)	HEAD LOSS IN HYDRAULIC CONDUITS (FT.)
A	85	0.50	210	$0.0000024 \times Q^2$
B	85	0.50	210	$0.0000024 \times Q^2$
C	85	0.50	400	$0.0000028 \times Q^2$
D	85	0.50	400	$0.0000028 \times Q^2$
E	85	0.45	210	$0.0000024 \times Q^2$

Note: Q = Flow in cubic feet per second.

TABLE 4-6

POWER STUDIES SUMMARY

Development Alternative	Installed Capacity (MW)	Average Annual Energy		Average Annual Flow	
		Firm (GWh)	Secondary (GWh)	Power Diversion (CFS)	Provisional Instream (CFS)
A	400	1752	153	3322	0
B	330	1446	124	2701	679
C	300	1314	139	3230	0
D	300	1314	130	3239	30
E	330	1301	290	2274	685

Note: Period of record January 1, 1960 to December 31, 1970
Average annual inflow to Chakachamna Lake 3547 cfs (2.6 million AF)
Alternatives A, B - Development via McArthur tunnel
Alternatives C & D - Development via Chakachatna tunnel

Period of record May 1, 1949 to April 30, 1979
Average annual inflow to Chakachamna Lake 3781 cfs (2.7 million AF)
Alternative E - Development via McArthur Tunnel

Power diversion flows are the flows needed to meet firm energy requirements.

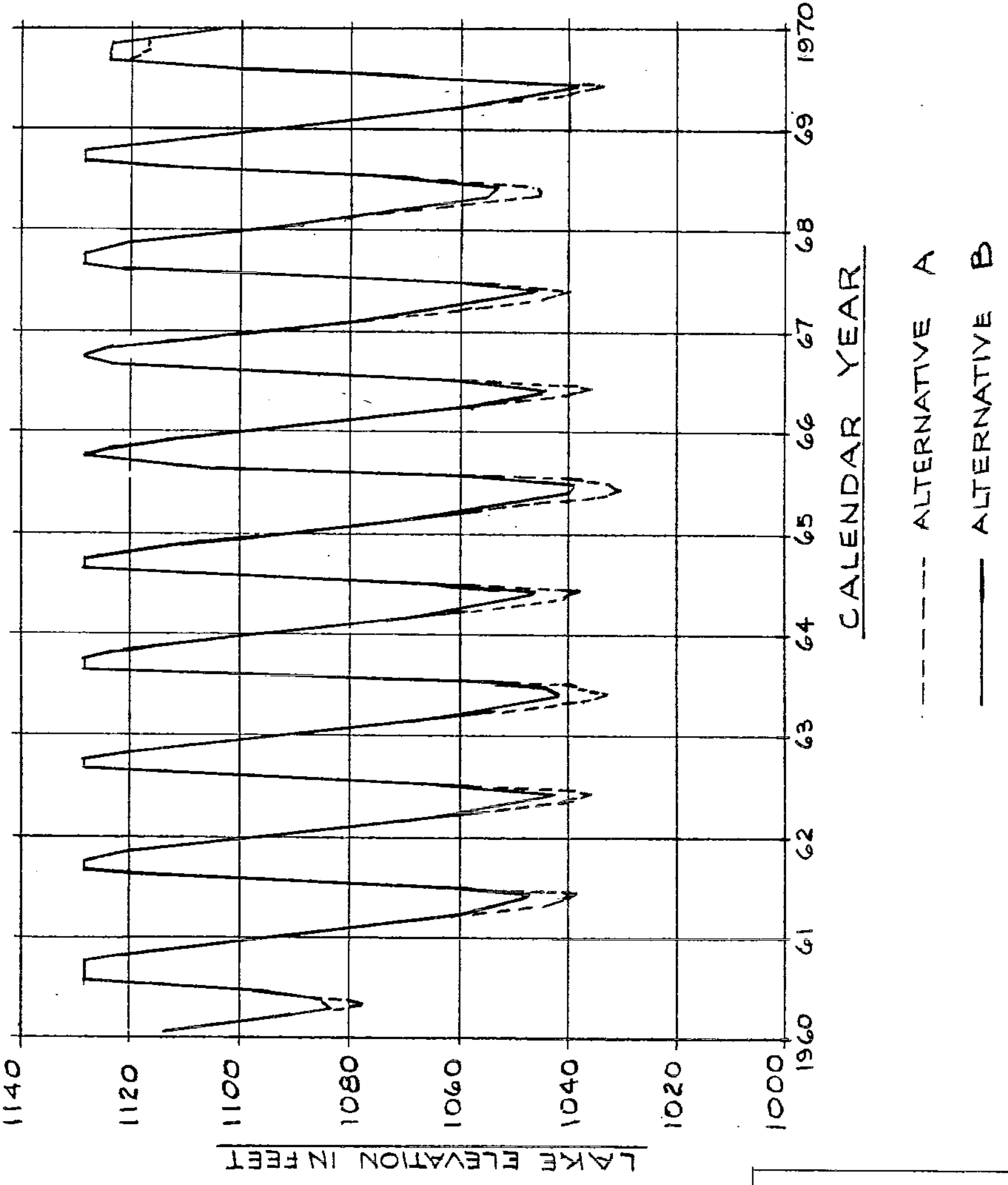
inflow, and with the parameters used in the studies, the optimum development via the McArthur Tunnel could support a powerplant of 400 MW installed capacity when all controlled water is used for power generation as in Alternative A. At 50% plant factor, this provides an average annual 1,752 GWh of firm energy. The provisional instream flow requirements of Alternative B discussed in Section 7.3.2 of this report represent about 19% of the average annual flow in the Chakachatna River during the period of record. If that amount of water is reserved for instream flow, the installed capacity of powerplant that could be justified at the McArthur River would be reduced to 330 MW and the firm average annual energy would be 1446 GWh.

