University of Minnesota
St. Anthony Falls Hydraulic Laboratory

Project Report No. 184

THE EFFECTS OF DIFFERENT OPERATING PLANS FOR THE SIX MISSISSIPPI RIVER HEADWATERS DAMS, PART I

by

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SYLLABUS

The study reported herein is part of a larger study concerning the hydraulic and economic effects of implementing various operating plans for the six Mississippi River Headwaters Dams. This portion of the study involved assembling supportive data, determining investigative techniques, conducting computer runs involving program HEC-5C, and preparing a preliminary report concerning four operating plans. These plans are: (1) present operating plan, (2) natural flow plan (assuming dams do not exist), (3) low-flow plan (to provide a minimum flow of 1600 cfs at Anoka, Minn.), (4) high-flow plan (similar to present operating plan, but with the primary objective of protecting Aitkin from flooding).

Data on reservoir elevations, reservoir releases and flows at selected points down to St. Paul were assembled. Reverse routing was used to determine inflow to the reservoirs. Using actual releases, the local inflow was determined for river segments or reaches from the reservoirs to St. Paul. Using computer program HEC-5C and actual releases from the reservoirs, the input data were checked. Runs were then performed using HEC-5C and the four operating plans.

Approximately 374 graphs were then plotted to show output from these runs and analysis of the data. These included: reservoir elevations and releases on a monthly bases for the period 1932 to 1976 for each of the four plans; selected daily flows at Aitkin and Anoka; high and low elevation probabilities for the six reservoirs; high-flow probabilities at Aitkin; and low flow probabilities at Anoka. Sample copies of the graphs are included in the text, but a major portion are included in the Appendices, which are available in only a few copies of the report.

Using damage curves for the reservoirs and Aitkin, damage probability curves were plotted and integrated to determine mean annual damage for the reservoirs and Aitkin (these were prepared for the period 1 May to 30 September). Potential losses were also determined for the Twin City metropolitan area due to river flows below 1600 cfs at Anoka.

Comparisons of this data for the four operating plans indicated the following:

1. Considering the six reservoirs plus Aitkin, the Present Operating Plan has the minimum annual damage of $757,386 compared to the next higher values of $876,737 for the Low-Water Plan.
2. Considering the six reservoirs, Aitkin and "potential losses" for the Twin City metropolitan area, the Low-Water Plan is best, with damages plus potential losses of $1,981,000 per year. The next higher value would be $4,523,135 for the High-Water Plan, followed by $5,245,886 for the Present Operating Plan.
3. Considering only the fluctuation of reservoir levels (subtotal for the 6 reservoirs) the Present Operating Plan is best with annual damages of $447,786 as compared to $576,217 for the Low-Water Plan.
4. Plates 93 and 95 and Table 8 are helpful in evaluating the four plans.

Additional computer runs are desirable. Consideration should be given to possible increases in the low flows at Anoka by changes in index levels and possibly by changes in other features or input data for program HEC-5C.

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University students who actively participated in the study included Carlton Gutschick, Nels P. Nelson, Wesley Schevenius, John Falch, and Gary Beck.

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BACKGROUND

The Corps of Engineers constructed six water control dams on lakes in the headwaters area of the Mississippi River between 1881 and 1913 (Plate 1), primarily to benefit river navigation with incidental benefits for logging. Most of the land bordering the lakes was originally owned by the Federal Government, and flowage easements were acquired on all other riparian lands. Much of the land owned in fee was later sold, although the Government reserved, and still retains, all flowage rights on lands required for full operation of the lakes. All homesites, resorts, and commercial establishments on the shores of these lakes have been developed on lands leased from the Government or on privately-owned lands subject to Government rights.

The need for water release to aid navigation was greatly reduced by completion of a 9-foot navigation channel below Minneapolis in the 1930's. With the development of recreation as a business, recreation interests exerted constantly increasing pressure on the Government to stabilize water levels in the lakes. Both upstream and downstream interests became increasingly concerned about the flood control effects of headwaters lakes operation. Successive modifications of the operating regulations were made by which minimum levels were raised and flood storage capacity drastically reduced. The following two tables, Plates 1 and 2, summarize current Mississippi River Headwater Lakes elevation and other pertinent data.

GENERAL OPERATING DATA - MISSISSIPPI RIVER HEADWATERS RESERVOIRS

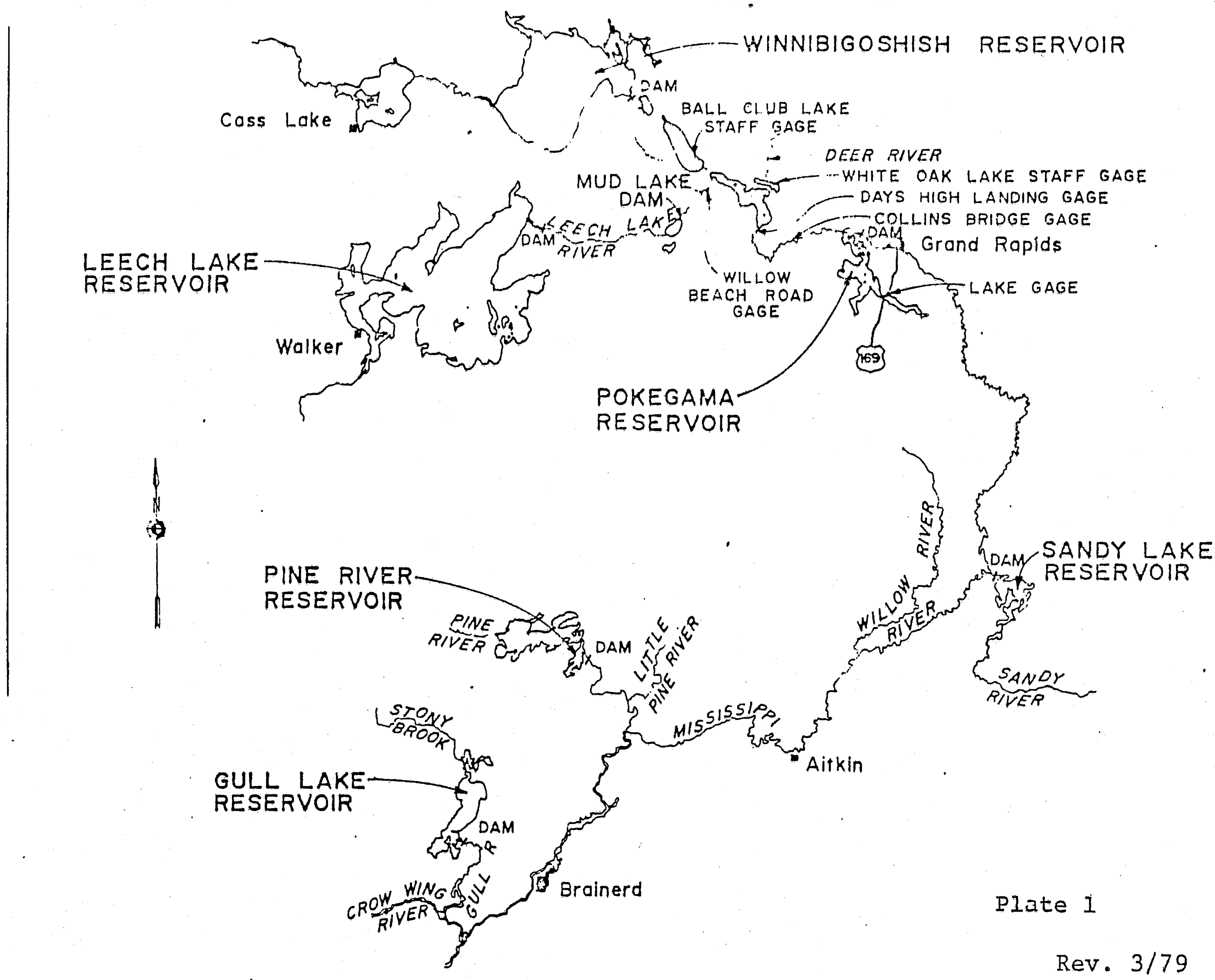


Plate 1

Rev. 3/79

LAKE ELEVATIONS IN FEET - 1929 ADJ.

RESERVOIR	WINNI-BIGOSHISH	LEECH	POKEGAMA	SANDY	PINE	GULL
NORMAL SPRING STAGE (DATE)	1296.94(3/1)	1293.20 (3/1)	1270.42(3/15)	1214.31(2/15)	1227.32(2/15)	1192.75(2/15)
DESIRABLE SUMMER RANGE	1298.94-1299.44	1294.50-1294.90	1273.17-1273.67	1216.06-1216.56	1229.07-1229.57	1193.75-1194.00
ORIGINAL OPERATING LIMITS	1288.94-1303.14	1292.20-1297.94	1268.92-1276.42	1207.91-1218.31	1217.62-1234.82	1188.75-1194.75
CAPACITY, ORIGINAL OPERATING LIMITS, AC-FT	982,600	742,500	97,500	78,600	177,900	71,600
PRESENT OPERATING LIMITS	1294.94-1303.14	1292.70-1297.94	1270.42-1276.42	1214.31-1218.31	1225.32-1231.32	1192.75-1194.75
PRESENT ORDINARY OPERATING LIMITS	1296.94-1300.94	1293.20-1295.70	1270.42-1274.42	1214.31-1218.31	1226.32-1230.32	1192.75-1194.75
DESIRABLE OPERATING LIMITS	1296.94-1299.44	1293.20-1295.70	1271.42-1274.42	1214.31-1218.31	1227.32-1230.32	1192.75-1194.75
CAPACITY, PRESENT OPERATING LIMITS, AC-FT	668,800	689,000	80,100	37,600	79,900	26,000
FLOWAGE RIGHTS ACQUIRED TO ELEVATION OF	1306.94+	1301.70+	1280.42+	1222.31+	1238.82+	1198.75+
MAXIMUM ELEVATION EVER ATTAINED	1303.39	1297.88	1277.92	1224.82	1234.56	1195.05
NUMBER OF TIMES UPPER OPERATING LIMIT HAS BEEN EXCEEDED	2	0	18	18	0	8
NO. TIMES FLOWAGE LIMITS HAVE BEEN EXCEEDED	0	0	0	1	0	0
MAXIMUM ELEVATION ATTAINED 1950	1303.17	1296.81	1277.39	1224.82	1231.41	1195.01
RESERVOIR IN OPERATION	1884	1884	1884	1895	1886	1912

STAGES IN USE PRIOR TO JULY 1973

RESERVOIR	WINNI-BIGOSHISH	LEECH	POKEGAMA	SANDY	PINE	GULL
NORMAL SPRING STAGE (DATE)	8.0 (3/1)	0.5 (3/1)	6.0 (3/15)	7.0 (2 15)	11.0 (2/15)	5.0 (2/15)
DESIRABLE SUMMER RANGE	10.0-10.5	1.8-2.2	8.75-9.25	8.75-9.25	12.75-13.25	6.0-6.25
ORIGINAL OPERATING LIMITS	0'-14.2'	-0.5'-5.24'	4.5'-12'	0.6'-11'	1.3'-18.5'	1.0'-7.0'
CAPACITY, ORIGINAL OPERATING LIMITS AC-FT	982,600	742,500	97,500	78,600	177,900	71,600
PRESENT OPERATING LIMITS	6'-14.2'	0'-5.24'	6'-12'	7'-11'	9-15.0	5'-7'
PRESENT ORDINARY OPERATING LIMITS	8'-12'	0.5'-3.0'	6'-10'	7'-11'	10'-14'	5'-7'
DESIRABLE OPERATING LIMITS	8'-10.5'	0.5'-3.0'	7'-10'	7'-11'	11'-14'	5'-7'
CAPACITY, PRESENT OPERATING LIMITS AC-FT	668,800	689,000	80,100	37,600	79,900	26,000
FLOWAGE RIGHTS ACQUIRED TO STAGE OF	18'+	9'+	16'+	15'+	22.5'+	11.0'+
MAXIMUM STAGE EVER ATTAINED	14.45'	5.18'	13.50'	17.51'	18.24'	7.3'
NUMBER OF TIMES UPPER OPERATING LIMIT HAS BEEN EXCEEDED	2	0	18	18	0	8
NO. TIMES FLOWAGE LIMITS HAVE BEEN EXCEEDED	0	0	0	1	0	0
MAXIMUM STAGE ATTAINED IN 1950	14.23'	4.11'	12.97'	17.51'	15.09'	7.26'
ZERO OF GAGE:						
(U.S.E., DATUM)	1290.08'	1293.76'	1265.27'	1209.00'	1218.20'	1190.00'
(M.S.L., 1912 ADJ.)	1289.47'	1293.23'	1264.89'	1207.70'	———	1188.14'
(M.S.L., 1929 ADJ.)	1288.94'	1292.70'	1264.42'	1207.31'	1216.32'	1187.75'
RESERVOIR IN OPERATION	1884	1884	1884	1895	1886	1912
TOP OF PIERS	15.42	6.84	14.0	14.0	19.5	10.0
SILL	-4.78	-4.96	0.00	0.00	+0.33	+1.0

Plate2

Scope of the Study

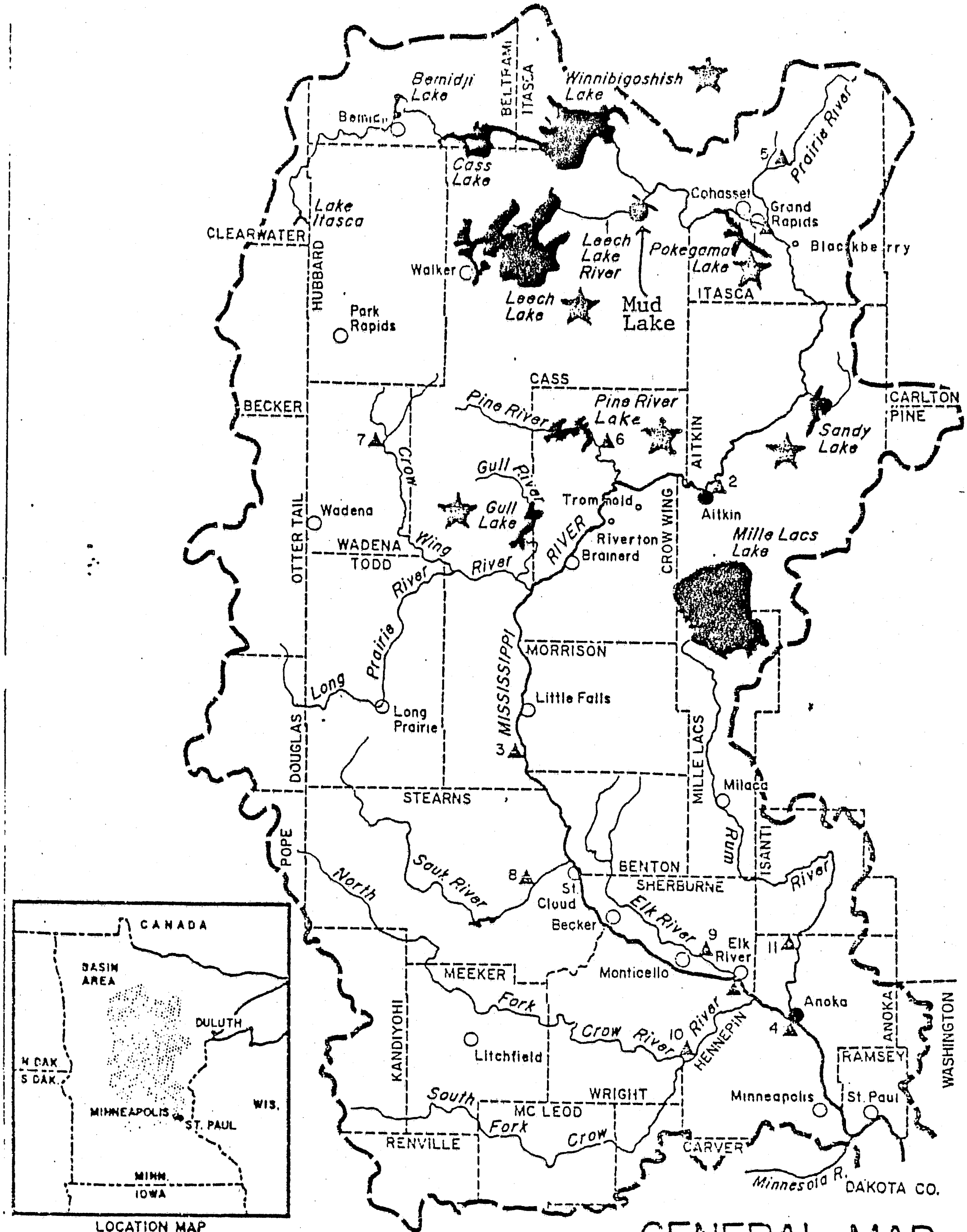
This investigation of the six Mississippi River headwaters lakes centers upon the comparison of alternative plans for operating the six Corps constructed dams. The study is restricted to evaluating only 4 plans that will produce a significant variation in effects at 8 key locations. The 8 locations (Plate 3) are the six Mississippi River headwaters lakes themselves, the City of Aitkin, and the Minneapolis-St. Paul, Minnesota metropolitan area (represented by the Anoka, Minnesota location, immediately upstream of the metropolitan area). It is also the intent of this study to establish the investigative techniques that can be readily used to evaluate additional operation plans in the future.

Prior Work

A special study of the operation of the six Corps-controlled Mississippi River headwaters lakes was undertaken by the St. Paul District from 1962 to 1966. This was an electronic computer study to evaluate the effects on the six controlled lakes, if added flow releases were made available for downstream interests. The study was prompted by the increased interest of the State of Minnesota, in taking over the operation of the six Corps dams, and by the concerns expressed by both upstream and downstream interests in the overall operation of the lakes.

The study objectives were to evaluate several operating plans and their effects on lakeshore property owners and downstream flooded interests. Investigation of possible low-flow augmentation for the Minneapolis-St. Paul Metropolitan area was a large part of the computer study. The effects on fish and wildlife and wild rice were also of concern, but probably not to the degree such a study would consider, if conducted today.

The study included an economic evaluation of the effects of several plans of reservoir operation in comparison with each other. An extensive field damage survey around each lake was conducted during the period 1962-1963. Loss of business and flood damages caused by observed fluctuating lake levels were summarized in the form of high and low stage versus damage curves. These curves were then used to estimate the average annual damage which would occur with a particular plan of operation.



LEGEND

Corps Dams

STREAMFLOW GAGING STATIONS

0 10 20 30
SCALE IN MILES

GENERAL MAP
UPPER MISSISSIPPI RIVER BASIN ABOVE THE MINNESOTA RIVER

Plate 3

A total of 8 computer runs or alternate plans were scheduled for evaluation from both a hydrologic and economic aspect. However, the study ended inconclusively with no final report being prepared. Lack of study completion money, a shift in emphasis on other studies, and major flood problems within the district prevented completion of the study. However, the general feeling at the cessation of study effort, was that the current plan of operation for the six headwaters dams was reasonably satisfactory and fair to affected interests.

THE CURRENT STUDY

Introduction

The study reported herein is Part I of a proposed larger study concerning the "hydraulic and economic effects of implementing a number of different operating plans for the six Mississippi headwaters dams (Winnibigoshish, Leech, Pokegama, Sandy, Pine River and Gull)."

"Part I involves assembling supportive data; determining investigative techniques; conducting computer runs using the HEC-5C computer program; and preparing a preliminary report on the present plan of operation, natural flows, and high flow and low flow plans of operation for the six Mississippi River headwaters dams." The 4 plans are defined in more detail in a following section.

The study products are as follows:

a) Plots of both low and high-stage frequency curves for each of six headwaters reservoirs for the period 1932 to 1976, for each of the operating plans investigated. The curves are developed for the recreation season, 1 May to 30 September because many damages in the reservoir region would be of primary concern during the recreation season.

b) Plots of high flow frequency curves at Aitkin, Minnesota and plots of low flow frequency curves at the St. Paul gauge (later changed to the Anoka gauge) for the period of 1932 to 1976, for each of the plans investigated. The curves are developed for the recreation season, 1 May to 30 September.

c) Plots of four plans (present operation, natural, high flow and low flow) at the Anoka gauge and at each of the six headwaters lakes for the 1932 to 1976 period.

d) Summary of average May-Sept. damages to Aitkin and annual losses at the Anoka gauge for the four operating plans.

e) A tabulation which conveniently compares the results of all computer runs in terms of economic and hydrologic effects on flow at Aitkin and the Anoka gauge and in terms of economics and hydrologic effects on stages in each of the six headwaters reservoirs.

In the past, significant problems have involved the following:

1. Excessively high water in the reservoirs has caused damage to structures around the reservoirs.

2. Excessively low water has created objectionable conditions relative to recreational uses of the reservoirs.

3. Variations in reservoir level have interfered with wild rice growing and fish spawning.

4. High river flows have caused both urban and agricultural damage in the vicinity of Aitkin.

5. Low flows in the Mississippi River have been a matter of concern in downstream areas, particularly the Minneapolis-St. Paul metropolitan area. Of primary concern are water supply and wastewater dilution.

In some instances, the operation of the reservoirs for one objective will interfere with other objectives.

As noted above, the present study involves four operating plans. These are:

1. <u>Present Plan of Operation</u>

The present plan of operation is the product of continual refinement and adjustments to broad operating limits for each of the lakes. The plan has been developing since the headwaters dams were constructed in the late 1800's and early 1900's. Cumulative refinements and adjustments have been made as a result of public hearings and studies that have been carried out since that time.

Winnibigoshish and Leech Lakes, the two larges lakes, are operated to provide flood storage early in the spring so that outflows can be reduced to near zero during high stages at Aitkin, Minnesota. The operation of the two lakes farther downstream, Pokegama and Sandy Lakes, is regulated parallel with the observed stages at Aitkin, Minnesota, to cause the least total damage in the Pokegama, Sandy, and Aitkin areas.

During floods, the three damage-prone areas of Pokegama, Sandy, and Aitkin are currently operated to follow as closely as possible a rule curve which minimizes total area flood damages and which equalizes flood damages between Pokegama and Sandy Lakes.

2. Natural Conditions

This alternative considers the hydrologic results of returning to natural conditions; that is, the conditions with no dams controlling elevations or flows from the six headwaters lakes provides a useful comparison. A natural condition analysis is essential to compare the effects that an operating plan has had on natural lake levels and flows.

3. Flood Control Plan for Aitkin or High Flow Plan

This plan assumes the lakes are to be operated exclusively for flood control at Aitkin with less regard to damage to lake property. In contrast, the present approach to providing flood protection for the Aitkin area by controlling outflow from the four upstream lakes (Winnibigoshish, Leech, Pokegama, and Sandy) is limited primarily by established minimum drawdown levels in the lakes, maximum water levels that can be tolerated by lake property owners, hydraulic limitations of channel capacities, and the outflow capacities of the control dams.

4. Water Supply Plan for the Twin Cities or Low Flow Plan

The proposed plan would allow additional flow releases to insure that flows in the Twin Cities metropolitan area would not drop below approximately 1,600 cfs. This flow is considered to be the minimum required to meet water supply and steam power needs in the Twin Cities area in the year 2015. This flow would also meet navigation and irrigation requirements upstream of Anoka. Table 1 summarizes minimum upper Mississippi River flow requirements (including the Twin Cities).

Table 1

Preliminary Summary of Upper Mississippi River Low-Flow Water Needs,
Including the Twin Cities

Use	Need (in million gallons per day)				
	1970	1980	1990	2000	2015
Navigation[1]	225	225	225	225	225
Irrigation upstream of Anoka[2]	20	47	67	87	120
Hydropower and steam electric demands[3]	437	437	437	437	437
Twin Cities area water supply					
Total[4]	306.1	381.2	509.1	679.2	1,010[6]
Surface water only[5]	101.1	151.2	189.1	256.2	485[6]
Amount required to meet surface water needs (irrigation, hydropower, and Twin Cities surface water supply)	558.1 (865 cfs)	635.2 (985 cfs)	693.1 (1,075 cfs)	780.2 (1,210 cfs)	1,042 (1,615 cfs)

(1) Minneapolis-St. Paul Level B Study, June 1977, page IX-3.
(2) 9 September 1964 summary of water quality and irrigation needs by Corps of Engineers.
(3) Based on peak cooling demand at Riverside steam power plan (from Level B, Minneapolis-St. Paul Water Supply Task Group Technical Paper).
(4) Minneapolis-St. Paul Level B Study, June 1977, Page V-5.
(5) From figure 1 (same source as footnote 3).
(6) Extrapolation.

Examination of the Anoka, Minnesota, stream gauge flow records for the period 1931-1976 indicates that there were 38 months when the average monthly flow was below 1,600 cfs (year 2015 requirements). The metro area would need headwaters lakes supplementary flow releases during these months if the deficit were to come from Mississippi River flows.

The period of record also shows that supplementary flow releases would be required in only 3 months to insure a flow rate of 985 cfs (1980 needs) and would be required in only 1 month to insure a flow rate of 865 cfs (1970 needs). The 1 month with flow less than 1970 needs was August 1934.

Plate 3 is a map showing the general study area and the six headwater reservoirs. It involves an area of 19,100 square miles, above Anoka, Minnesota.

Plate 4 is a schematic sketch of the flow system to illustrate primary elements in the computer solution of the system.

METHODS

Hydrologic Analysis (HEC-5C)

To assist in the evaluation of the various plans, it was stipulated that the following computer program be used in the present study:

HEC-5C Simulation of Flood Control
and Conservation Systems

This program was developed by the Hydrologic Engineering Center of the Corps of Engineers, Davis, California.

The program was developed to assist in planning studies for evaluating proposed reservoirs in a system and to assist in sizing the flood control and conservation storage requirements for each project recommended for the system. The program can be used in studies made immediately after the occurrence of a flood to evaluate pre-project conditions and to show the effects of existing and/or proposed reservoirs on flows and damages in the system. The program should also be useful in selecting the proper reservoir releases throughout the system during flood emergencies in order to minimize flooding as much as possible and yet empty the system as quickly as possible while maintaining a balance of flood control storage among the reservoirs.

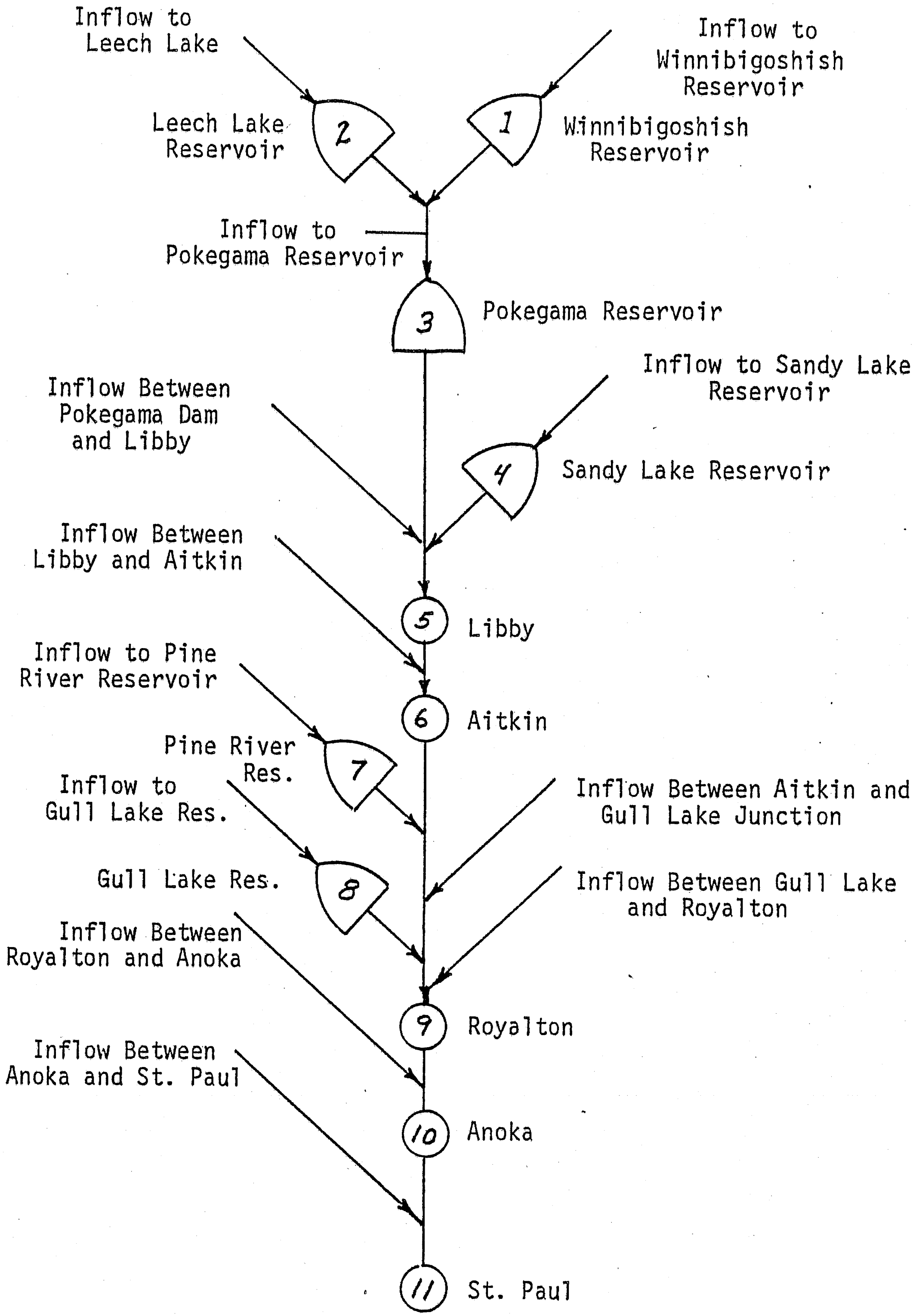


Plate 4

Schematic Representation of
Mississippi River Headwaters
Computer Model

The above purposes are accomplished by simulating the sequential operation of a system of reservoirs of any configuration for short interval historical or synthetic floods or for long duration non-flood periods or for combinations of the two. The program was developed on a CDC 7600 computer with 65K words (decimal) of central memory and 500K words of extended memory.

Dimension limits for the CDC 7600 computer allow the simulation of 35 reservoirs and 55 control points. In the current study the CYBER 74 computer at the University of Minnesota was used for a major portion of the runs. This required 231K (octal). A few runs were made on the Boeing Computer (Seattle).

a) Configuration of System

1) Any reservoir system configuration may be used as long as dimension limits are not exceeded for number of reservoirs, number of control points, number of diversions, etc. (6 in this problem).

2) The most upstream control point on each tributary must be a reservoir.

3) Reservoirs which have flood control storage may be operated to minimize flooding at any number of downstream control points.

4) Reservoirs without flood storage will be operated for their own requirements (power or low flow) and can be operated to provide low flow requirements for any number of downstream control points.

5) Reservoirs in the system that operate for a common control point are kept in balance as much as possible.

b) Reservoir Description

1) Each reservoir must have a starting storage and storage values for each target level. Target levels can vary monthly or remain constant.

2) Each reservoir operates for itself and as many downstream points as desired.

3) Each reservoir must have a table of outlet capacities as a function of reservoir storages.

4) Each reservoir is also considered a control point and requires control point data.

5) Additional data on reservoir areas, elevations, and costs can be given as a function of reservoir storages.

c) Control Point Description

1) Each control point must have an operating channel capacity. The channel capacity can be constant or increase with channel flows.

2) Each control point is linked to the next downstream point by specifying the channel routing criteria.

d) Flow Data

1) The program uses average incremental local flows (flows between) adjacent control points) in the system routings.

2) Incremental local flows can be calculated from observed discharges and reservoir releases.

e) Stream Routing

1) The following stream routing methods are available: Straddle-stagger, Tatum Muskingum, Modified Puls, and Working R & D. The Straddle-Stagger or Progressive Average Lag method was used in the current study.

f) Reservoir Releases	Case*
1) Can be based on channel capacity at dam	.01
2) Can be based on rate of change of release	.02
3) Can be based on not exceeding the top of conservation pool	.03
4) Can be based on emergency releases:	
a) Surcharge routing (maximum outlet capacity)	.06
b) Pre-release up to channel capacity using specified foresight	.04
c) Pre-release which may be greater than the channel capacity using specified foresight	.04
5) Can be based on keeping tandem reservoirs in balance using target levels	.05
6) Can be based on maximum outlet capacity for given pool elevation	.06

7) Can be based on not drawing reservoir empty (level 1) .07

8) Can be based on minimum required low flows read on CP card .08

9) Can be based on releases to draw to top of buffer pool .09

10) Can be based on primary energy demand for hydropower .10

11) Can be based on minimum release if all higher priority reservoirs in parallel with this project are not releasing .11

12) Can be based on release given on QA card .99

13) Can be based on minimum desired low flows read from CP or MR or QM cards .00

14) Can be based on filling downstream channel at location X and future time period Y for flood control or conservation operation X.Y

The appropriate case number on the right of the above list is printed in the output to indicate the purpose of each reservoir release.

g) Multifloods

1) The multiflood option may be used to operate the system for a continuous period of record with a mixture of computation intervals. A monthly operation can be used for a few years (assuming no routing is desired) and then operate for daily or hourly flows during a major flood (with detailed flood routing) and then back to a weekly or monthly routing interval, etc. An unlimited number of events can be simulated in this manner.

In the current study the period 1932 to 1976 was divided into 21 periods of monthly data interspersed with 20 periods of daily data, as shown in Table 2.

The periods represented in months are usually lower flows; the periods in days are usually flood flows.

Table 2

TIME PERIODS FOR HEC5C

From/To	
1/32 - 4/38	(76 months)
5/38	(31 days)
6/38 - 3/41	(34 months)
*4/41 - 5/41	(61 days)
6/41 - 5/43	(24 months)
*6/43 - 7/43	(61 days)
8/43 - 5/44	(10 months)
6/44 - 7/44	(61 days)
8/44 - 2/45	(7 months)
3/45 - 5/45	(92 days)
6/45 - 3/48	(34 months)
4/48 - 5/48	(61 days)
6/48 - 3/50	(22 months)
4/50 - 6/50	(91 days)
7/50 - 3/52	(21 months)
4/52 - 8/52	(153 days)
9/52 - 6/53	(10 months)
7/53 - 8/53	(62 days)
9/53 - 3/54	(7 months)
4/54 - 6/54	(91 days)
7/54 - 3/56	(21 months)

From/To	
4/56 - 5/56	(61 days)
6/56 - 3/65	(106 months)
4/65 - 6/65	(91 days)
7/65 - 3/66	(9 months)
4/66 - 5/66	(61 days)
6/66 - 3/67	(10 months)
4/67 - 5/67	(61 days)
6/67 - 3/69	(22 months)
4/69 - 5/69	(61 days)
6/69 - 3/70	(10 months)
4/70 - 5/70	(61 days)
6/70 - 3/71	(10 months)
4/71 - 5/71	(61 days)
6/71 - 3/72	(10 months)
4/72 - 5/72	(61 days)
6/72 - 3/74	(22 months)
4/74 - 6/74	(91 days)
7/74 - 3/75	(9 months)
4/75 - 5/75	(61 days)
6/75 - 12/76	(19 months)

*Not originally included

h) Expected Annual Damages

1) The program has the capability of computing annual flood damages downstream of the reservoirs. This requires the input of appropriate damage-elevation curves for each segment of stream. However, there is no provision for computation of damage in the reservoirs. It is understood that this may be provided in future modifications of the program. Also, the program does not compute low flow damages. As a result, the analysis requires hand computation of damages for some studies.

i) Input Data

1) All data cards use the first two columns for identification.

2) Input is coded in 8 column fields, except for the first field.

j) Output

1) Output includes: flow data, reservoir data, reservoir releases and control point flow, summary of flooding, summary of maximum and minimum values for each flood, frequency curve printer plot, incremental local flows, hydrographs at selected points.

k) Index Levels

Index levels, assigned by the program user to each reservoir, are used to determine priority of releases among reservoirs. The program operates to meet specified constraints throughout the system and then to keep all reservoirs in the system in balance, if possible. A system is "in balance" when all reservoirs are at the same index level. In establishing the reservoir index level at a given point in time during a system operation, the program interpolates linearly on an input table of index level vs. storage. In balancing levels among reservoirs, priority for releases is governed by index levels such that reservoirs at the highest levels at the end of the current time period (assuming no releases) are given first priority for the current time period.

Adaption of HEC-5C to the Mississippi Headwater Reservoirs - Table 3 illustrates the index levels selected for the current study. Level 1 is the top of the inactive pool, level 2 is the top of the buffer, level 3 is the bottom of the summer operating range, level 4 is the top of the conservation pool and the top of the desired summer range, and level 5 is the top of the flood pool. Any level above 5 is objectionable and should be lowered to level 5 as soon as possible.

Table 3

Index Levels

Level	Action
	Drawdown as fast as possible to level 5. Discharge may exceed channel capacity and contribute to flooding.
5 Top of Flood Pool	
	Drawdown to level 4. Do not exceed channel capacity or contribute to flooding
4 Top of Conservation Pool	
	Release to meet minimum desired flow at dam or any downstream control point.
3 (See Below)	
2 Top Buffer	
	Release to meet minimum required flow at dam or downstream.
1 Top Inactive	
	No release possible

The allowable releases are shown on the right side of Table 3. The combination of levels 3 and 4 assure that all reservoirs will be closely balanced in the summer and will reach the bottom of the summer range at the same time.

The index levels are varied throughout the year to achieve the desired reservoir level preferably without exceeding channel capacity or increasing flooding. These objectives cannot always be achieved. Further reference will be made to the index levels following a discussion of the 4 operation plans.

Channel Capacity

For each control point a channel capacity is specified. The program will use all upstream reservoirs to prevent or reduce flows beyond the channel capacity, until level 5 is reached. When any reservoir reaches level 5, it increases discharge to stay at or below level 5. Channel capacities are as follows:

Winnibigoshish Outlet Channel	2000 cfs
Leech Lake " "	1500 cfs
Pokegama " "	6000 cfs
Sandy " "	1000 cfs
Aitkin " "	8000 cfs
Pine River " "	1620 cfs
Gull Lake	950 cfs
Anoka	100,000 cfs

The capacity at Royalton and St. Paul were set very high because the headwater reservoirs would have a very small effect on flooding in the areas south of Royalton.

Minimum Desired Flow

Program will use releases from all upstream reservoirs to keep flow at or above this level until reservoirs reach level 2.

Minimum Required Flow

Program will use releases from all upstream reservoirs to keep flow at or above this level until reservoirs reach level 1.

Foresight

When a reservoir is operated for a downstream control point, the program determines the correct release by assuming certain local inflows downstream in the future and certain minimum releases for future periods and then routing an unknown discharge for the present period from the reservoir to the control point. The routing of an unknown quantity which cannot exceed certain limits (for conservation or flood protection) results in a linear equation which can be solved to determine the proper release.

Foresight instructs the program how far in the future it should "look" when determining its releases. Since Aitkin is the critical flood control point and Pokegama and Sandy control for Aitkin, the travel times for the Pokegama-Aitkin and Sandy-Aitkin reaches are of importance. Winnibigoshish and Leech reservoirs also operate in conjunction with Pokegama, so the Winni-Pokegama and Leech-Pokegama travel times are also important. A preliminary analysis indicated that in most cases the majority of the effect of a release is complete downstream to Aitkin within 4 days.

Numerous trial runs confirmed that 4 days foresight is apparently ample. With less than 4 days the program was unable to foresee the results of its actions and oscillated wildly. More than 4 days produced little or no improvement and increased computer time required for a run.

The longer travel times from the reservoirs to Anoka were not considered because Anoka was important only during low flow conditions and these were handled in monthly subperiods. No channel routing is done for monthly operations, but a time delay can be provided.

Rate of Change

To impose some restraint on the program's reservoir release decisions, a rate of change of discharge can be specified. This is entered as a fraction of the channel capacity of the reservoir. After some testing, a rate of change of 0.5 was chosen. This is best for Pokegama but somewhat low for the others. However, of the four upper lakes, Pokegama, with 3,265 square miles of contributing drainage area, is the major control location in relation to Aitkin flooding and, therefore, has priority over the others. Sandy, with 421 square miles of contributing area, also affects flooding at Aitkin. The rate of change is overridden if the reservoir is at or above level 5.

Contingency Allowance Factor

In computing the releases, the program uses future local inflows between the reservoir and the downstream control point. Since it is impossible in actual practice to perfectly predict the inflows that will occur, some simulation of the uncertainty is required. The contingency allowance factor is a coefficient of flood control releases. This causes the computer to overestimate the future inflows and to err on the conservative side in operation.

For conservation operations, the inflows are multiplied by (2-(contingency-allowance factor)), which causes the program to underestimate the local inflows and over-release to meet downstream requirements.

After consulting with the Reservoir Regulation branch of the St. Paul District Office, it was decided to use a contingency allowance factor of 1.3.

Damage Analysis

The damage analysis used in this study was conducted by the Corps of Engineers, the details of which will be described more fully in a later feasibility report by their office.

The Corps developed an economic analysis of the Mississippi River headwaters lakes that would compare lake area damages with prospective gains to downstream interests. Economic losses in each of the headwaters lake areas were determined by means of either a field survey or through extrapolation of field survey and other available data. Losses in the downstream Aitkin area were derived through field survey and through updating observed losses from recent flood events. Potential gains from supplemental low flows for the Twin Cities area were derived from estimated water supply values.

Elevation damage curves were derived for each of the six headwaters lakes and for Aitkin, Minnesota, in October, 1977 prices, and are shown on Plates 5-15. An area flooded curve for the Aitkin agricultural area is shown on Plate 14.

The elevation-damage curves for each of the six headwaters lakes (Plates 5-10) show both the low- and high-water damage relationships. High-water damages consist of flood fight or preparedness measures, damage and loss of personal property, and cleanup and repair for both residential and commercial units. In addition to the above damages, commercial establishments also receive a decline in net income because of the high water. Loss of property from erosion is also reflected in the curves.

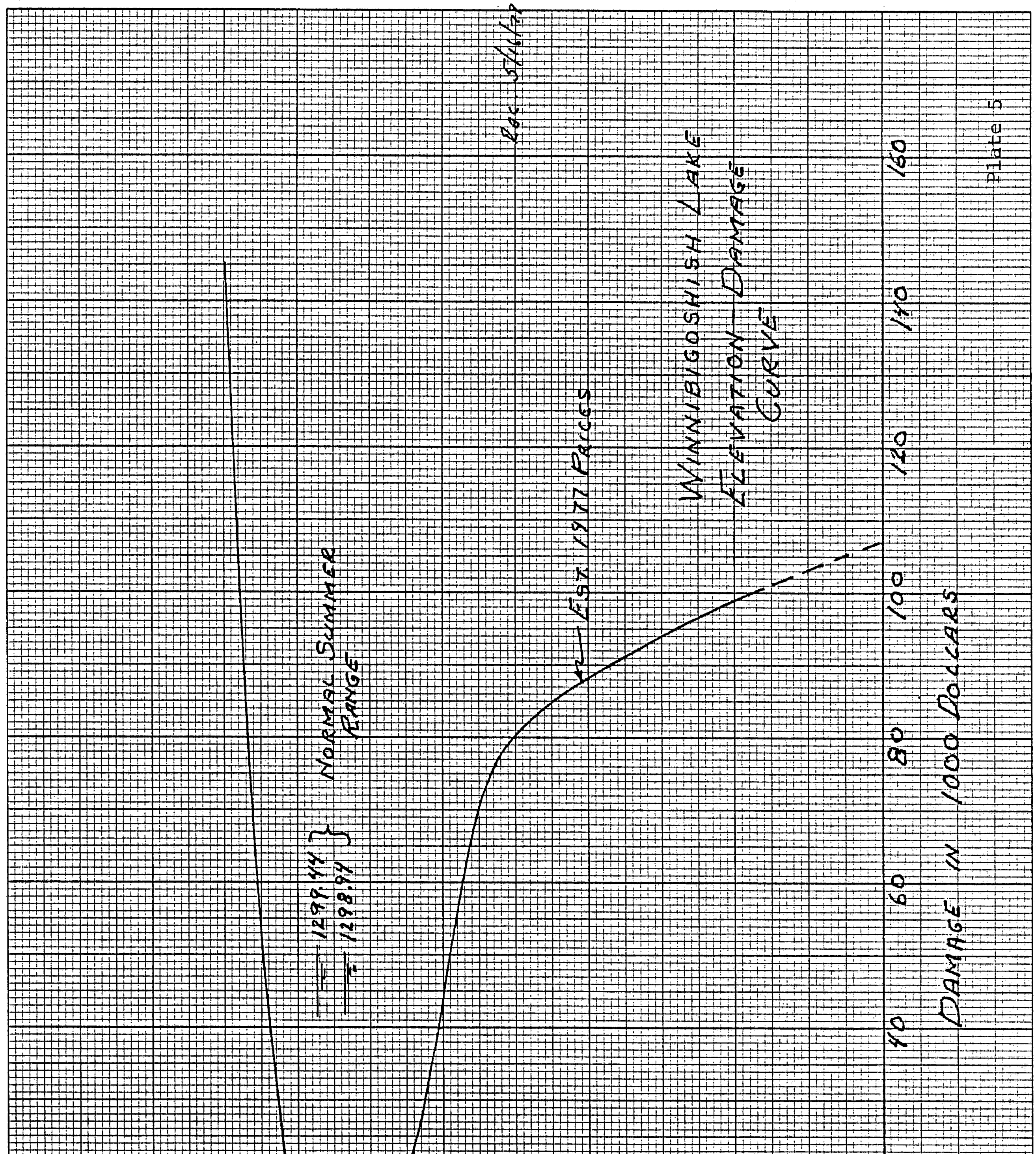
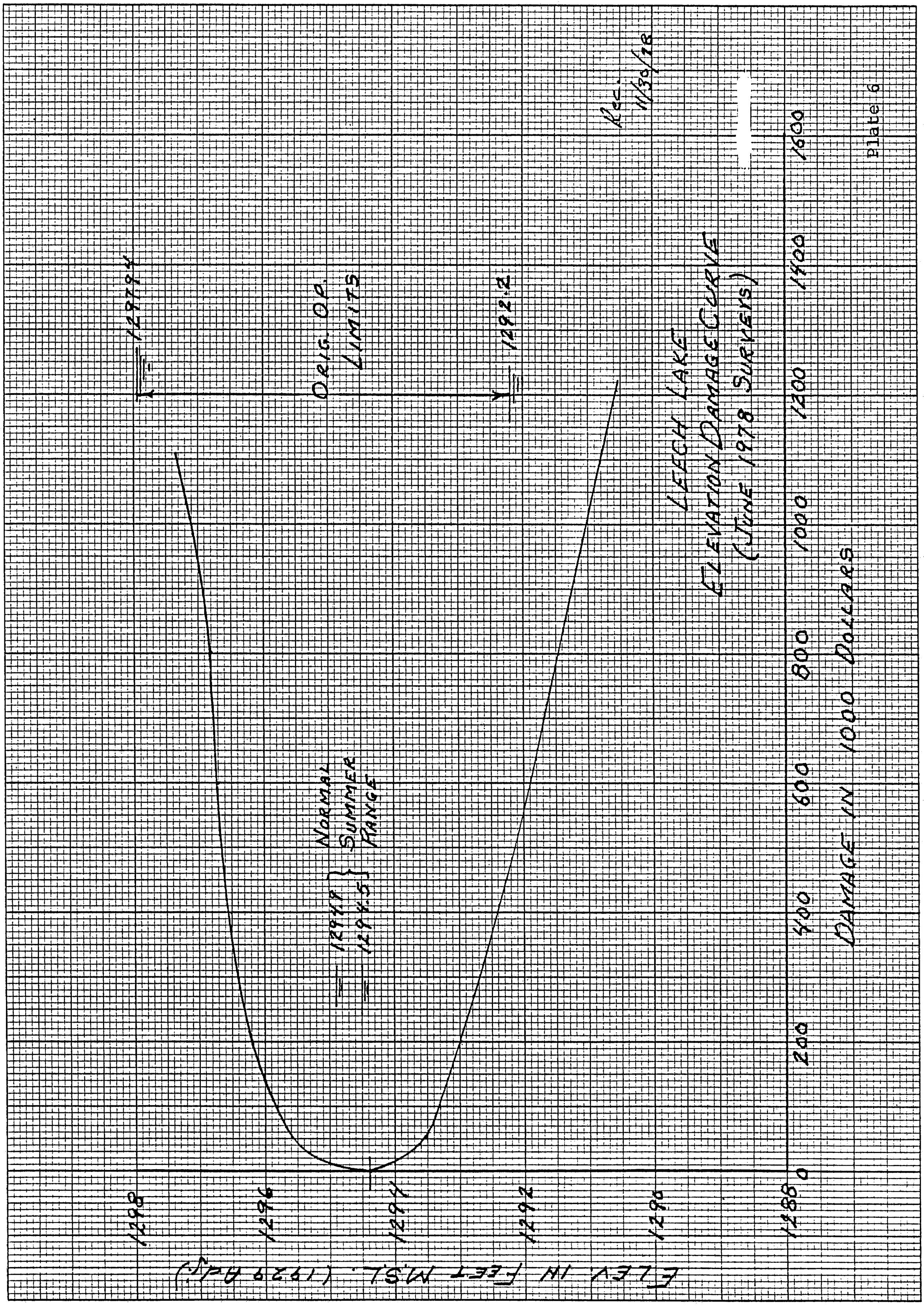

WINNIBIGOSHISH LAKE
ELEVATION - DAMAGE
CURVE
EST 1977 PRICES
1299.44
1298.94
NORMAL SUMMER
RANGE
1298.9
DAMAGE IN 1000 DOLLARS
0
20
40
60
80
100
120
140
160
ELEV IN FEET M.S.L. (1929 Adj.)
1284
1288
1292
1296
1300
1304

Plate 5


LEECH LAKE
ELEVATION DAMAGE CURVE
(JUNE 1978 SURVEYS)
DAMAGE IN 1000 DOLLARS
ELEV IN FEET M.S.L. (1929 Adj.)
0
200
400
600
800
1000
1200
1400
1600
1288
1290
1292
1294
1296
1298
ORIG. OP. LIMITS
1292.2
1294.5
NORMAL SUMMER RANGE
Rec. 11/30/78
Plate 6

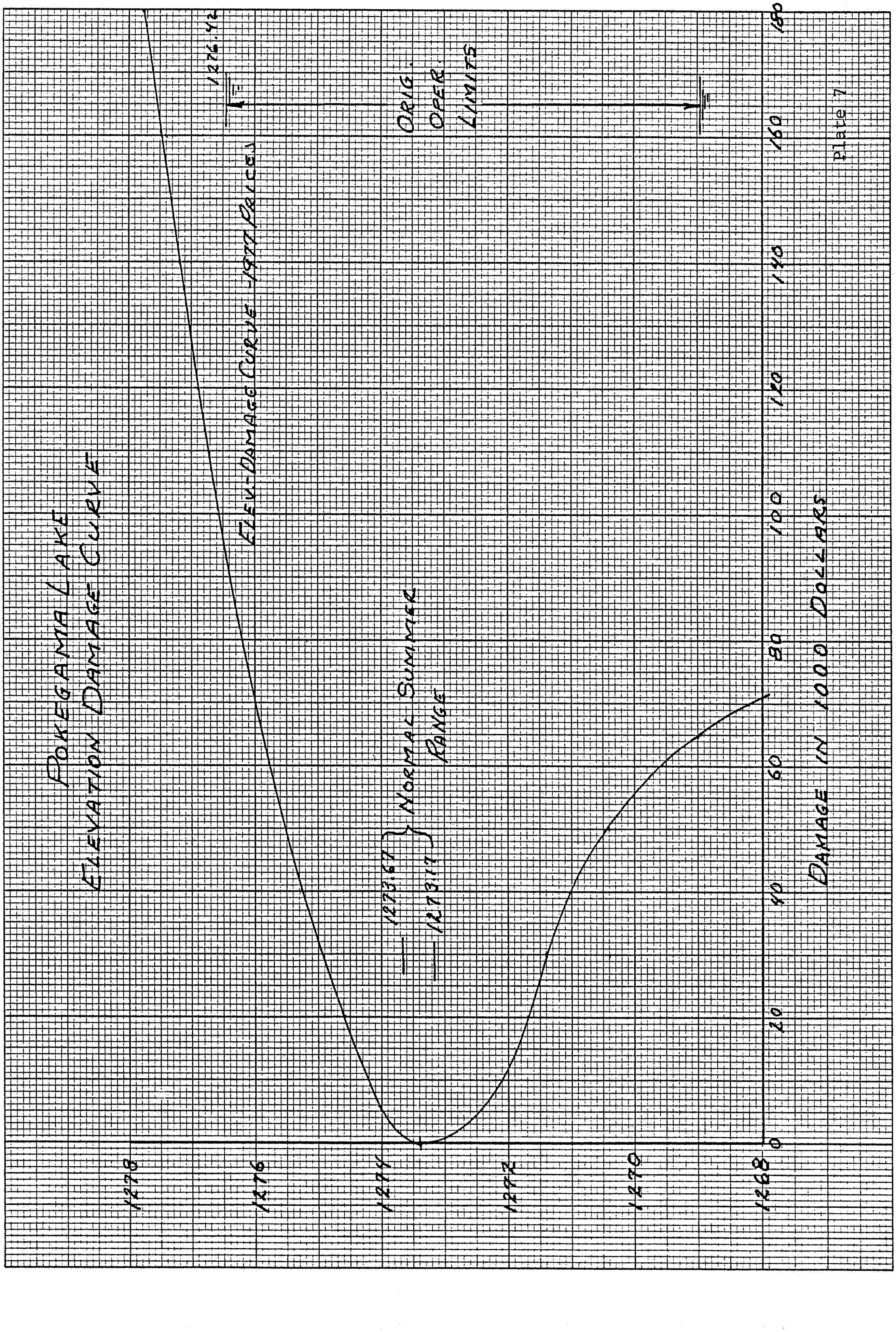

POKEGAMA LAKE
ELEVATION DAMAGE CURVE
ELEV-DAMAGE CURVE -1977 PRICES
1276.42
ORIG. OPER. LIMITS
1273.67
1273.17
NORMAL SUMMER RANGE
DAMAGE IN 1000 DOLLARS
0
20
40
60
80
100
120
140
160
180
1268
1270
1272
1274
1276
1278

Plate 7

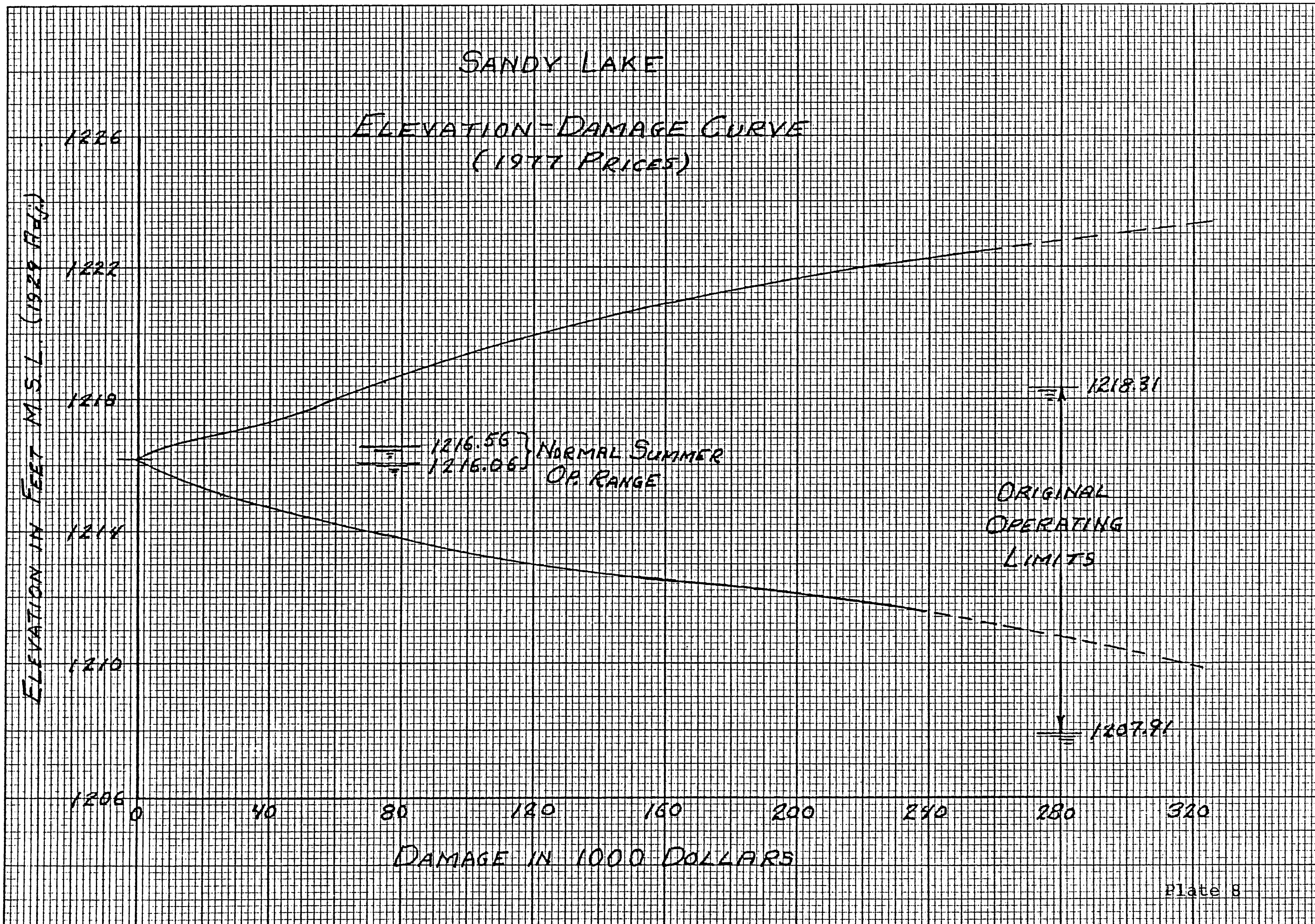

SANDY LAKE
ELEVATION-DAMAGE CURVE
(1977 PRICES)
1226
1222
1218
1214
1210
1206
ELEVATION IN FEET M.S.L. (1929 ADJ.)
1216.56
1216.06
NORMAL SUMMER
OP. RANGE
1218.31
ORIGINAL
OPERATING
LIMITS
1207.91
0
40
80
120
160
200
240
280
320
DAMAGE IN 1000 DOLLARS

Plate 8

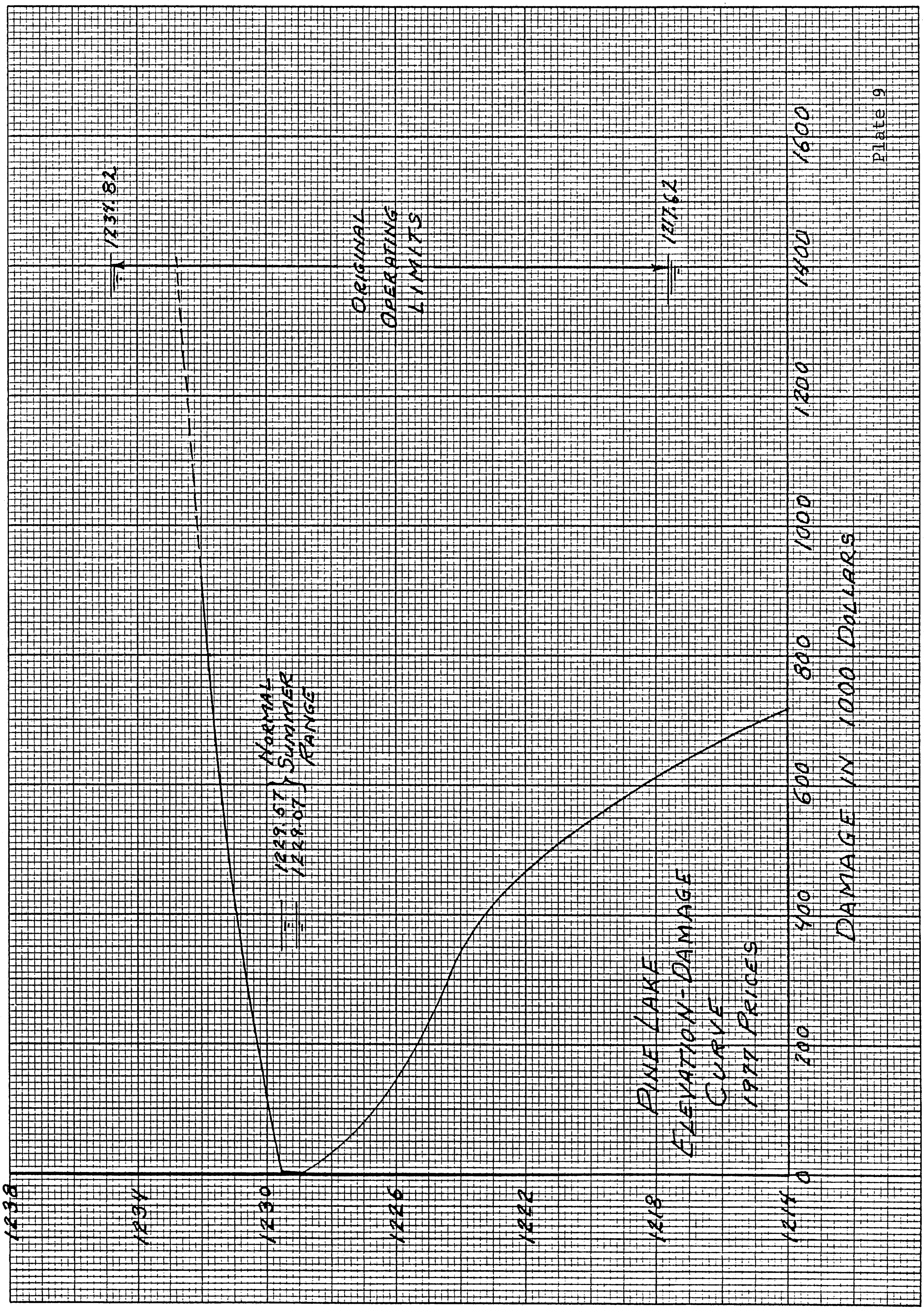

PINE LAKE
ELEVATION-DAMAGE
CURVE
1977 PRICES
DAMAGE IN 1000 DOLLARS
0
200
400
600
800
1000
1200
1400
1600
1214
1218
1222
1226
1230
1234
1238
1234.82
1217.62
ORIGINAL
OPERATING
LIMITS
1229.57
1229.07
NORMAL
SUMMER
RANGE

Plate 9

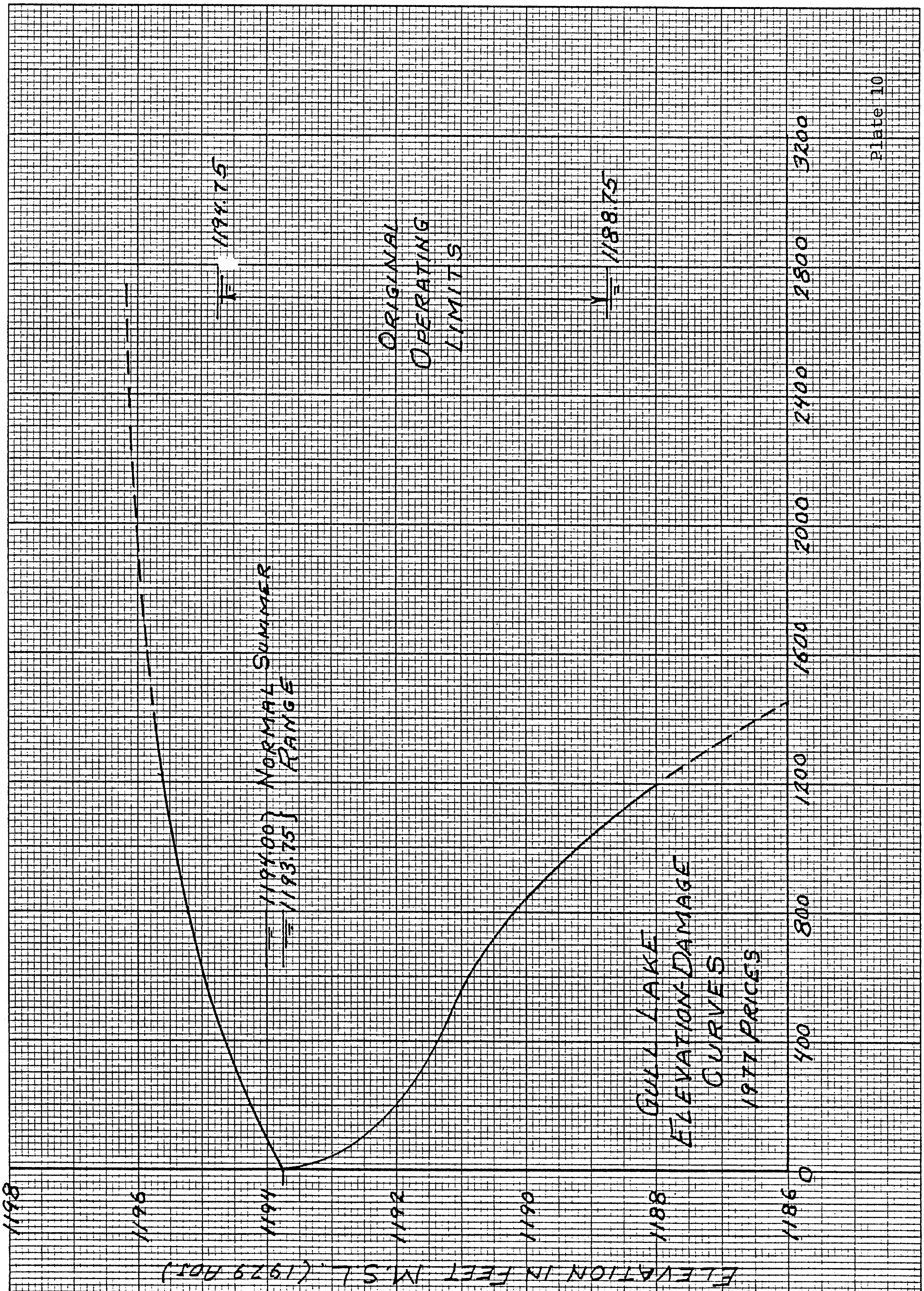

GULL LAKE
ELEVATION DAMAGE
CURVES
1977 PRICES
ELEVATION IN FEET M.S.L. (1929 ADJ.)
1198
1196
1194
1192
1190
1188
1186
0
400
800
1200
1600
2000
2400
2800
3200
1194.00
1193.75
NORMAL SUMMER
RANGE
ORIGINAL
OPERATING
LIMITS
1194.75
1188.75

Plate 10

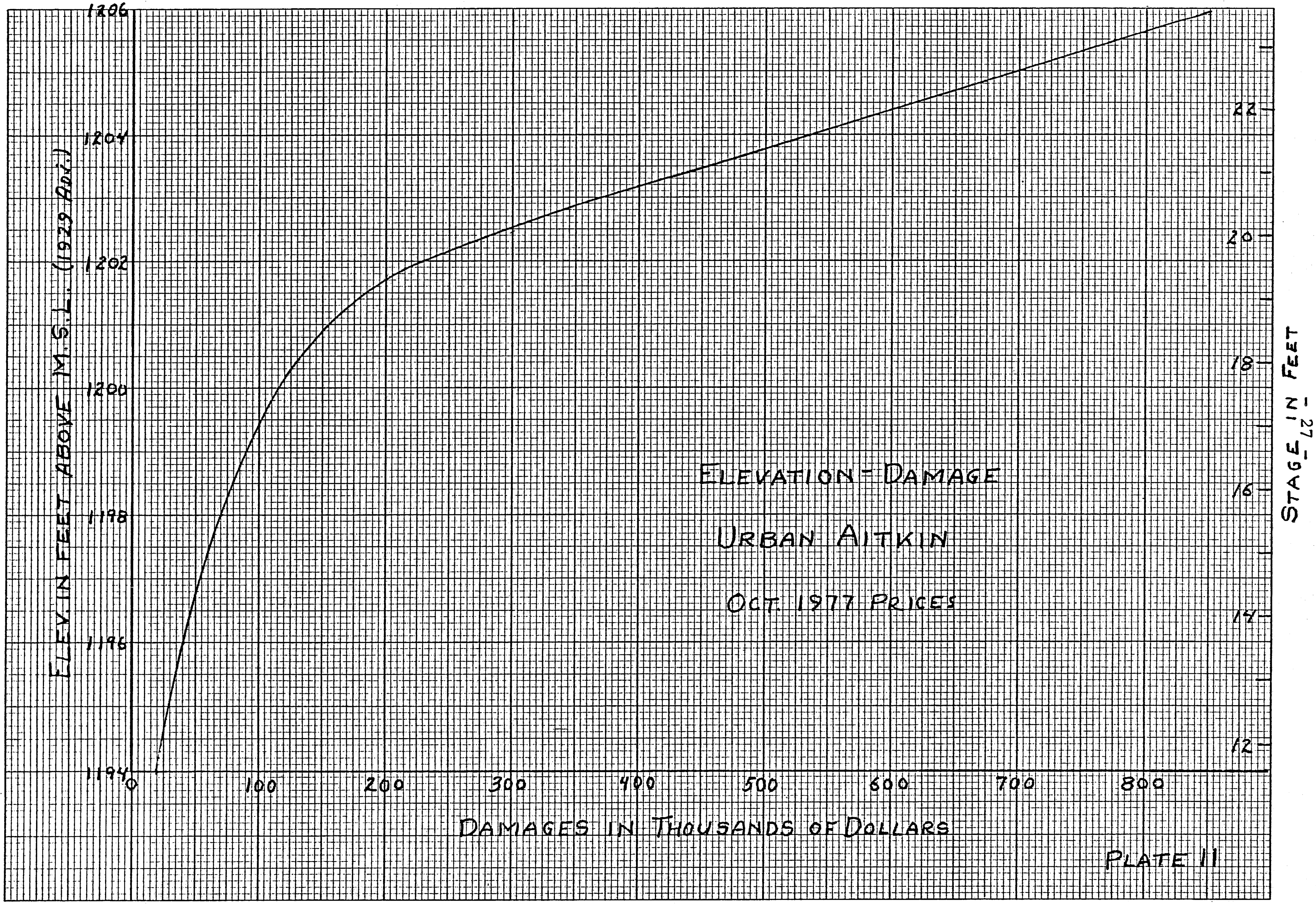
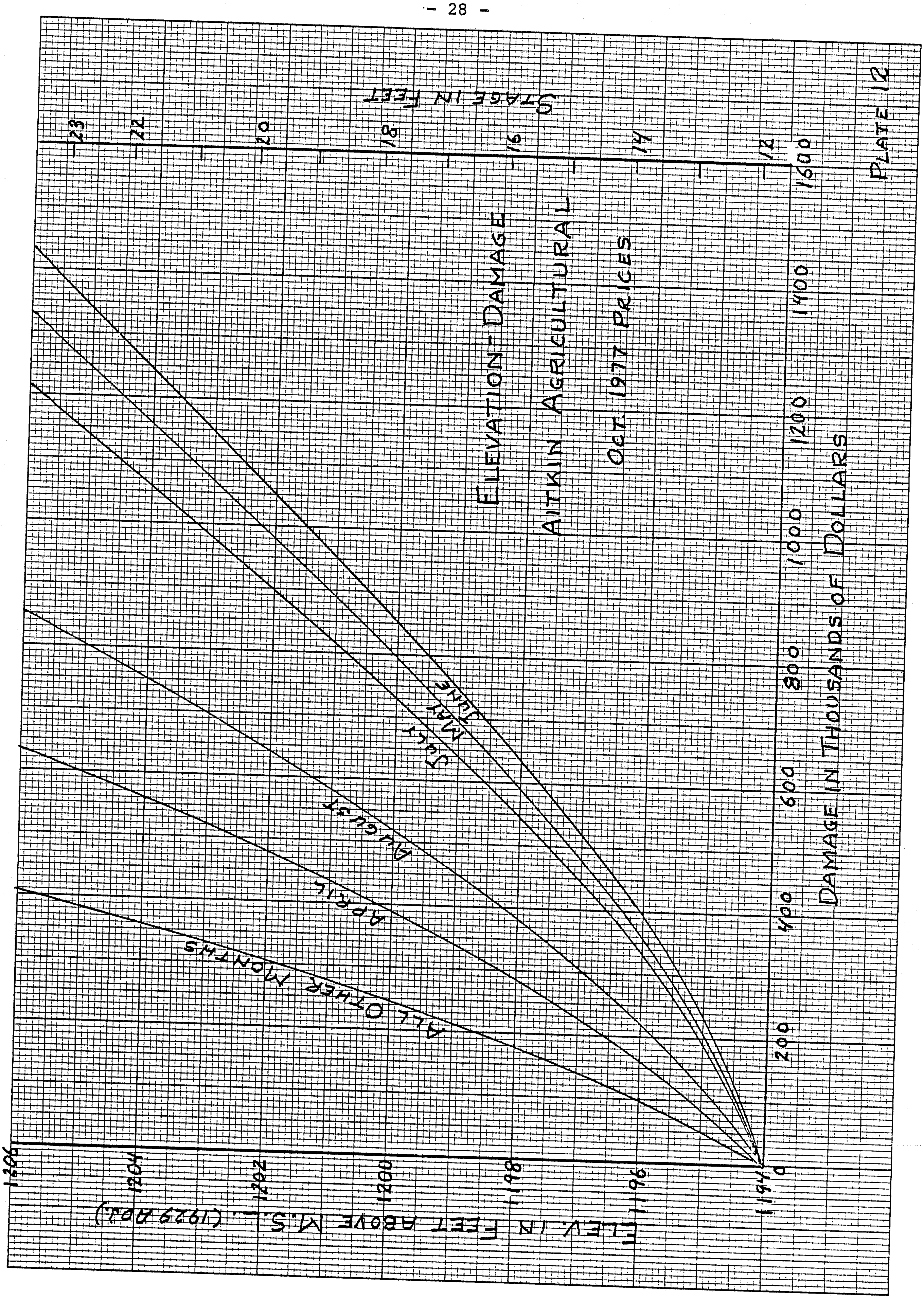

ELEVATION - DAMAGE
URBAN AITKIN
OCT. 1977 PRICES
ELEV. IN FEET ABOVE M.S.L. (1929 ADJ.)
STAGE IN FEET
DAMAGES IN THOUSANDS OF DOLLARS
1194
1196
1198
1200
1202
1204
1206
12
14
16
18
20
22
0
100
200
300
400
500
600
700
800

PLATE 11


ELEVATION-DAMAGE
AITKIN AGRICULTURAL
OCT. 1977 PRICES
PLATE 12
STAGE IN FEET
23
22
20
18
16
14
12
DAMAGE IN THOUSANDS OF DOLLARS
0
200
400
600
800
1000
1200
1400
1600
ELEV. IN FEET ABOVE M.S.L. (1929 ADJ.)
1194
1196
1198
1200
1202
1204
1206
JUNE
MAY
JULY
AUGUST
APRIL
ALL OTHER MONTHS

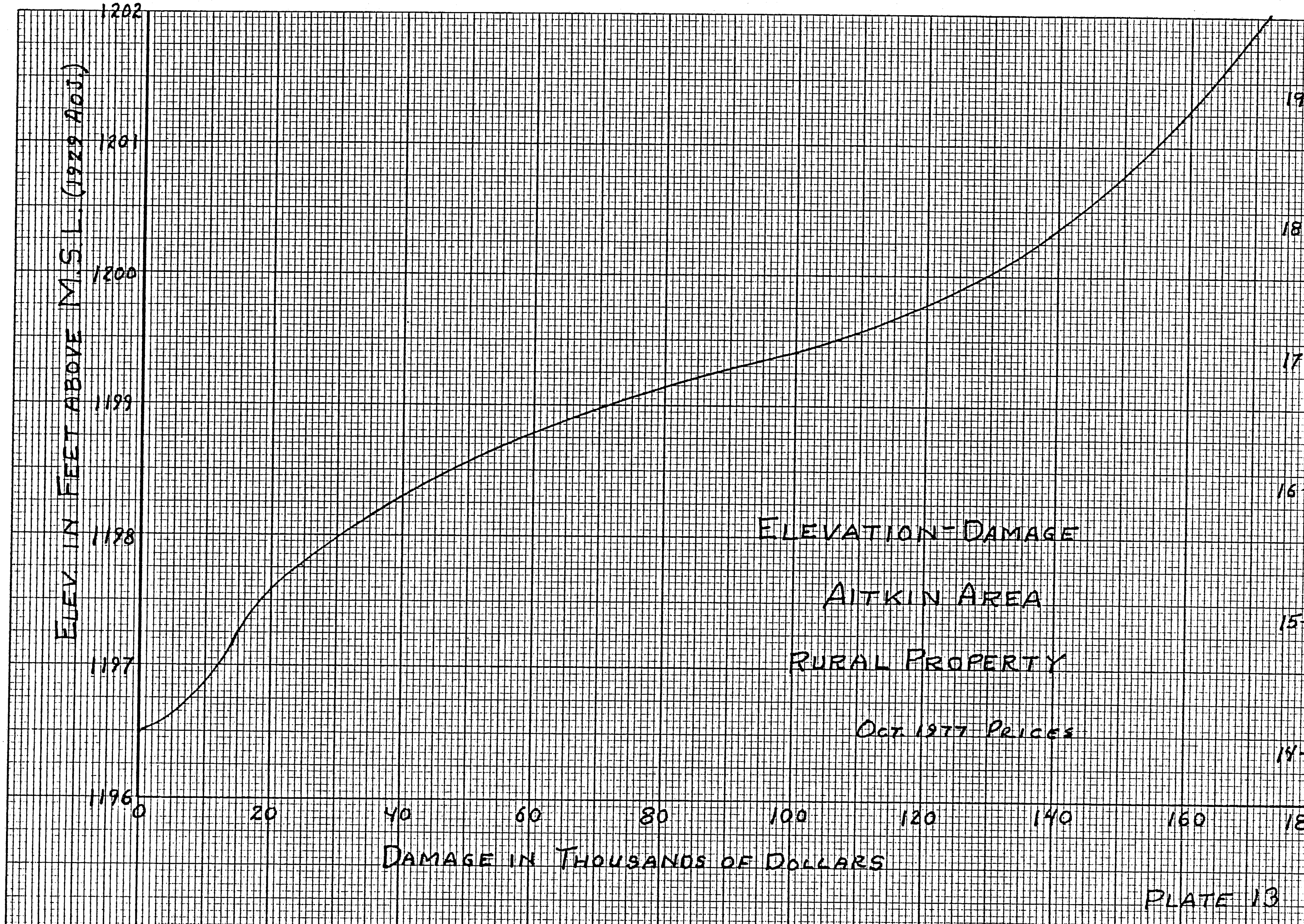
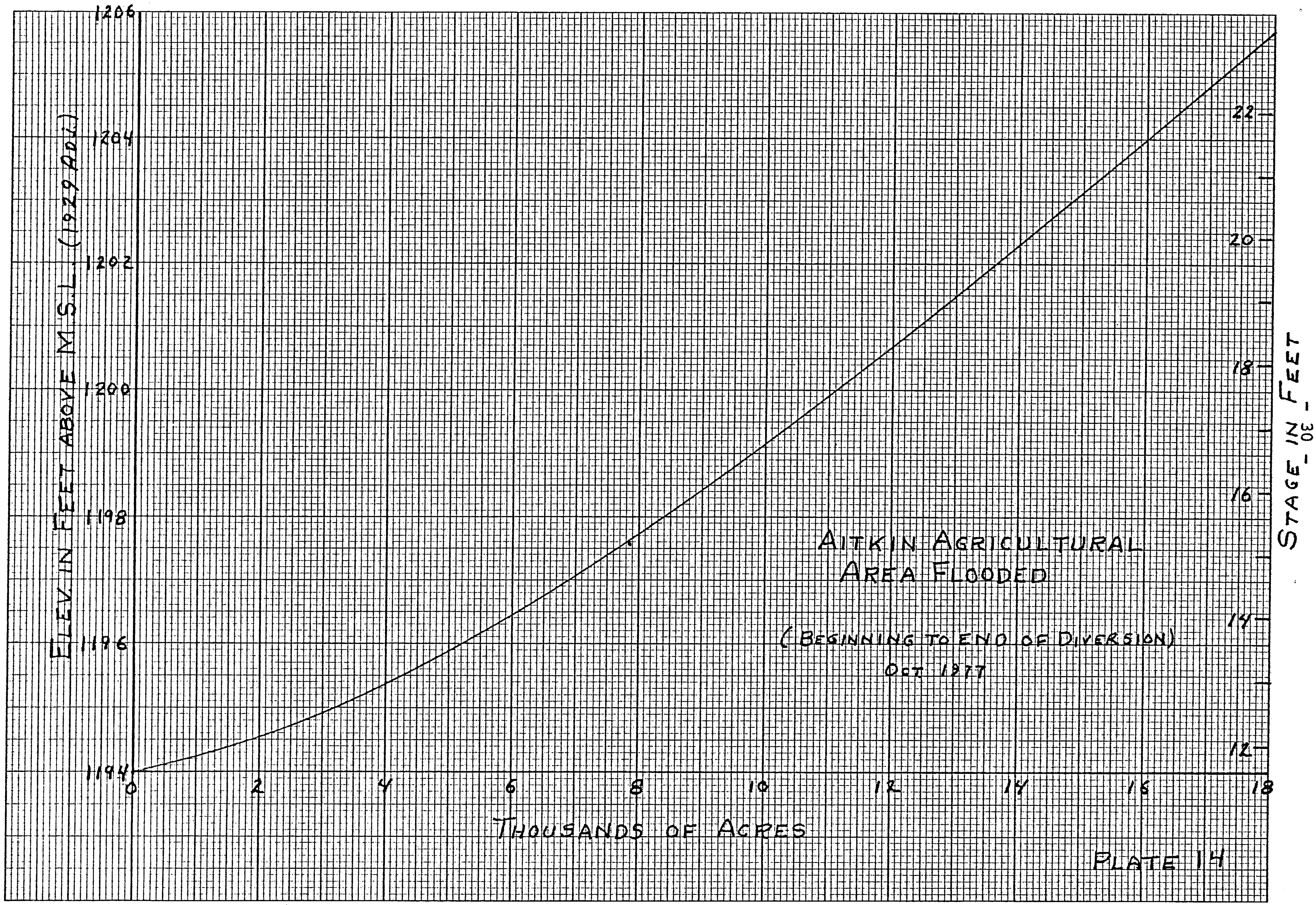

ELEVATION-DAMAGE
AITKIN AREA
RURAL PROPERTY
OCT. 1977 PRICES
ELEV. IN FEET ABOVE M.S.L. (1929 ADJ.)
STAGE IN FEET
DAMAGE IN THOUSANDS OF DOLLARS
1196
1197
1198
1199
1200
1201
1202
14
15
16
17
18
19
0
20
40
60
80
100
120
140
160
180

PLATE 13


AITKIN AGRICULTURAL
AREA FLOODED
(BEGINNING TO END OF DIVERSION)
OCT 1977
ELEV IN FEET ABOVE M.S.L. (1929 ADJ.)
1194
1196
1198
1200
1202
1204
1206
STAGE IN FEET
12
14
16
18
20
22
THOUSANDS OF ACRES
0
2
4
6
8
10
12
14
16
18
PLATE 14

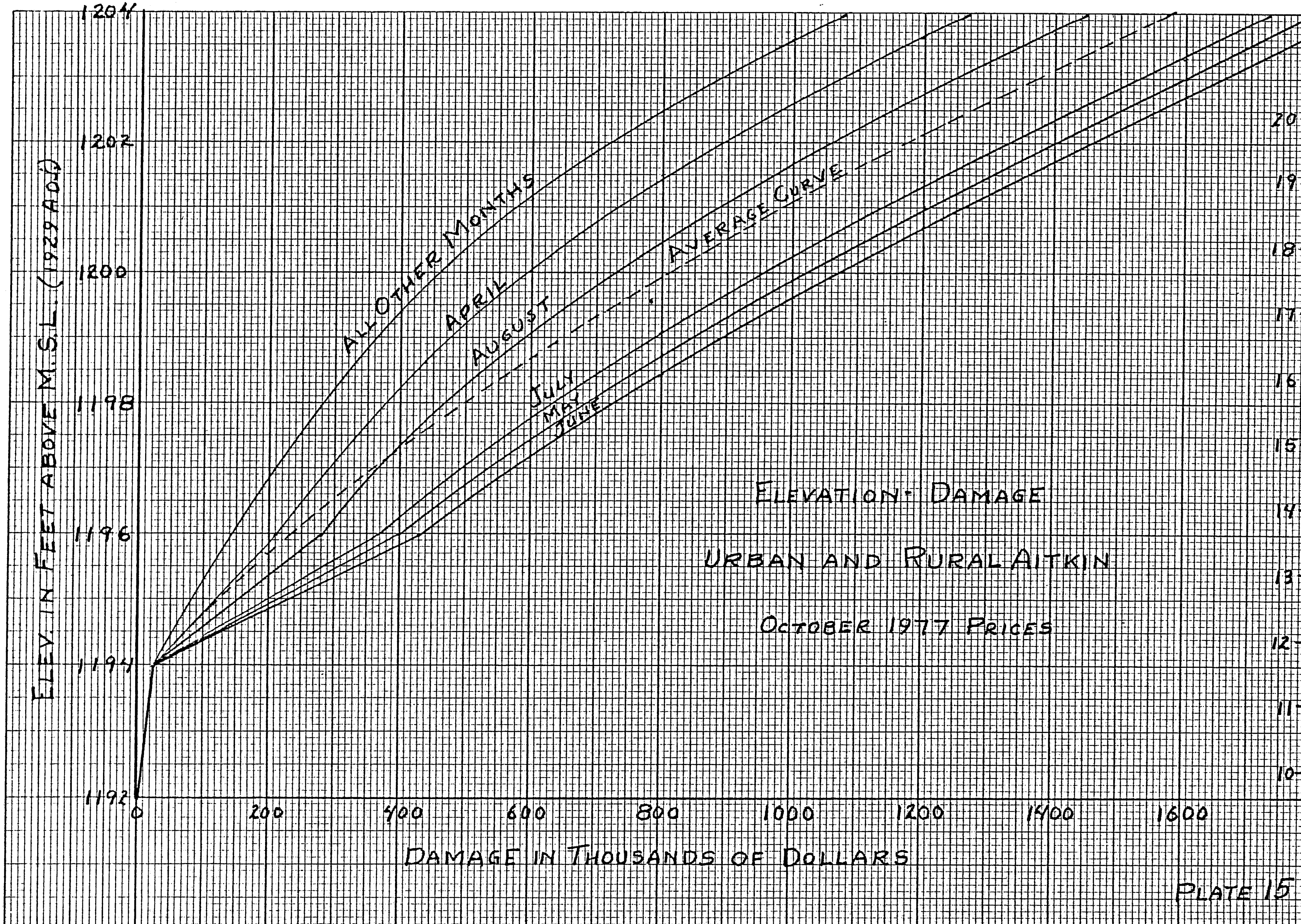

ELEV. IN FEET ABOVE M.S.L. (1929 ADJ.)
1204
1202
1200
1198
1196
1194
1192
0
200
400
600
800
1000
1200
1400
1600
DAMAGE IN THOUSANDS OF DOLLARS
STAGE IN FEET
10
11
12
13
14
15
16
17
18
19
20
ALL OTHER MONTHS
APRIL
AUGUST
AVERAGE CURVE
JULY
MAY
JUNE
ELEVATION - DAMAGE
URBAN AND RURAL AITKIN
OCTOBER 1977 PRICES

PLATE 15

Low-water damages consist of changes in net income to commercial activities. They represent a gross estimate of a single event, i.e. a short-term low water. A permanent change in operating plan (e.g. natural conditions) would actually result in a changed base condition. These changes would consist of one-time losses and gains to the existing properties, the future income stream of commercial properties, potential damages to new development, and the success of property owner adjustment to the new water level fluctuation. Without a detailed review of the current lake bottom contours and existing development on each lake, it is impossible to accurately assess what the damages would be with a changed operating plan to natural conditions (without dams).

Some of the low-water losses are increased expenditures for harbor maintenance, reduced or canceled reservations because of access problems to fishing areas, shortened stays because of poor fishing, and damaged equipment because of shallow depths, etc. Private landowners also experience increased expenses and equipment damages from low water. Low-water damages are especially severe on lakes with very gradually sloping bottoms.

Damage Surveys

Detailed damage surveys were conducted on Pokegama and Sandy Lakes and in the Aitkin area. Damage estimates for the four remaining headwaters lakes were made without benefit of detailed surveys, although a partial damage survey was conducted of Leech Lake and adjoining lakes. The partial survey of Leech Lake included interviews of all commercial properties. A resume of the damage surveys is as follows:

Pokegama Lake Area

Pokegama Lake area properties were inventoried along approximately 60 miles of shoreline during June 1977. Each visible unit was photographed, sighted with a hand level, and located on a U.S. Geological Survey quadrangle map. Approximately 800 photos were taken of 966 shoreline units. Residential units comprise 896 of the units. The remaining 70 units were privately owned, belonging to commercial holdings such as resorts.

The above survey was further supplemented by a 3-day "open-house" conducted at Pokegama Dam, by damage interviews conducted at a Pokegama Property

Owner's Association meeting, and by the results of a questionnaire mailed out by the Pokegama Property Owner's Association in their July 1977 newsletter.

Sandy Lake Area

Sandy Lake property was inventoried in a manner similar to Pokegama Lake. The survey on Sandy Lake was conducted along approximately 82 miles of shoreline during September 1977. Each visible unit was photographed, sighted with a hand level, and located on a U.S. Geological Survey quadrangle map of the area. Over 700 photographs were taken, showing 904 private and 12 resort/commercial units.

The above survey was supplemented by a field sample survey distributed to approximately 150 property owners and by interviews with most of the owners of the 12 commercial units.

Leech Lake Area

In June 1978, a damage survey was conducted of all commercial establishments on all lakes affected by the operation of Leech Lake Dam. A total of 107 commercial property owners were contacted. This represents a 99 percent sample. Each property owner was asked to describe and quantify damages, changes in operating procedures, and changes in net income resulting from the 5 July 1975 high-water and the 1977 low-water. Private property damages on Leech and adjoining lakes were estimated as described in the next paragraph for Winnibigoshish, Pine, and Gull Lakes. There were an estimated 1,493 private properties around Leech Lake and principal connecting bays.

Winnibigoshish, Pine River and Gull Lakes

Damage estimates for the three remaining headwaters lakes were made without benefit of field surveys. Estimates were based on the total number of property units around each lake totaled from U.S. Geological Survey quadrangle sheets. These totals were further increased by 28.5 units per year, from the date of the quandrangle sheet to date. The 28.5-unit annual growth rate was the average rate determined for Sandy and Pokegama Lakes from the year of their quadrangle sheets to the 1977 field survey. The number of commercial units for each of the three lakes was obtained from representatives of the Mississippi River Headwaters Association. Total commercial and private properties on these 3 lakes are as follows:

Lake Area	Number of Units	
	Private	Commercial
Winnibigoshish	452	16
Pine River	2139	88
Gull	1480	27

Aitkin Area

Field surveys were conducted of the Aitkin agricultural area in August 1977. A survey sample was made of 20-30 percent of the area farmers. There are approximately 45 farm units and 35 other non-residential units in the Aitkin study area.

No economic damage field surveys were made for urban Aitkin because sufficient information was available from prior surveys. There are some 200 homes and 44 business establishments that are subject to flood damage in the area, as indicated by the 1950 flood.

Plates 11-15 illustrate the urban and rural damage relationships for the Aitkin area. As may be noted in Plate 12, agricultural damages vary with the month of year. Plate 15 illustrates combined rural and urban damages and an urban damages and an average summer (May-Sept.) curve. The average curve was initially used in the current study, but damages were recomputed in terms of the monthly curves. Currently, HEC-5C accepts only an average curve.

Twin City Area

No field surveys were necessary in the Twin Cities area as the headwaters lakes are located too far upstream to have any appreciable effect on flood stages at this downstream location. Estimates of low flow benefits to the Twin Cities were based on a dollar value per cubic feet per second for emergency water supply.

For this study the low-flow plan for emergency Twin City area water supply would maintain flows at Anoka above 1,600 cfs. Economic benefit values assigned to the plan are based on $385 per month for every cubic foot per second that must be supplemented to maintain the desired 1,600 cfs flow. The $358 per cfs is equivalent to $0.60 per 1,000 gallons which is the current consumer cost of Minneapolis water supplied to customers outside the city.

The computer program HEC-5C has the capability of using flood damage curves downstream of the dams but is not capable of handling (1) damage in the head-water reservoirs, and (2) low flow damages. As these are the major portion of the damage computations, it was necessary to resort to hand calculation of damage.

The procedure for hand calculation was as follows:

1. The high and low elevations for each dam (for each plan), for the period May-Sept., were determined from the computer print-out.

2. Graphs of high-elevation probability and low-elevation probability for each reservoir and each plan, were prepared. (These were required as part of the contract and were plotted on normal probability paper.)

3. The high elevation damage and low elevation damage were determined for each reservoir, and year, and each plan. (If both the high elevation and low elevation for a reservoir were on the high elevation curve, damage for the low elevation was listed as zero. Likewise if both high and low elevation were on the low elevation curve, the high elevation damage was listed as zero.)

4. The sum of the high and low damages was determined for each year. At Aitkin, damage was restricted to flood damage on the high elevation. As in the reservoirs, the analysis was restricted to the tourist season, May-Sept. At Anoka, damage was restricted to low-flow periods, as noted in an earlier section. Also, it was analyzed for the full year as low flow potential loss could occur in all months of the year. Monthly flows were used for Anoka. Whenever the average flow for the month fell below 1600 cfs, it was subtracted from 1600 and the difference multiplied by $385. The monthly potential losses at Anoka were then added up for each month.

5. Damages for each year at each site were then sorted in descending order and the Exceedance Frequency in Percent (or in events per year) determined. These data were then plotted on linear coordinate paper with damage in dollars on the ordinate and Exceedance Frequency in events per year on the abscissa. The area under this curve represents the mean annual damage or for the reservoirs and Aitkin, the annual May-Sept. damages. The area under the damage-probability curve (in square inches) was determined by a Numonics planimeter. This value was then multiplied

by the product of the two graphical scales to give mean annual damage in dollars. One set of 6 graphs was also analyzed by "counting squares" on the graphical plots to determine annual damage. There was excellent agreement between the two methods but the Numonics planimeter was much faster even though each graph was planimetered 3 to 4 times.

CRITERIA

The following report section discusses the operating criteria utilized in applying the HEC-5C computer program to the 4 previously described operating plans. There were considerable difficulties in adjusting the HEC-5C computer format to the Mississippi River Headwaters System. These difficulties are discussed in more detail in a later section.

Present Operating Plan

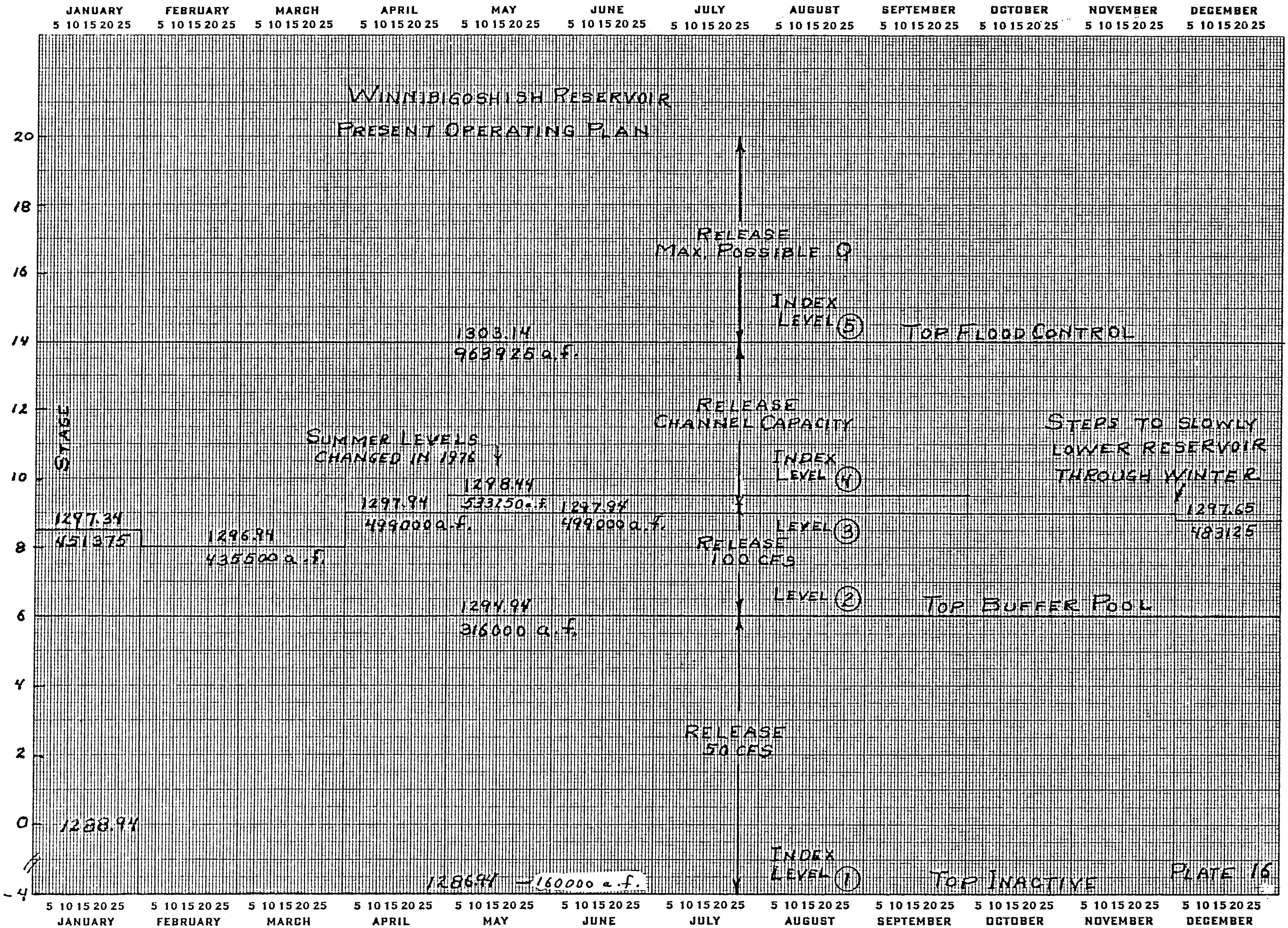
The accompanying graphs, Plates 16-21, summarize the Present Operating Plan for each of the 6 headwater lakes. It was difficult to reduce the Corp's operating plan to HEC-5C format for several reasons. First, the plan for controlling flooding at Aitkin is summarized in the Pokegama-Sandy-Aitkin rule curve, Plates 22 and 23, and in the established procedure of reducing Winnibigoshish and Leech outflows to "zero" prior to Flood Peaks at Aitkin. HEC-5C cannot accomodate rule curve operation. A compromise solution suggested by the St. Paul District Office Reservoir Regulation Branch is shown on Plates 16-21.