For development via the Chakachatna tunnel, the optimum power development using all controlled water for power generation, Alternative C, would have an installed capacity of 300 MW and firm annual average energy would be 1314 GWh for a 50% plant factor. The provisional minimum instream flow reservations in Alternative D, discussed in Section 7.3.3 of this report, represent less than 1% of the average annual flow during the period of record. Thus, the installed capacity and firm energy in Alternative D for practical purposes would remain the same. There would however be about 15% reduction in the amount of secondary energy that could be generated.

Alternatives A through D cannot firmly support the capacities determined from the 11 years of inflow during the 1981 studies and the recommended Alternative E cannot firmly support 330 MW at 50% plant factor due to two consecutive dry years (1973-74) that occur during the 31 years of correlated lake inflow. These two years do not occur in the 11 calendar years (1960-1970) of inflow used in the 1981 power studies for Alternates A through D and some additional analyses should be made in future studies of the project. Using the 31 years of inflow, and 330 MW installed capacity, Alternate E could produce 1301 GWh at 45% load factor.

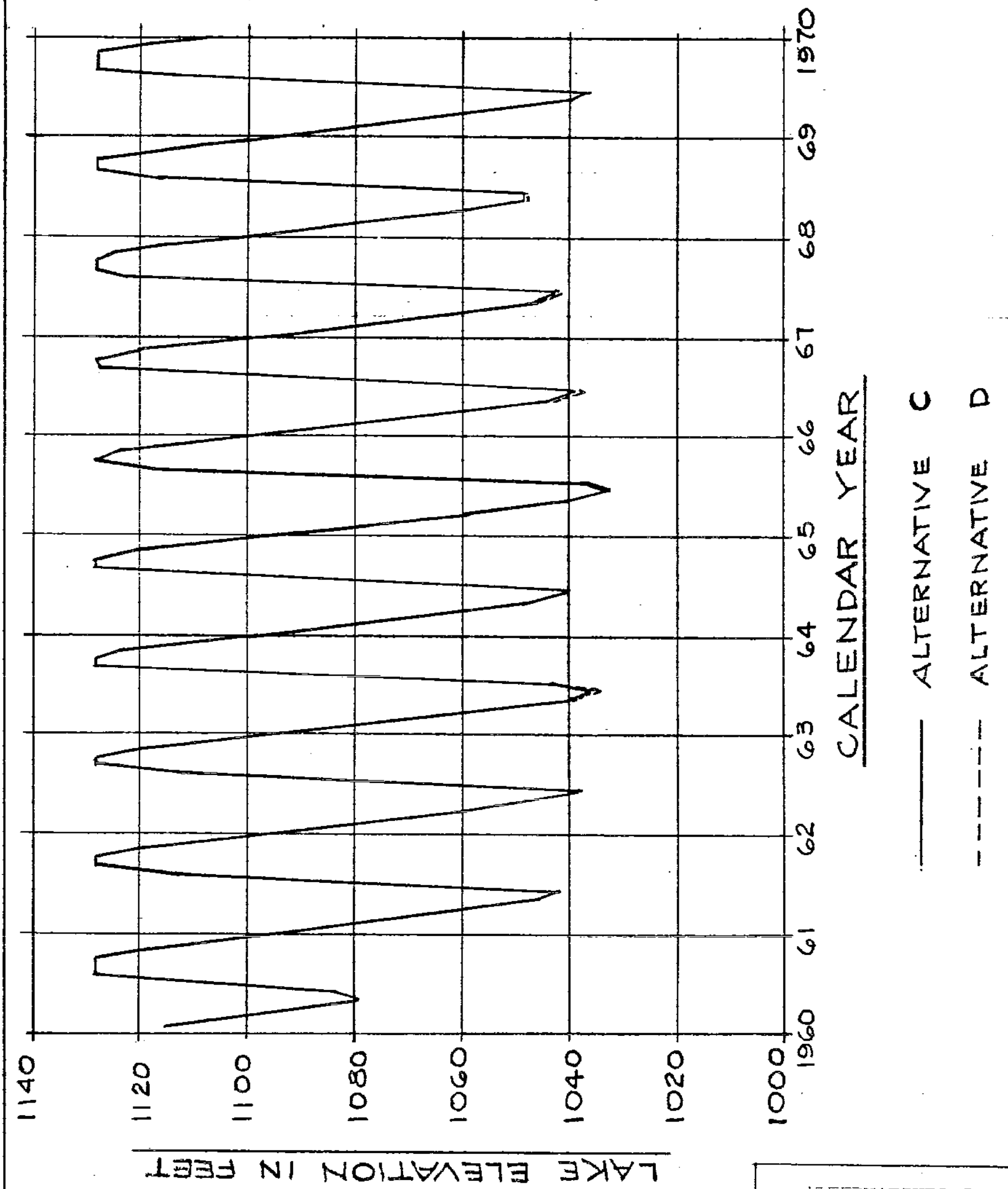
4.7 Variations in Lake Water Level

The variations in lake water-surface elevation calculated at the end of the month during the course of the power studies for each of the five alternatives and cases listed in Table 4-6 are shown in the computer output included in the Appendix to Section 4.0, and are also plotted in Figures 4-4 and 4-5.



ALTERNATIVES A & B
LAKE LEVEL VARIATIONS

FIGURE 4-4



ALTERNATIVES C & D
LAKE LEVEL VARIATIONS

FIGURE 4-5