Second, the Corp operates on a more flexible plan than can be specified by monthly changes in index levels. Long-range predictions of ultimate spring melt effects can be made and some initial flooding is allowed in the Aitkin area to preserve upstream lake storage for later flood peak reduction. The HEC-5C program does not have any simulation of this long-term, intuitive "feel" for the system.

Finally, the program does not simulate backwater effects. Sandy and Pine reservoirs, especially, are restricted in discharge capacity by the head difference between the reservoir and the downstream river. Since the largest discharges will be released when the reservoir is high or the river very low, the restrictions may not be of great importance. Damages around the reservoir depend on the local level of the Mississippi River, as well as inflow to Sandy.

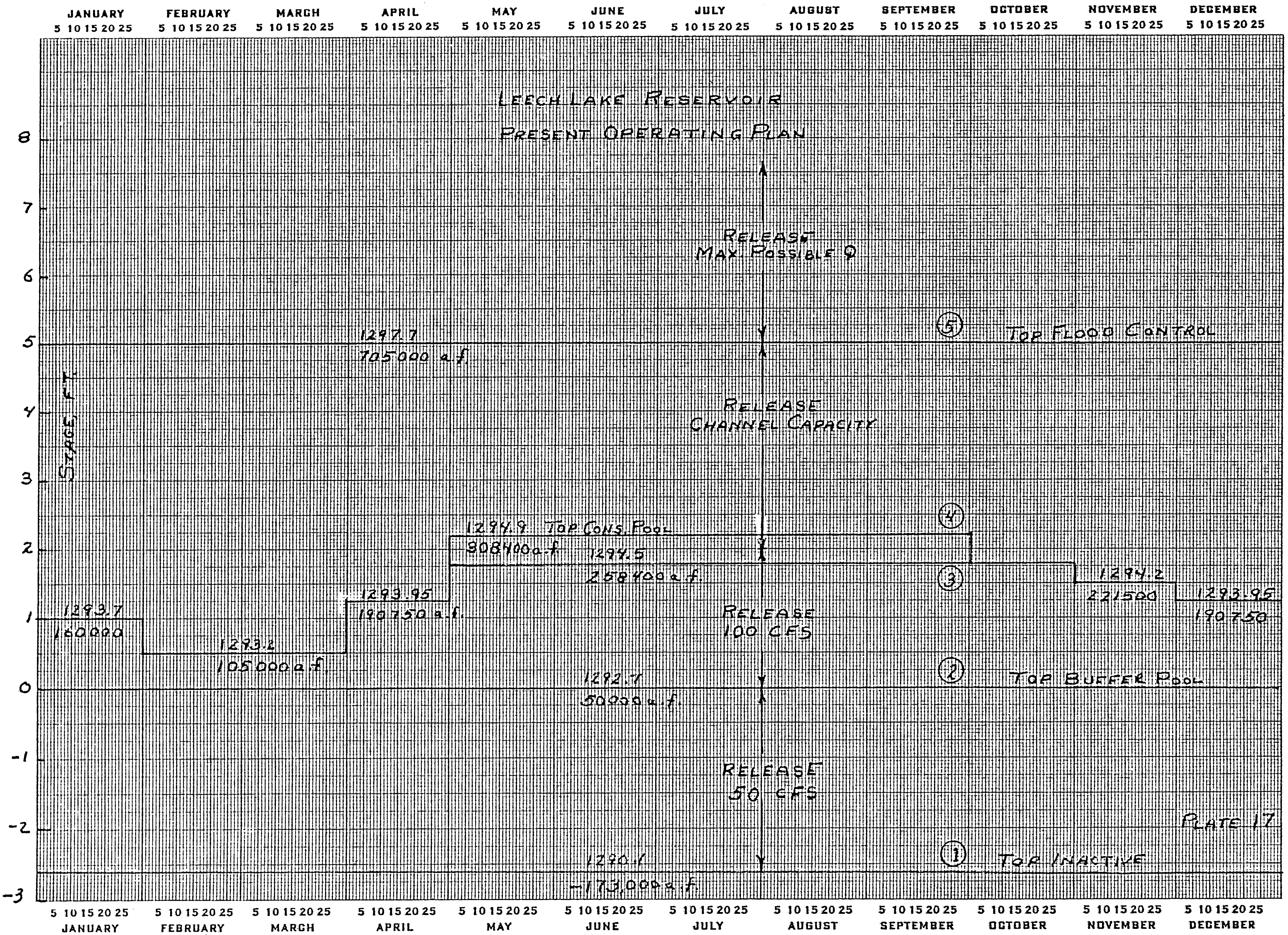
NO. 340-T15 DIETZGEN GRAPH PAPER
ONE YEAR BY DAYS — CALENDAR YEAR
366 DAYS X 250 [10 PER UNIT] DIVISIONS

EUGENE DIETZGEN CO.
MADE IN U. S. A.



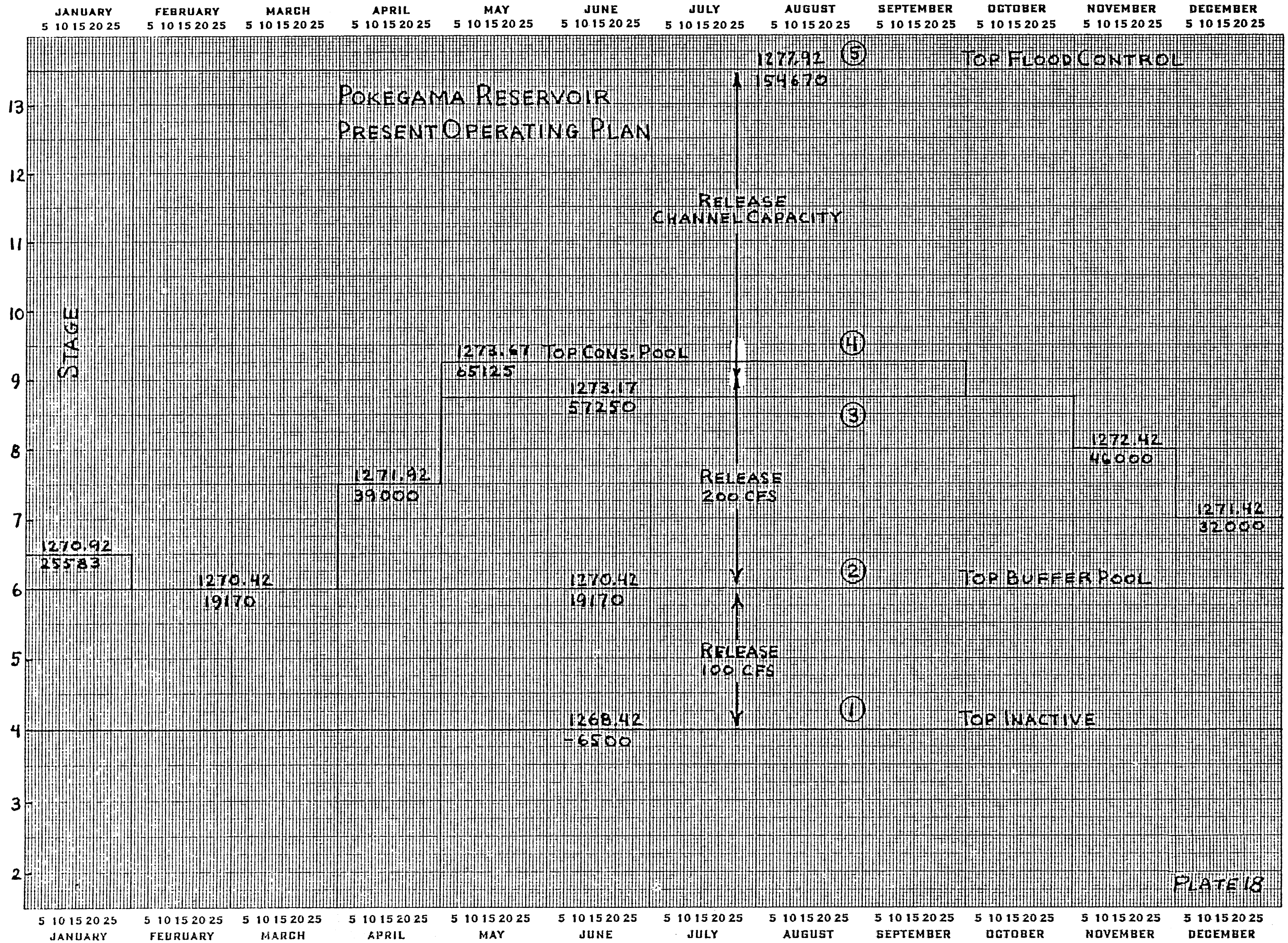
NO. 340-T15 DIETZGEN GRAPH PAPER
ONE YEAR BY DAYS — CALENDAR YEAR
366 DAYS X 250 [10 PER UNIT] DIVISIONS

EUGENE DIETZGEN CO.
MADE IN U. S. A.

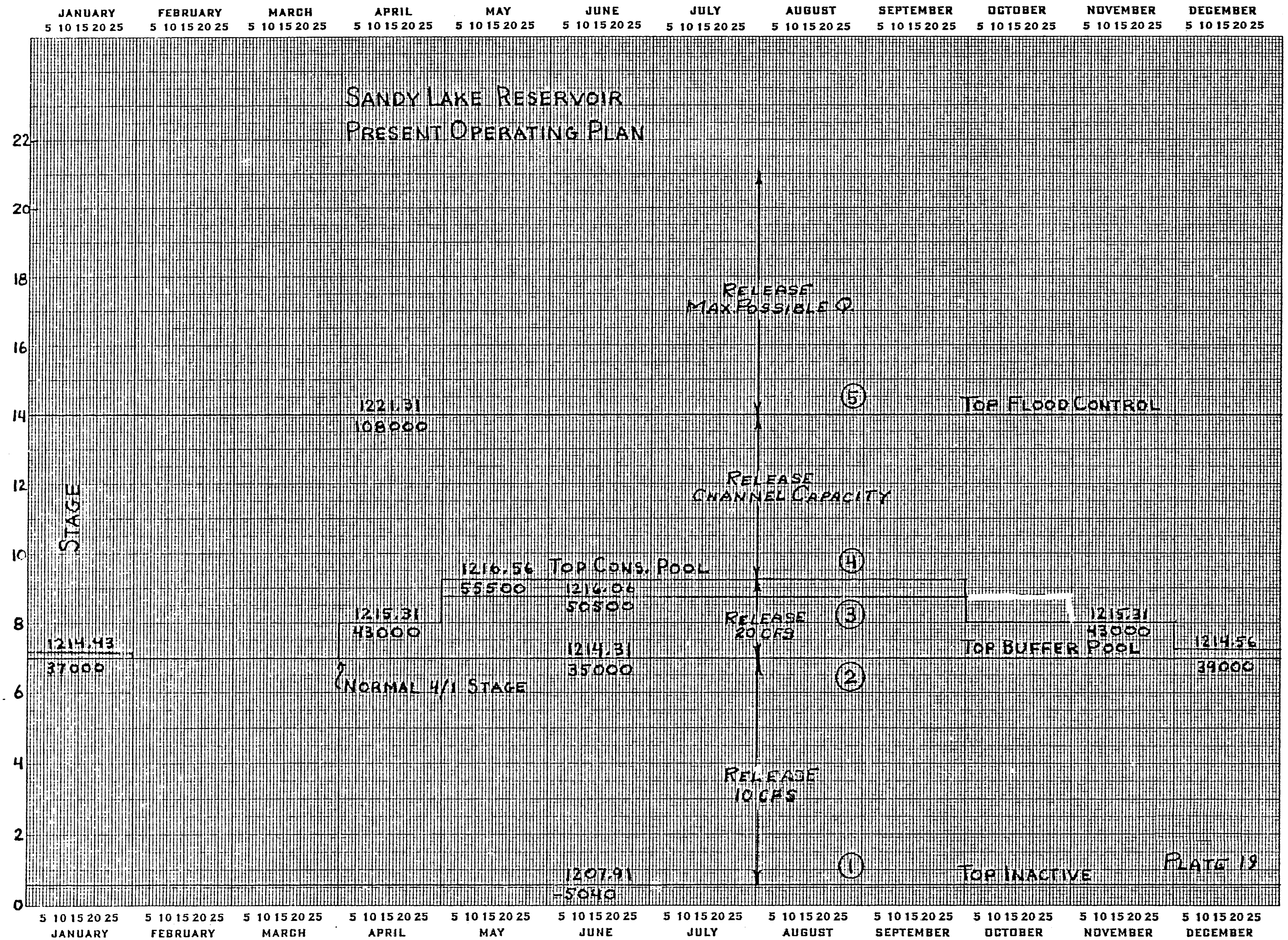


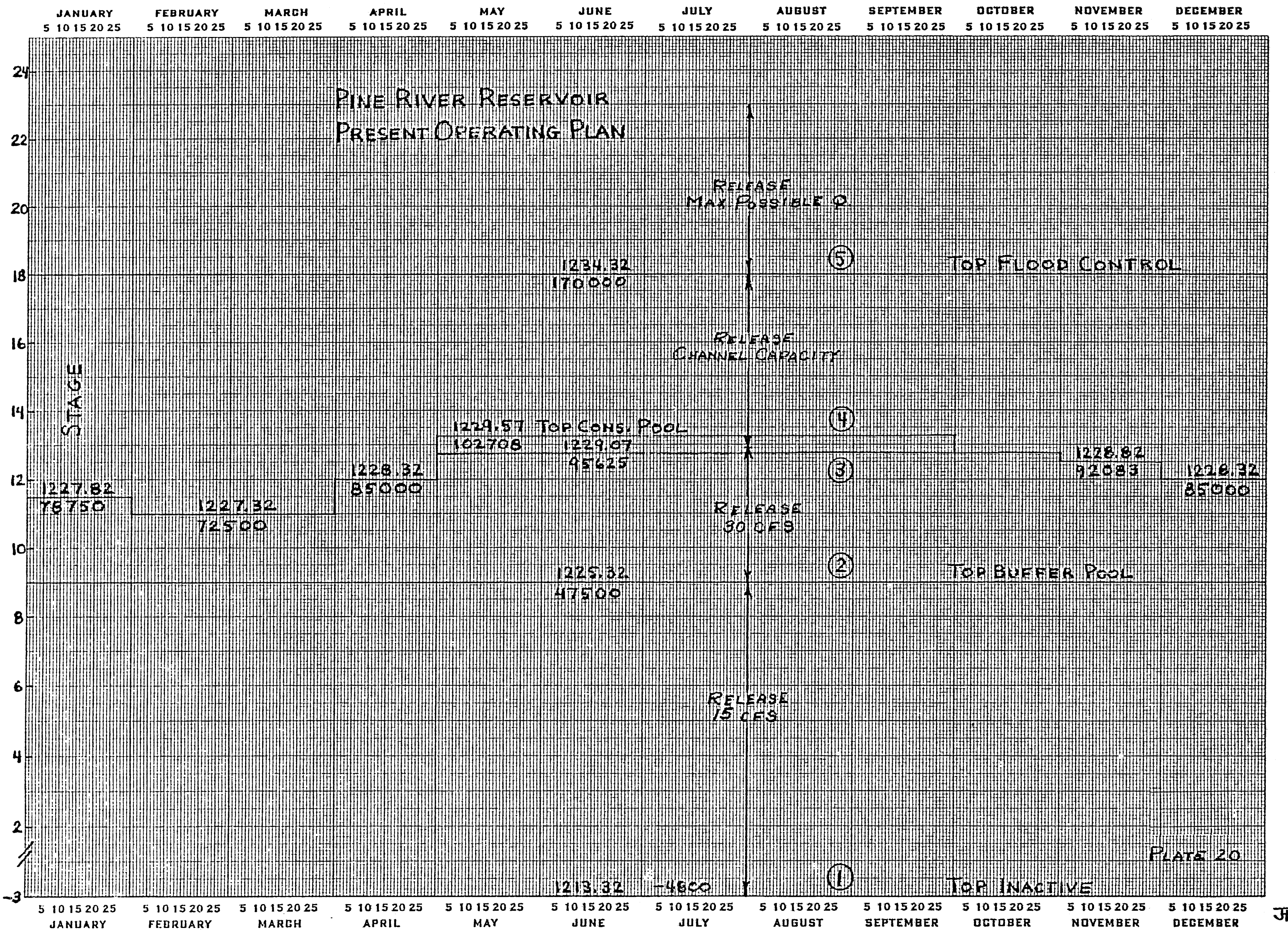
NO. 340-T15 DIETZGEN GRAPH PAPER
ONE YEAR BY DAYS — CALENDAR YEAR
366 DAYS X 250 [10 PER UNIT] DIVISIONS

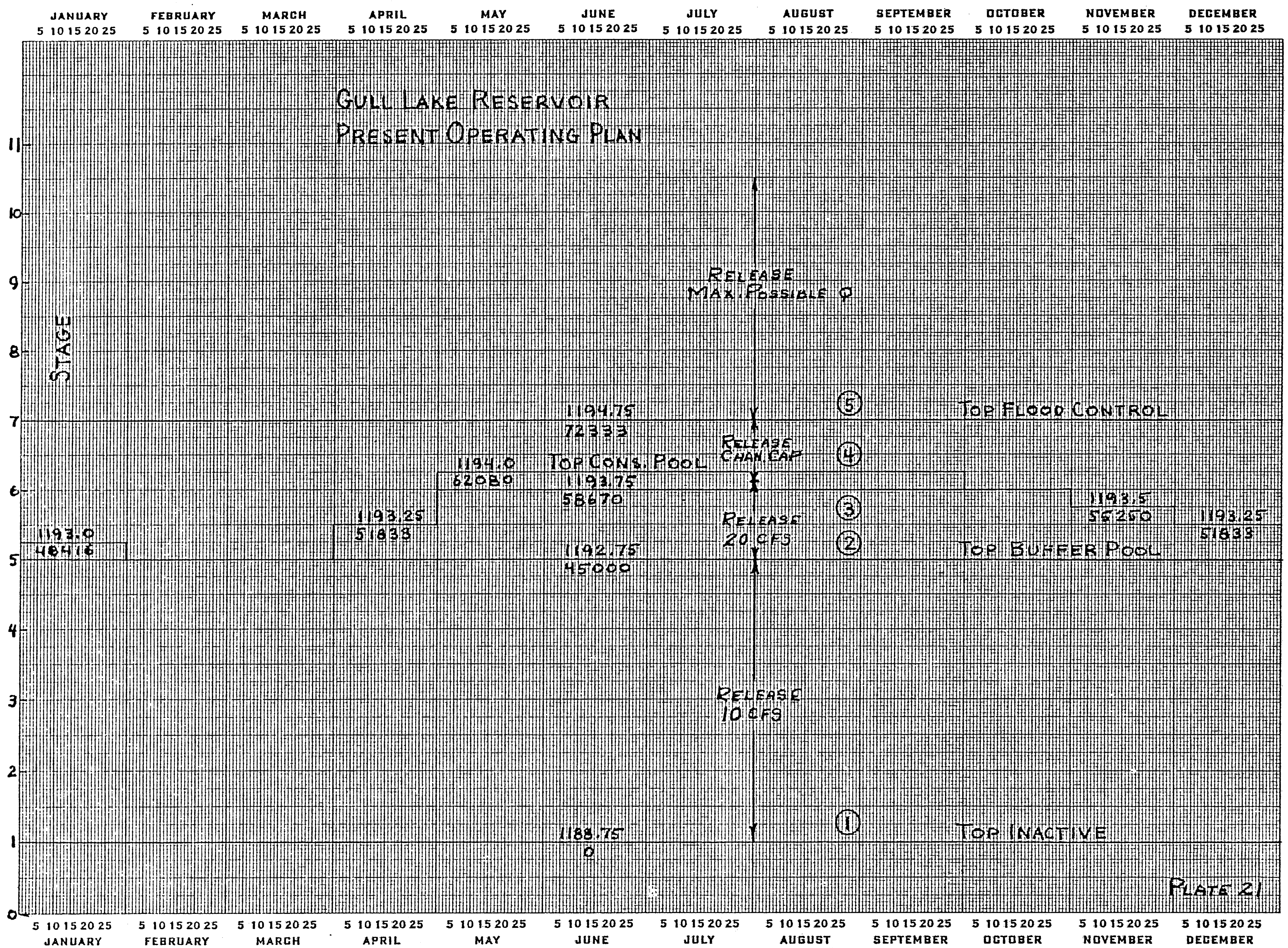
EUGENE DIETZGEN CO.
MADE IN U. S. A.

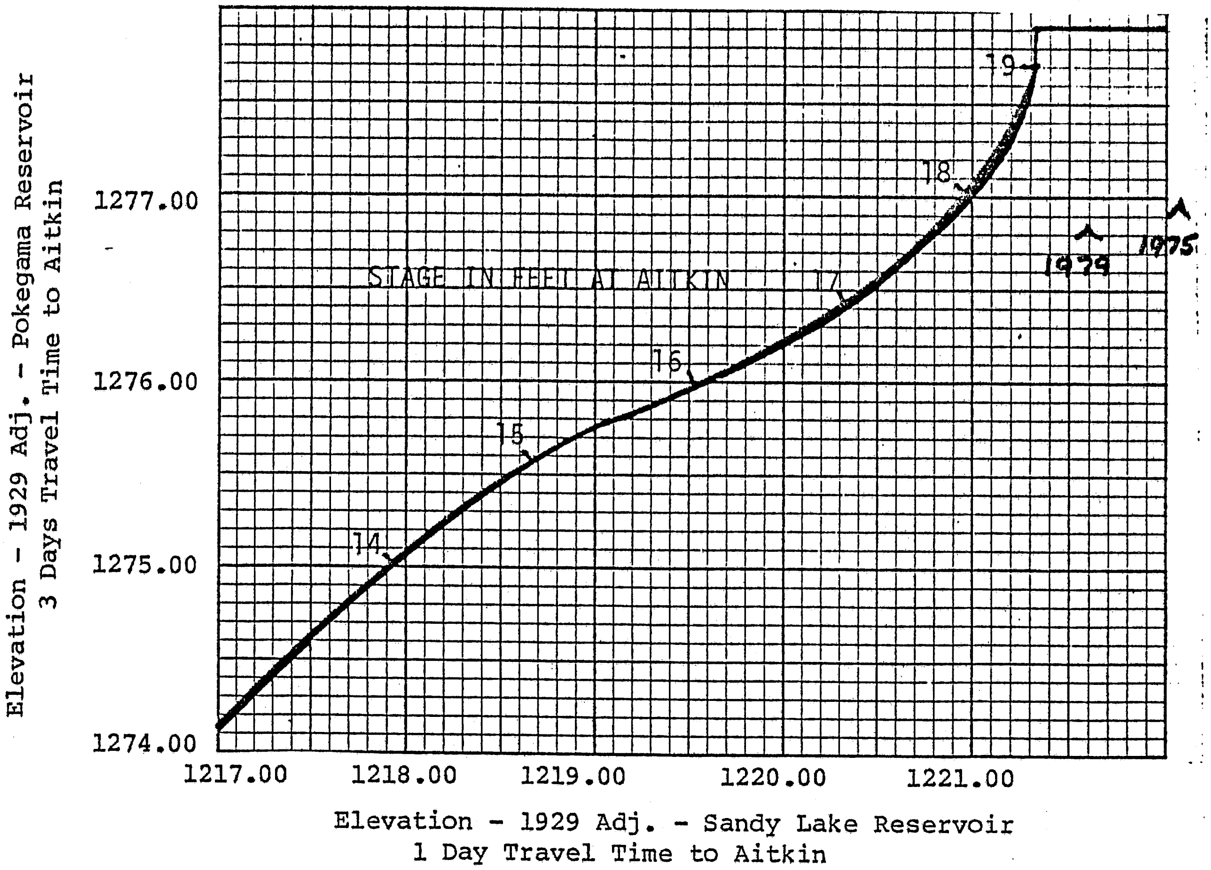


JF


SANDY LAKE RESERVOIR
PRESENT OPERATING PLAN
STAGE
RELEASE
MAX. POSSIBLE Q
RELEASE
CHANNEL CAPACITY
RELEASE
20 CFS
RELEASE
10 CFS
5
4
3
2
1
1221.31
108000
TOP FLOOD CONTROL
1216.56 TOP CONS. POOL
55500
1216.06
50500
1215.31
43000
1215.31
43000
1214.43
37000
1214.31
35000
TOP BUFFER POOL
1214.56
39000
NORMAL 4/1 STAGE
1207.91
-5040
TOP INACTIVE
PLATE 19
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER


PINE RIVER RESERVOIR
PRESENT OPERATING PLAN
STAGE
JANUARY FEBRUARY MARCH APRIL MAY JUNE JULY AUGUST SEPTEMBER OCTOBER NOVEMBER DECEMBER
RELEASE
MAX POSSIBLE Q
5
TOP FLOOD CONTROL
1234.32
170000
RELEASE
CHANNEL CAPACITY
4
1229.57 TOP CONS. POOL
102708
1229.07
95625
3
1227.82
76750
1227.32
72500
1228.32
85000
1228.82
92083
1228.32
85000
RELEASE
30 CFS
2
TOP BUFFER POOL
1225.32
47500
RELEASE
15 CFS
1
TOP INACTIVE
1213.32
-4600
PLATE 20
JF

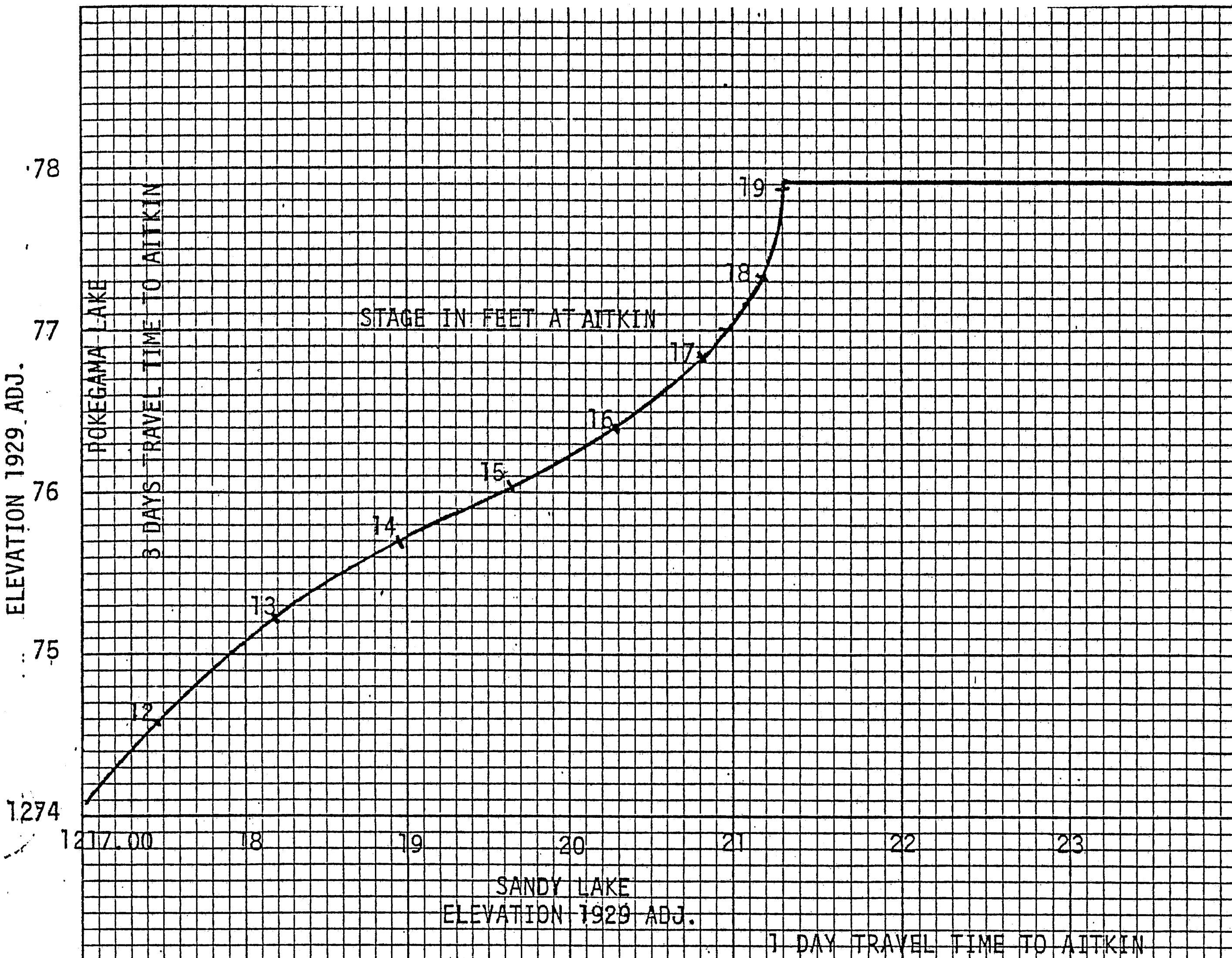

GULL LAKE RESERVOIR
PRESENT OPERATING PLAN
STAGE
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER
RELEASE
MAX. POSSIBLE Q
1194.75
72333
5
TOP FLOOD CONTROL
RELEASE
CHAN CAP
4
1194.0
62080
TOP CONS. POOL
1193.75
58670
3
1193.5
55250
1193.25
51833
1193.25
51838
1193.0
48416
RELEASE
20 CFS
2
1192.75
45000
TOP BUFFER POOL
RELEASE
10 CFS
1188.75
0
1
TOP INACTIVE
PLATE 21



NOTE: Curve shows relation between maximum reservoir stages and corresponding peak flood stage on the Mississippi River at Aitkin which, under operating procedures now in effect, will result (on the average) in the minimum total flood damages to affected interests in the three principal damage areas.

Navigation and Flood Control Mississippi River, Minnesota Headwaters Dams and Reservoirs Master Reservoir Regulation Manual, Tentative Guide Curve, Spring Floods (Mar.-15 May).

Plate 22



NOTE

Curve shows relation between maximum reservoir stages and corresponding peak flood stage on the Mississippi River at Aitkin which, under operating procedures now in effect, will result (on the average) in the minimum total flood damages to affected interests in the three principal damage areas.

NAVIGATION AND FLOOD CONTROL
MISSISSIPPI RIVER, MINNESOTA
HEADWATERS DAM AND RESERVOIRS
MASTER
RESERVOIR REGULATION MANUAL
TENTATIVE GUIDE CURVE
SUMMER FLOODS (15 May-Sept)

SUMMER

PLATE 23

FEB 28 1977

The normal summer operating level for Lake Winnibigoshish was lowered 1 foot from the 10.0 to 10.5 foot stage (1298.94 to 1299.44 elevation) to the 9.0 to 9.5 stage (1297.94 to 1298.44 elevation) in 1976. This lower level will be maintained for a 5-year trial period as a result of a 19 March 1975 letter request from the governor of Minnesota. The stage range of 9 to 9.5 feet was used in this study for the Present Operating Plan and the Low Level Plan. The range of 10 to 10.5 was used with the High Flow Plan.

The graphs on Plates 16 through 21 summarize the index levels for each reservoir on a monthly basis. The spring drawdown to accommodate snowmelt flooding is accomplished by lowering levels 3 and 4 through the winter in "stairstep" fashion. They are then allowed to rise through April and May and hold steady through the summer.

Water supply at Anoka is not considered in this plan. Flood control is a factor in operation, and Winnibigoshish, Leech, Pokegama, and Sandy are operated to the extent practical, to prevent more than 10,600 cfs discharge (15 foot stage) at Aitkin. However, it is not possible to prevent Aitkin flows from exceeding the 10,600 cfs limit during moderate to large floods. The uncontrolled drainage area below Pokegama and Sandy Lakes alone can cause this flow level to be exceeded. This was the case in 1975 when 95 percent of the 14,300 cfs flood peak at Aitkin resulted from the uncontrolled area below Pokegama and Sandy. (Reference June 1975 Flood Plain Information, Aitkin, Minnesota", U.S. Army Corps of Engineers.)

Low Flow Plan--Water Supply at Anoka

The Low Flow Plan uses the same index levels as the Present Operating Plan but allows releases from all reservoirs to maintain a flow of 1,600 cfs at Anoka. Since 1,600 cfs is both the desired and required flow, the reservoirs can be lowered to the inactive pool level to maintain the Anoka discharge.

The Corps of Engineers estimated water demand for the year 2015 for Minneapolis and St. Paul is 1,600 cfs as noted above. For this study the derivation of 1,600 cfs was discussed on pages 69-71 of the Corps of Engineers February 1978 Draft Stage 2 Report, Mississippi River Headwater Lake Study.

Flooding at Aitkin is also considered as a factor in operation, with flood discharge set at 10,600 cfs. Spring drawdown is moderate and summer levels are the same as the present operating plan. This plan, therefore, places some importance on Twin Cities' water supply, but this priority is balanced against flood protection and reservoir stage stability.

High Flow Plan--Flood Protection at Aitkin

This plan differs from the Present Operating Plan by placing more importance on flood protection at Aitkin and less on reservoir stage stability.

The operating range of the four reservoirs upstream from Aitkin is increased to the limits of the structure, as shown in Plates 24-27; spring drawdown is almost to the inactive pool. This adds about 336,000 A.F. of flood protection at Winnibigoshish, 80,000 A.F. at Leech, 19,000 A.F. at Pokegama, and 30,000 A.F. at Sandy (over and above the Present Operating Plan).

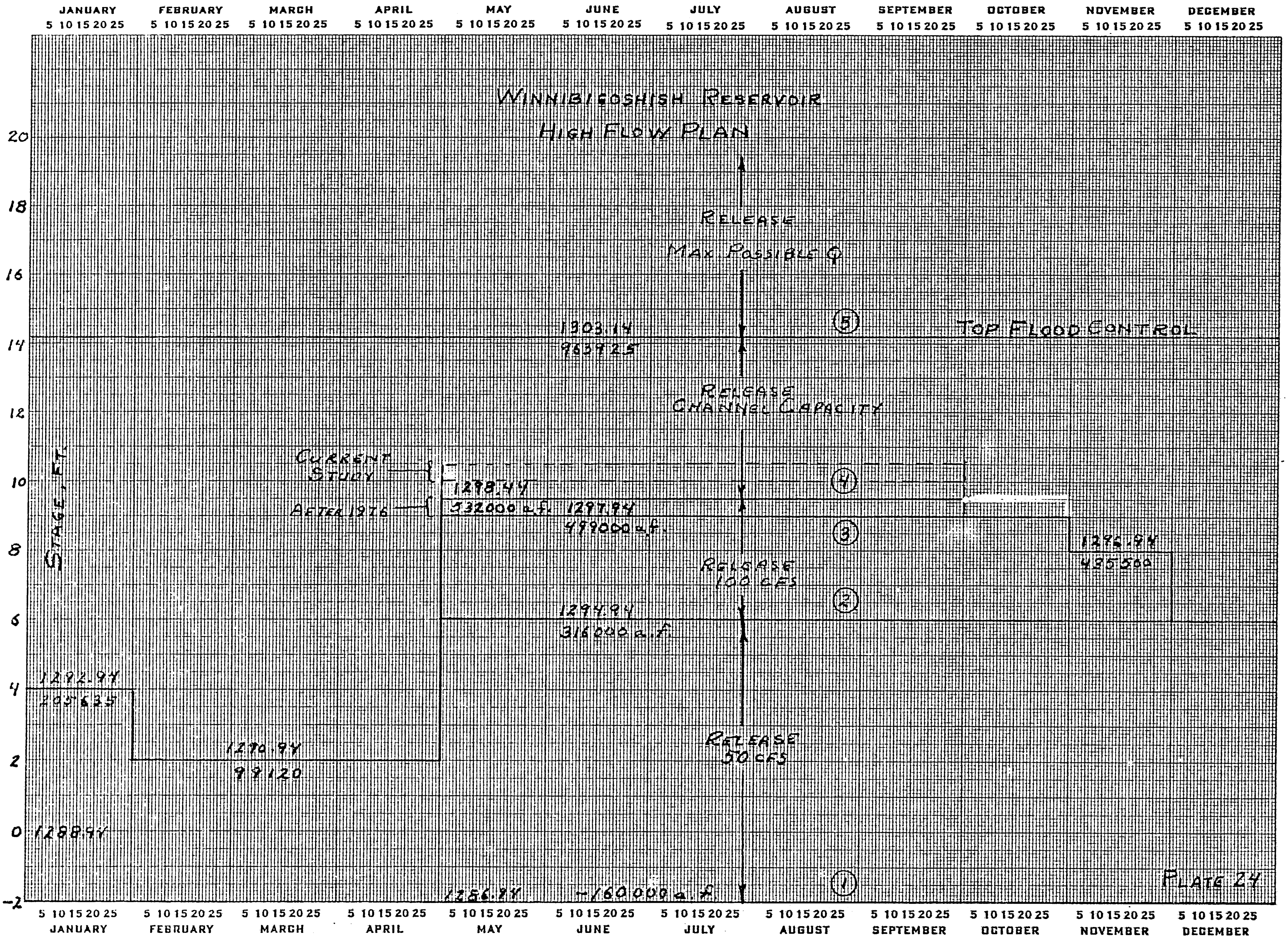
The spring drawdown corresponds to the following elevations: Winnibigoshish elevation, 1290.94; Leech elevation, 1292.2; Pokegama elevation, 1268.92; and Sandy elevation, 1207.91. The total increase of 465,000 A.F. represents a possible average flow reduction at Aitkin of 3,900 cfs for two months.

Water supply at Anoka is not a consideration in this plan and desired summer levels are the same as in the Present Operating Plan.

Natural Flows

The natural flows were calculated by using HEC-5C in a rather unorthodox manner. It was necessary that discharges be calculated only on the basis of the reservoir stage, according to the natural stage-discharge curve. The program follows such a curve when storage is above level 5 and the dam is in danger of being overtopped. The maximum possible release corresponding to that reservoir level is then specified, to lower the reservoir as quickly as possible.

To calculate natural flows, the natural stage discharge curve is used instead of the curve for the gates of the dam. The index levels are all placed very low, below the zero discharge, so that no matter how much water is released, the program always finds the reservoir in flood condition (over level 5), and specifies the maximum possible discharge. This combination produces natural routing through the reservoir, a capability which HEC-5C does not normally have.


WINNIBIGOSHISH RESERVOIR
HIGH FLOW PLAN
JANUARY FEBRUARY MARCH APRIL MAY JUNE JULY AUGUST SEPTEMBER OCTOBER NOVEMBER DECEMBER
STAGE, FT.
20
18
16
14
12
10
8
6
4
2
0
-2
RELEASE
MAX POSSIBLE Q
1303.14
963925
5
TOP FLOOD CONTROL
RELEASE
CHANNEL CAPACITY
CURRENT STUDY
AFTER 1976
1298.44
532000 a.f.
1297.94
499000 a.f.
4
3
1295.94
435500
RELEASE
100 CFS
2
1294.94
316000 a.f.
1292.94
205635
1290.94
99120
RELEASE
50 CFS
1288.94
1286.94
-160000 a.f.
1
PLATE 24

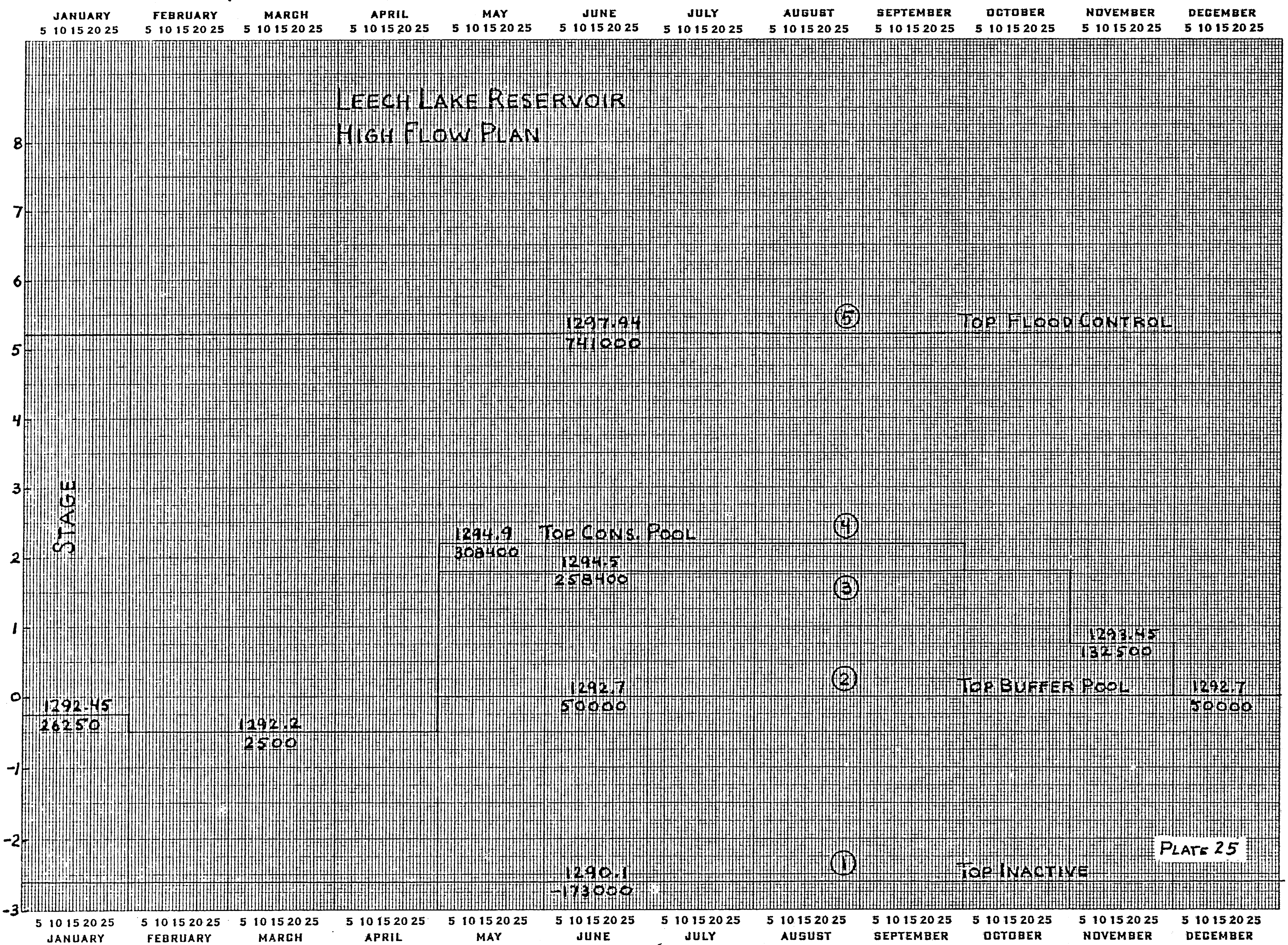

LEECH LAKE RESERVOIR
HIGH FLOW PLAN
STAGE
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER
1297.94
741000
TOP FLOOD CONTROL
1294.9
308400
TOP CONS. POOL
1294.5
258400
1293.45
132500
1292.7
50000
TOP BUFFER POOL
1292.7
50000
1292.45
26250
1292.2
2500
1290.1
-173000
TOP INACTIVE
5
4
3
2
1

PLATE 25

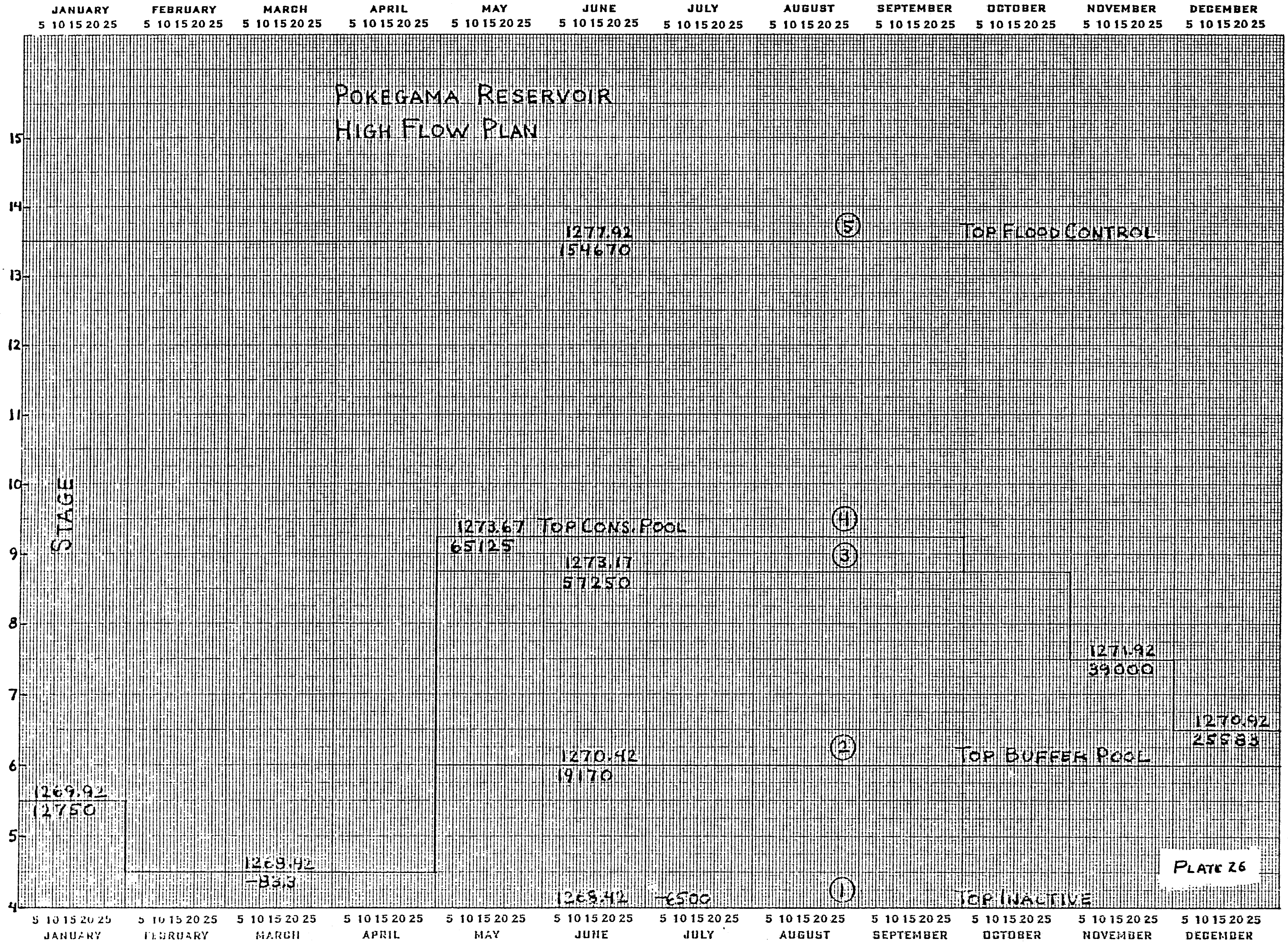

POKEGAMA RESERVOIR
HIGH FLOW PLAN
STAGE
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER
5 10 15 20 25
15
14
13
12
11
10
9
8
7
6
5
4
1277.92
154670
TOP FLOOD CONTROL
5
1273.67 TOP CONS. POOL
65125
4
1273.17
57250
3
1271.92
39000
1270.92
25583
1270.42
19170
TOP BUFFER POOL
2
1269.92
12750
1269.42
-833
1268.42
-6500
1
TOP INACTIVE

PLATE 26

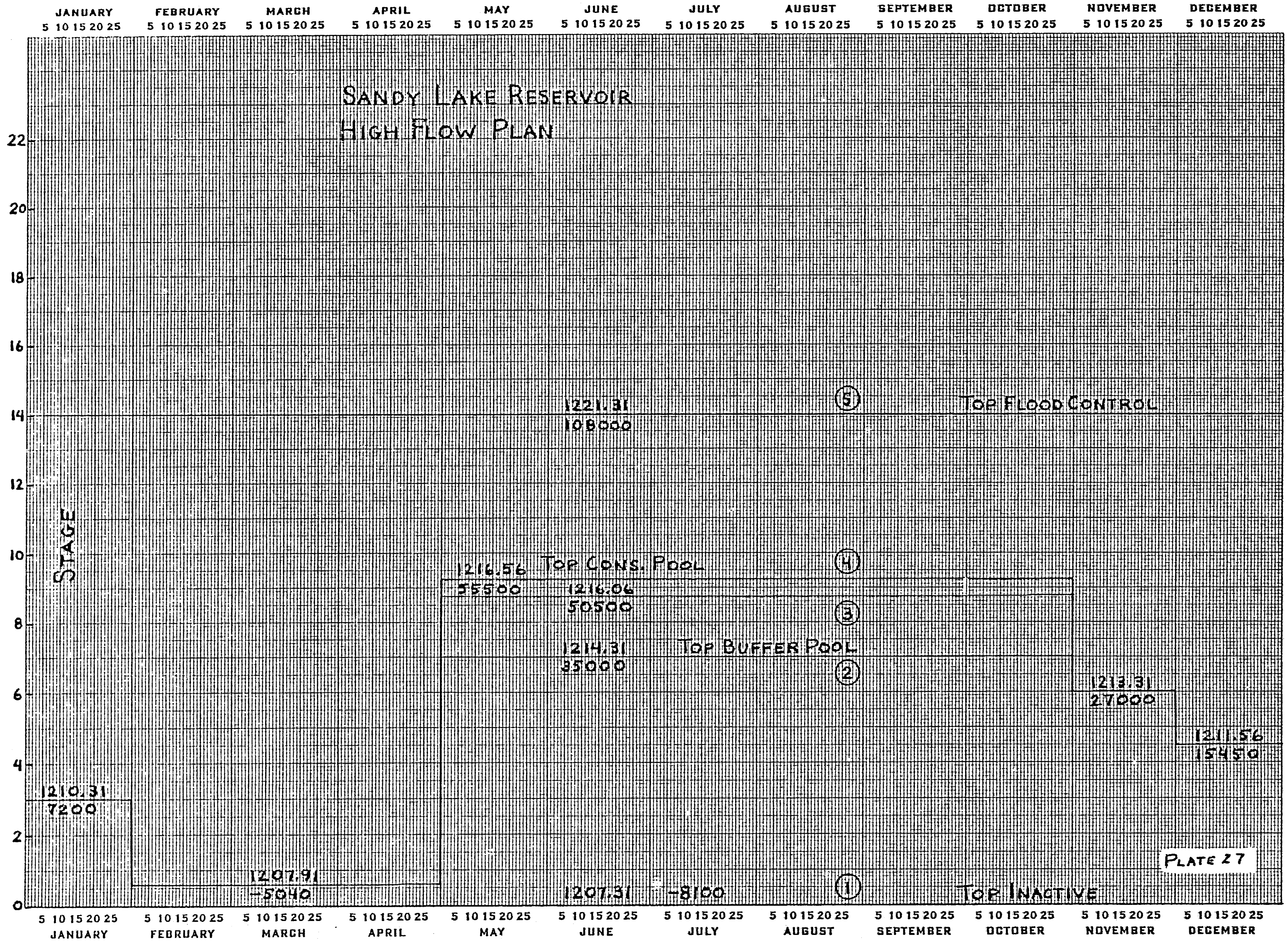

SANDY LAKE RESERVOIR
HIGH FLOW PLAN
STAGE
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER
1221.31
108000
TOP FLOOD CONTROL
5
1216.56
55500
TOP CONS. POOL
4
1216.06
50500
3
1214.31
35000
TOP BUFFER POOL
2
1213.31
27000
1211.56
15450
1210.31
7200
1207.91
-5040
1207.31
-8100
1
TOP INACTIVE

PLATE 27

A major problem with this is that Sandy Lake Reservoir under natural conditions did not have a single stage-storage curve, but a family of curves based on backwater effects from the Mississippi River. After consulting with the Reservoir Regulation Branch of the St. Paul District Office, it was decided to set Sandy Lake out-flows equal to in-flows and, in effect, to eliminate the reservoir for natural flows. HEC-5C has an option which allows a reservoir to be eliminated, but one unusual result was noted with this option: when negative in-flows occurred, the program did not use a negative out-flow. Instead, it used zero out-flow and subtracted the negative flow from the next positive in-flow. Ultimately, it was considered that this procedure was at least as good as the expected result (i.e., passing negative flows on to the Mississippi).

The problems encountered in getting the program to simulate natural flows are summarized in Appendix G.

Plate 28 is a rating curve for the Mississippi River at Aitkin, based on published data from the U.S. Geological Survey. The zero on this gauge was lowered 3 ft on 30 September 1967 to eliminate negative gauge readings. This has caused some confusion in the use of data at this site.

Plate 29 is a log-log plot of a composite curve from Plate 28. It is of interest for limited extrapolation of the data and was used in the current study.

The computer output for each of the four primary runs ranged up to 2000 sheets of printout. This included numerous tables, graphs, and related material. Consideration was given to the uses of various graphics methods to present the data, but it was finally decided to hand plot all of the graphs.

Also, because of the large amount of reference material, only sample copies of some plotted output material are included in the report text; the remainder are included in the Appendices. (The Appendices are included with only a few copies of the text.) These Appendices are as follows:

A. Elevation, Discharge: Present Operating Plan

B. Elevation, Discharge: Natural Flows

C. Elevation, Discharge: Low Flow Plan

D. Elevation, Discharge: High-Flow Plan

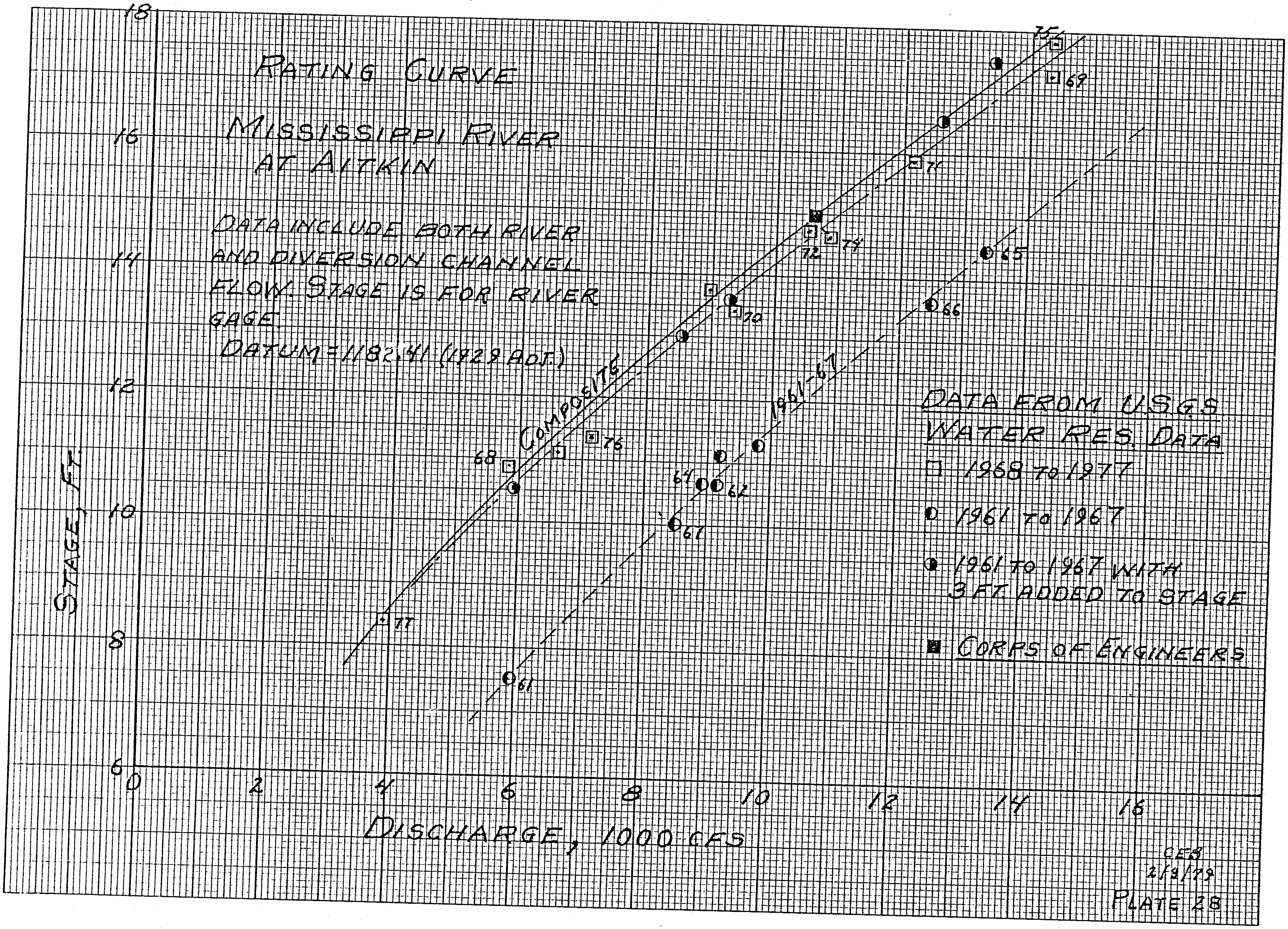
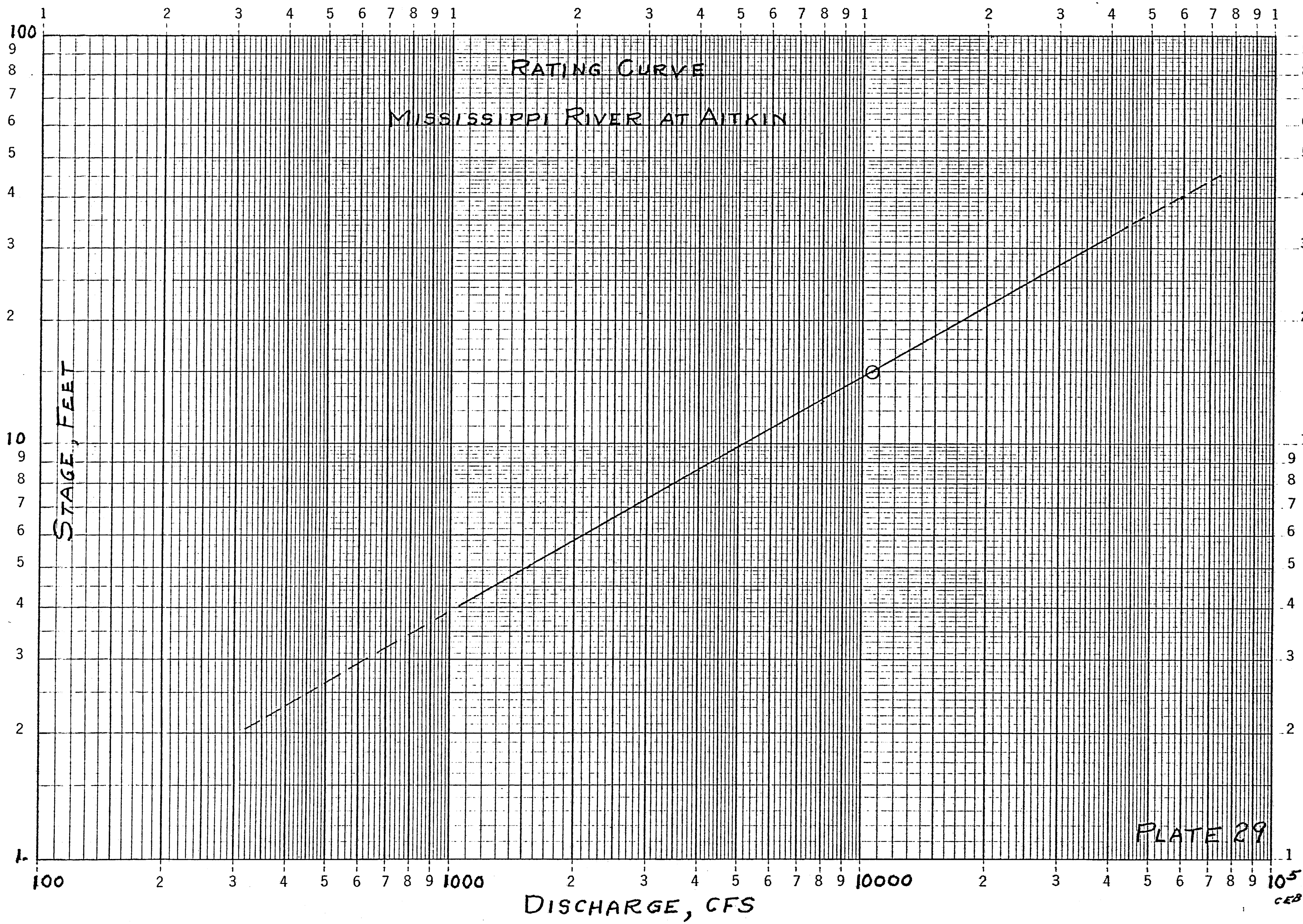

RATING CURVE
MISSISSIPPI RIVER
AT AITKIN
DATA INCLUDE BOTH RIVER AND DIVERSION CHANNEL FLOW. STAGE IS FOR RIVER GAGE.
DATUM=1182.41 (1929 ADJ.)
COMPOSITE
1961-67
DATA FROM U.S.G.S. WATER RES. DATA
1968 TO 1977
1961 TO 1967
1961 TO 1967 WITH 3 FT. ADDED TO STAGE
CORPS OF ENGINEERS
STAGE, FT
DISCHARGE, 1000 CFS
0
2
4
6
8
10
12
14
16
18
CEB
2/9/79

PLATE 28


RATING CURVE
MISSISSIPPI RIVER AT AITKIN
STAGE, FEET
DISCHARGE, CFS
100
1000
10000
10^5
PLATE 29
CEB

E. Elevation, Discharge: Actual Release (Partial Set)

F. Elevation-Frequency Curves

G. Damage-Frequency Curves

H. Computer Program HEC-5C

I. Hydrologic Data

J. Calculations of Local Inflow

K. Notes on Final Data Deck

L. Computer Program Evaluation

M. Problems with Natural Flows

N. Miscellaneous Reference Material Used in Study

O. Output Tables: Maximum and Minimum Elevations

P. Notes on Computer Runs

Appendices A through G are the results of computer runs and analysis.

Appendices H through P include the reference material on the computer program, hydrologic data, stage-damage data, and miscellaneous other data.

RESULTS

Reviewing briefly, the procedures used in this study were as follows:

1. Reference material on the Mississippi River Headwater System was received from the Corps of Engineers, St. Paul District.

2. Reservoir elevations at 10-day intervals, for the period 1932-1976 were received from the Corps of Engineers.

3. Reservoir releases and flows of the Mississippi River at selected points such as Libby, Aitkin, Royalton, Anoka, and St. Paul were obtained on tape from the U.S. Geological Survey. (As some data were not available on tape, they were obtained from published Water Resources Data.)

4. Knowing the reservoir elevations at 10-day intervals, the reservoir releases were reverse routed through the reservoirs to obtain inflow to the reservoirs. This required development of a computer program to do the reverse routing. This "inflow" actually consisted of inflow plus precipitation, minus evaporation and minus some transpiration. In summer months the evaporation and other losses sometimes exceeded inflow plus precipitation, giving a "negative inflow". Wind "set-up" also affects the reservoir levels.

5. Using the actual releases from the reservoirs and HEC-5C, the flow was routed down to St. Paul to determine the local inflows between control points for the period 1932-1976. (In addition to the headwater reservoirs, the primary control points and the junction of their flows with the Mississippi River were Libby, Aitkin, Royalton, Anoka, and St. Paul.) While some of the inflow between these points is gauged, a large portion is not gauged. Thus, some method for introducing tributary flow is needed. After the local inflow was determined, using actual reservoir releases, the local inflows were assumed fixed for other runs in which the HEC-5C program was used to control releases. Routing in this phase of the study was by progressive average lag, or straddle stagger.

6. A data check was then prepared for use with (1) present operating plan and (2) actual releases.

In the early phases of the study an effort was made to check both input and generated output to eliminate errors. With 45 years of data from various sources plus the reverse routing and local inflow determinations, there were many opportunities to introduce errors.

Comparisons were made between computed flows and elevations and published flow data. Also, some comparisons were made between runs on the CYBER 74 at the University of Minnesota and other runs on the Boeing Computer in Seattle. Some of these are described in Appendix L.

A comparison between computed and observed flows at Aitkin and Anoka was also considered of special interest. Plates 30 to 33 show such a comparison for daily flows. Plate 34 is a similar comparison for monthly flows. The solid lines are daily flows for the Present Operating Plan as generated by the HEC-5C

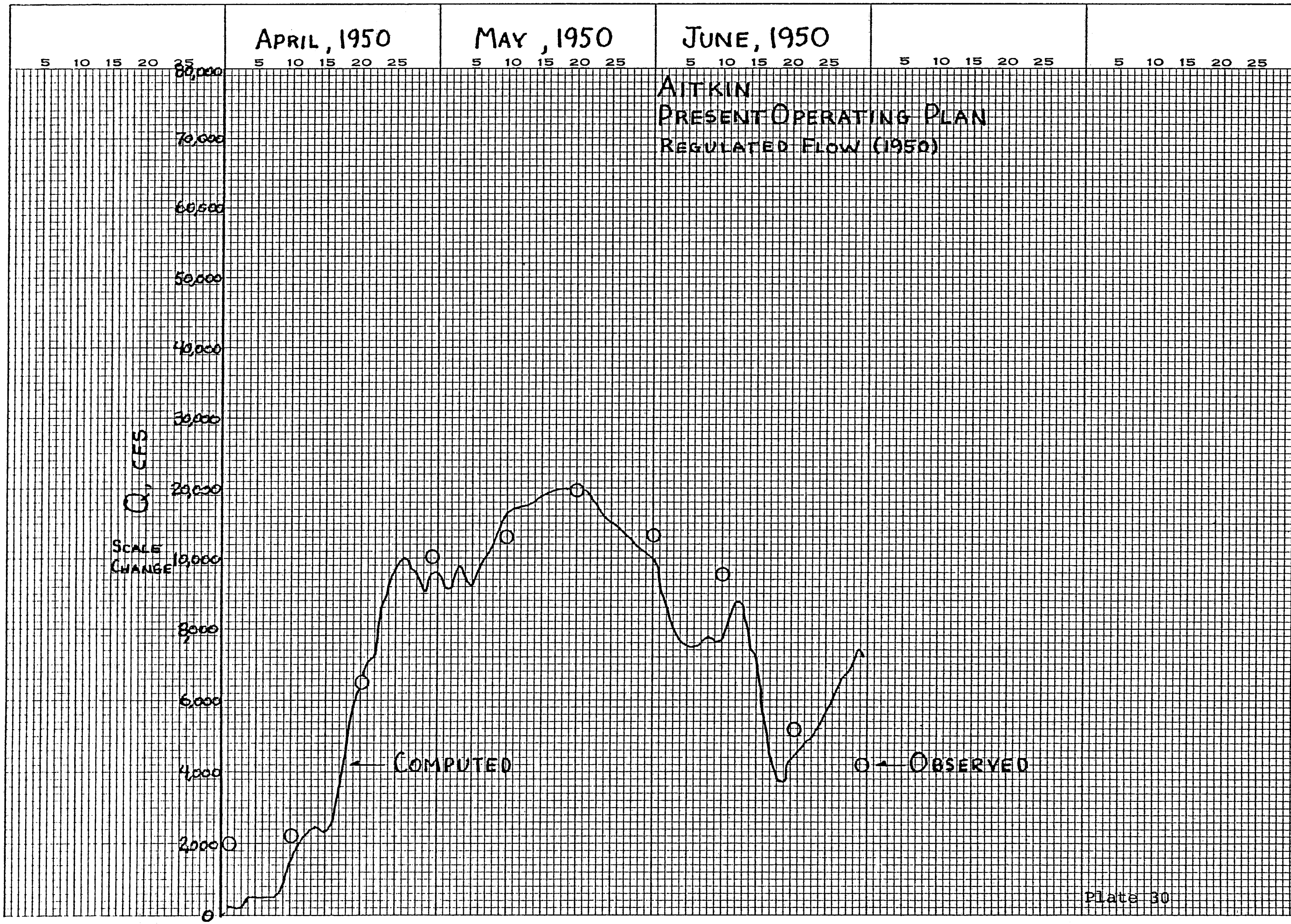

APRIL, 1950
MAY, 1950
JUNE, 1950
AITKIN
PRESENT OPERATING PLAN
REGULATED FLOW (1950)
Q, CFS
SCALE CHANGE
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
8,000
6,000
4,000
2,000
0
COMPUTED
OBSERVED

Plate 30

JF

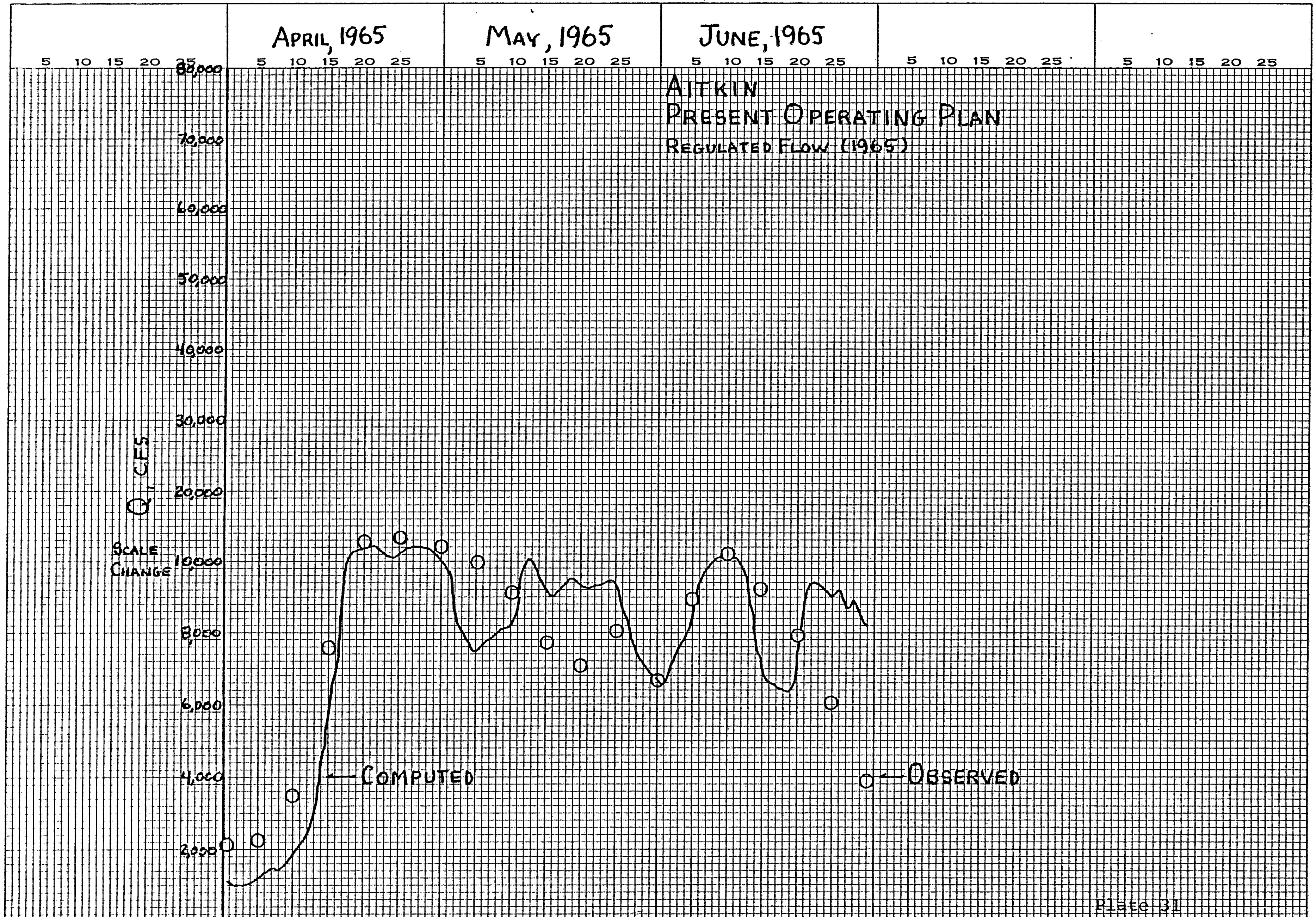
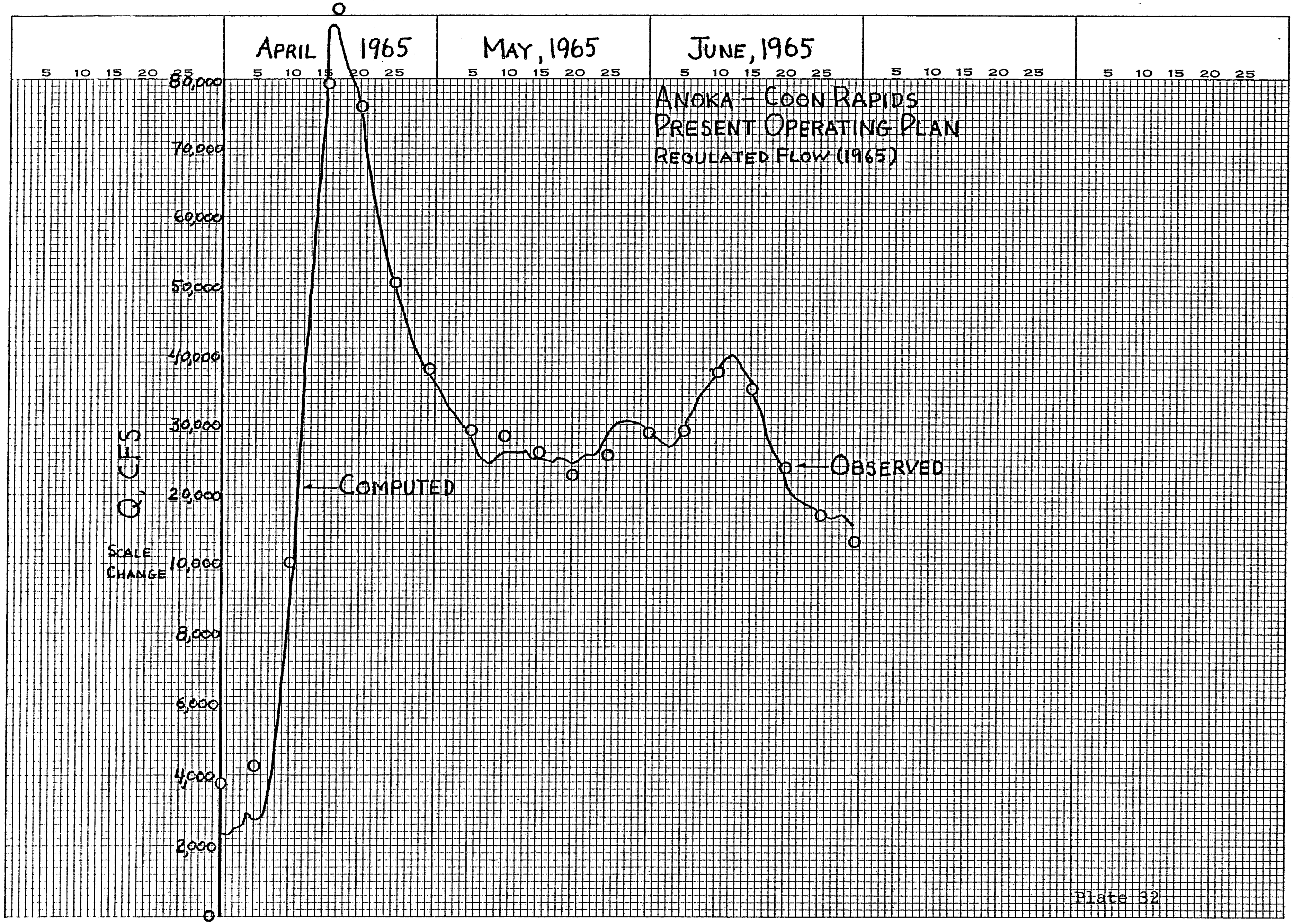
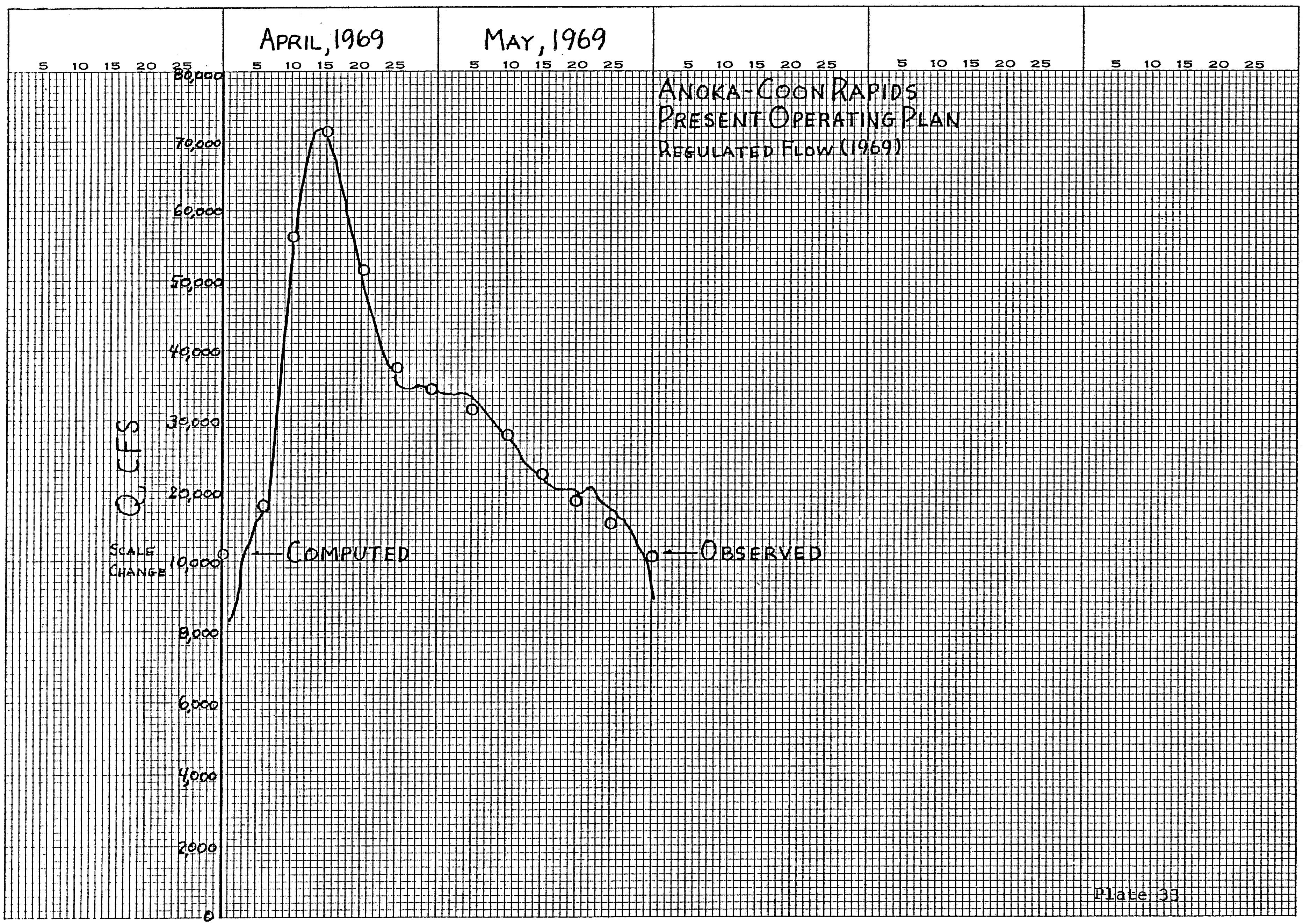

APRIL, 1965
MAY, 1965
JUNE, 1965
AITKIN
PRESENT OPERATING PLAN
REGULATED FLOW (1965)
Q, CFS
SCALE CHANGE
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
8,000
6,000
4,000
2,000
0
COMPUTED
OBSERVED

Plate 31


APRIL 1965
MAY, 1965
JUNE, 1965
5 10 15 20 25
ANOKA - COON RAPIDS
PRESENT OPERATING PLAN
REGULATED FLOW (1965)
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
8,000
6,000
4,000
2,000
0
Q CFS
SCALE CHANGE
COMPUTED
OBSERVED
Plate 32

JF


APRIL, 1969
MAY, 1969
5 10 15 20 25
ANOKA-COON RAPIDS
PRESENT OPERATING PLAN
REGULATED FLOW (1969)
Q CFS
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
8,000
6,000
4,000
2000
0
SCALE CHANGE
COMPUTED
OBSERVED
Plate 33

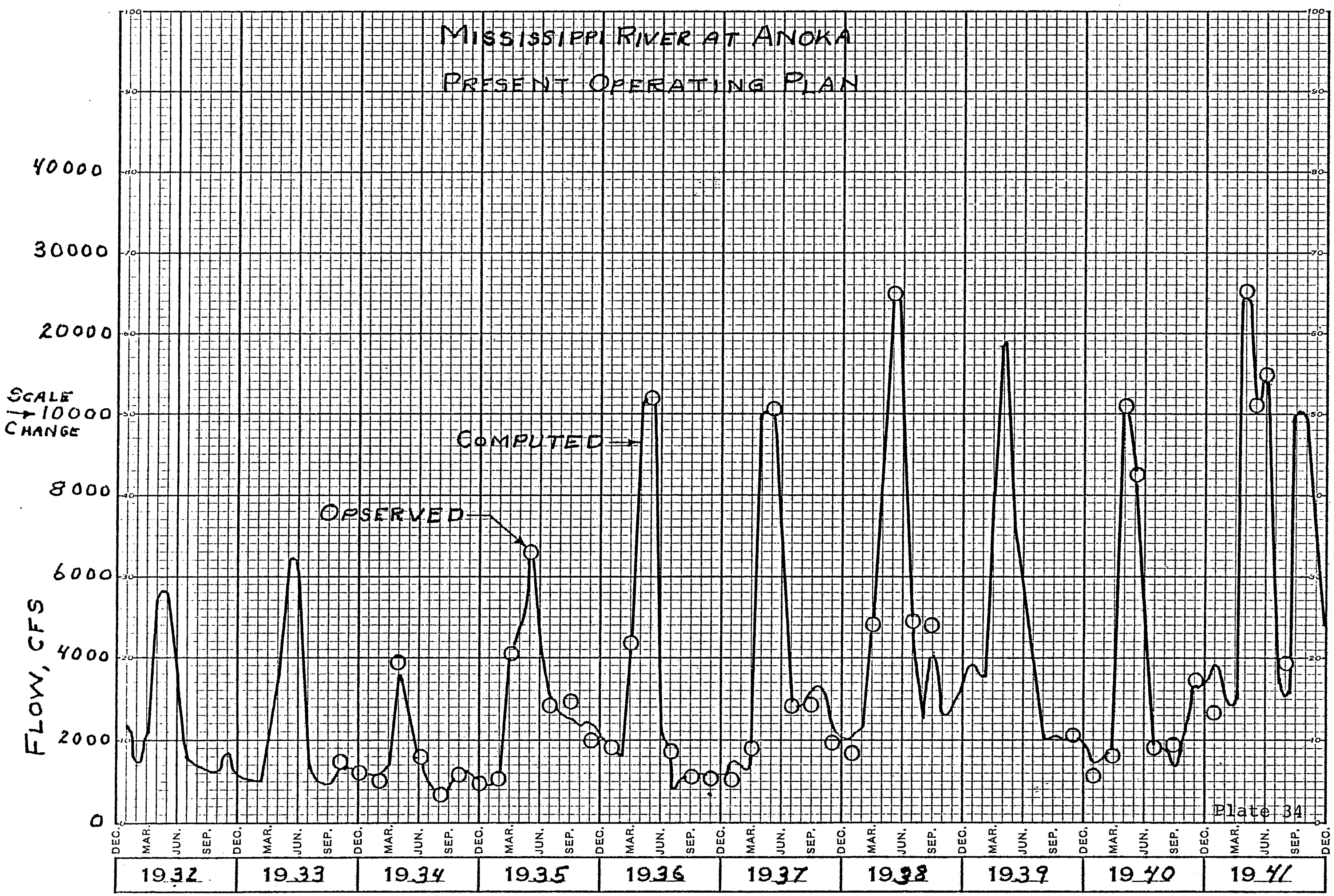

MISSISSIPPI RIVER AT ANOKA
PRESENT OPERATING PLAN
COMPUTED
OPSERVED
FLOW, CFS
40000
30000
20000
SCALE → 10000 CHANGE
8000
6000
4000
2000
0
DEC. MAR. JUN. SEP.
1932
1933
1934
1935
1936
1937
1938
1939
1940
1941

Plate 34

program. The circles are published data at Aitkin and Anoka for the same time period; data were selected at five day intervals from the published records.

HEC-5C does not exactly duplicate the actual Present Operating Plan and the plan may have changed somewhat over the years. Thus, some differences were anticipated between the computed (HEC-5C) curve and observed flow. As noted earlier, engineering judgement and forecasts of future conditions can influence actual releases. In spite of these potential differences, agreement between the computed and observed flows of Plates 30 to 34 is excellent. The peak flows also match very well. There are differences on the recession side of the curves at Aitkin, indicating an earlier and more gradual decrease in the actual releases.

However, it should be noted that at Anoka the headwater reservoirs have relatively small influence. This results because most of the flow at Anoka in an HEC-5C run is local inflow, relative to the headwater reservoirs. The comparisons are still of interest as a check on local inflow data used in the study and a partial check of reservoir releases under the Present Operating Plan.

Graphing of Results

The output of computer program HEC-5C in this study consisted of 45 years of data (1932-76) on reservoir elevation, reservoir releases, and flows of the Mississippi River at Libby, Aitkin, Royalton, Anoka, and St. Paul. Data on reservoir elevation and releases, plus flows at Aitkin and Anoka, have been plotted on graph paper (10 years per page) for 45 years of record and four operation plans.

In the computer printout 20 periods of daily flow were interspersed with 21 periods of monthly flow data. It was necessary to use a hand calculator to compute monthly flows from daily flows in order to complete the 45 year record of monthly flows. This was very time consuming and could be remedied by a change in the program.

Plotting of the monthly flows at 10 years per page gave 5 graphs per station for 45 years of record. For 8 locations (Winnibigoshish, Leech, Pokegema, Sandy, Pine River, Gull, Aitkin, and Anoka) and 4 operational plans, this resulted in 160 graphs. In addition, daily flows at Aitkin and Anoka were plotted for 1948, 1950, 1965, 1969, and 1971. This resulted in about 40 graphs. An analysis of high- and low- elevation probabilities in the reservoirs and damage analysis at 8 locations produced about 144 graphs; graphs of miscellaneous reference data produced about 30 graphs, for a total of about 374 graphs.

The effects of each of the 4 operating plans evaluated are reflected in the 10-year graphical plots of elevation and discharge versus time for each of the headwater reservoirs. These data are one of the principal outputs of this study.

It was concluded that the best way to present this information was by including in the body of the report examples of the elevation-discharge curves for the reservoirs, selected discharge curves for Aitkin and Anoka, and comparison graphs. The complete set of graphs was placed in the Appendices. A limited number of sets of the Appendices were prepared, as readers of the report will seldom need the complete set. Graphical comparisons and summary tables are presented in a later section of the main report.

The final computer printout of the four main runs is available. A typical card input deck and a tape copy of the HEC-5C source program are also available.

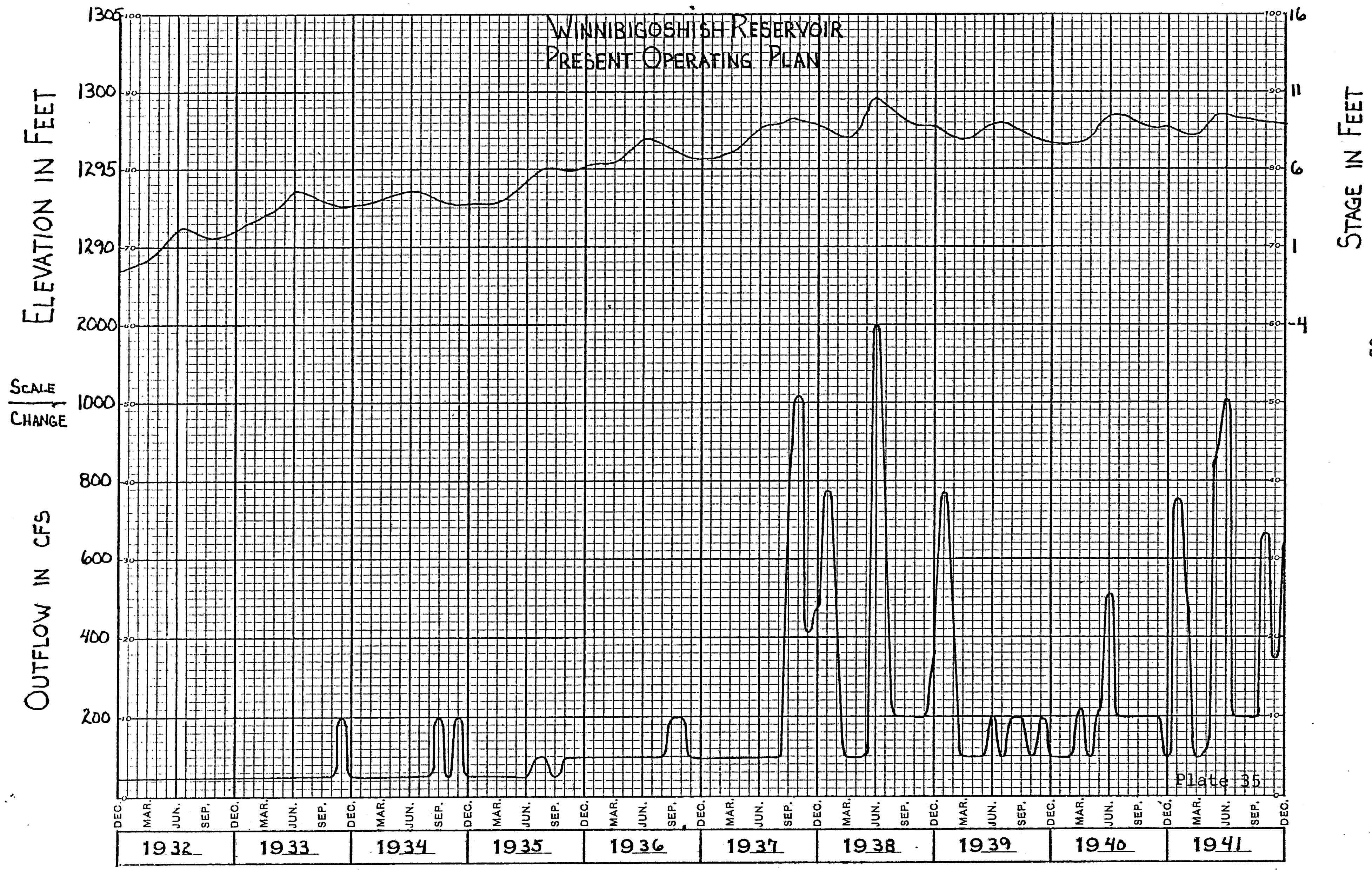
Present Operating Plan

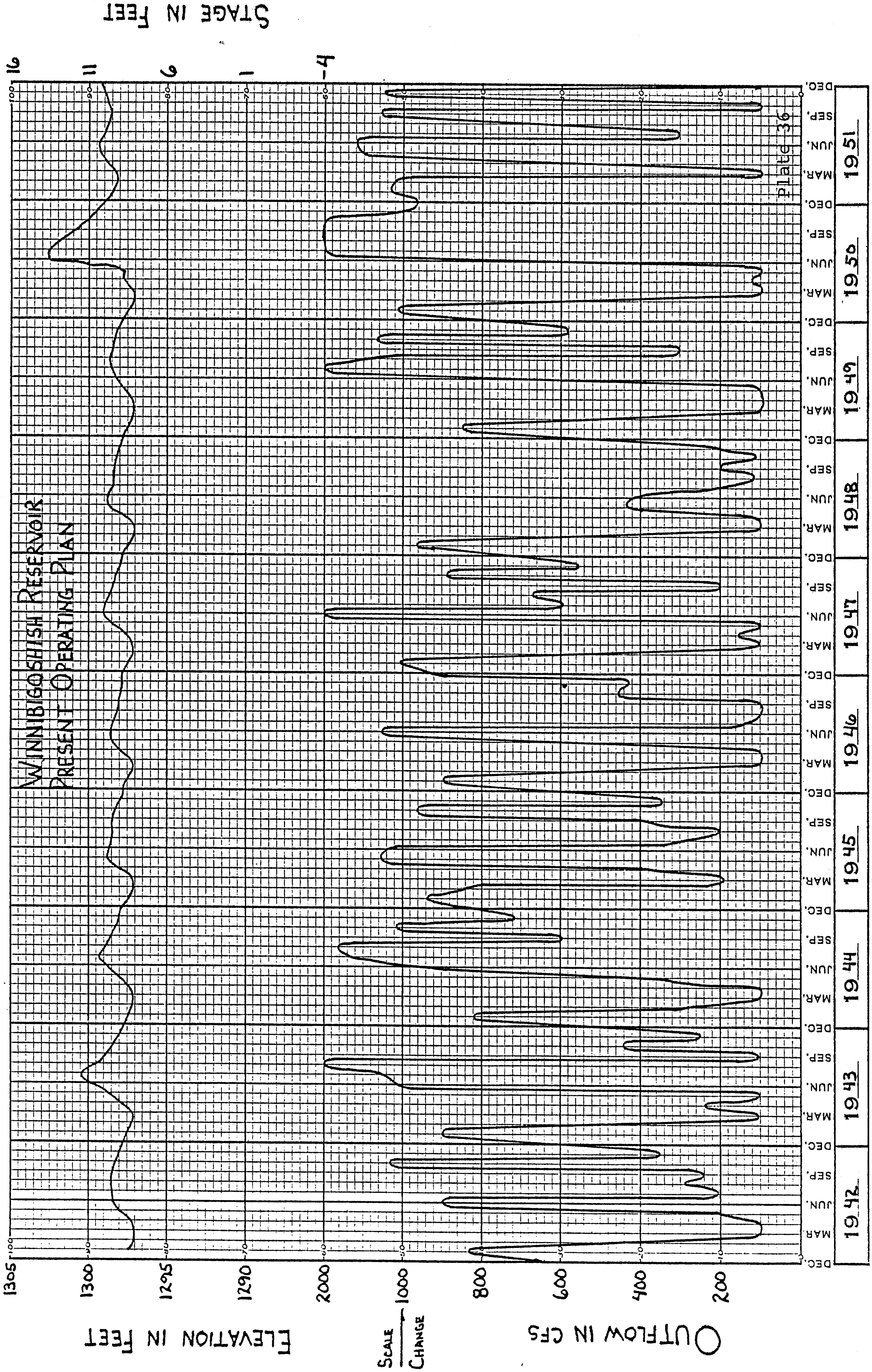
Plates 35 to 39 are graphs of the water surface elevation and reservoir releases for Winnibigoshish Reservoir for the 45 year period. One complete set has been provided to illustrate the complete period. For other reservoirs and other plans, only one graph is provided in the body of the report (1972 to 1976), as noted above.

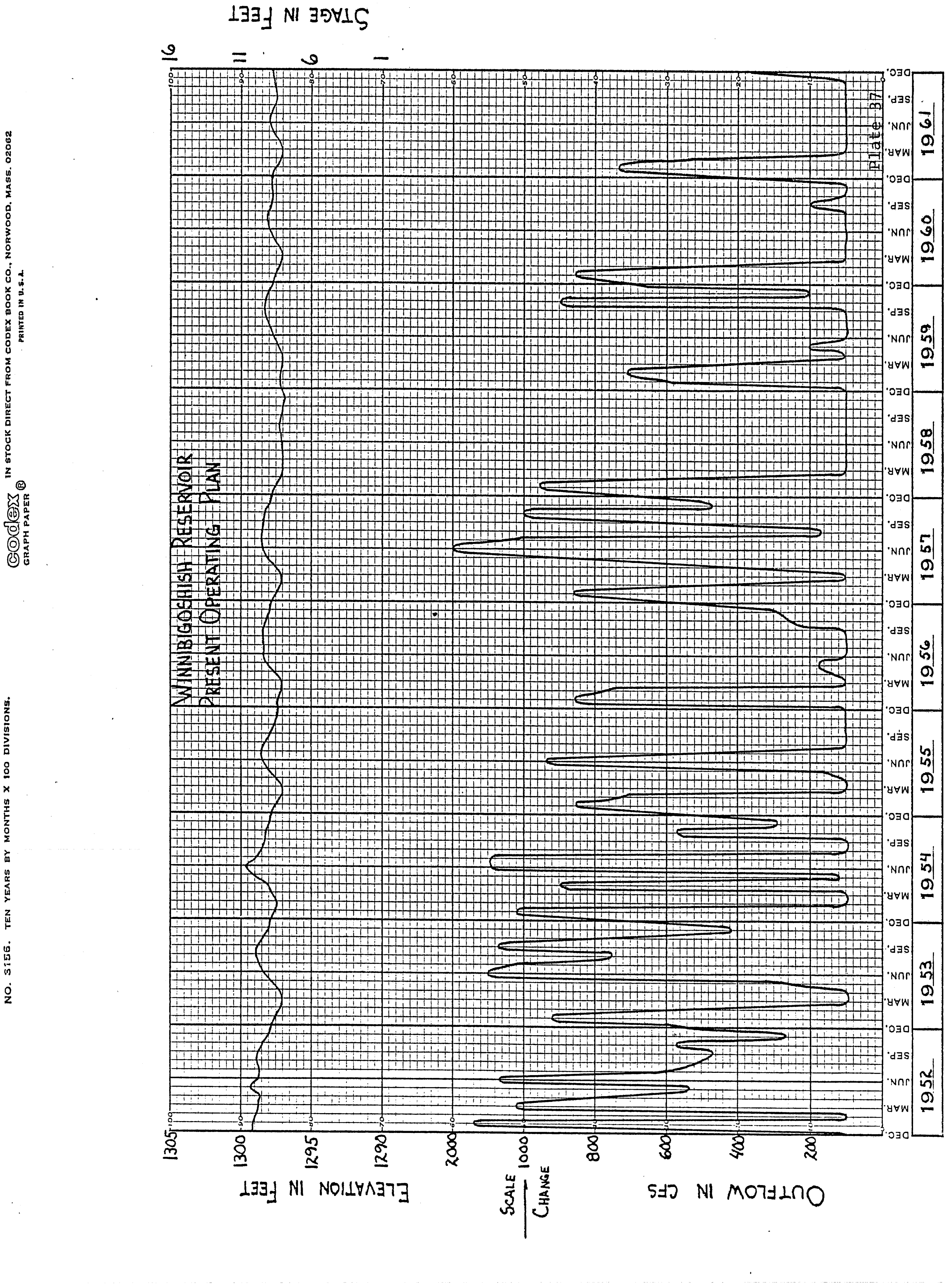
Referring to Plate 35, it may be noted that the Winnibigoshish Reservoir level would be very low in the early 1930's (this was also true with the actual releases for this period). The late 1950's and 1976 were also dry, but not as severe or extensive in length as the 1930's.

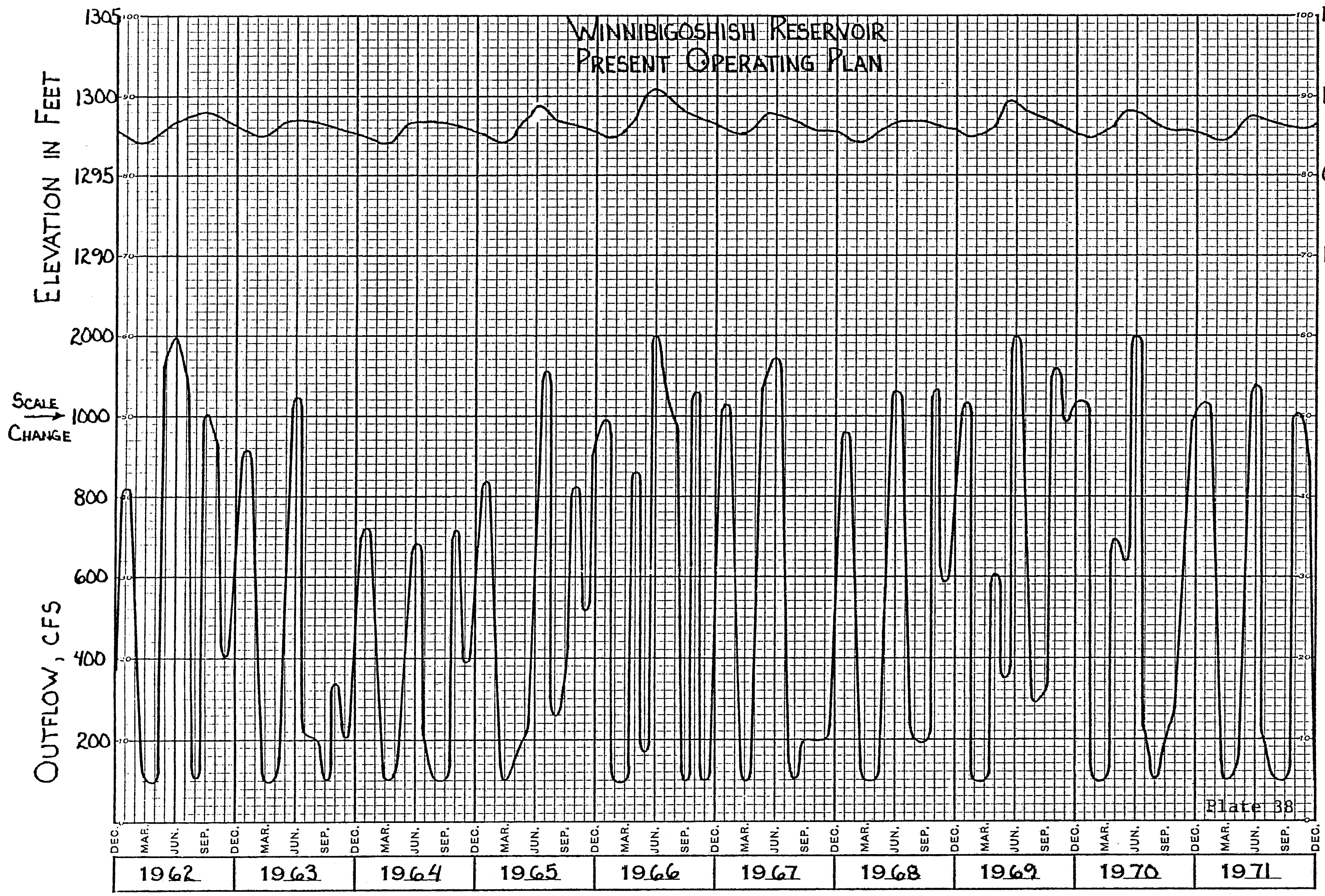
When 10 years of data are plotted on one page, the record is quite compressed, particularly with regard to reservoir releases. The releases generally range between the 100 cfs minimum and 2000 cfs (channel capacity for Winnibigoshish Reservoir).

The releases for Leech Lake Reservoir (Plate 40) generally would range between 100 cfs channel capacity, with the Present Operating Plan; Reservoir levels would range between 1291.5 in the 1930's to 1295.6.

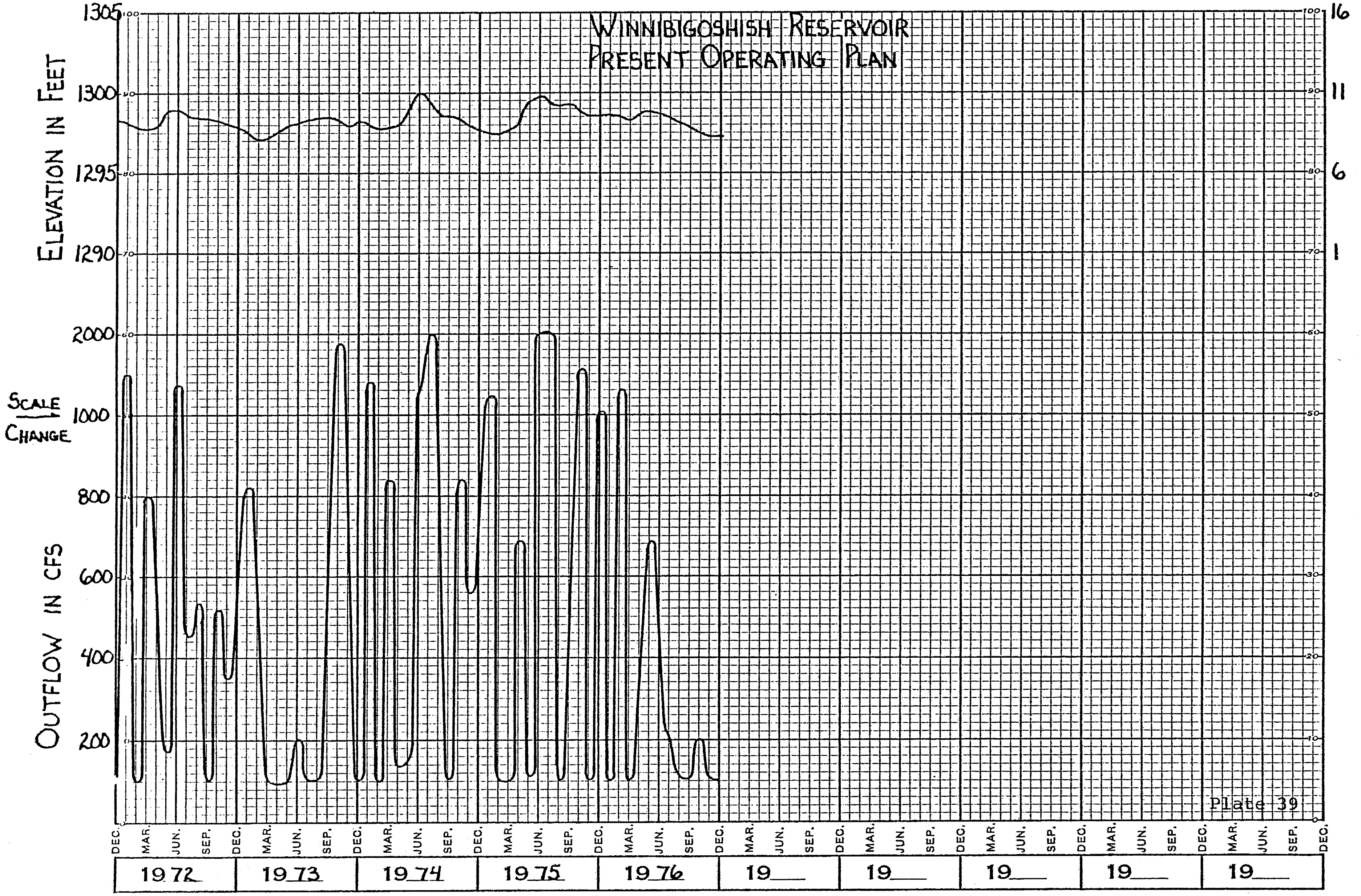

WINNIBIGOSHISH RESERVOIR
PRESENT OPERATING PLAN
ELEVATION IN FEET
1305
1300
1295
1290
SCALE CHANGE
2000
1000
800
600
400
200
OUTFLOW IN CFS
STAGE IN FEET
16
11
6
1
-4
DEC. MAR. JUN. SEP.
1932
1933
1934
1935
1936
1937
1938
1939
1940
1941
Plate 35


STAGE IN FEET
16
11
6
1
-4
WINNIBIGOSHISH RESERVOIR
PRESENT OPERATING PLAN
Plate 36
1305
1300
1295
1290
2000
1000
800
600
400
200
ELEVATION IN FEET
SCALE CHANGE
OUTFLOW IN CFS
1942
1943
1944
1945
1946
1947
1948
1949
1950
1951
DEC.
MAR.
JUN.
SEP.

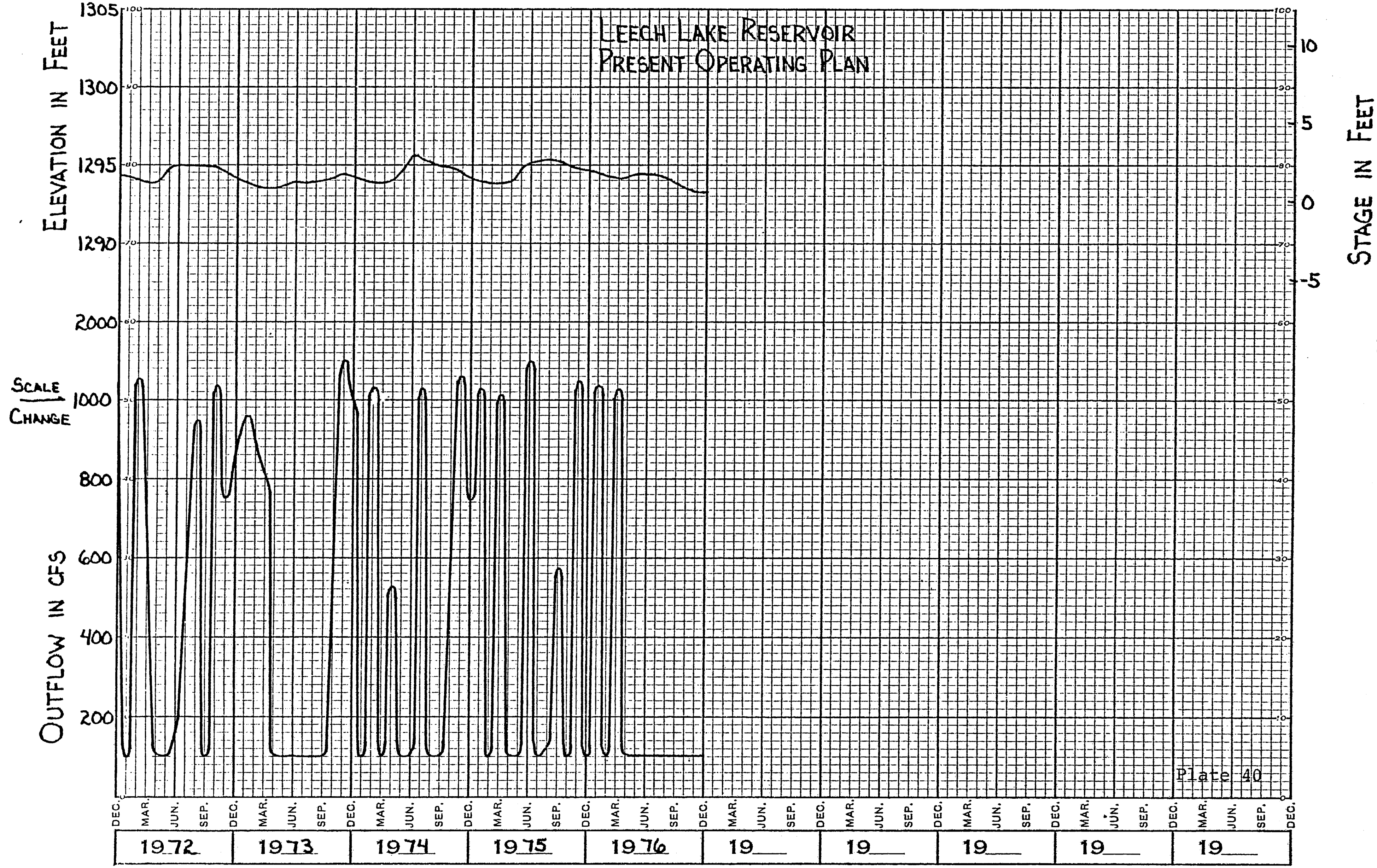

WINNIBIGOSHISH RESERVOIR
PRESENT OPERATING PLAN
Plate 37
STAGE IN FEET
16
11
6
1
ELEVATION IN FEET
1305
1300
1295
1290
SCALE CHANGE
2000
1000
800
600
400
200
OUTFLOW IN CFS
1952
1953
1954
1955
1956
1957
1958
1959
1960
1961
DEC.
MAR.
JUN.
SEP.
NO. 3156. TEN YEARS BY MONTHS X 100 DIVISIONS.
codex GRAPH PAPER ®
IN STOCK DIRECT FROM CODEX BOOK CO., NORWOOD, MASS. 02062
PRINTED IN U.S.A.


WINNIBIGOSHISH RESERVOIR
PRESENT OPERATING PLAN
ELEVATION IN FEET
1305
1300
1295
1290
2000
SCALE CHANGE
1000
800
600
400
200
OUTFLOW, CFS
STAGE IN FEET
16
11
6
1
DEC. MAR. JUN. SEP.
1962
1963
1964
1965
1966
1967
1968
1969
1970
1971
Plate 38

gob


WINNIBIGOSHISH RESERVOIR
PRESENT OPERATING PLAN
ELEVATION IN FEET
1305
1300
1295
1290
STAGE IN FEET
16
11
6
1
SCALE CHANGE
OUTFLOW IN CFS
2000
1000
800
600
400
200
DEC. MAR. JUN. SEP.
1972
1973
1974
1975
1976
19__
Plate 39

gob


LEECH LAKE RESERVOIR
PRESENT OPERATING PLAN
ELEVATION IN FEET
1305
1300
1295
1290
2000
SCALE CHANGE
1000
800
600
400
200
OUTFLOW IN CFS
STAGE IN FEET
10
5
0
-5
DEC. MAR. JUN. SEP.
1972
1973
1974
1975
1976
19__
Plate 40

Pokegama Reservoir (Plate 41) would have discharges ranging between 200 cfs and 4000 cfs, with water levels ranging from 1268.5 to 1277.7.

Sandy Lake (Plate 42) discharges would range up to 1600 cfs, with levels from 1214.2 to 1224.0.

Pine River Reservoir (Plate 43) would have discharges ranging from 30 to 1400 cfs and elevations from 1227.4 to 1230.0 feet MSL, for the Present Operating Plan.

Gull Lake Reservoir (Plate 44) would have releases from 10 to 850 cfs and reservoir elevations from 1192.4 to 1194.0.

With the Present Operating Plan, the flow at Aitkin (Plate 45) would range up to 20,000 cfs (1950).

The daily flows at Anoka (Plate 46) would range up to about 88,000 cfs (1965) and the monthly flows would go down to 728 cfs (1934).

Natural Flows

As noted in an earlier section, there sometimes is interest in the flow conditions that would have prevailed if the Headwaters Dams had not been built. These are referred to as natural flows (Plates 47 to 53).

Low Flow Plan

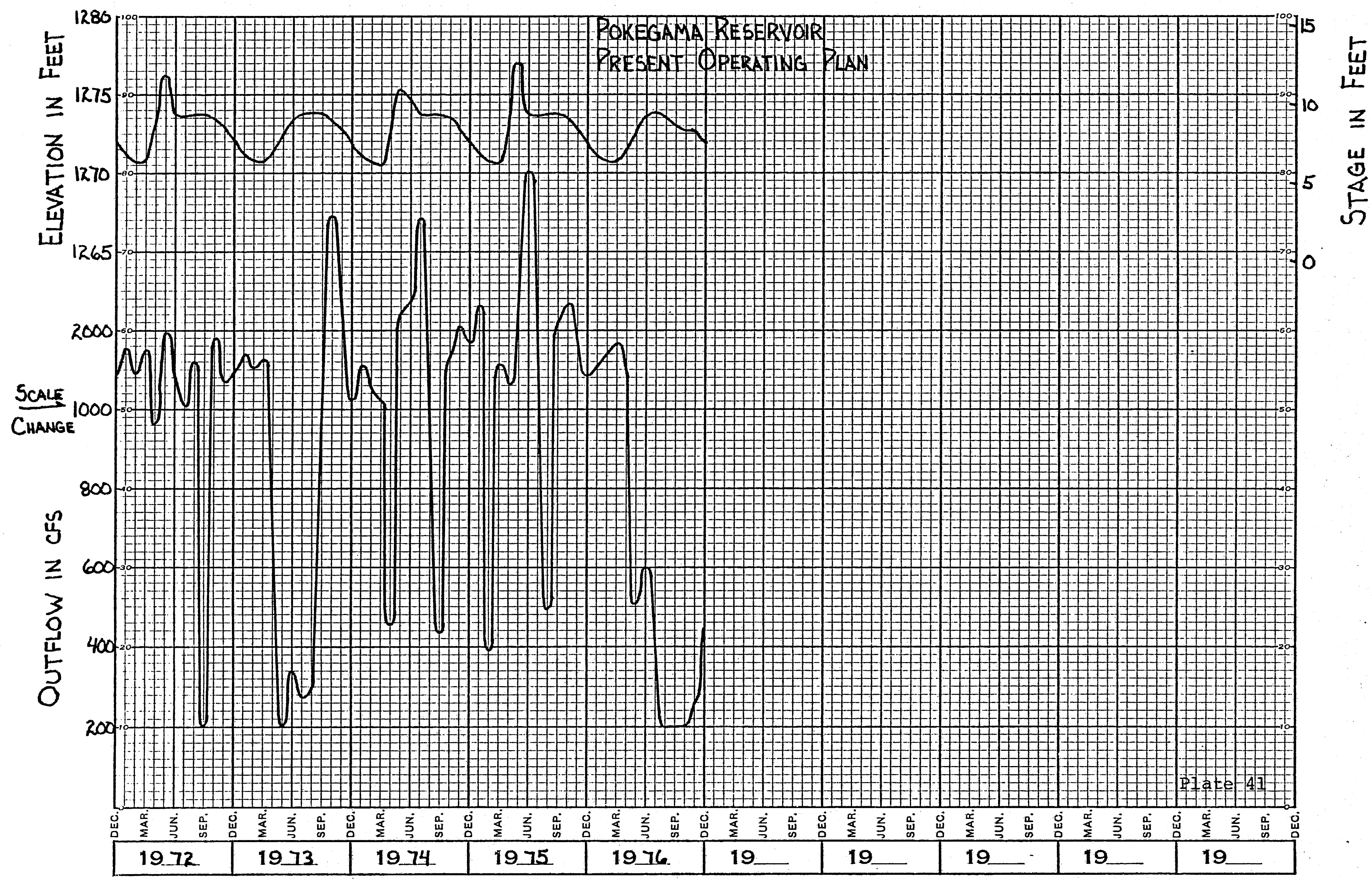
Plates 54 to 61 illustrate sample reservoir elevations and flows for the low-flow plan. With this plan, prime emphasis would be placed on maintaining a minimum flow of 1600 cfs at Anoka.

High Flow Plan

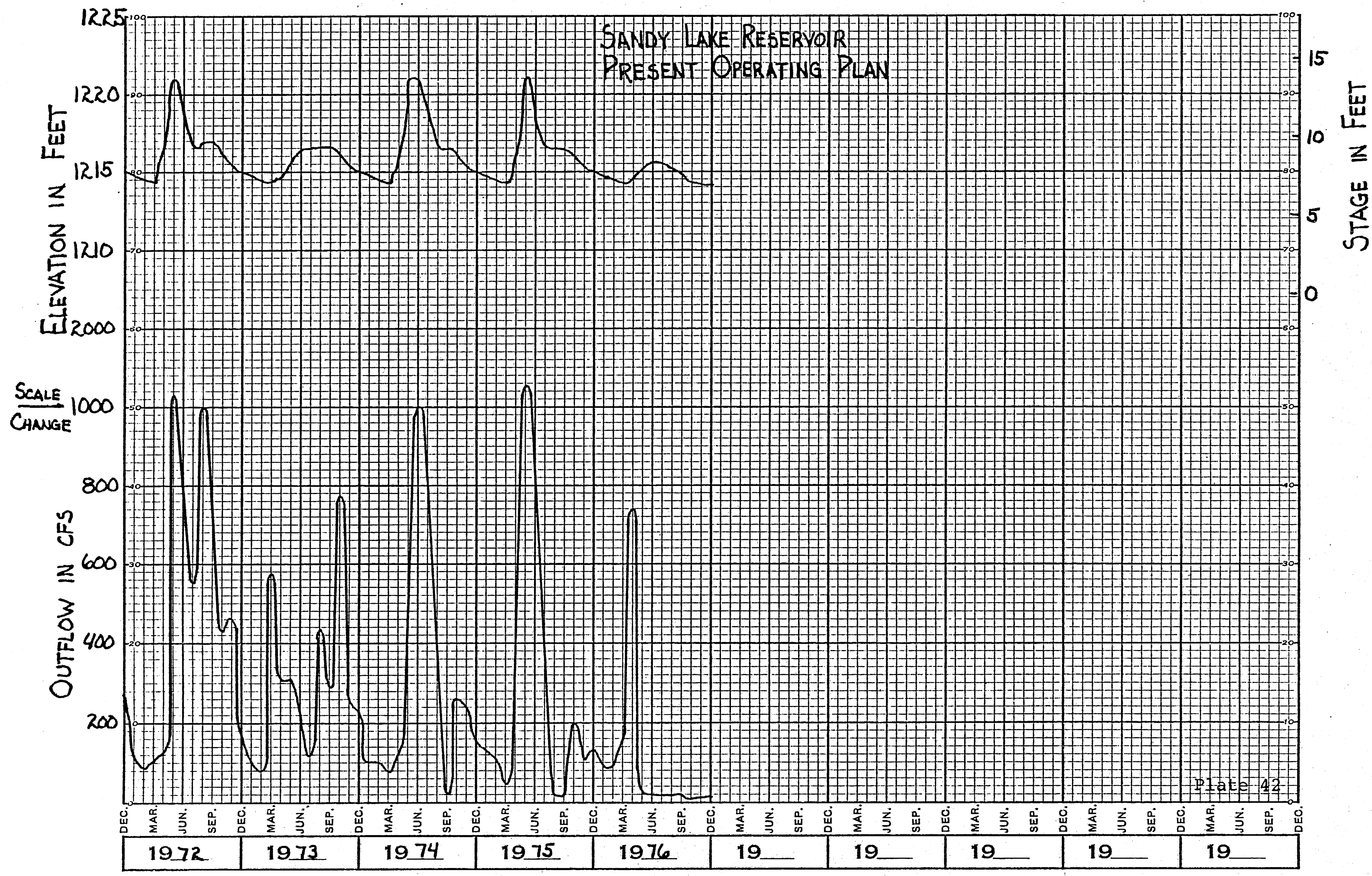
Plates 62 to 69 illustrate sample reservoir elevations and flows for the high flow plan.

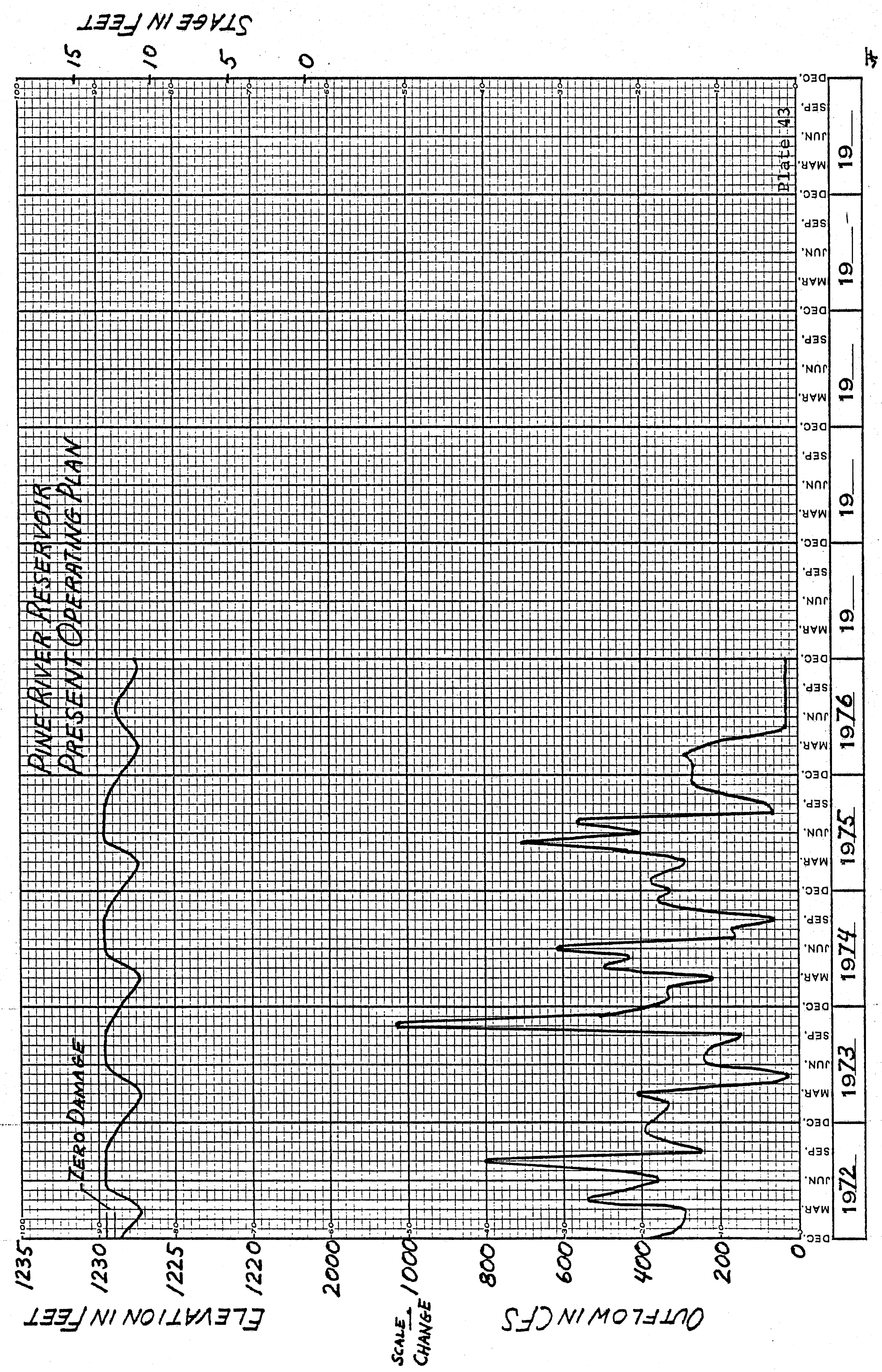
Damage Analysis

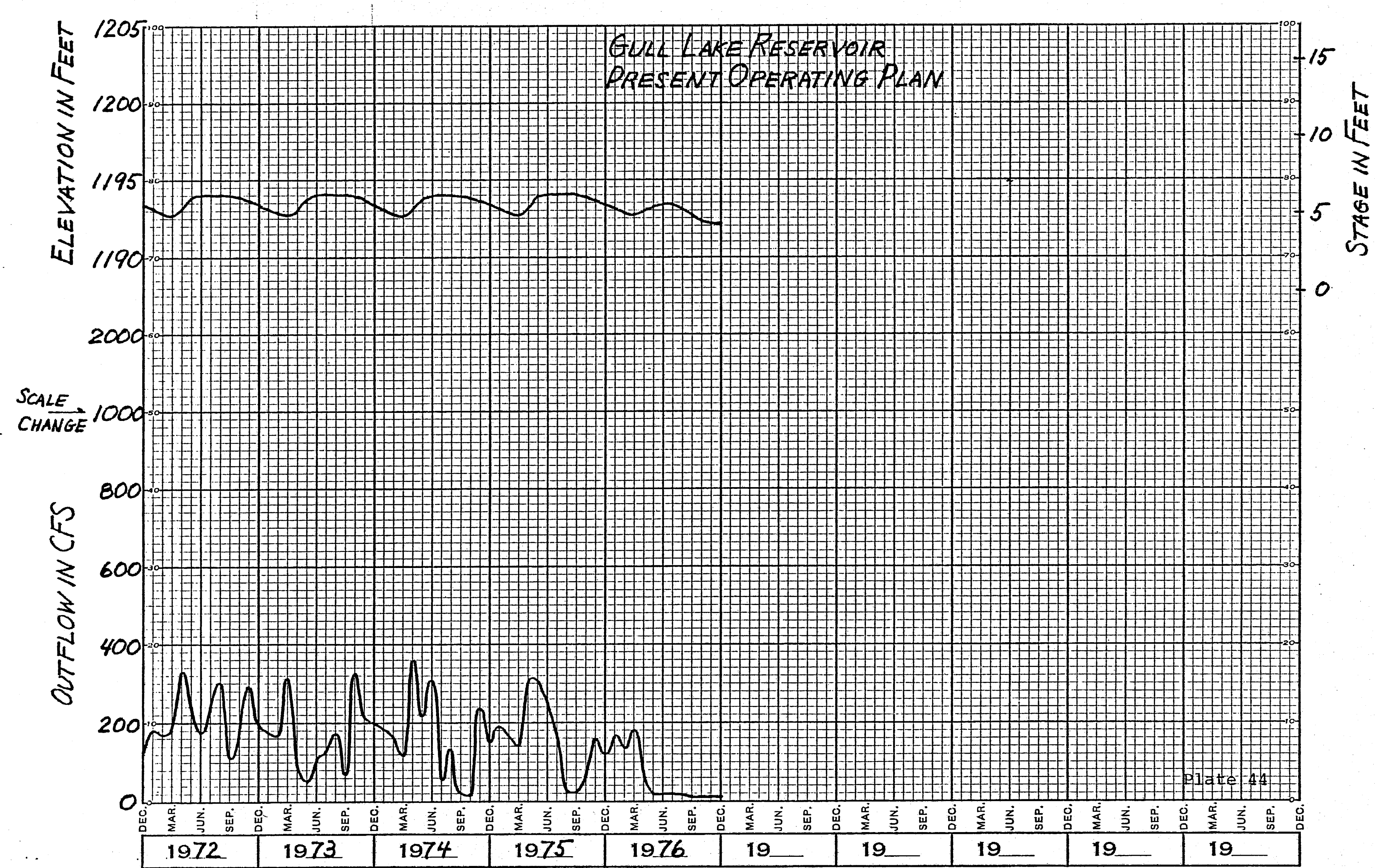
Data were selected from the computer print-outs for maximum and minimum stages in the reservoirs for the period 1 May to 30 September of each year (1932-76). These are presented in Tables 4 to 11. Data were also obtained on the maximum flow at Aitkin during the period 1 May to 30 September and for all periods with flows less than 1600 cfs at Anoka. These are included in the same tables.


POKEGAMA RESERVOIR
PRESENT OPERATING PLAN
ELEVATION IN FEET
1280
1275
1270
1265
2000
SCALE CHANGE
1000
800
600
400
200
OUTFLOW IN CFS
STAGE IN FEET
15
10
5
0
DEC. MAR. JUN. SEP.
1972
1973
1974
1975
1976
19__
Plate 41

98


SANDY LAKE RESERVOIR
PRESENT OPERATING PLAN
ELEVATION IN FEET
1225
1220
1215
1210
2000
SCALE CHANGE
1000
800
600
400
200
OUTFLOW IN CFS
STAGE IN FEET
15
10
5
0
DEC. MAR. JUN. SEP.
1972
1973
1974
1975
1976
19__
Plate 42


STAGE IN FEET
15
10
5
0
PINE RIVER RESERVOIR
PRESENT OPERATING PLAN
ZERO DAMAGE
Plate 43
1972
1973
1974
1975
1976
19
DEC.
MAR.
JUN.
SEP.
1235
1230
1225
1220
2000
1000
800
600
400
200
0
ELEVATION IN FEET
SCALE CHANGE
OUTFLOW IN CFS


GULL LAKE RESERVOIR
PRESENT OPERATING PLAN
ELEVATION IN FEET
1205
1200
1195
1190
2000
SCALE CHANGE
1000
800
600
400
200
0
OUTFLOW IN CFS
STAGE IN FEET
15
10
5
0
DEC. MAR. JUN. SEP.
1972
1973
1974
1975
1976
19__
19__
19__
19__
19__
Plate 44

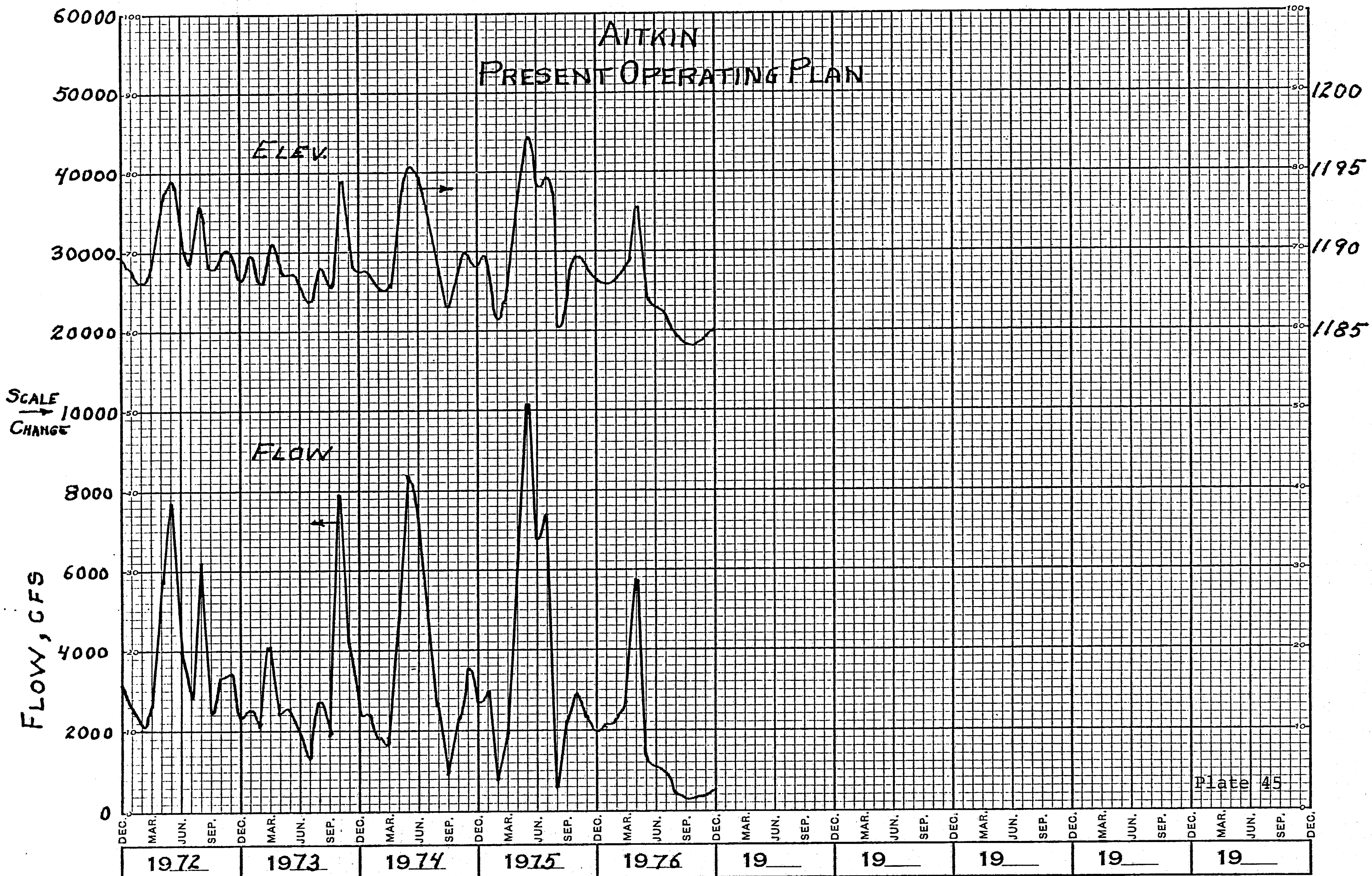

AITKIN
PRESENT OPERATING PLAN
ELEV.
FLOW
60000
50000
40000
30000
20000
SCALE CHANGE
10000
8000
6000
4000
2000
0
FLOW, CFS
1200
1195
1190
1185
ELEVATION, FT.
DEC. MAR. JUN. SEP.
1972
1973
1974
1975
1976
19__

Plate 45

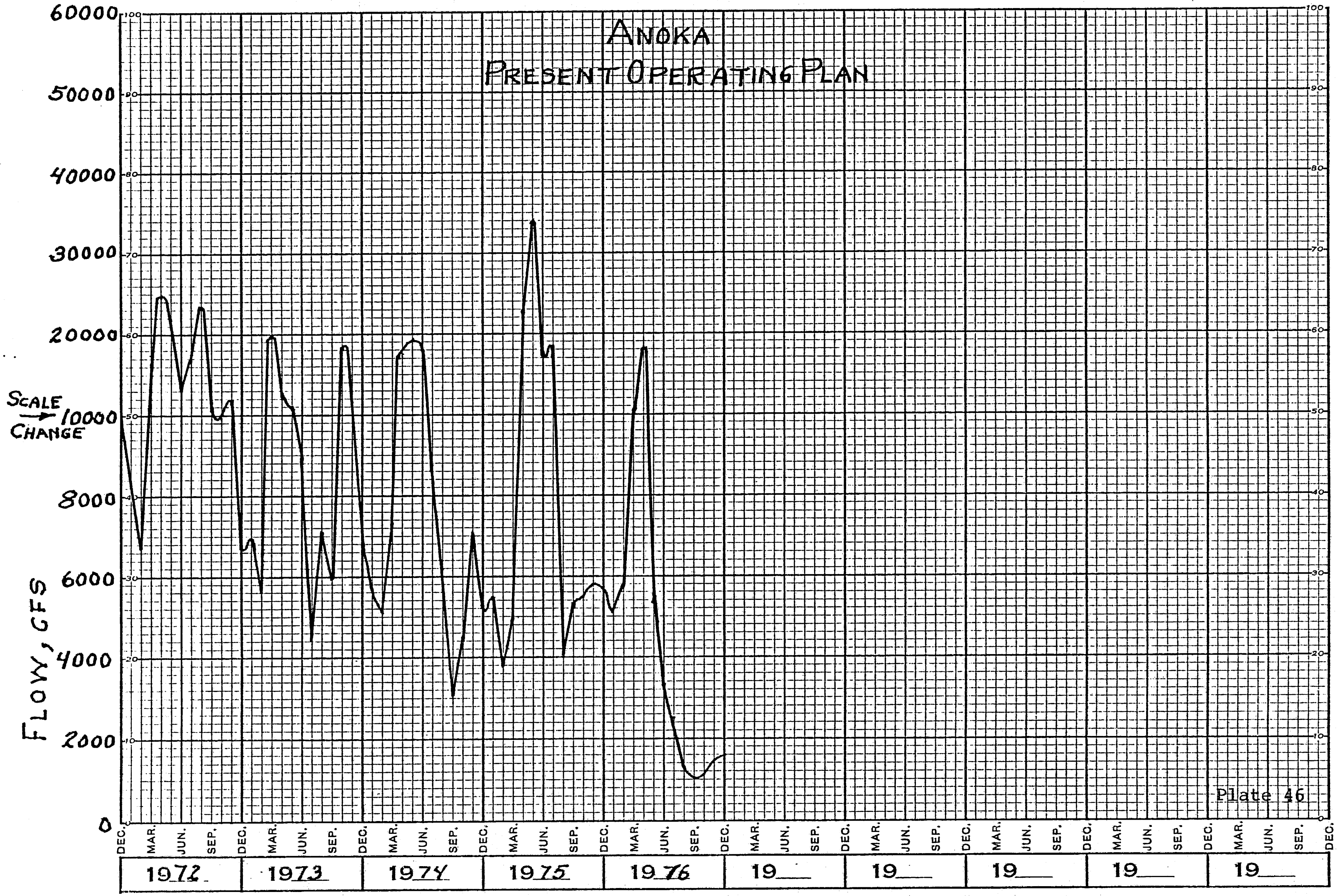
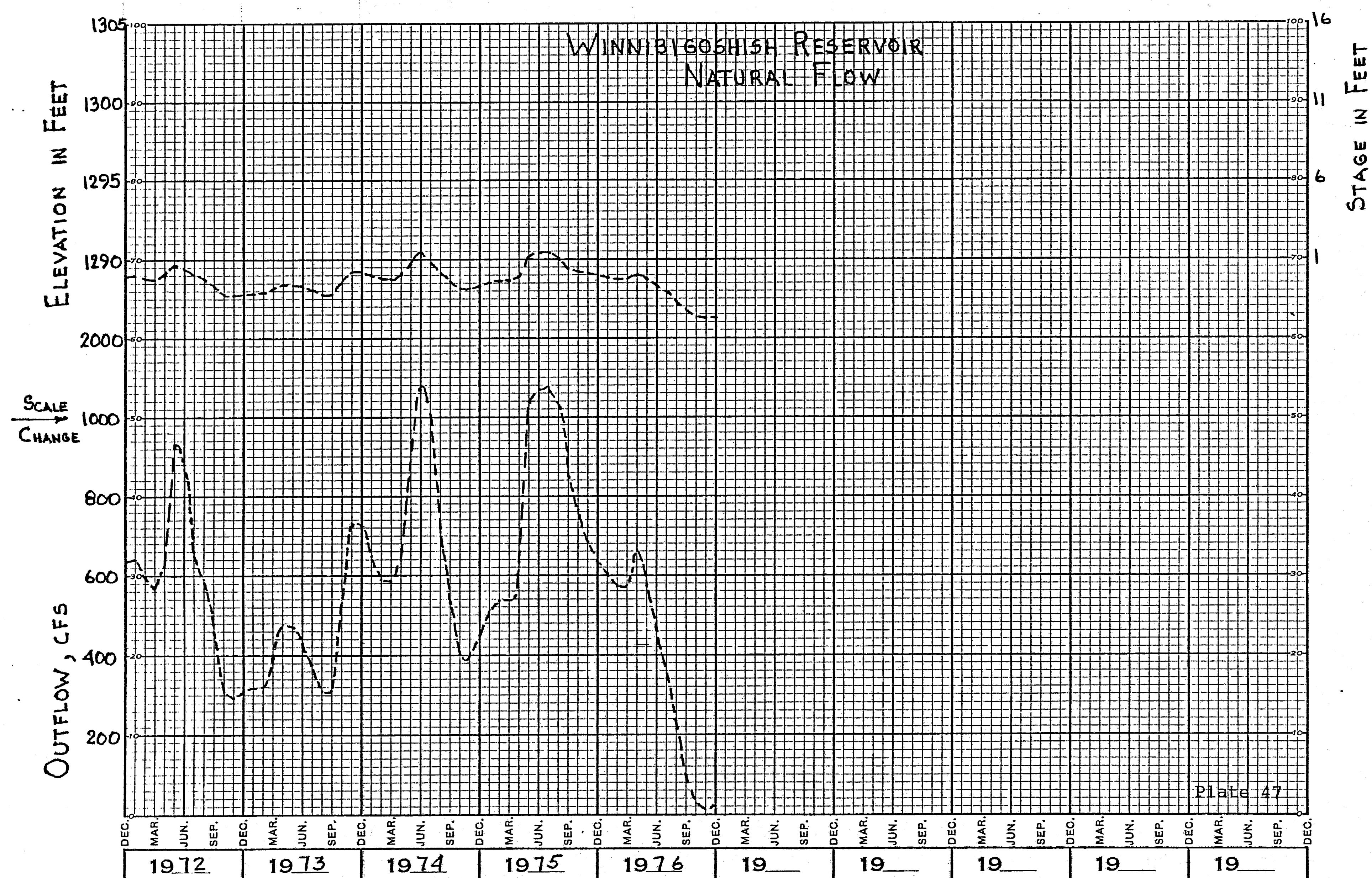

ANOKA
PRESENT OPERATING PLAN
FLOW, CFS
60000
50000
40000
30000
20000
SCALE CHANGE
10000
8000
6000
4000
2000
0
DEC. MAR. JUN. SEP.
1972
1973
1974
1975
1976
19__
19__
19__
19__
19__

Plate 46

- 75 -


WINNIBIGOSHISH RESERVOIR
NATURAL FLOW
ELEVATION IN FEET
1305
1300
1295
1290
2000
SCALE CHANGE
1000
800
600
400
200
OUTFLOW, CFS
STAGE IN FEET
16
11
6
1
DEC. MAR. JUN. SEP.
1972
1973
1974
1975
1976
19__
19__
19__
19__
19__
Plate 47

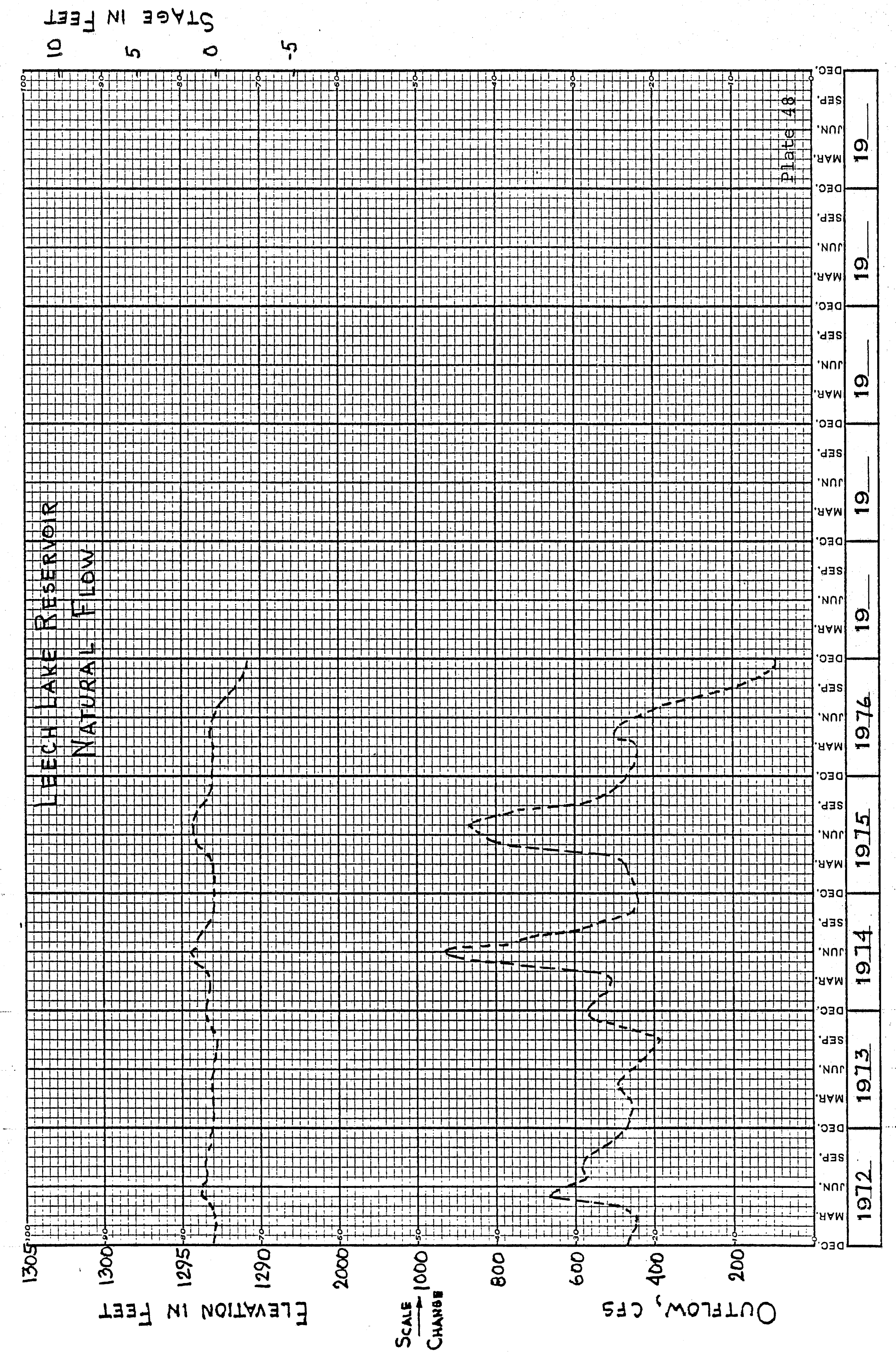

LEECH LAKE RESERVOIR
NATURAL FLOW
STAGE IN FEET
10
5
0
-5
ELEVATION IN FEET
1305
1300
1295
1290
SCALE CHANGE
OUTFLOW, CFS
2000
1000
800
600
400
200
1972
1973
1974
1975
1976
19
MAR.
JUN.
SEP.
DEC.

Plate 48

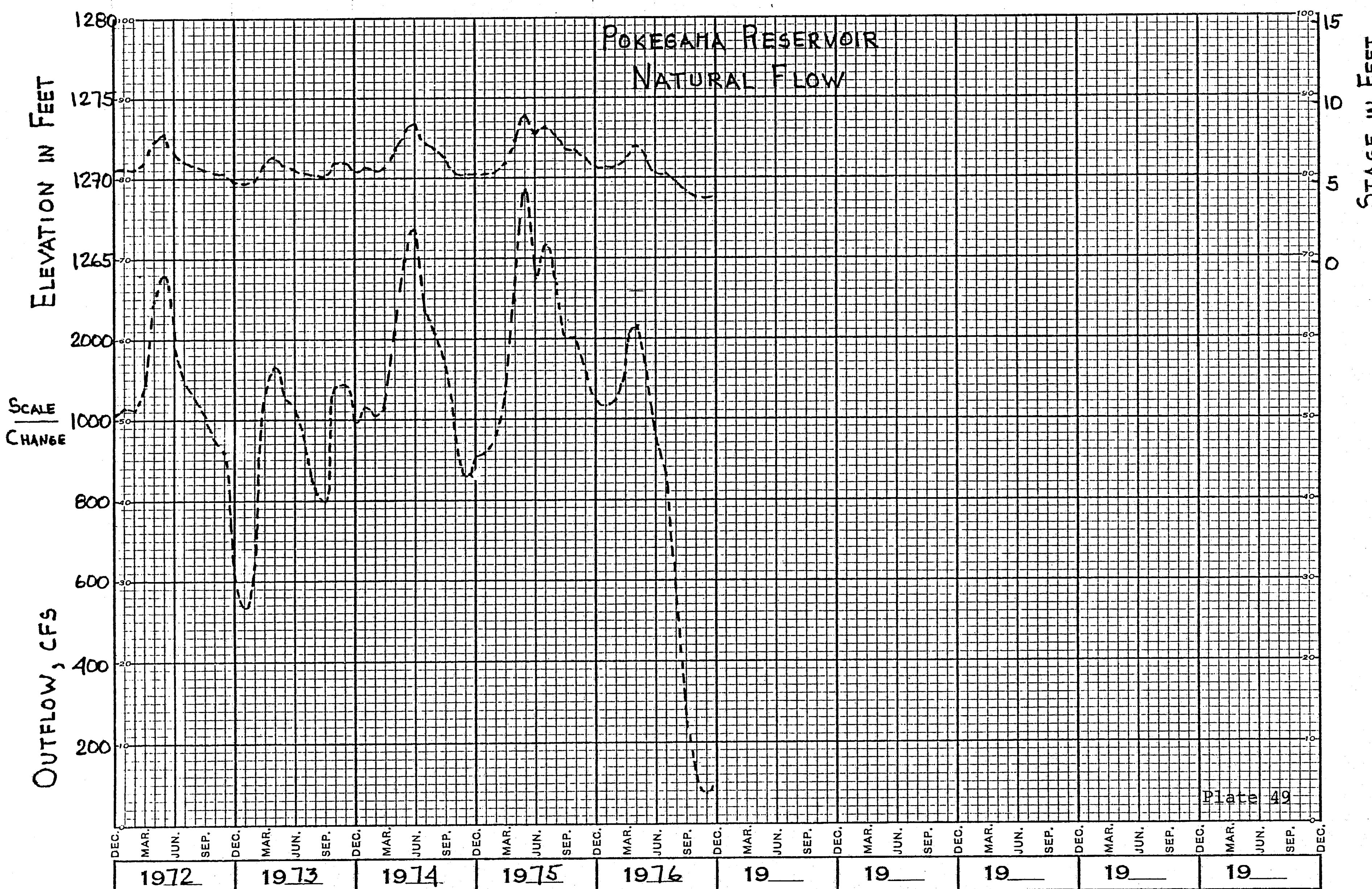

POKEGAMA RESERVOIR
NATURAL FLOW
ELEVATION IN FEET
1280
1275
1270
1265
SCALE CHANGE
2000
1000
800
600
400
200
OUTFLOW, CFS
STAGE IN FEET
15
10
5
0
DEC. MAR. JUN. SEP.
1972
1973
1974
1975
1976
19__
19__
19__
19__
19__

Plate 49

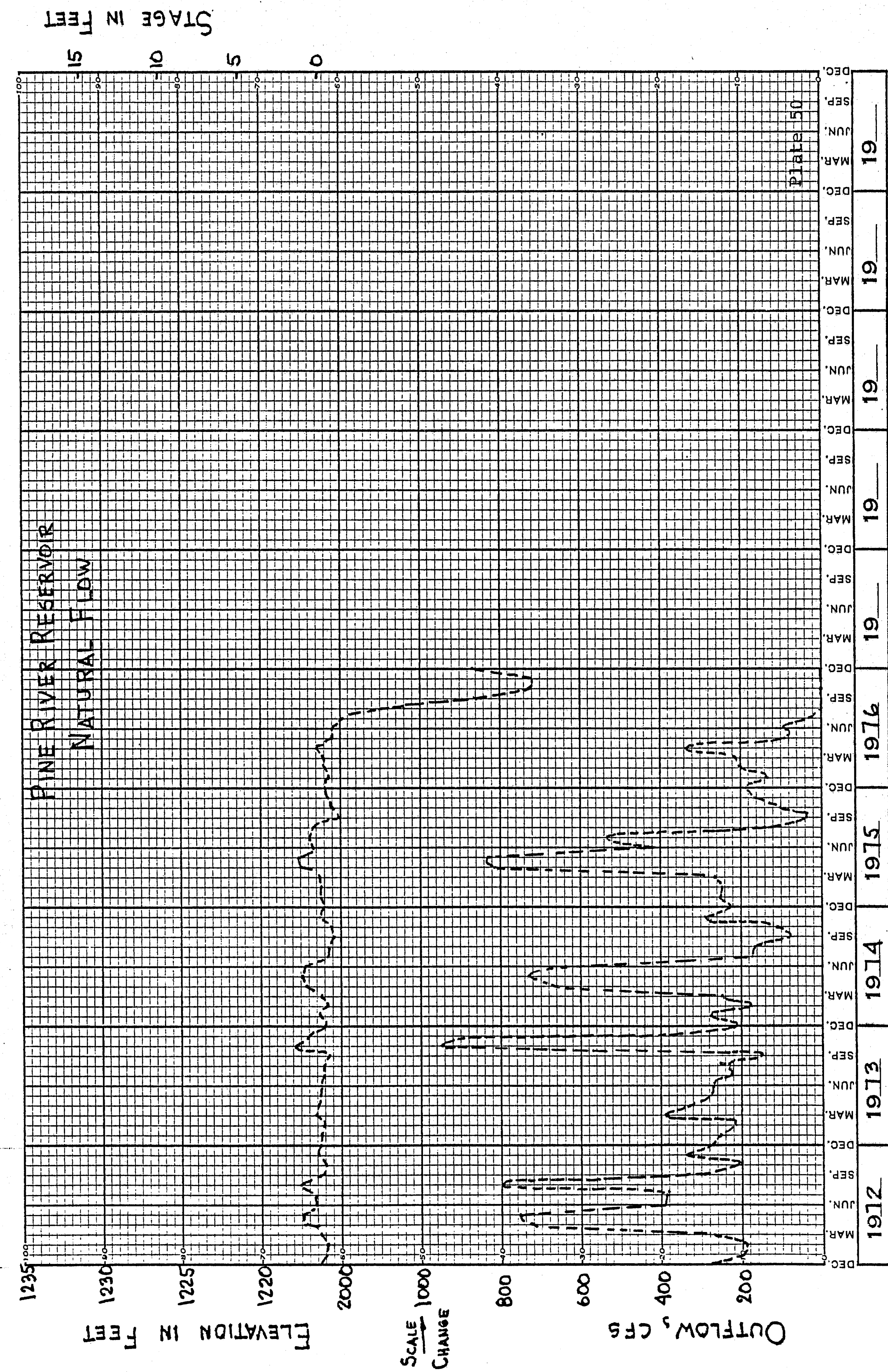
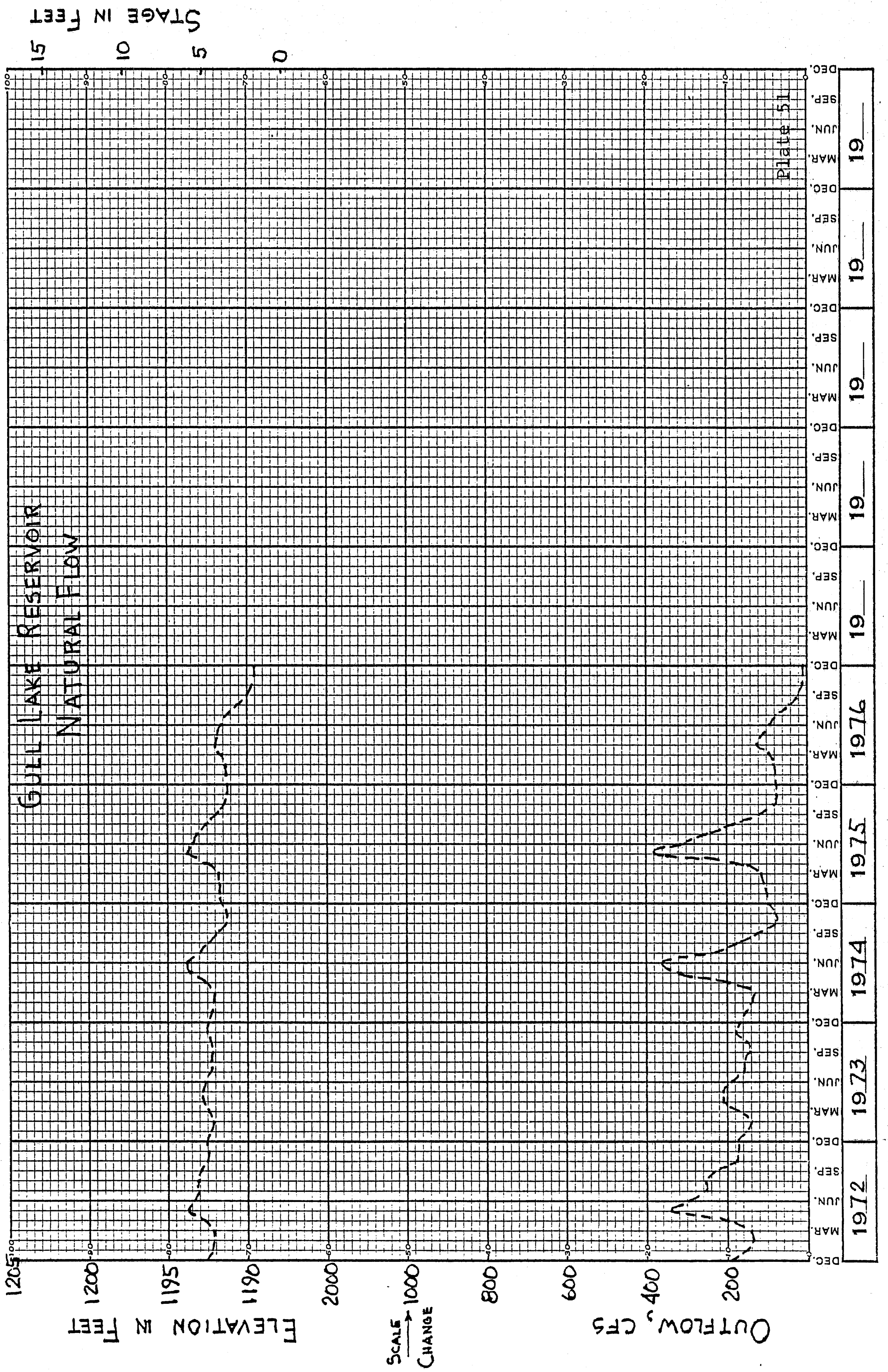
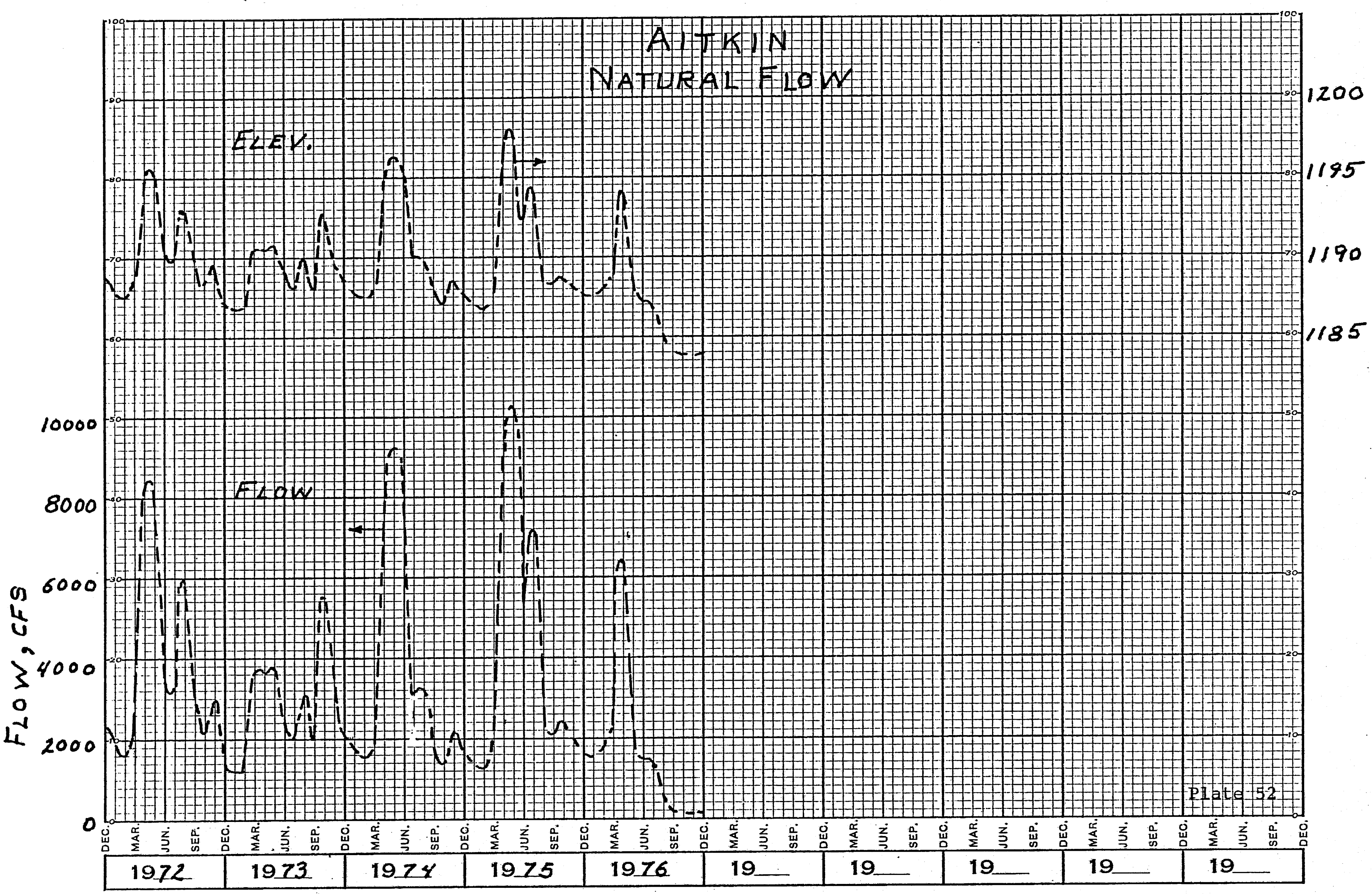

PINE RIVER RESERVOIR
NATURAL FLOW
STAGE IN FEET
15
10
5
0
ELEVATION IN FEET
1235
1230
1225
1220
2000
SCALE CHANGE
1000
800
600
400
200
OUTFLOW, CFS
1972
1973
1974
1975
1976
19
19
19
19
19

Plate 50


GULL LAKE RESERVOIR
NATURAL FLOW
Plate 51
STAGE IN FEET
15
10
5
0
ELEVATION IN FEET
1205
1200
1195
1190
SCALE CHANGE
2000
1000
800
600
400
200
OUTFLOW, CFS
MAR.
JUN.
SEP.
DEC.
1972
1973
1974
1975
1976
19__


AITKIN
NATURAL FLOW
ELEV.
FLOW
1200
1195
1190
1185
ELEVATION, FT.
10000
8000
6000
4000
2000
0
FLOW, CFS
1972
1973
1974
1975
1976
Plate 52

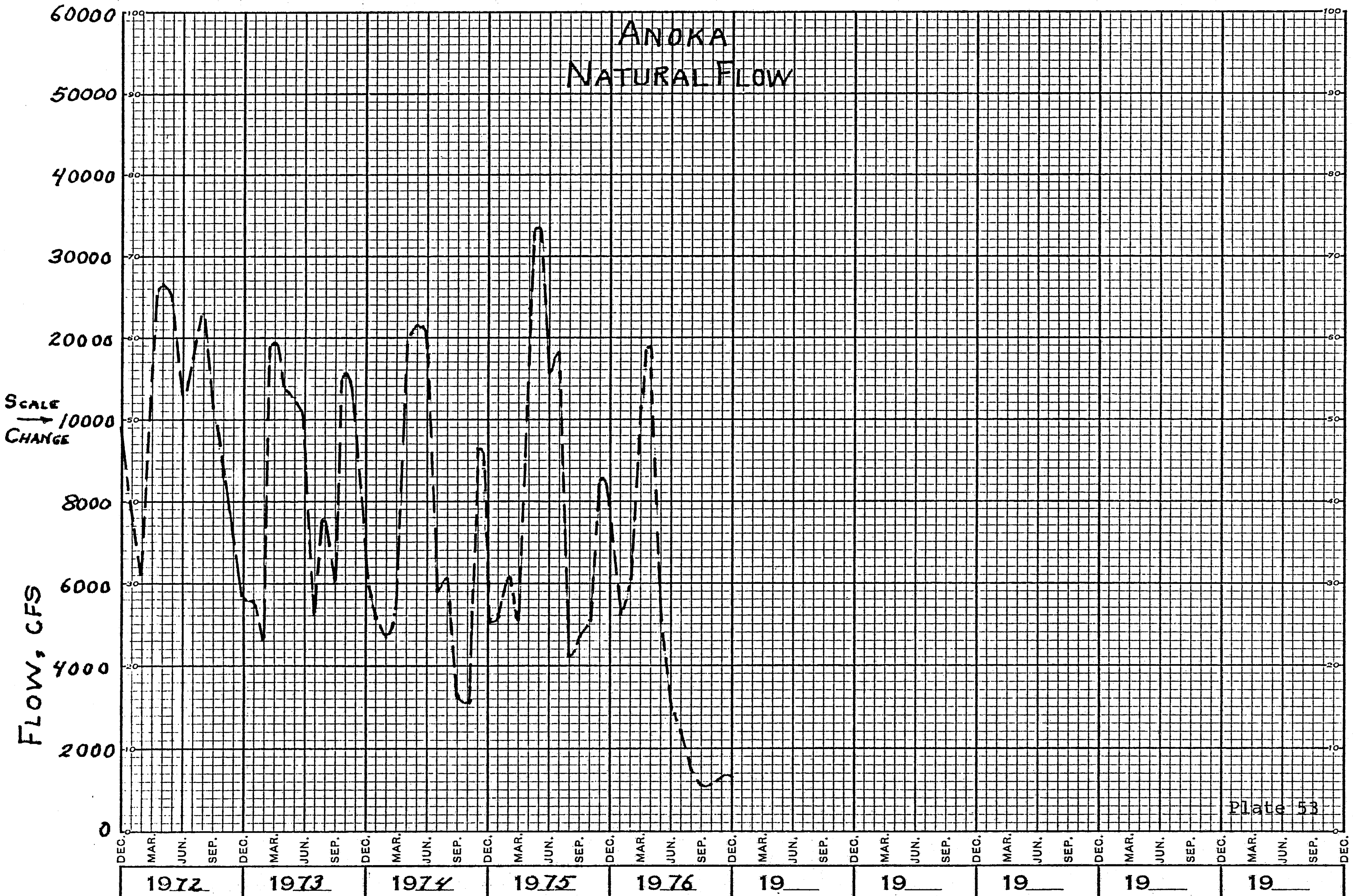

ANOKA
NATURAL FLOW
60000
50000
40000
30000
20000
SCALE CHANGE 10000
8000
6000
4000
2000
0
FLOW, CFS
DEC. MAR. JUN. SEP.
1972
1973
1974
1975
1976
19__
19__
19__
19__
19__

Plate 53

WLF-5

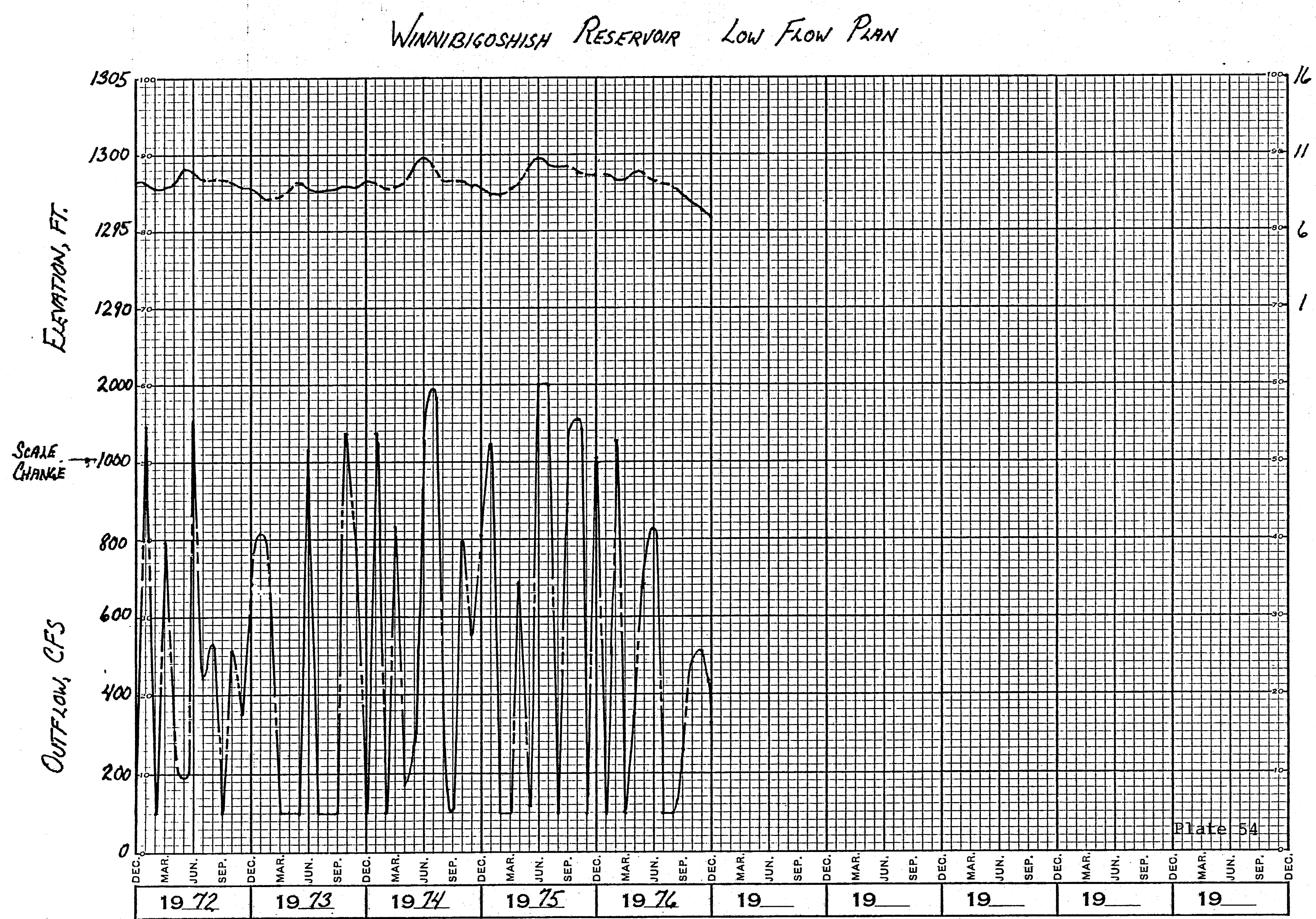
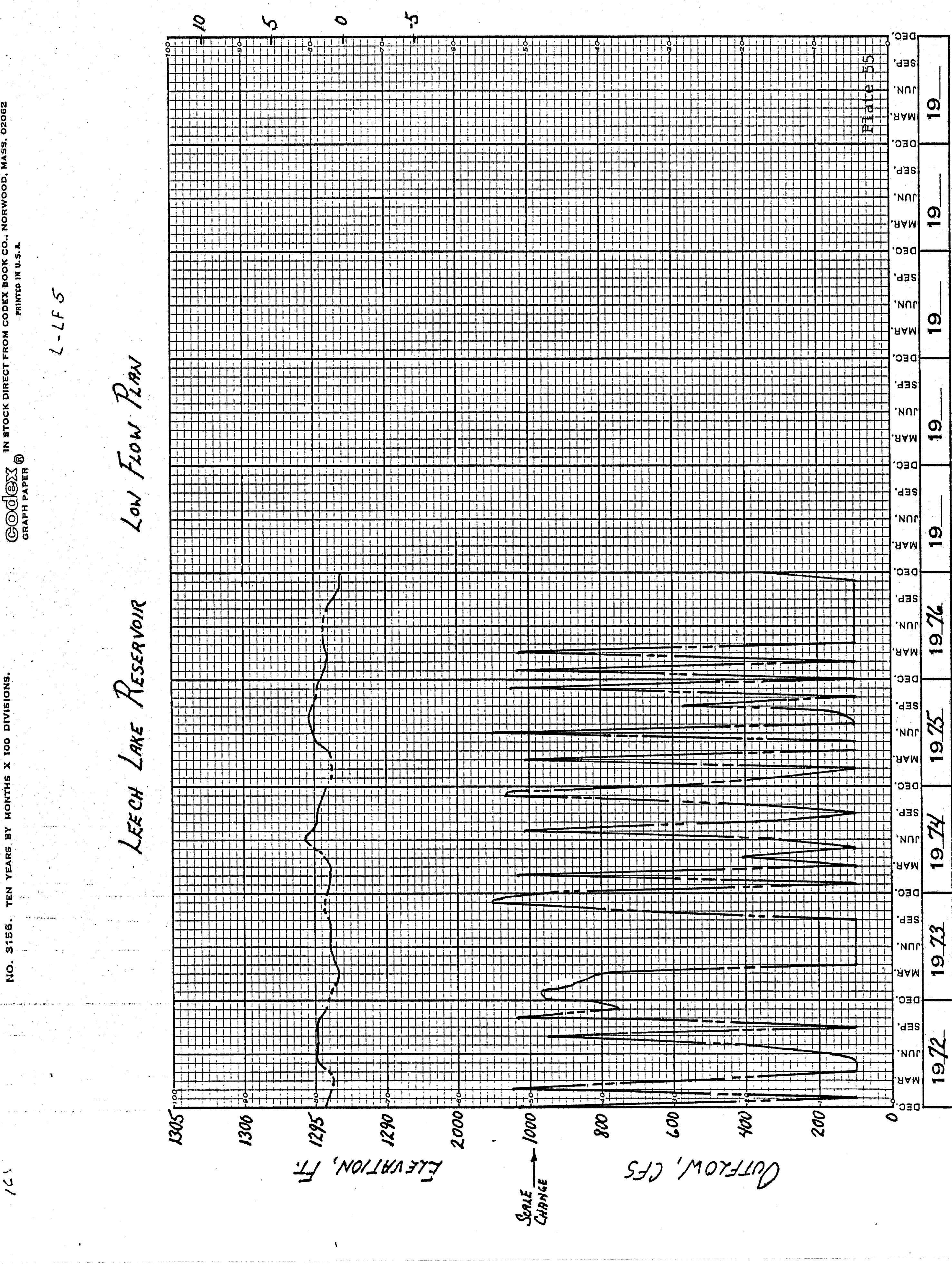


Plate 54



Leech Lake Reservoir
Low Flow Plan
L-LF5
Plate 55
Stage, Ft.
10
5
0
-5
Elevation, Ft.
1305
1300
1295
1290
Outflow, CFS
2000
1000
800
600
400
200
0
Scale Change
1972
1973
1974
1975
1976
DEC.
MAR.
JUN.
SEP.
NO. 3156. TEN YEARS BY MONTHS X 100 DIVISIONS.
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P₀ - LF 5

POKEGAMA RESERVOIR LOW FLOW PLAN

Plate 56

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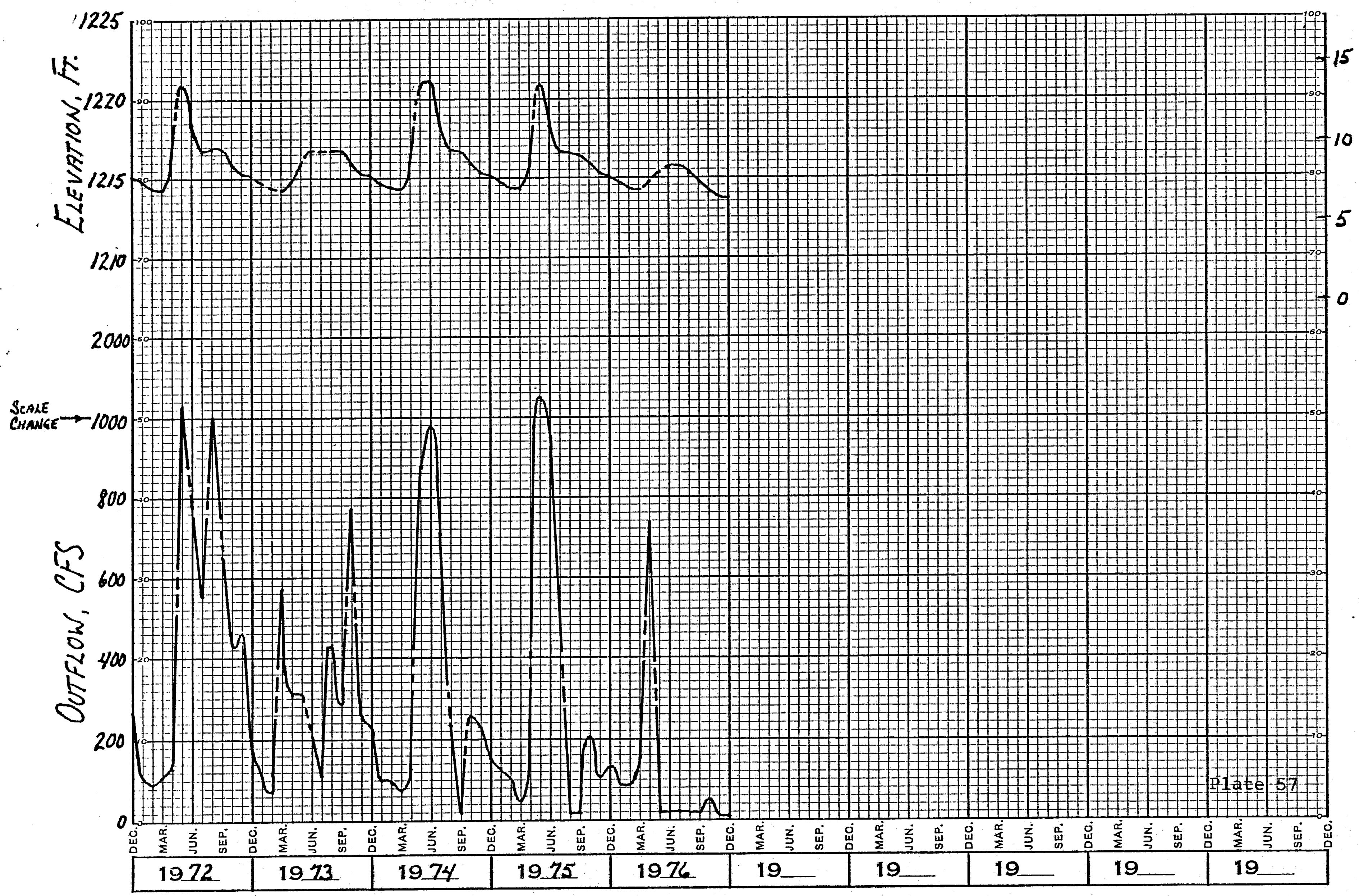
S-LF5

SANDY LAKE RESERVOIR LOW FLOW PLAN



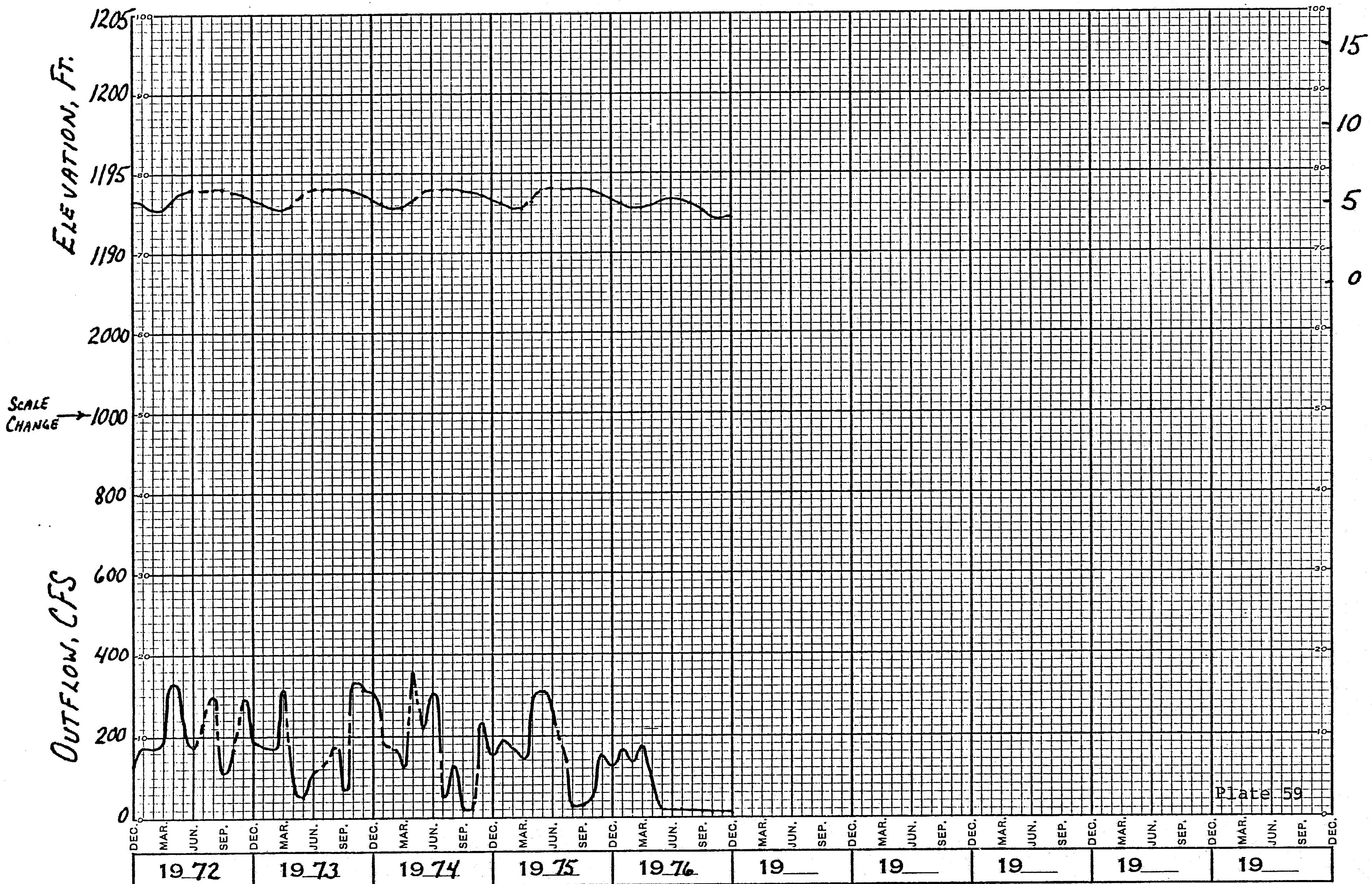
906

PINE RIVER RESERVOIR LOW FLOW PLAN

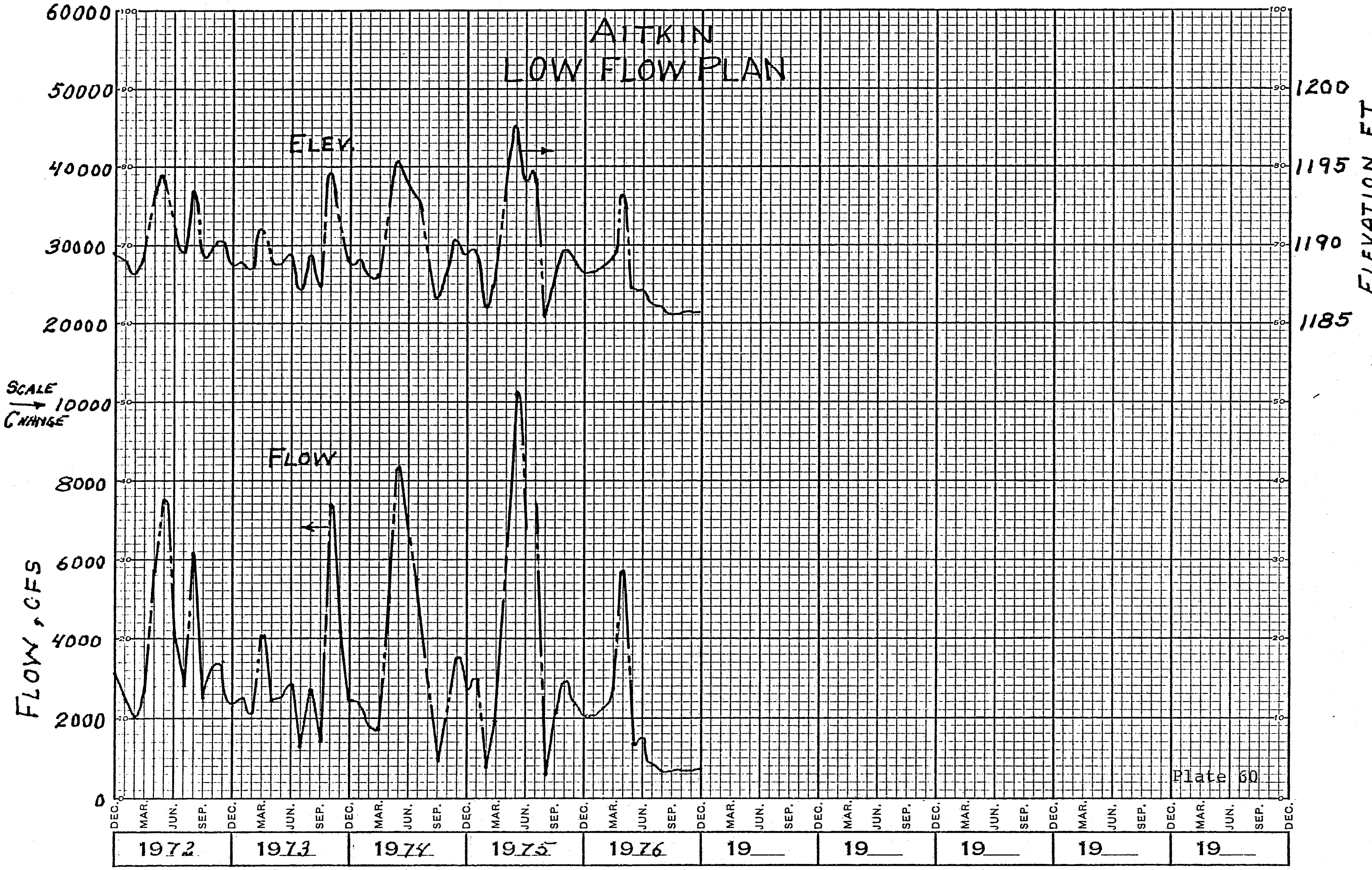
906

G-LF5

GULL LAKE RESERVOIR LOW FLOW PLAN



906


AITKIN
LOW FLOW PLAN
ELEV.
FLOW
SCALE CHANGE
60000
50000
40000
30000
20000
10000
8000
6000
4000
2000
0
FLOW, CFS
1200
1195
1190
1185
ELEVATION, FT.
DEC. MAR. JUN. SEP.
1972
1973
1974
1975
1976
19__
19__
19__
19__
19__
Plate 60

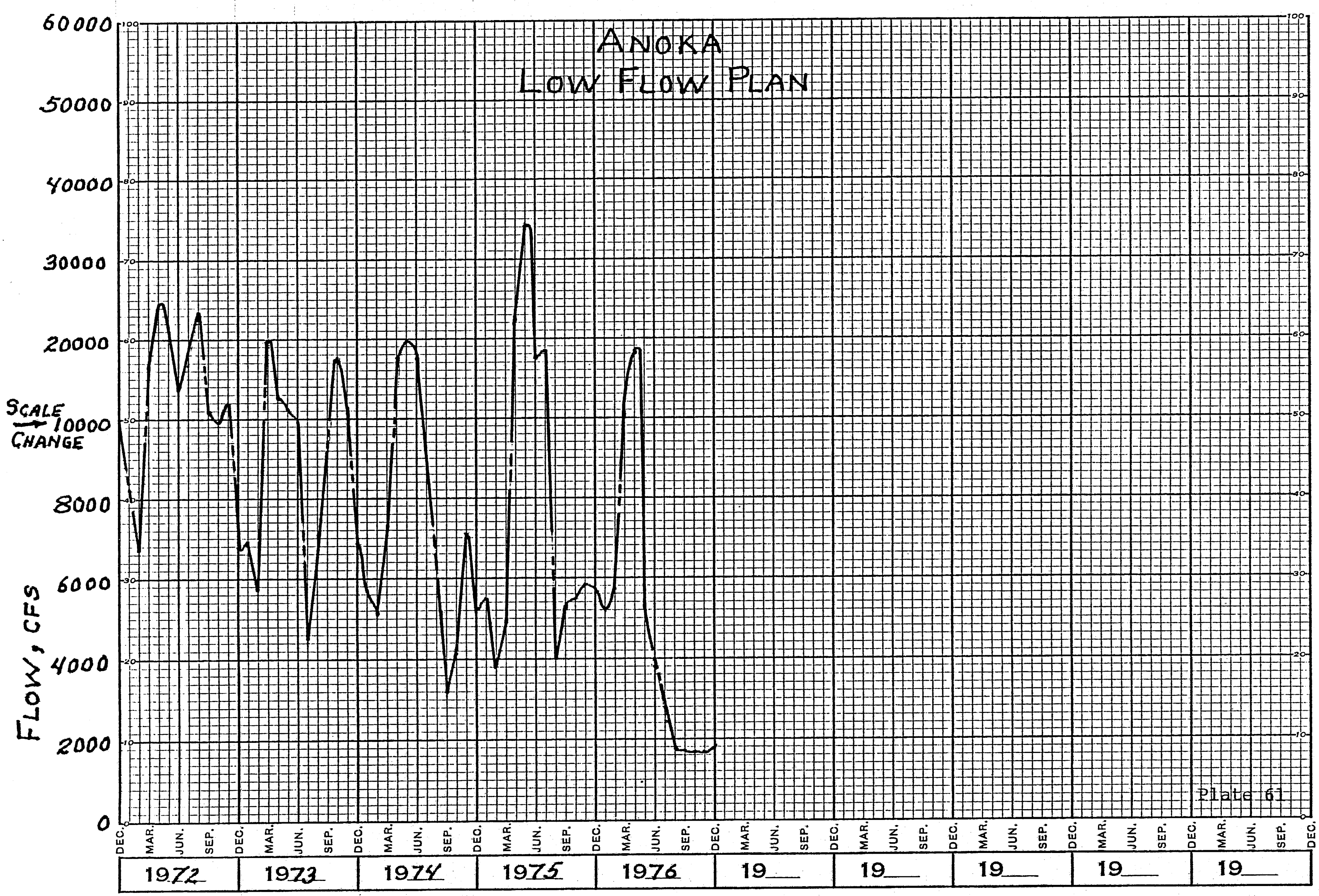
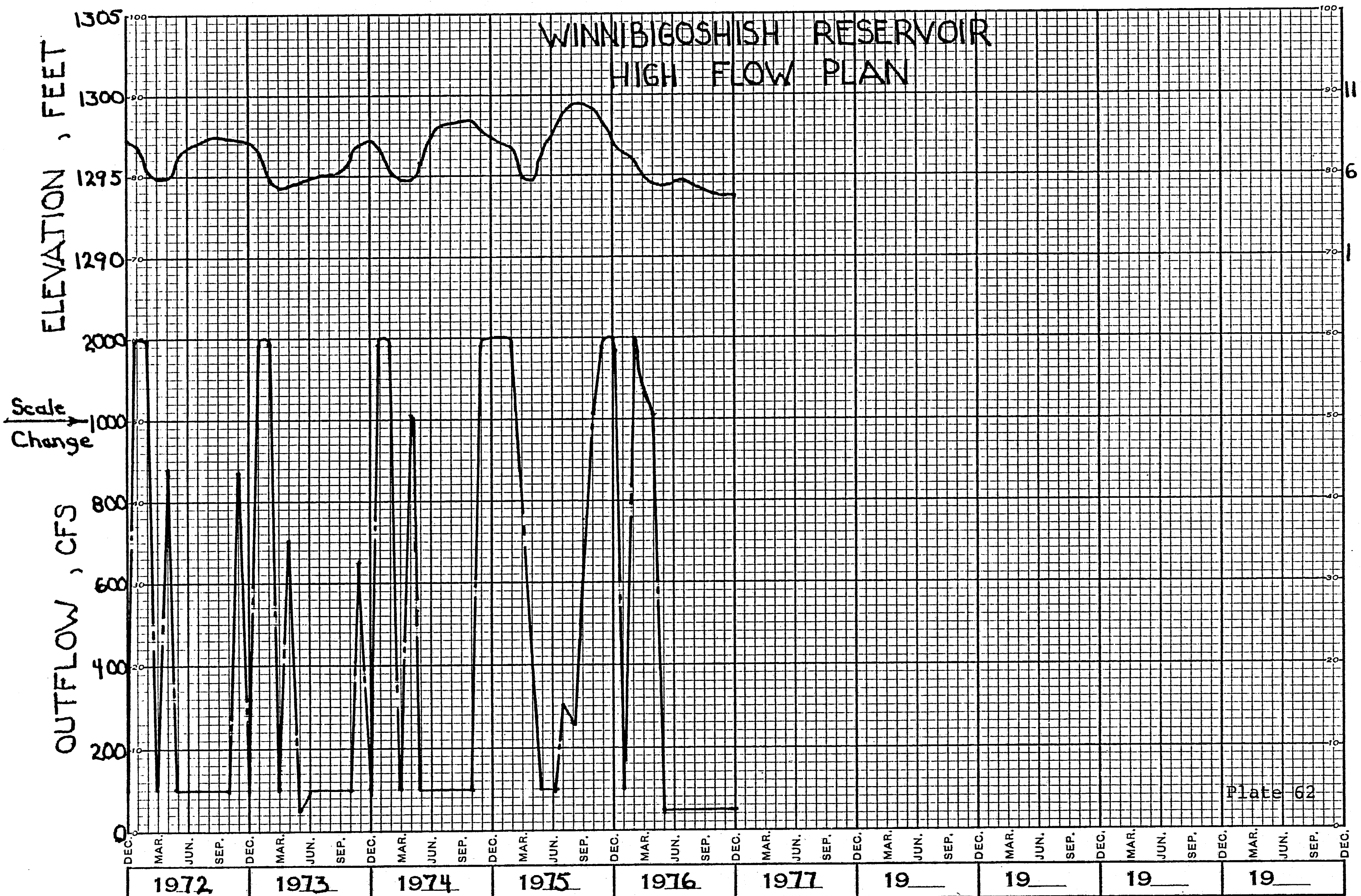
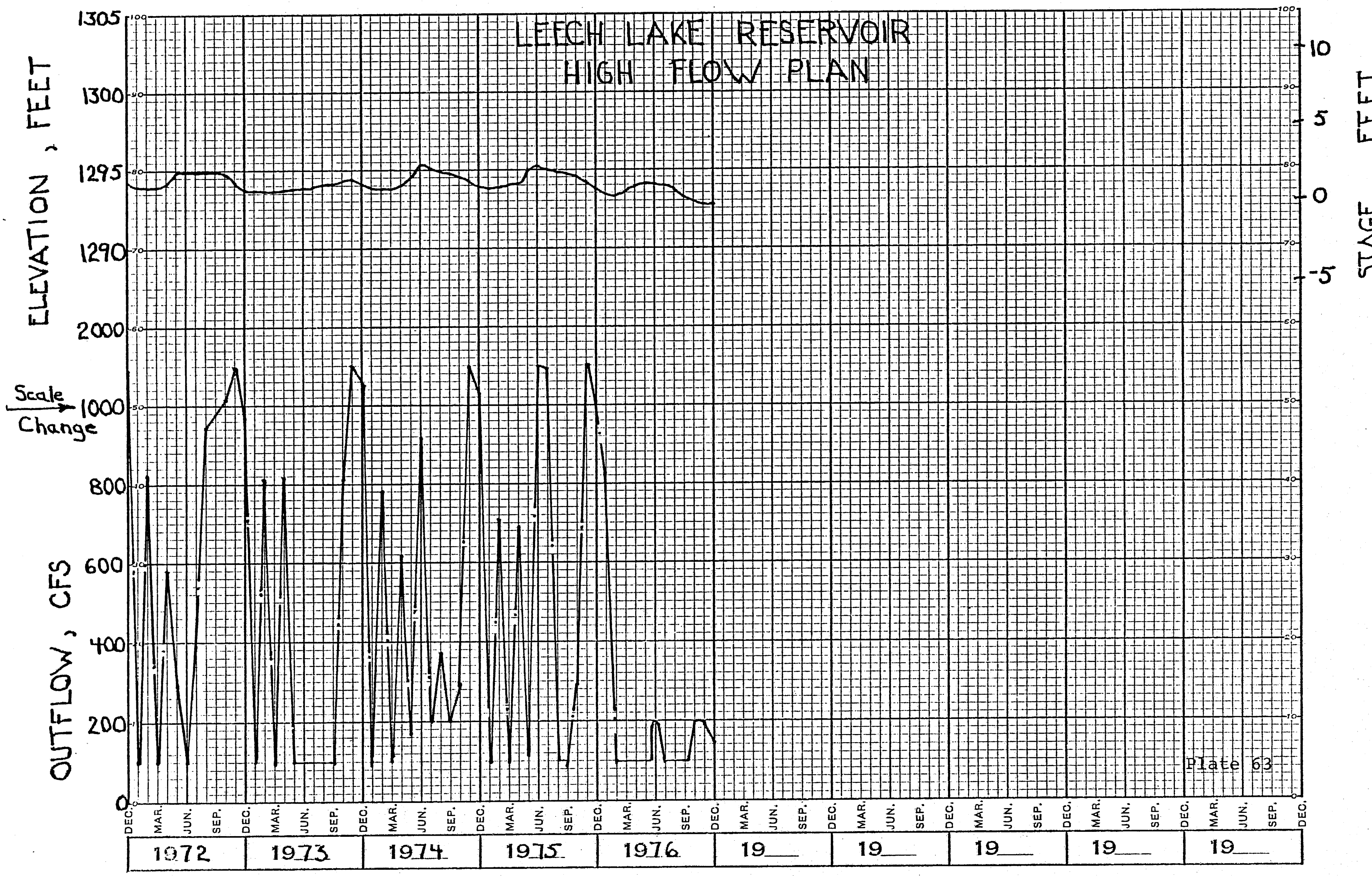
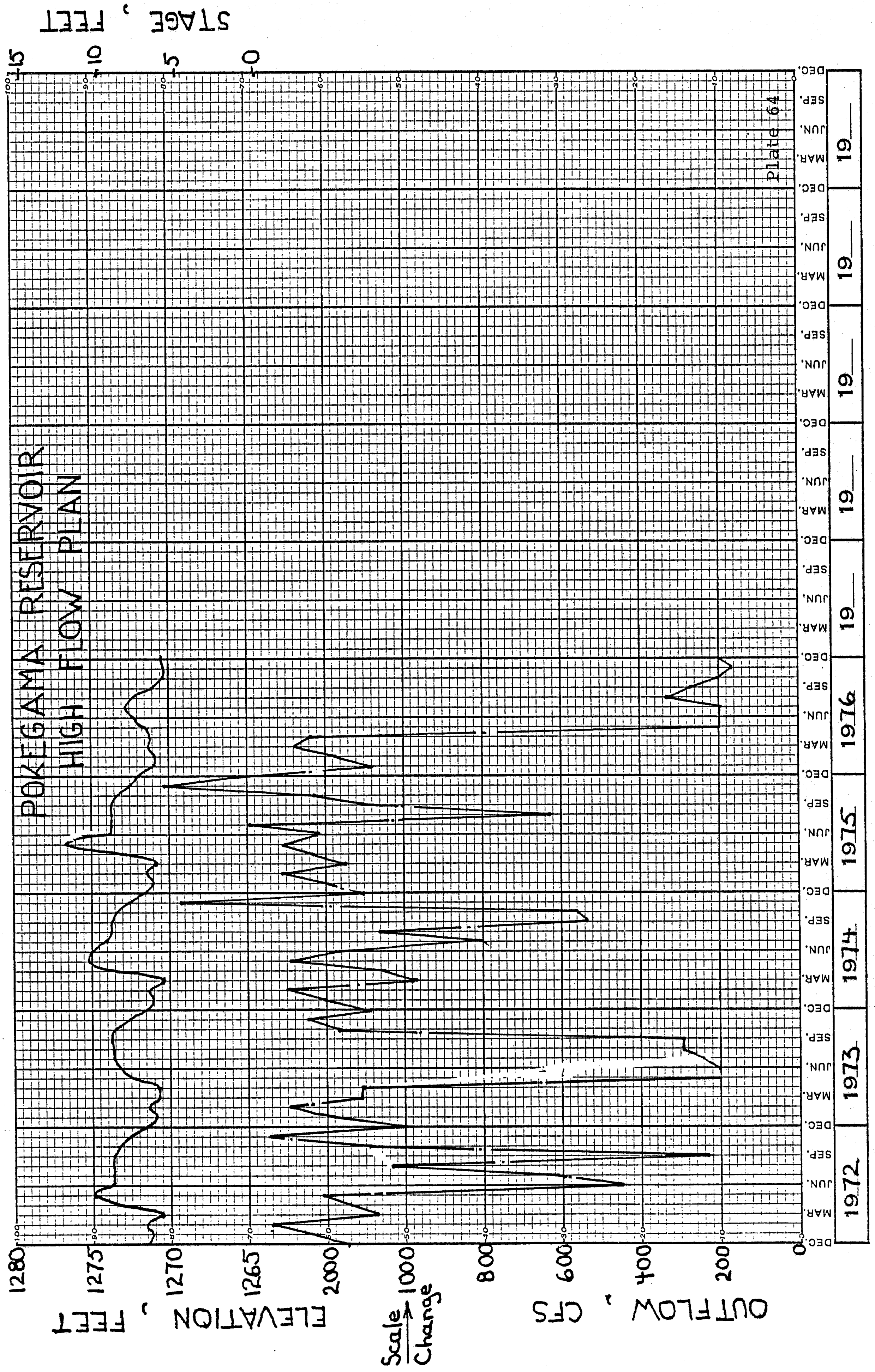
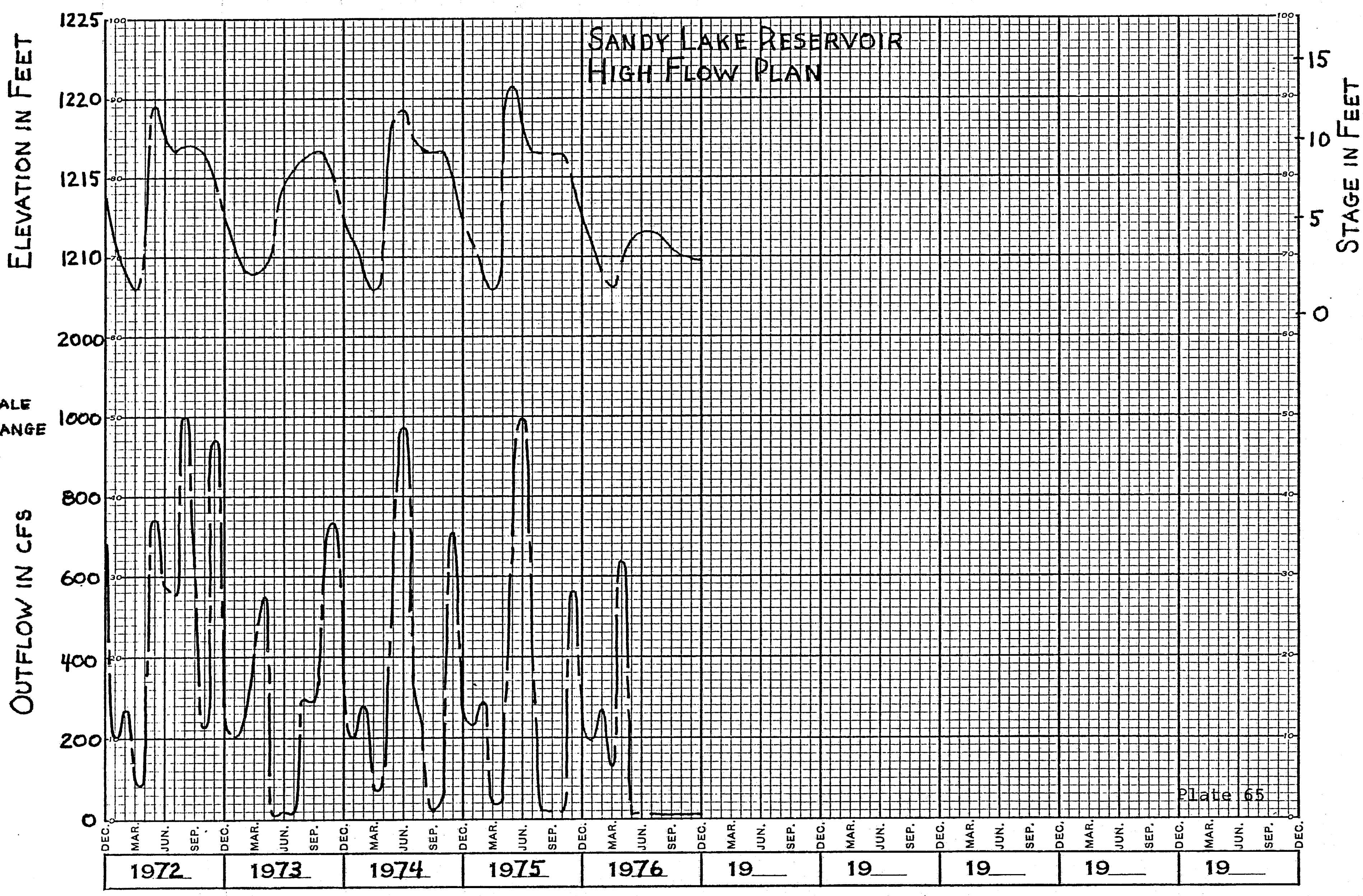

ANOKA
LOW FLOW PLAN
60000
50000
40000
30000
20000
SCALE CHANGE 10000
8000
6000
4000
2000
0
FLOW, CFS
DEC. MAR. JUN. SEP.
1972
1973
1974
1975
1976
19__
19__
19__
19__
19__

Plate 61


WINNIBIGOSHISH RESERVOIR
HIGH FLOW PLAN
ELEVATION, FEET
1305
1300
1295
1290
2000
Scale Change
1000
800
600
400
200
0
OUTFLOW, CFS
STAGE, FEET
11
6
1
DEC. MAR. JUN. SEP.
1972
1973
1974
1975
1976
1977
19__
19__
19__
19__
Plate 62


LEECH LAKE RESERVOIR
HIGH FLOW PLAN
ELEVATION, FEET
1305
1300
1295
1290
2000
Scale Change
1000
800
600
400
200
0
OUTFLOW, CFS
STAGE, FEET
10
5
0
-5
DEC. MAR. JUN. SEP.
1972
1973
1974
1975
1976
19__
19__
19__
19__
19__
Plate 63

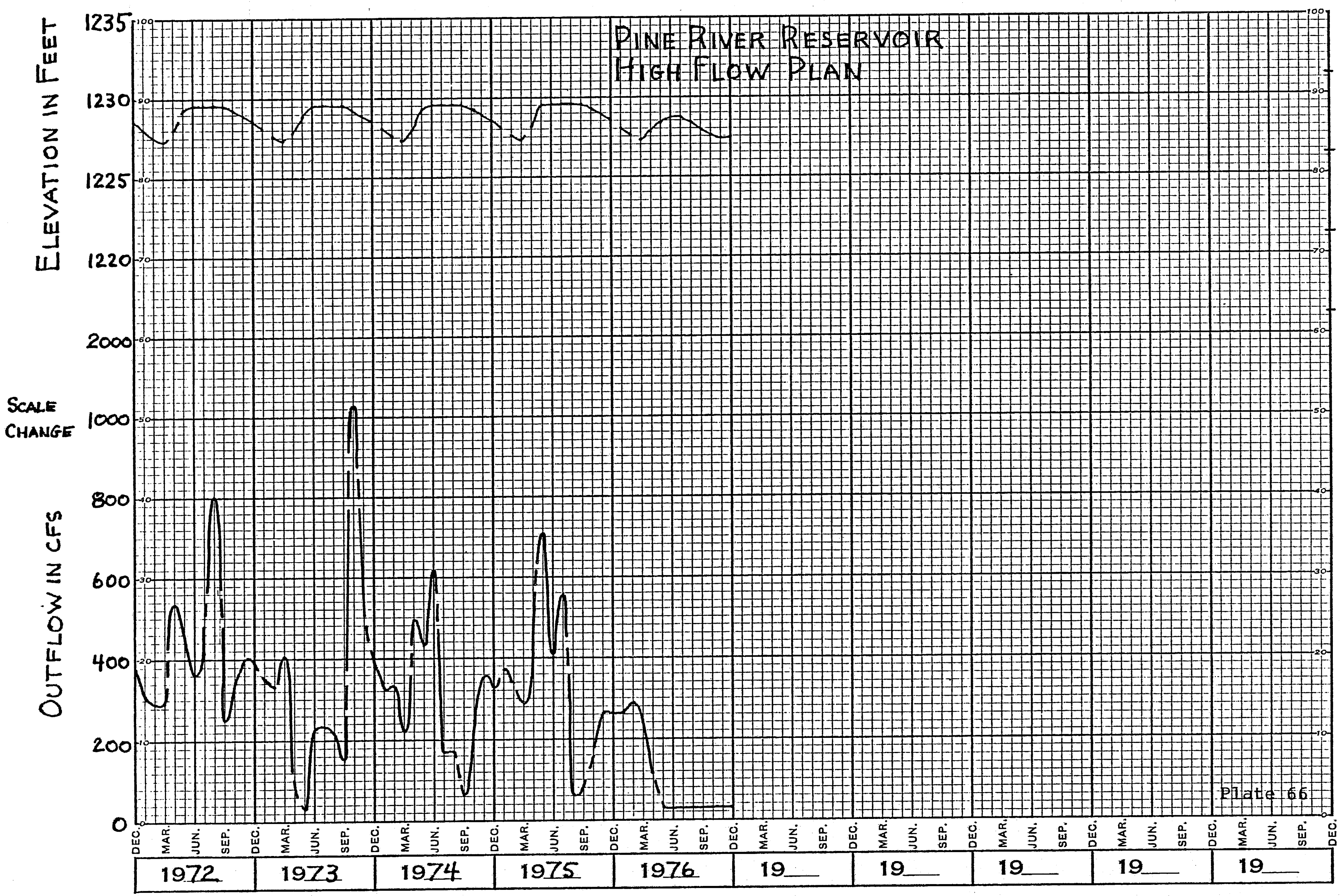

POKEGAMA RESERVOIR
HIGH FLOW PLAN
STAGE, FEET
0
5
10
15
ELEVATION, FEET
1280
1275
1270
1265
Scale Change
OUTFLOW, CFS
2000
1000
800
600
400
200
0
1972
1973
1974
1975
1976
19__
Plate 64

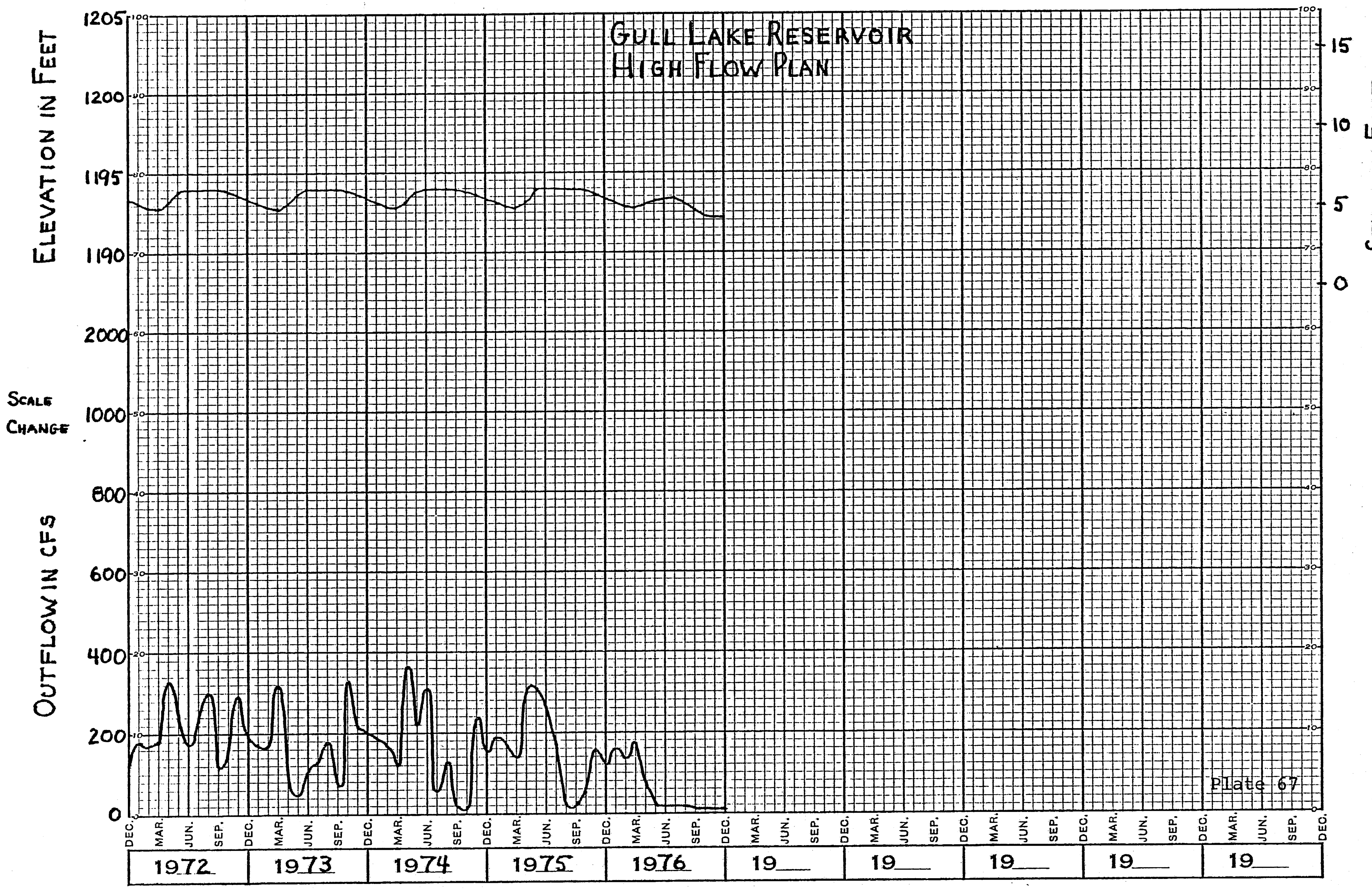


SANDY LAKE RESERVOIR
HIGH FLOW PLAN
ELEVATION IN FEET
1225
1220
1215
1210
2000
SCALE CHANGE
1000
800
600
400
200
0
OUTFLOW IN CFS
STAGE IN FEET
15
10
5
0
DEC. MAR. JUN. SEP.
1972
1973
1974
1975
1976
19__
19__
19__
19__
19__

Plate 65

JF


PINE RIVER RESERVOIR
HIGH FLOW PLAN
ELEVATION IN FEET
1235
1230
1225
1220
2000
SCALE CHANGE
1000
800
600
400
200
0
OUTFLOW IN CFS
STAGE IN FEET
15
10
5
0
1972
1973
1974
1975
1976
19__
Plate 66


GULL LAKE RESERVOIR
HIGH FLOW PLAN
ELEVATION IN FEET
1205
1200
1195
1190
SCALE CHANGE
OUTFLOW IN CFS
2000
1000
800
600
400
200
0
STAGE IN FEET
15
10
5
0
DEC. MAR. JUN. SEP.
1972
1973
1974
1975
1976
19__
Plate 67

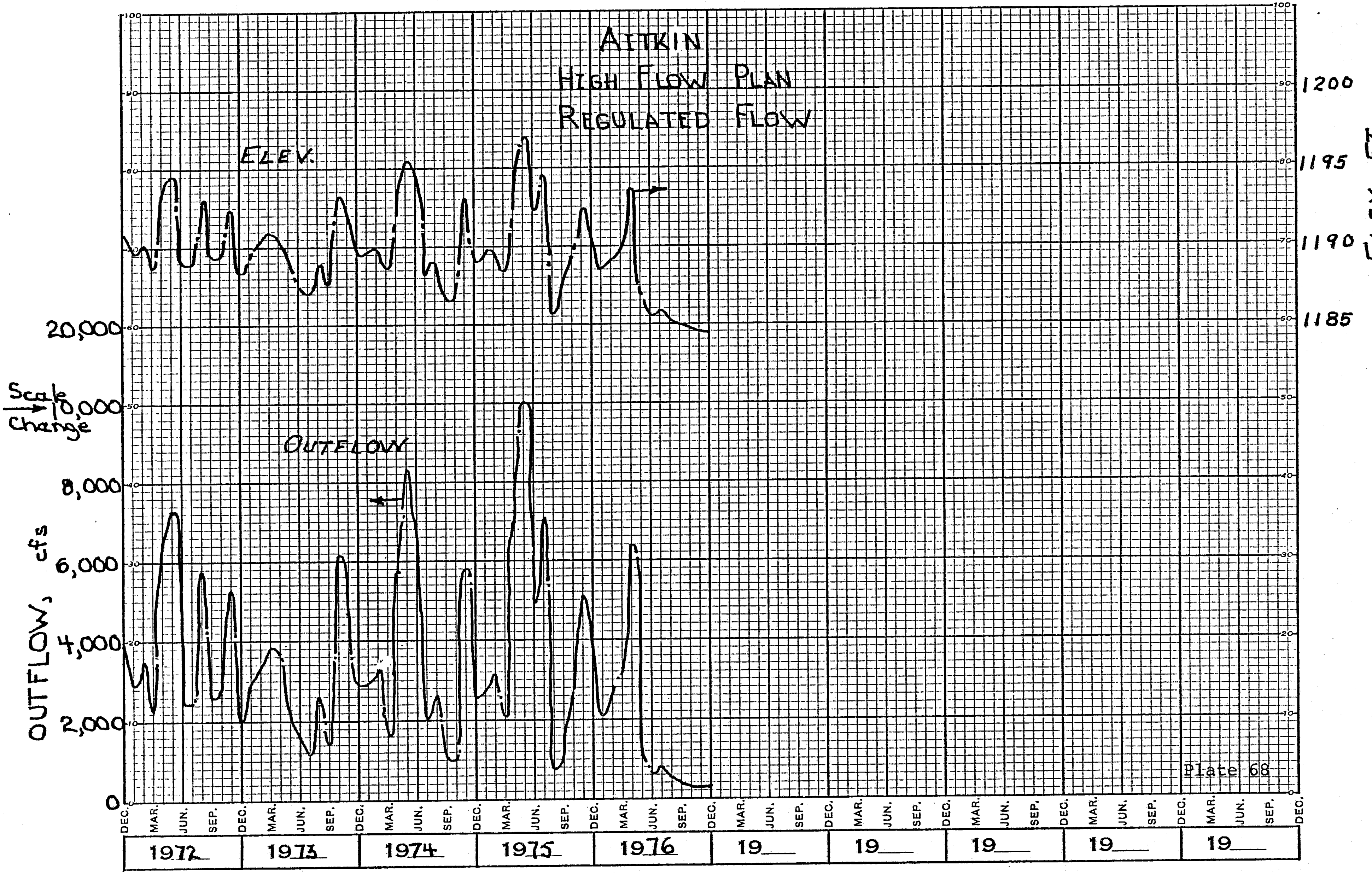

AITKIN
HIGH FLOW PLAN
REGULATED FLOW
ELEV.
OUTFLOW
ELEV. FT.
1200
1195
1190
1185
OUTFLOW, cfs
20,000
Scale Change
10,000
8,000
6,000
4,000
2,000
0
DEC. MAR. JUN. SEP.
1972
1973
1974
1975
1976
19__
19__
19__
19__
19__

Plate 68

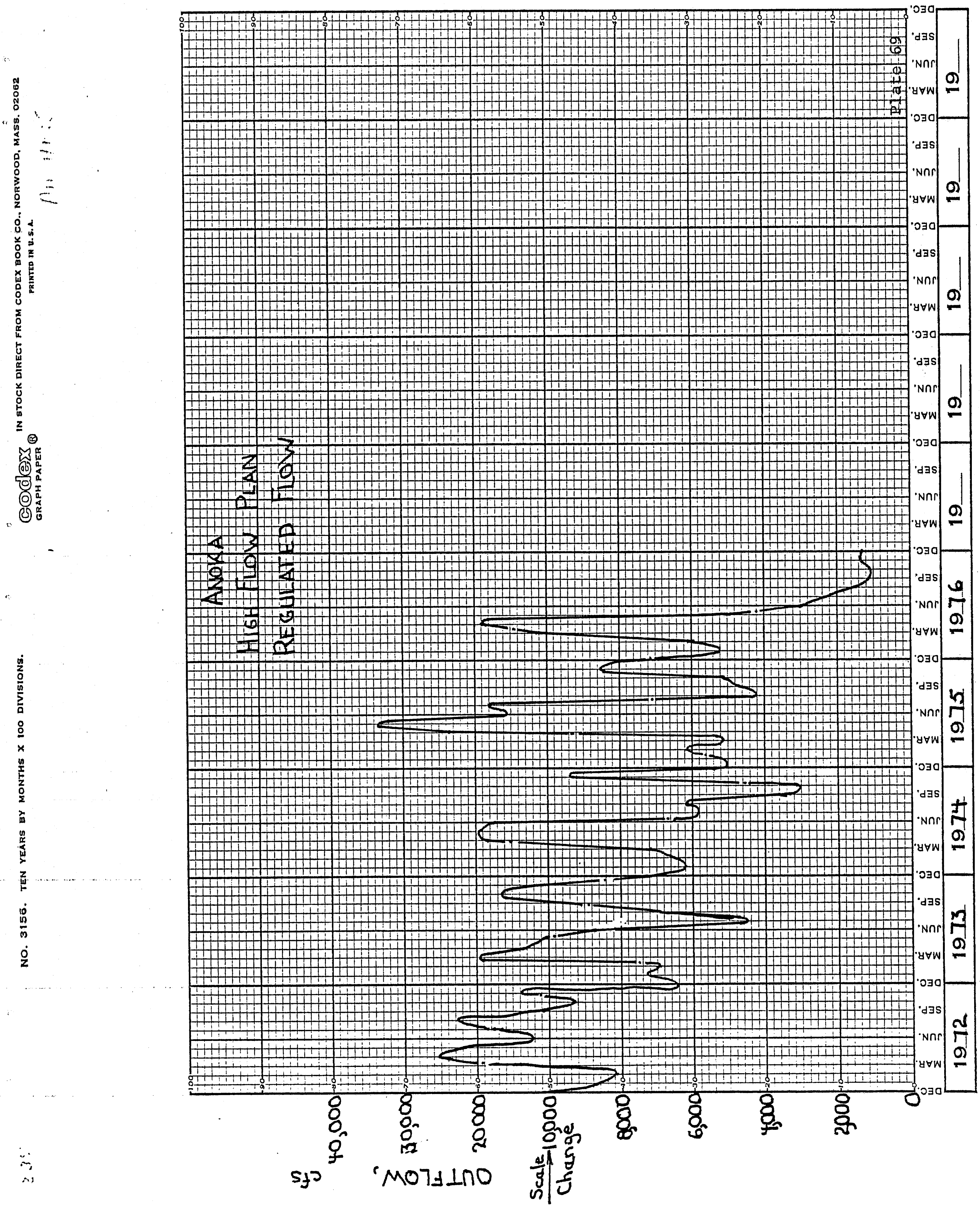


Plate 69
ANOKA
HIGH FLOW PLAN
REGULATED FLOW
OUTFLOW, cfs
40,000
30,000
20000
Scale Change
10000
8000
6000
4000
2000
0
1972
1973
1974
1975
1976
19
DEC.
MAR.
JUN.
SEP.
NO. 3156. TEN YEARS BY MONTHS X 100 DIVISIONS.
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The probability of high and low water-surface elevation was then determined and plotted on probability paper. A few examples of such curves are included in the text (Plates 70 to 73 inclusive). The complete set is available in Appendix F.

Plates 70 and 71 show the high- and low-elevation probabilities for Winnibigoshish Reservoir, for the Present Operating Plan. It may be noted that these have a rather unusual shape due to the fact that the reservoir is controlled to have a narrow range of water-surface elevations (1297.94) to 1298.44) during the summer months, whenever possible. Referring to Plate 70, there is a 1 percent chance that a reservoir elevation of 1302.1 feet will occur in any one year. Another way of expressing this is to say that you would expect this elevation on an average once in 100 years; however, that occasion could be next year. Once every 10 years (on an average) you would expect a high water elevation of 1300.1.

Referring to Plate 71, there is a two percent chance that a low-elevation of 1290.0 will occur in any one year (or once in 50 years on an average). Once in 10 years (10 percent probability) a low elevation of 1296.0 will be achieved with the Present Operating Plan.

Plates 72 and 73 show the high- and low-elevation probabilities for Winnibighoshish Reservoir with the Natural Flow Plan. There is a 1 percent probability that an elevation of 1292.3 will occur in any one year with the Natural Flow Plan (no dams). This is about 9.8 feet lower than would occur with the Present Operating Plan. The 2 percent or 50-year low elevation with the Natural Flow Plan would be 1286.0, about 4 feet lower than the Present Operating Plan. Thus, the effect of the dam on Winnibigoshish Reservoir would raise the lake level from 4 to 10 feet for present conditions.

Plate 74 shows the high-elevation probability for Gull Lake Reservoir with the Present Operating Plan as an illustration of elevation probabilities for another lake. This shows that the normal high water (50 percent probability) is about 1194.0. This is the upper limit of the desired summer range.

Plate 75 shows the high flow probability at Aitkin with the Present Operating Plan. This shows that the 1 percent probability or 100-year flood is 22,000 cfs (stage = 22.5 ft), the 2 percent or 50-year flood is 19,100 cfs (stage = 21.0 ft),

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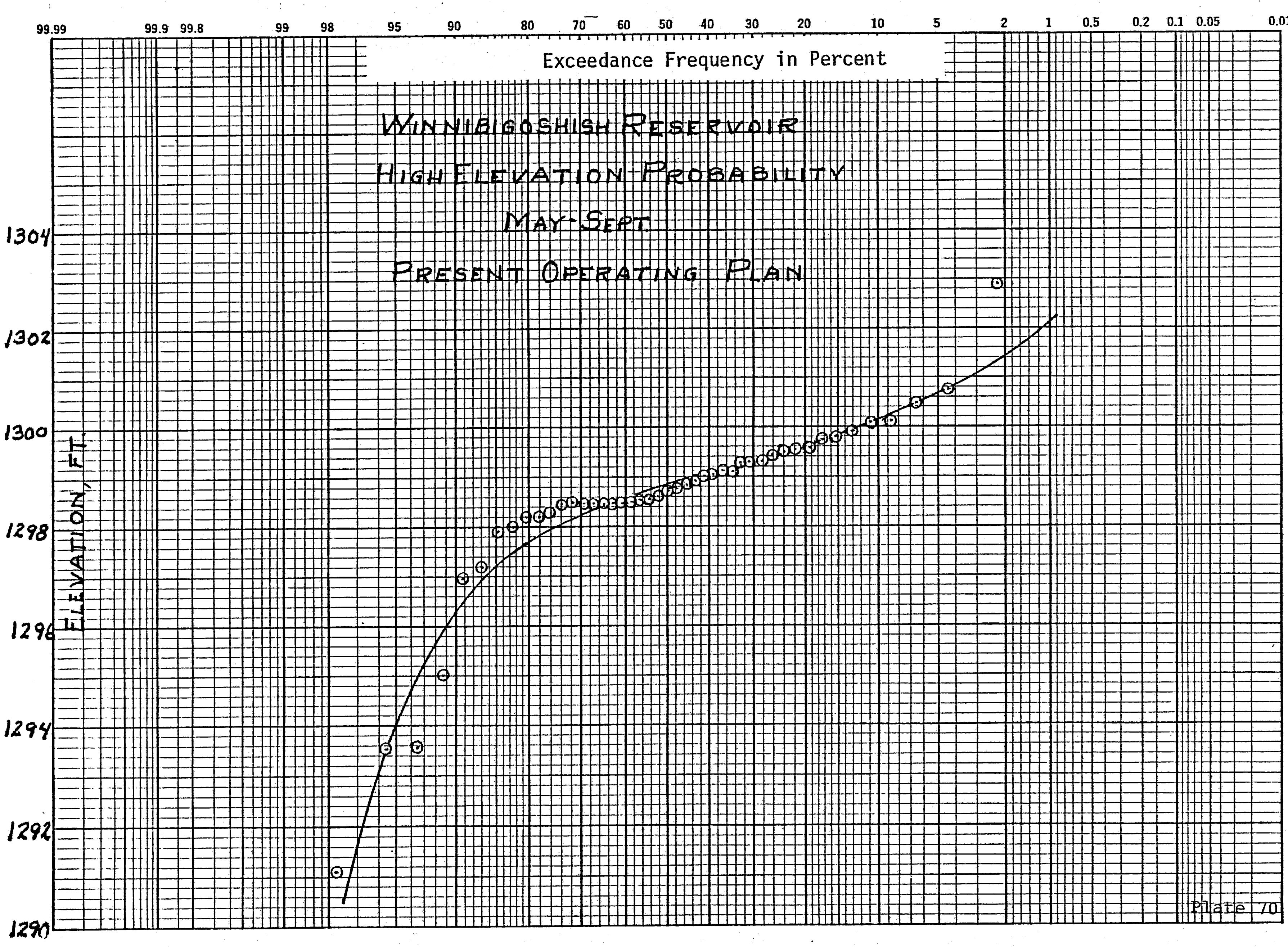

Plate 70

24P

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PROBABILITY X 90 DIVISIONS

DIETZGEN CORPORATION
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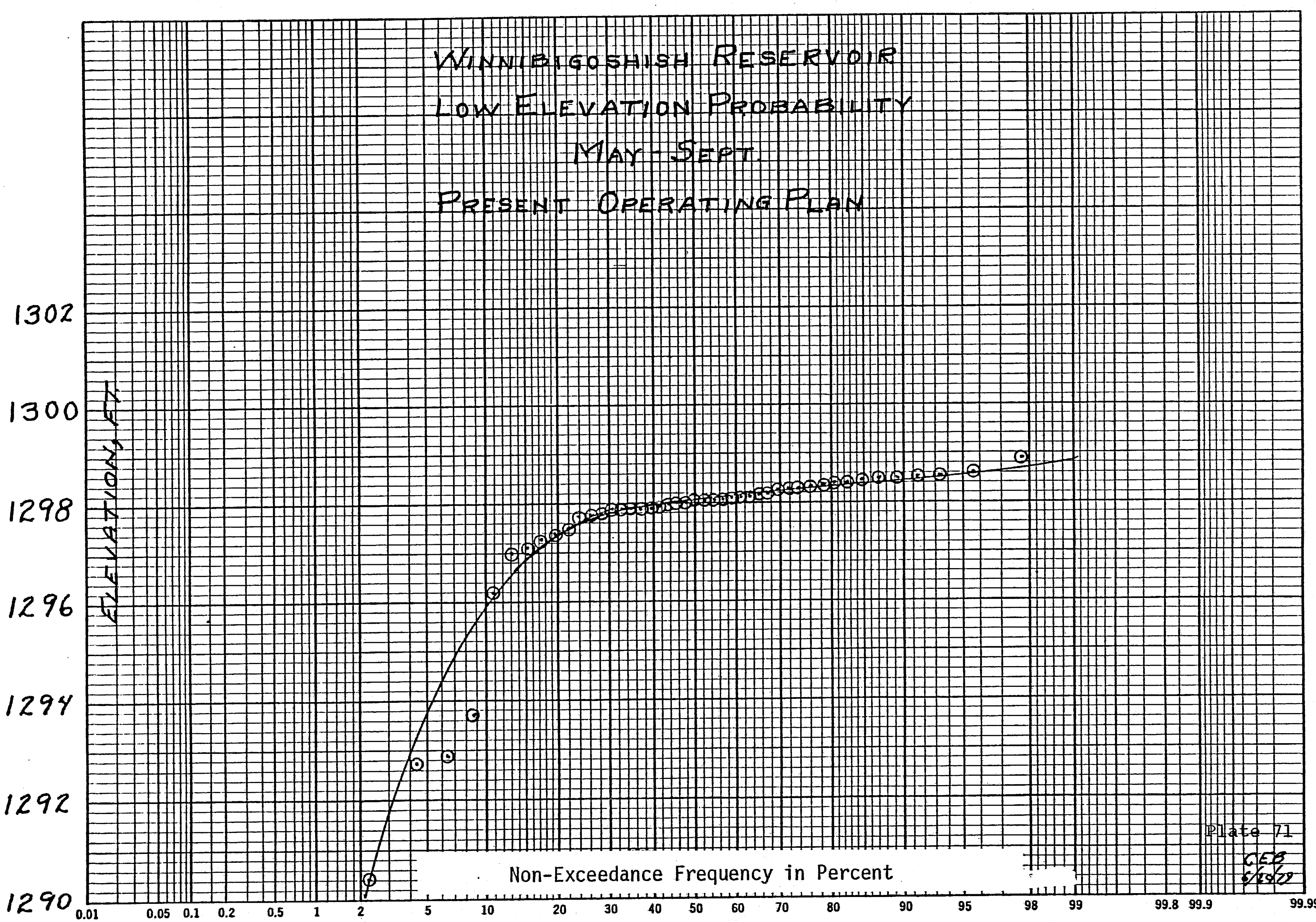


Plate 71

CEB

NO. 340-PS 90 DIETZGEN GRAPH PAPER
PROBABILITY X 90 DIVISIONS

DIETZGEN CORPORATION
MADE IN U.S.A.

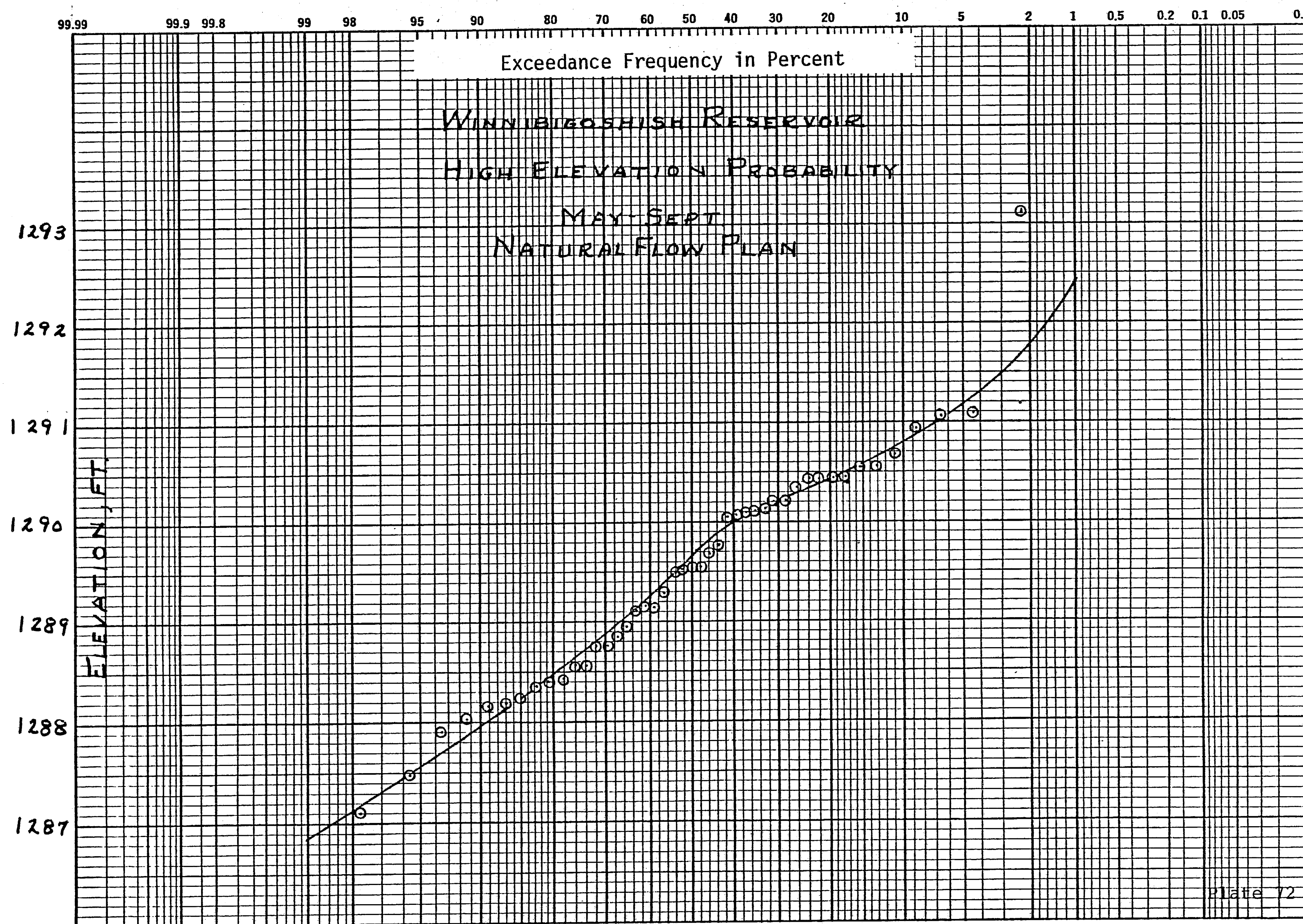
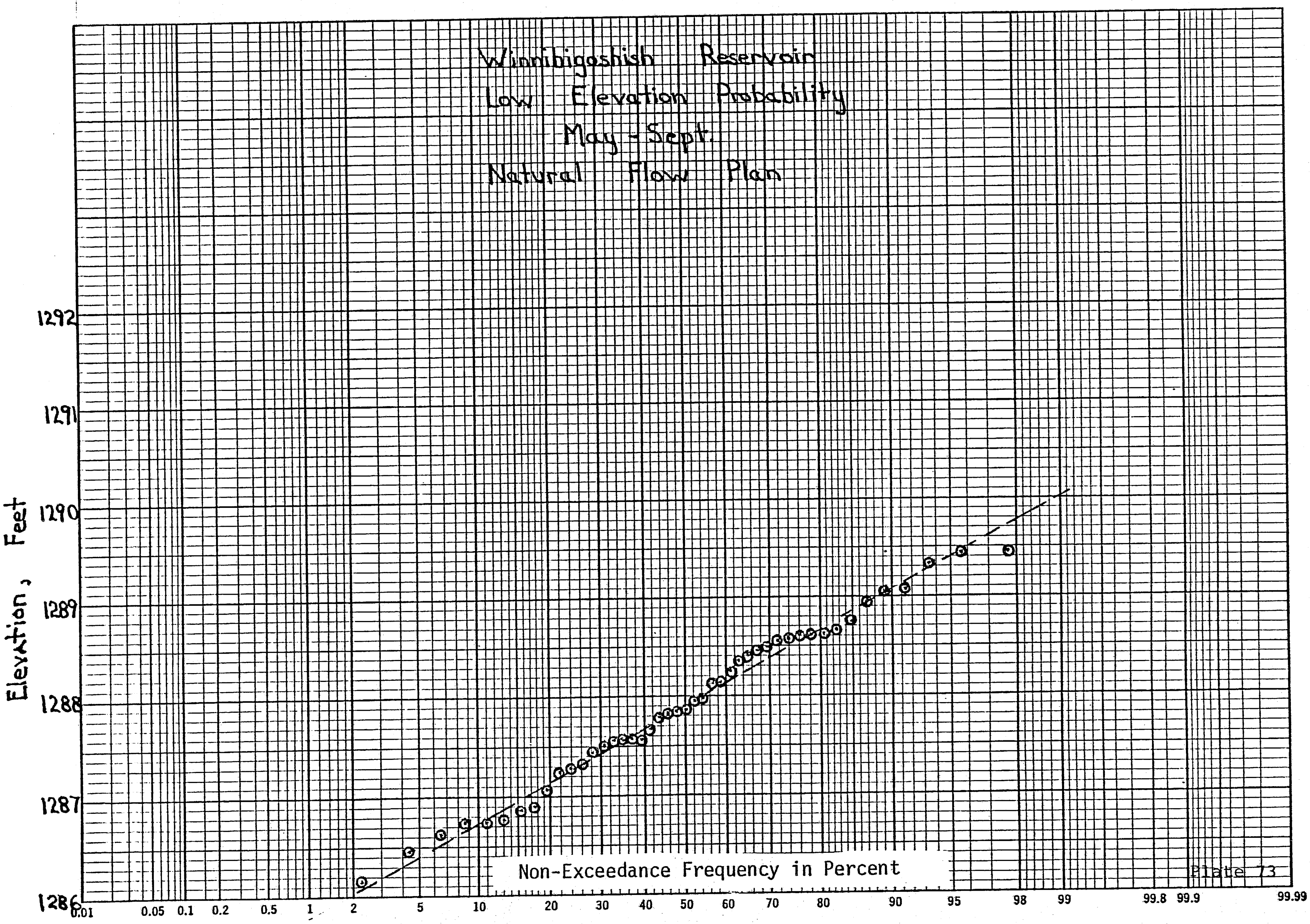


Plate 72

262


Winnibigoshish Reservoir
Low Elevation Probability
May - Sept.
Natural Flow Plan
Elevation, Feet
1286
1287
1288
1289
1290
1291
1292
Non-Exceedance Frequency in Percent
0.01
0.05
0.1
0.2
0.5
1
2
5
10
20
30
40
50
60
70
80
90
95
98
99
99.8
99.9
99.99
Plate 73

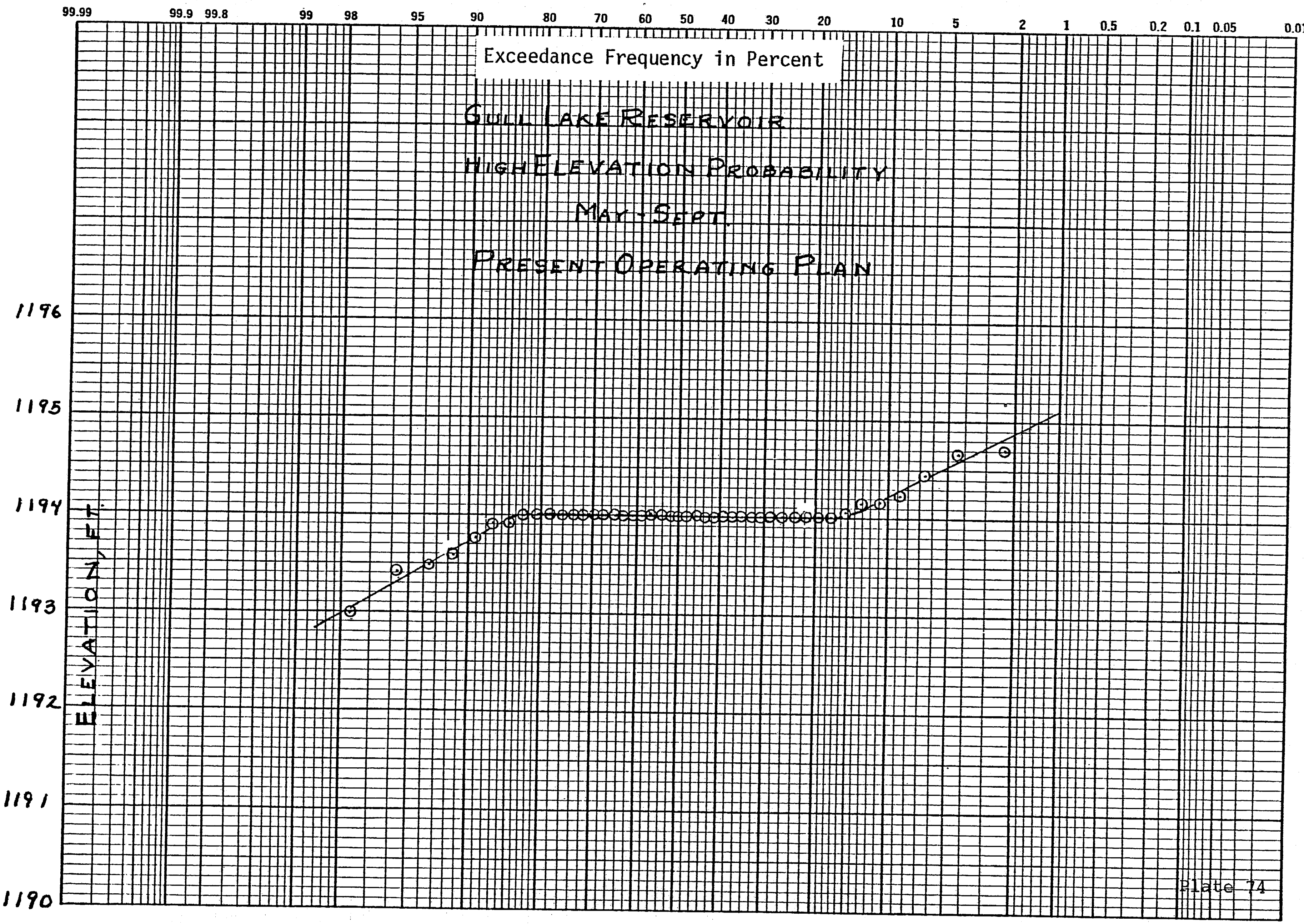

Exceedance Frequency in Percent
GULL LAKE RESERVOIR
HIGH ELEVATION PROBABILITY
MAY - SEPT.
PRESENT OPERATING PLAN
99.99
99.9
99.8
99
98
95
90
80
70
60
50
40
30
20
10
5
2
1
0.5
0.2
0.1
0.05
0.01
ELEVATION, FT
1196
1195
1194
1193
1192
1191
1190

Plate 74

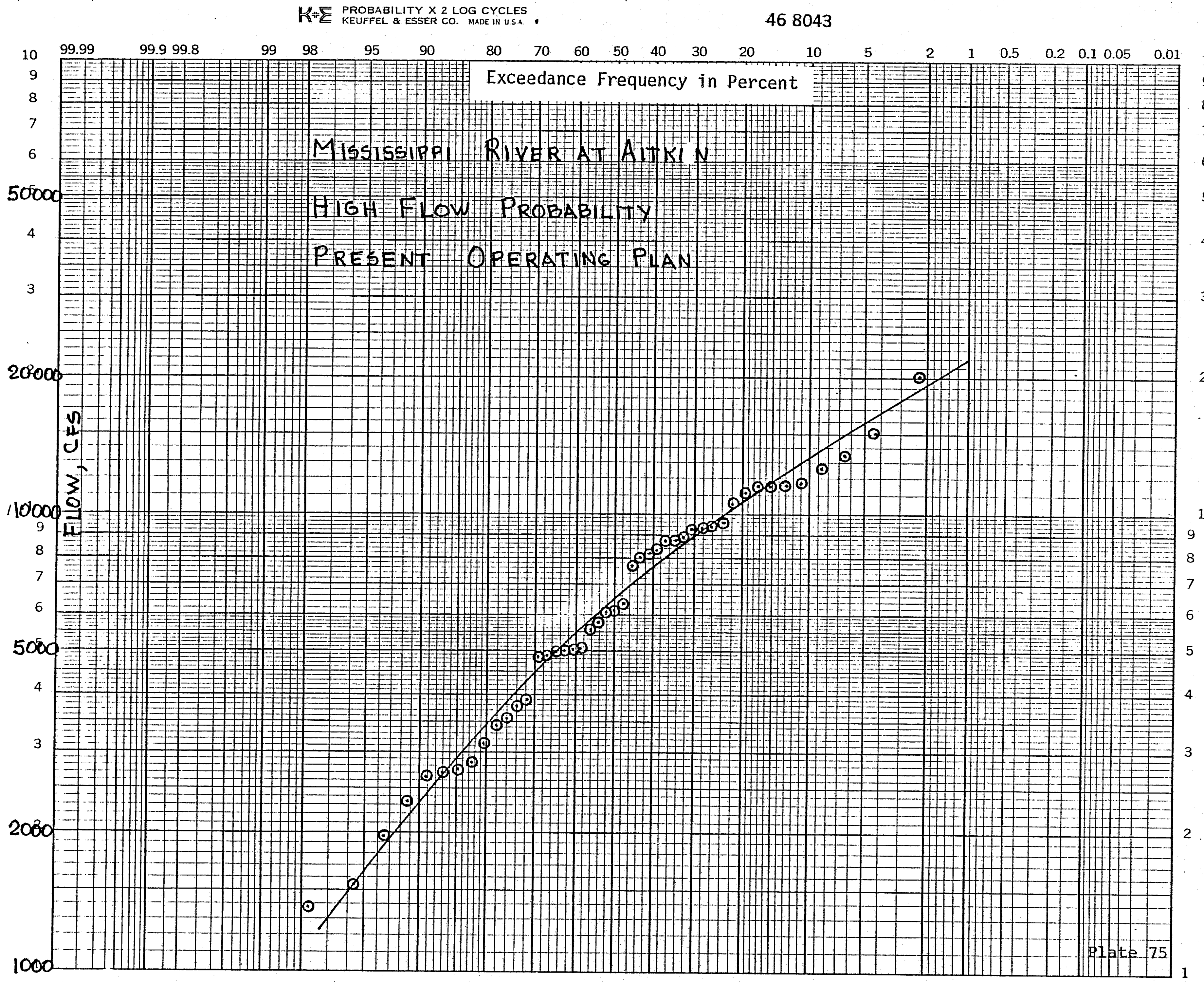

K+E PROBABILITY X 2 LOG CYCLES
KEUFFEL & ESSER CO. MADE IN U.S.A.
46 8043
Exceedance Frequency in Percent
MISSISSIPPI RIVER AT AITKIN
HIGH FLOW PROBABILITY
PRESENT OPERATING PLAN
FLOW, CFS
99.99
99.9
99.8
99
98
95
90
80
70
60
50
40
30
20
10
5
2
1
0.5
0.2
0.1
0.05
0.01
50000
20000
10000
5000
2000
1000

Plate 75

the 10 percent or 10-year flood is 13,200 cfs (stage - 17 ft), and the 50 percent or 2-year flood is 6,500 cfs (stage is 11.2 ft).

Flood stage at Aitkin is on the order of 15 feet or a discharge of 10,600 cfs. This would be equalled or exceeded by 20 percent of the May-September floods or about once every 5 years with the Present Operating Plan.

Plate 76 is an example of the low-flow probabilities at Anoka for the Present Operating Plan. Referring to the bottom scale, there is a 1 percent chance that the monthly average flow will be below 400 cfs in any one year or on an average of once in 100 years. There is a 10 percent chance that the flow will be below 1200 cfs in any one year or on an average once in every 10 years. There is a 17 percent chance that the flow will drop below the desired minimum of 1600 cfs in any one year. Conversely, there is an 83 percent chance that the minimum monthly flow will be above 1600 cfs. These values are all for the Present Operating Plan.

For data on the elevations of other lakes and other operating plans the reader is referred to Appendix F.

Damage Frequency Curves

Plates 77 and 78 illustrate damage frequency curves for the Present Operating Plan. The remainder are presented in Appendix G. The data for these graphs were obtained by the following procedure:

1. The high and low reservoir elevation in the period 1 May to 30 September were determined for each reservoir for each year.
2. The damages caused by the high and low water elevations were determined from the elevation damage curve (Plates 5 to 10). If the lowest water surface elevation was above the zero damage point, it was assumed that the low water caused no damage because the high reservoir elevation would cause the largest flood damage. Likewise, if the high level were below the zero damage point, it was assumed to cause no added low water damage.
3. For each year, the high and low damage were added to determine total damage. The total damage values were ranked in decreasing magnitude and

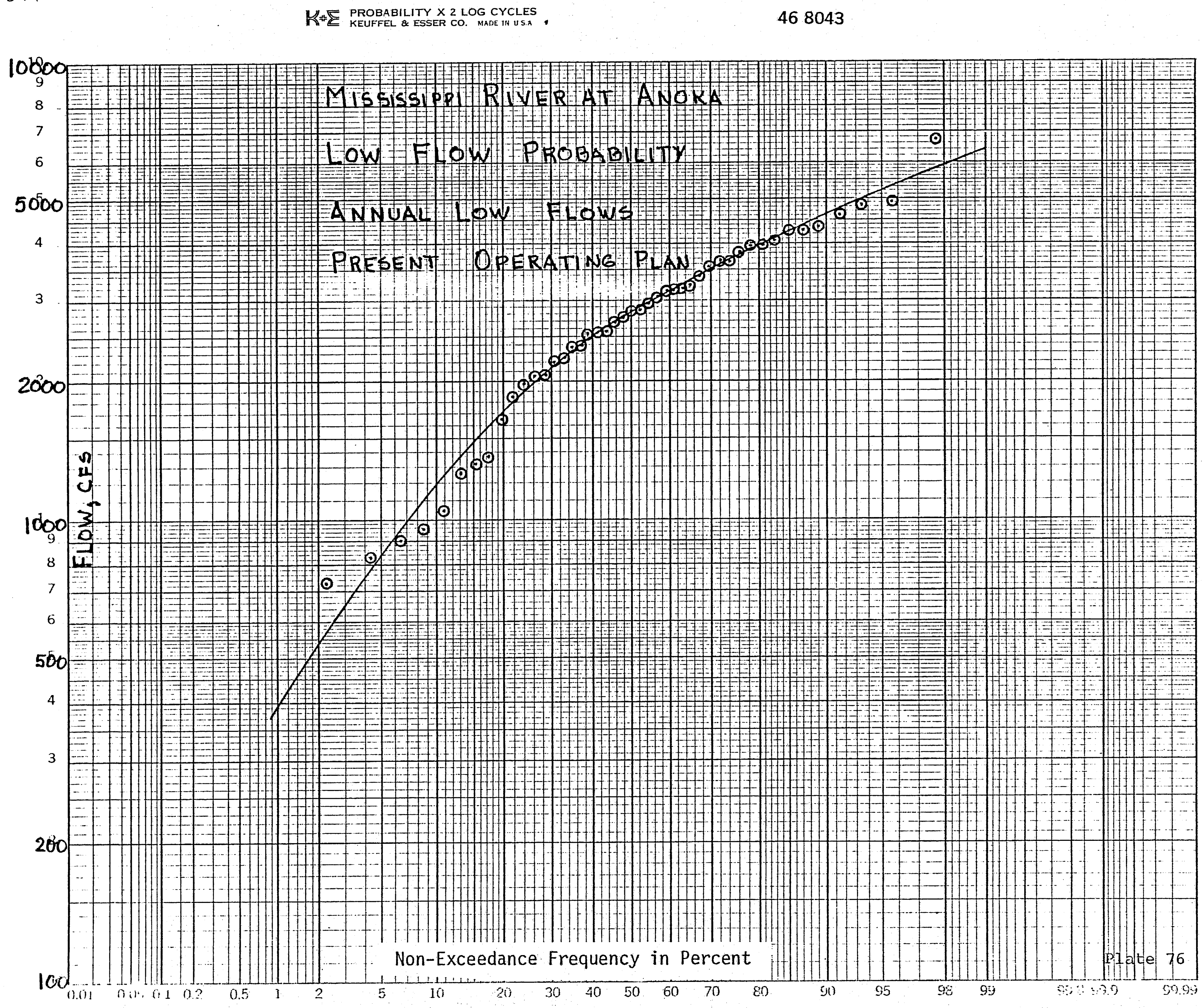

K+E PROBABILITY X 2 LOG CYCLES
KEUFFEL & ESSER CO. MADE IN U.S.A.
46 8043
MISSISSIPPI RIVER AT ANOKA
LOW FLOW PROBABILITY
ANNUAL LOW FLOWS
PRESENT OPERATING PLAN
FLOW, CFS
10000
5000
2000
1000
500
200
100
Non-Exceedance Frequency in Percent
0.01
0.1
0.2
0.5
1
2
5
10
20
30
40
50
60
70
80
90
95
98
99
99.99

Plate 76

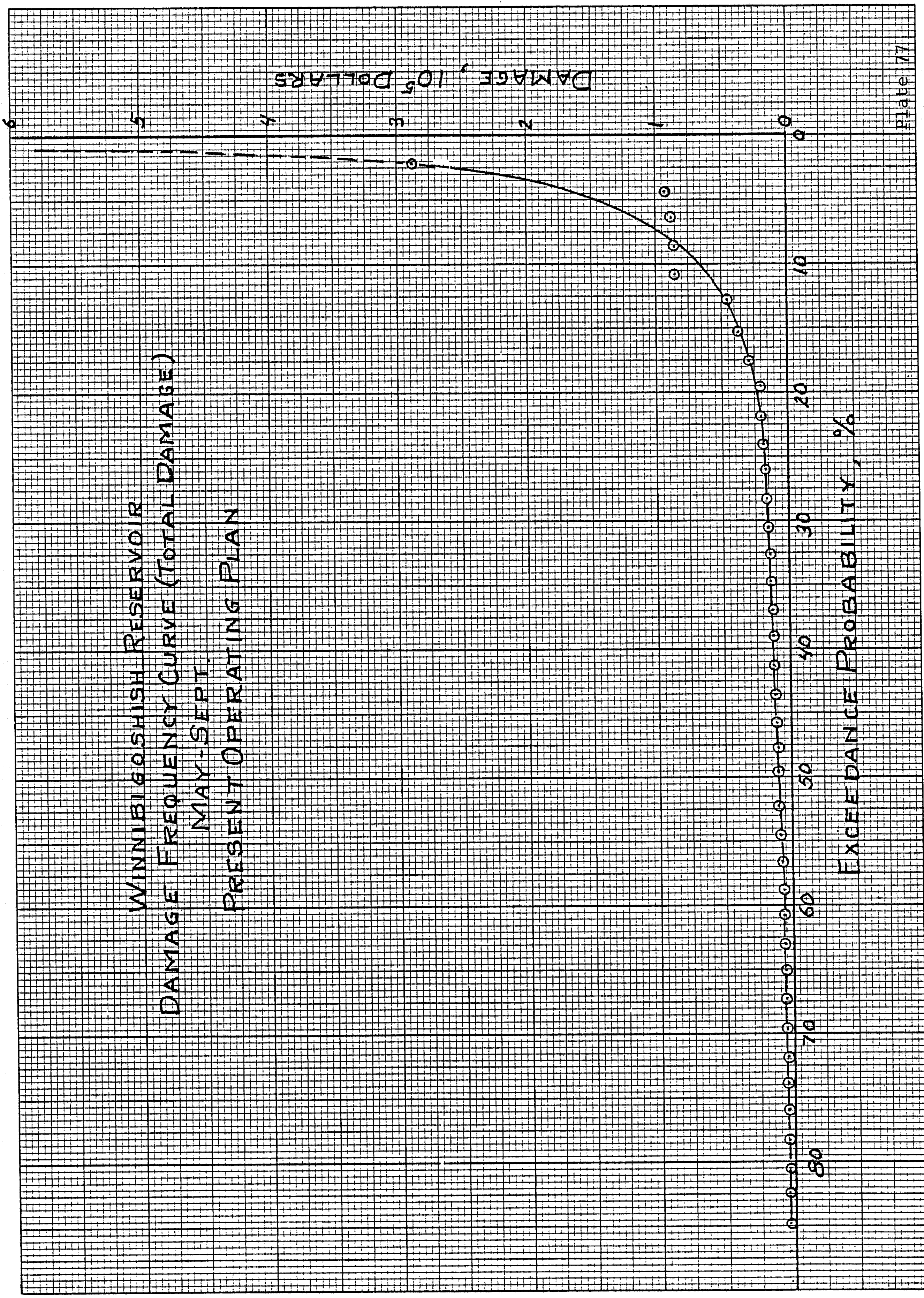

WINNIBIGOSHISH RESERVOIR
DAMAGE FREQUENCY CURVE (TOTAL DAMAGE)
MAY-SEPT.
PRESENT OPERATING PLAN
DAMAGE, 10^5 DOLLARS
0
1
2
3
4
5
6
EXCEEDANCE PROBABILITY, %
0
10
20
30
40
50
60
70
80

Plate 77

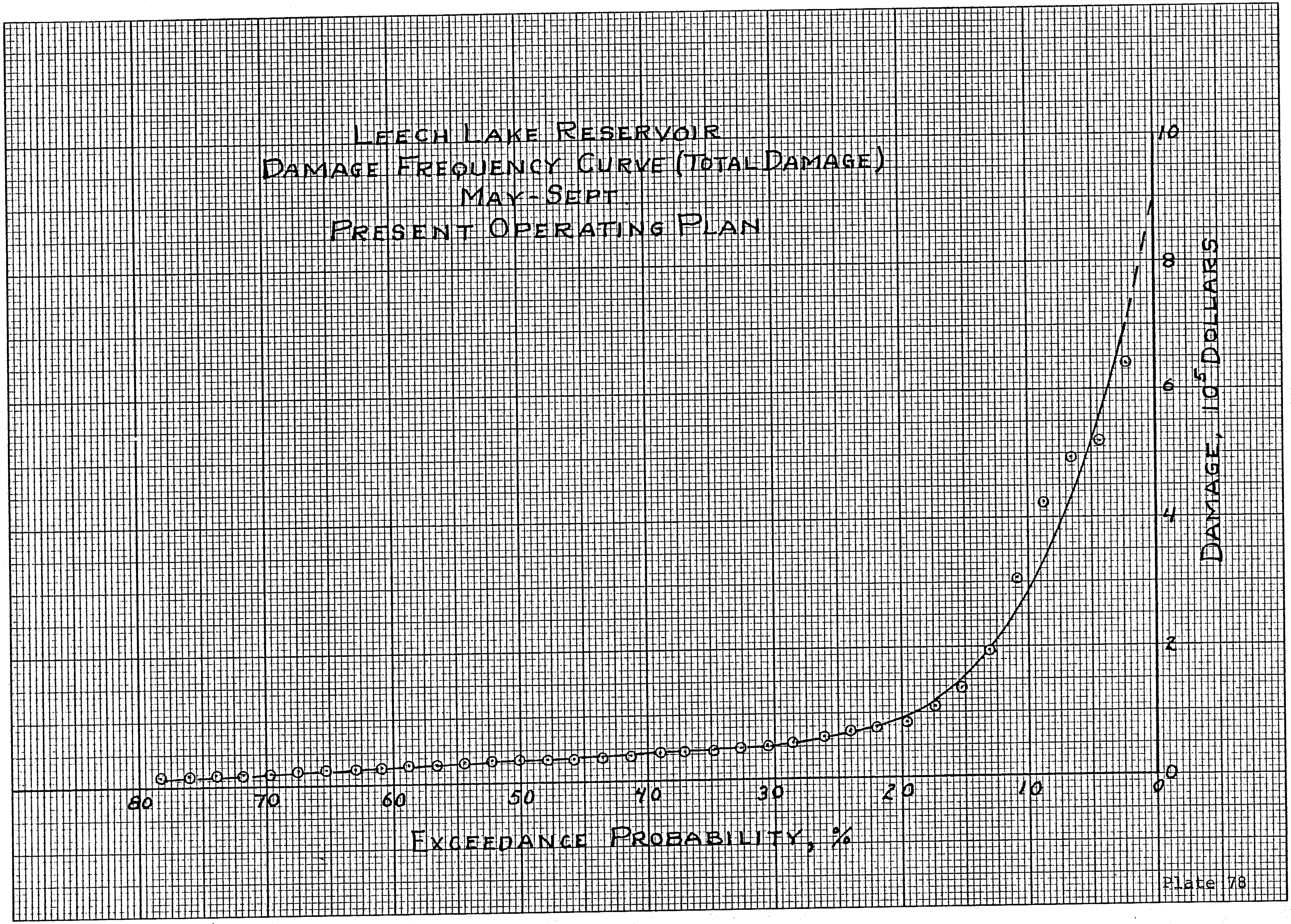

LEECH LAKE RESERVOIR
DAMAGE FREQUENCY CURVE (TOTAL DAMAGE)
MAY-SEPT.
PRESENT OPERATING PLAN
DAMAGE, 10^5 DOLLARS
0
2
4
6
8
10
EXCEEDANCE PROBABILITY, %
80
70
60
50
40
30
20
10
0

Plate 78

plotted on linear coordinate paper. The data were also plotted on log-probability paper to assist in extending the curves to 0.5 percent probability. (It was assumed that this probability was zero percent on the linear graph paper.

4. Single event annual damage at Aitkin was also based on the period 1 May to 30 September and included both agricultural and urban damage (as noted in Plates 11 to 15).

5. For both the 6 reservoirs and Aitkin the mean annual damage was determined by integrating the area under the damage curves of the type shown in Plates 77 and 78.

6. The loss computed for Anoka was not damage in the usual sense, but as noted above, was a potential loss to water supply due to inability to maintain an assured minimum flow of 1600 cfs at Anoka. It was computed for the full year. It is shown as a damage in the graphs and tables, but should be considered as a potential loss.

7. Program HEC-5C uses a series of daily and monthly data, with periods of daily data interspersed between periods of monthly data. The drainage analysis used the maximum or minimum value for each actual data set. A hand computation of a homogeneous set of high elevation data produced less severe flood flows for long recurrence intervals. In other words, the method used in the study was apparently more conservative (higher damages). For low flow data the curve for homogeneous data was very close to that for mixed data.

8. Damage computations were based on single events rather than multiple events per season.

The low water damages, represented on the six headwaters lakes elevation damage curves, represents a gross estimate of a single event, i.e. a short-term low water. A permanent change in operating plan (e.g. natural conditions) would actually result in a changed base condition. These changes would consist of one-time losses and gains to the existing properties, the future income stream of commercial properties, potential damages to new development, and the success of property owner adjustment to the new water level fluctuation. Without a detailed review of the current lake bottom contours and existing development on each lake, it is impossible to accurately assess what the damages would be with a changed operating plan to natural conditions (without dams).

The following table contains a summary of the percent damage caused by low-elevations in the reservoirs as compared to damage caused by high water-surface elevations.

Plan	Low W.S. Elevations %	High W.S. Elevations %
Pres. Operating Plan	33	67
Natural Flows	93	7
Low Flow Plan	50	50
High Flow Plan	59	41

Individual reservoirs depart from these figures but the trends are in accordance with these data.

Two-thirds of the damage under the Present Operating Plan is caused by high reservoir water-surface elevations.

With natural flows, 93 percent of the damage was caused by low flows. However, if the dams had not been built, it is assumed that many structures would be at a lower elevation and these percentages would change.

The low-flow plan achieved a good balance between high and low water surface damage (50 percent vs 50 percent).

The high-flow plan had 59 percent damage by low water-surface elevations as compared to 41 percent by high elevations. This results because the reservoirs have lower index levels to provide flood storage.

Comparisons

As noted in an earlier section, the complete set of curves for the 4 operating plans are included in Appendices A through D.

Tables 4 through 11 summarize maximum and minimum reservoir elevations, high flows at Aitkin and low monthly flows at Anoka for the 4 operating plans for the

Table 4

PRESENT OPERATING PLAN: High and Low Elevations from May 1 to Sept. 30: Reservoirs

	Winni		Leech		Pokegama		Sandy		Pine		Gull	
	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
1932	1290.42	1291.10	1292.18	1292.85	1271.06	1273.49	1215.94	1216.56	1228.58	1229.17	1192.65	1193.48
33	92.76	93.57	92.12	93.25	70.96	73.76	15.62	16.50	28.73	29.57	93.18	94.00
34	92.87	93.54	91.81	92.65	69.76	71.21	15.16	16.01	27.58	28.29	92.45	92.99
35	93.70	95.00	92.68	93.34	72.24	73.67	15.94	16.56	28.74	29.57	93.42	94.00
36	96.20	96.96	92.37	93.57	71.57	73.67	15.65	16.56	28.70	29.56	93.00	93.91
37	97.08	98.20	93.41	93.74	72.82	73.67	15.94	16.56	28.88	29.57	93.62	94.00
38	97.79(d)	99.81(d)	93.71(d)	94.70	72.12(d)	76.90(d)	15.47(d)	21.31(d)	28.31(d)	29.57	93.34(d)	94.71(d)
39	97.37	97.99	93.28	93.87	72.14	72.91	15.93	16.56	28.69	29.49	93.38	93.91
1940	97.93	98.44	93.57	94.07	72.67	73.67	15.94	16.56	28.88	29.50	93.53	93.77
41	98.11	98.72(d)	94.07(d)	94.46	73.22	75.38(d)	16.56	19.38(d)	28.34(d)	29.57	93.41(d)	94.00
42	98.07	98.44	93.81	94.76	72.82	73.67	15.94	16.56	28.94	29.57	93.62	94.00
43	1298.57	1300.46(d)	94.19	95.34(d)	72.82	76.99(d)	15.94	20.49(d)	28.94	29.88(d)	93.62	94.17(d)
44	98.02	1299.54(d)	93.93	95.49(d)	72.82	75.00(d)	15.94	21.33(d)	28.94	29.63(d)	93.62	94.44(d)
45	98.42	98.84(d)	94.45(d)	94.67	72.03(d)	74.68(d)	16.38(d)	17.64(d)	28.34(d)	29.57	93.27(d)	94.00
46	98.03	98.55	94.04	94.74	72.82	73.67	15.94	16.56	28.72	29.57	93.54	94.00
47	98.37	99.09	94.34	94.83	72.82	73.67	15.94	16.56	28.94	29.57	93.89	94.00
48	98.29	98.92(d)	94.10	94.41(d)	73.61	77.72(d)	16.41	21.31(d)	29.12(d)	29.57	93.34(d)	94.00
49	97.88	98.54	93.47	94.85	72.73	73.67	15.94	16.56	28.87	29.57	93.62	94.00
1950	98.49(d)	1302.89(d)	94.13(d)	95.94(d)	73.67	77.92(d)	16.23	25.29(d)	28.50(d)	30.45(d)	93.74	94.67(d)
51	98.56	1299.28	94.78	95.04	73.15	73.67	15.98	16.78	28.94	29.57	93.62	94.00
52	98.42(d)	99.41(d)	94.71(d)	95.20(d)	73.60(d)	77.88(d)	16.55(d)	21.50(d)	28.38(d)	29.57	93.28(d)	94.14(d)
53	97.98	99.25(d)	94.20	95.29(d)	72.82	77.92(d)	15.94	21.44(d)	28.94	29.57	93.62	94.00
54	98.27	99.75(d)	94.65(d)	95.46(d)	73.64(d)	77.92(d)	16.56	21.50(d)	28.38(d)	29.57	93.27(d)	94.00
55	97.92	98.44	94.10	94.54	72.82	73.67	15.60	16.56	28.62	29.57	93.32	94.00
56	97.90(d)	98.46(d)	93.68	94.03(d)	72.93(d)	73.70(d)	16.49	21.31(d)	28.35(d)	29.57	93.26(d)	94.00
57	98.30	98.59	94.07	94.84	72.82	73.67	15.94	16.56	28.88	29.57	93.52	94.00
58	96.99	97.19	93.02	93.35	72.18	73.67	15.01	16.56	27.97	28.91	93.34	93.99
59	97.26	98.27	93.43	94.16	72.57	73.67	15.80	16.56	28.54	29.57	93.56	94.00
1960	97.73	98.21	93.97	94.43	72.82	73.67	15.94	16.56	28.94	29.57	93.62	94.00
61	97.44	97.88	93.58	93.85	72.82	73.67	15.94	16.55	28.71	29.25	93.43	93.58
62	98.16	99.09	94.41	95.13	72.82	73.67	15.94	16.56	28.94	29.57	93.62	94.00
63	98.12	98.48	93.90	94.40	72.82	73.67	15.94	16.56	28.79	29.57	93.49	94.00
64	98.19	98.44	94.05	94.33	72.82	73.67	15.94	16.56	28.94	29.57	93.48	94.00
65	98.15(d)	99.58(d)	94.04(d)	95.38(d)	73.67	77.92(d)	16.56	21.99(d)	28.36(d)	30.24(d)	93.98(d)	94.22(d)
66	1298.89	1300.76(d)	94.93	95.50(d)	73.67	77.92(d)	16.56	21.34(d)	28.53(d)	29.57	93.42(d)	94.00
67	98.00	1299.02(d)	94.12	94.81	71.98(d)	74.08(d)	16.22	18.66(d)	28.37(d)	29.57	93.27(d)	94.00
68	98.18	98.44	93.95	94.52	72.82	73.67	15.94	16.56	28.94	29.57	93.49	94.00
69	98.52	99.92(d)	94.59	95.26(d)	73.50(d)	77.92(d)	16.38	21.41(d)	28.37(d)	29.57	93.28(d)	94.00

Note: (d) indicates a daily max. or min., not a monthly average

Table 4 (Cont.)

PRESENT OPERATING PLAN: High and Low Elevations from May 1 to Sept. 30: Reservoirs

	Winni		Leech		Pokegama		Sandy		Pine		Gull	
	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
1970	97.97	99.45(d)	94.02	94.84	72.73	75.07(d)	15.75	16.95(d)	28.37(d)	29.57	93.40(d)	94.00
71	98.06	99.00(d)	94.10(d)	94.51	73.51	77.92(d)	16.48	21.39(d)	28.35(d)	29.57	93.28(d)	94.00
72	98.35	99.30(d)	94.42(d)	95.01(d)	73.55	77.58(d)	16.56	21.36(d)	28.38(d)	29.57	93.36(d)	94.00
73	98.06	98.43	93.71	93.99	72.54	73.67	15.94	16.56	28.89	29.57	93.62	94.00
74	1298.47	1300.13(d)	94.50(d)	95.66(d)	73.67	76.34(d)	16.56	21.30(d)	28.36(d)	29.57	93.35(d)	94.00
75	1298.61(d)	1300.09(d)	94.48(d)	95.37	73.67	77.92(d)	16.46	21.76(d)	29.21(d)	29.57	94.00	94.05(d)
76	97.78	1298.76	93.68	94.43	72.82	73.67	14.67	15.56	27.91	28.74	92.60	93.41

Note: (d) indicates a daily max. or min., not a monthly average

Table 5

Present Operating Plan: Aitkin High Flow (May-Sept.)

Anoka Monthly Ave. Low Flow (Annual)					
	AITKIN			ANOKA	
Year	Date	May-Sept. High Flow (cfs)	May-Sept. High Elev. (ft.)	Date	Monthly Ave. Annual Low Flow (cfs)
1932	May	2,657	1189.15	Sept.	1,263
33	May	2,705	89.2	Sept.	958
34	May	1,638	87.55	Aug.	728
35	May	2,860	89.45	Jan.	901
36	May	4,875	92.0	July	827
37	May	3,903	90.8	Feb.	1,310
38	May 14	9,299	96.25	Jan.	2,060
39	May	2,350	88.7	Oct.	2,028
1940	May	3,444	90.25	Sept.	1,371
41	May 1	8,193	95.3	Aug.	2,827
42	May	4,848	91.95	Jan.	3,568
43	June 4	9,580	96.5	Dec.	3,979
44	June 7	11,554	98.1	Jan.	4,349
45	May 1	6,369	93.55	Jan.	4,276
46	June	5,770	92.95	Sept.	3,625
47	June	6,064	93.25	Aug.	3,373
48	May 2	11,523	98.1	Oct.	2,199
49	July	5,544	92.7	Sept.	2,560
1950	May 18	20,025	1203.9	Feb.	3,629
51	May	8,287	95.4	Jan.	4,244
52	July 22	11,565	98.1	Nov.	3,974
53	July 6	11,101	97.75	Jan.	4,832
54	May 7	11,836	98.35	Dec.	4,055
55	July	3,561	90.35	Nov.	3,149
56	May 1	8,874	95.9	Oct.	2,762
57	July	5,005	92.2	Jan.	3,059
58	July	1,983	88.1	Aug.	2,518
59	June	3,794	90.65	Feb.	2,379
1960	May	5,065	92.2	Aug.	1,977

Table 5 (Cont.)

Present Operating Plan: Aitkin High Flow (May-Sept.)

Anoka Monthly Ave. Low Flow (Annual)

Year	AITKIN Date	May-Sept. High Flow (cfs)	May-Sept. High Elev. (ft.)	ANOKA Date	Monthly Ave. Annual Low Flow (cfs)
1961	May	3,118	89.8	Aug.	1,642
62	May	7,705	94.85	March	2,391
63	June	4,972	92.05	Nov.	2,951
64	May	6,153	93.35	Aug.	2,571
65	June 9	10,605	97.35	March	2,841
66	May 4	13,512	99.6	Dec.	4,904
67	May 1	8,025	95.1	Nov.	2,234
68	June	5,037	92.15	Feb.	3,181
69	May 1	12,682	99.0	Sept.	2,685
1970	May 12	8,747	95.8	Sept.	1,858
71	May 1	9,287	96.25	Sept.	3,126
72	May 27	8,744	95.75	Feb.	6,734
73	Aug.	2,724	89.25	July	4,609
74	May 14	9,379	96.3	Sept.	3,196
75	May 3	15,041	1200.6	Feb.	3,819
1976	May	1,387	1187.1	Sept.	1,048

Table 6

Natural Flow Plan - High and Low Elevations from May 1 to Sept. 30: Reservoirs

	Winni		Leech		Pokegama		Sandy		Pine		Gull	
	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
1932	1286.87	1288.56	1291.22	1292.33	1269.01	1270.78	1208.75	1212.60	1211.09	1216.22	1190.01	1191.70
33	86.46	88.35	90.49	92.01	68.53	70.61	1208.75	12.45	11.81	17.16	90.15	91.71
34	86.15	87.10	90.09	91.15	68.04	69.60	1208.75	09.40	10.17	15.38	89.60	90.35
35	87.58	88.15	91.19	91.96	69.62	70.14	1208.75	11.70	15.12	16.21	91.19	91.75
36	86.63	88.42	90.16	91.85	68.48	71.15	1208.75	15.15	06.35	16.56	90.07	91.72
37	87.98	88.56	91.57	91.84	69.82	70.85	1208.75	13.50	15.08	16.45	91.67	92.37
38	87.43	90.45	91.84	92.95(d)	69.51	73.04(d)	1208.75	20.15	14.82	18.54(d)	91.61	94.15(d)
39	86.75	88.02	91.22	92.25	69.18	70.74	1208.75	11.47	12.06	16.12	90.76	92.36
1940	87.23	88.74	91.20	92.12	69.06	70.93	1208.75	13.00	14.48	16.39	90.59	91.58
41	87.85	89.29	92.35	92.70	69.74	72.16(d)	1208.87	15.87(d)	15.34	16.91(d)	92.00	93.74(d)
42	88.25	89.13	92.47	92.92	69.81	71.43	09.10	15.27	15.59	17.31	92.45	93.43
43	88.93	91.09(d)	93.12	94.00(d)	70.75	73.39(d)	08.82	21.60(d)	15.73	19.56(d)	92.36	94.74(d)
44	88.49	90.69(d)	92.62	94.07(d)	71.02	73.34(d)	10.94	23.30(d)	15.49(d)	19.41(d)	92.68	94.62(d)
45	88.46	90.12(d)	92.86	83.88(d)	70.49	72.51(d)	10.35	15.55(d)	15.48	16.95(d)	92.14	93.53(d)
46	87.58	89.53	92.89	93.49	70.21	71.61	09.00	13.20	15.56	17.12	92.35	93.70
47	88.62	90.10	92.69	93.60	70.64	72.61	08.75	16.52	14.92	17.32	91.60	94.04
48	87.56	89.49(d)	92.19	93.24(d)	70.04	73.67(d)	08.75	20.80(d)	15.49	18.27(d)	91.57	93.27(d)
49	88.12	90.54	92.02	93.30	70.59	72.11	10.17	13.42	14.48	16.35	91.19	92.32
1950	89.32	93.12(d)	93.32	94.72(d)	72.39	75.94(d)	0 8.75	30.70(d)	15.16	20.05(d)	91.50	94.92(d)
51	89.03	90.43	93.13	93.87	71.31	73.49	10.55	17.95	15.52	17.17	92.13	93.07
52	88.74	89.51(d)	93.26(d)	93.85(d)	70.75(d)	73.29(d)	09.44(d)	19.10(d)	15.44(d)	18.21(d)	92.29(d)	93.88(d)
53	88.61	90.44(d)	93.30	94.20(d)	71.87	73.94(d)	13.71	23.56(d)	15.76(d)	17.43(d)	92.39	93.21(d)
54	88.13	90.08(d)	93.20	94.24(d)	70.83	74.45(d)	09.51	23.47(d)	15.46	18.18(d)	91.50	93.22(d)
55	87.32	89.11	92.32	93.24	70.06	71.79	09.66	12.21	15.66	16.68	91.38	91.91
56	87.29	88.84(d)	91.79	92.69(d)	69.75	72.00(d)	08.96	17.05(d)	15.11	16.97(d)	91.35	92.74(d)
57	89.07	90.33	92.50	93.09	70.84	71.89	08.87	14.47	15.38	16.69	91.69	92.74
58	86.91	87.48	91.21	91.83	69.25	70.07	09.04	10.62	15.14	15.68	90.91	91.31
59	87.94	88.23	91.57	92.19	70.01	70.78	08.91	12.33	15.04	16.49	91.07	91.98
1960	87.06	88.19	91.90	92.91	69.50	71.51	08.75	15.42	15.01	16.96	91.09	92.41
61	86.78	87.91	91.96	92.03	69.34	70.55	08.75	12.53	14.80	16.13	90.52	91.17
62	89.45	90.93	93.24	94.10	72.28	72.81	09.16	15.73	15.74	17.49	91.53	92.79
63	87.68	89.14	92.49	93.05	70.38	71.69	09.01	12.96	14.99	16.53	91.18	92.01
64	87.79	88.96	92.20	92.77	70.31	71.85	11.64	16.13	15.59	16.72	91.47	92.08
65	88.54	90.05(d)	93.13	93.95(d)	70.01	74.54(d)	09.13	18.34(d)	15.98	20.02(d)	92.20	94.79(d)
66	88.67	91.07(d)	93.79	94.62(d)	70.92	75.84(d)	10.40	22.12(d)	16.06	18.94(d)	91.99	94.27(d)
67	87.87	90.11	92.47	94.01(d)	69.78	72.91(d)	09.23	17.45(d)	14.37	17.50(d)	91.12	92.70(d)

Sandy Elevation Data is not from computor run - artificially generated using elevation difference - outflow curves

Note: (d) indicates a daily elevation value, not a monthly value.

Table 6 (Cont.)

Natural Flow Plan - High and Low Elevations from May to Sept. 30: Reservoirs

	Winni		Leech		Pokegama		Sandy		Pine		Gull	
	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
1968	88.40	89.54	92.48	92.97	70.71	71.22	09.73	13.63	15.34	16.55	91.67	92.82
69	88.57	90.22(d)	92.84	93.96(d)	70.77	75.29(d)	09.58	20.50(d)	14.97	17.79(d)	91.12	93.74(d)
1970	87.50	90.21(d)	92.19	93.72(d)	69.48	73.67(d)	08.75	20.05(d)	09.63	17.80(d)	90.89	92.86(d)
71	87.57	89.68(d)	92.39	93.32(d)	69.81	73.59(d)	08.76	20.20(d)	15.00	17.09(d)	91.33	93.15(d)
72	88.35	89.77(d)	93.51	93.88(d)	70.55	73.74(d)	10.75	19.87(d)	16.36	18.12(d)	92.97	93.79(d)
73	87.82	88.40	92.71	93.14	70.09	70.83	12.65	12.38	15.74	16.33	92.17	92.84
74	88.61	90.58(d)	93.34	94.55(d)	71.31	74.20(d)	10.16	20.14(d)	15.42	18.05(d)	91.95	93.97(d)
75	89.43	90.46(d)	93.67	94.33	71.79	74.95(d)	10.25	24.38(d)	15.06	18.67(d)	91.91	93.99(d)
1976	86.73	88.77	91.56	93.15	69.16	71.32	08.75	10.72	06.12	15.48	91.88	90.03

Note: Sandy Elevation Data is not from computor run 0 artificially generated using elevation difference - outflow curves.
(d) denotes a daily max. or min., not a monthly average

Table 7

Natural Flow Plan: High Flow at Aitkin (May-Sept.)
Monthly Ave. Low Flow at Anoka (Annual)

AITKIN				ANOKA	
DATE	YEAR	MAY-SEPT. HIGH FLOW (cfs)	MAY-SEPT. HIGH FLOW (ft.)	DATE	MONTHLY AVE. ANNUAL LOW FLOW (cfs)
1932	May	3,920	1190.8	Oct.	1,124
33	"	3,821	90.7	Sept.	765
34	"	2,041	88.25	Aug.	554
35	"	3,646	90.5	Jan.	792
36	"	5,953	93.15	July	898
37	"	5,010	92.15	Feb.	1,004
38	May 11	13,837	99.9	Feb.	1,347
39	"	3,581	90.4	Dec.	1,613
1940	"	4,444	91.45	Jan.	1,122
41	May 1	9,155	96.1	Feb.	2,412
42	May	5,787	93.0	Jan.	2,546
43	June 20	12,912	99.15	Dec.	3,216
44	June 8	13,368	99.5	Jan.	3,029
45	May 1	8,032	95.15	"	3,383
46	June	5,593	92.8	Feb.	3,322
47	May	6,879	94.05	"	3,735
48	May 1	15,130	1200.7	Oct.	2,194
49	July	4,444	91.45	Jan.	2,298
1950	May 21	23,616	1205.9	Feb.	2,573
51	May	8,339	1195.45	Jan.	3,052
52	July 23	12,497	98.85	Dec.	3,318
53	Aug. 9	15,249	1200.8	Jan.	3,354
54	May 7	14,153	1200.15	Dec.	3,075
55	July	4,301	91.3	Jan.	2,756
56	May 1	7,727	94.9	Oct.	2,338
57	May	5,109	92.25	Feb.	2,134
58	July	2,423	88.8	Dec.	2,264
59	June	4,248	91.25	Feb.	1,680

Table 7 (Cont.)

Natural Flow Plan: High Flow at Aitkin (Map-Sept.)
Monthly Ave. Low Flow at Anoka (Annual)

AITKIN				ANOKA	
DATE	YEAR	MAY-SEPT. HIGH FLOW (cfs)	MAY-SEPT. HIGH FLOW (ft.)	DATE	MONTHLY AVE. ANNUAL LOW FLOW (cfs)
1960	May	6,487	93.7	Dec.	1,746
61	"	4,077	91.05	Jan.	1,498
62	"	6,396	93.6	Feb.	1,736
63	June	4,590	91.65	Dec.	2,266
64	May	7,058	94.25	Feb.	2,023
65	June 9	13,284	99.45	"	2,414
66	May 1	13,970	1200.0	Dec.	3,726
67	May 1	7,712	94.85	Dec.	2,135
68	June	4,856	91.95	Jan.	1,935
69	May 1	11,669	98.2	Sept.	3,418
1970	May 1	10,418	97.2	"	2,027
71	"	13,431	99.55	Jan.	2,898
72	"	13,321	99.5	Dec.	5,756
73	May	3,866	90.75	Feb.	4,693
74	May 1	12,720	99.0	Oct.	3,464
75	"	21,154	1204.5	Jan.	3,809
1976	May	2,557	1189.0	Oct.	1,004

Table 8

Low Flow Plan - High and Low Elevations from May 1 to Sept. 30: Reservoirs

	Winni		Leech		Pokegama		Sandy		Pine		Gull	
	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
1932	1290.42	1291.10	1292.00	1292.72	1271.17	1273.59	1214.88	1216.56	1226.45	1228.67	1292.65	1193.48
33	92.76	93.57	91.50	92.69	69.73	73.67	12.45	15.02	23.89	27.40	91.39	92.80
34	90.72	91.67	91.00	91.89	69.15	70.21	07.88	12.97	13.50	23.53	89.25	90.32
35	90.52	92.01	91.91	92.79	72.05	73.62	15.49	16.56	23.63	25.33	91.18	92.78
36	93.83	94.67	91.91	93.18	69.93	73.66	13.06	16.56	24.31	28.40	91.79	93.91
37	93.00	94.90	92.77	93.10	72.82	73.67	15.73	16.56	24.98	27.75	92.87	94.00
38	96.83(d)	98.93(d)	93.54(d)	94.55	72.12(d)	76.87(d)	15.47(d)	21.31(d)	28.31(d)	29.57	93.34(d)	94.71(d)
39	96.44	97.58	93.23	93.75	72.12	73.03	15.93	16.56	28.69	29.49	93.49	93.91
1940	97.22	98.20	93.34	93.87	72.82	73.67	15.94	16.56	28.88	29.50	93.53	93.77
41	97.81	98.47(d)	93.97(d)	94.37	73.19	75.38(d)	16.56	19.38(d)	28.34(d)	29.57	93.41(d)	94.00
42	97.85	98.15	93.81	94.67	72.20	73.67	15.94	16.56	28.94	29.57	93.62	94.00
43	98.07	1300.46(d)	94.19	95.34(d)	72.82	76.99(d)	15.94	20.49(d)	28.94	29.88(d)	93.62	94.17(d)
44	98.02	1299.54(d)	93.93	95.49(d)	72.82	74.99(d)	15.94	21.33(d)	28.94	29.63(d)	93.62	94.44(d)
45	98.33	98.84(d)	94.45(d)	94.67	72.03(d)	74.68(d)	16.38(d)	17.64(d)	28.34(d)	29.57	93.27(d)	94.00
46	97.76	98.54	94.04	94.74	72.82	73.67	15.94	16.56	28.72	29.57	93.54	94.00
47	98.38	99.09	94.34	94.83	72.82	73.67	15.94	16.56	28.94	29.57	93.89	94.00
48	98.11	98.90(d)	94.10	94.41(d)	73.58	77.72(d)	16.41	21.31(d)	29.12(d)	29.57	93.34(d)	94.00
49	97.88	98.54	93.47	94.85	72.73	73.67	15.94	16.56	28.87	29.57	93.62	94.00
1950	98.44(d)	1302.86(d)	94.13(d)	95.94(d)	73.67	77.92	16.23	29.29(d)	28.50(d)	30.45(d)	93.74	94.67(d)
51	98.56	1299.27	94.78	95.04	73.15	73.67	15.98	16.78	28.94	29.57	93.62	94.00
52	98.42(d)	99.41(d)	94.71(d)	95.20(d)	73.60(d)	76.38(d)	16.55(d)	21.50(d)	28.38(d)	29.57	93.28(d)	94.14 (d)
53	97.98(d)	99.34(d)	94.20(d)	95.31(d)	72.82(d)	77.92(d)	15.94(d)	21.47(d)	28.94(d)	31.05	93.62(d)	94.37
54	98.27	99.67(d)	94.65(d)	95.45(d)	73.67(d)	77.92(d)	16.56	21.50(d)	28.38(d)	29.57	93.38(d)	94.00
55	97.69	98.23	94.10	94.54	72.82	73.67	15.60	16.56	28.62	29.57	93.32	94.00
56	97.68(d)	98.31(d)	93.87	94.22(d)	73.47(d)	73.67	16.49	21.31(d)	28.35(d)	29.57	93.26(d)	94.00
57	98.33	98.63	94.11	94.91	72.82	73.67	15.94	16.56	28.88	29.57	93.52	94.00
58	96.99	97.19	93.02	93.35	72.18	73.67	15.01	16.56	27.97	28.91	93.34	93.99
59	96.73	97.52	93.43	94.16	72.57	73.67	15.80	16.56	28.54	29.57	93.56	94.00
1960	97.71	98.21	93.97	94.43	72.82	73.67	15.94	16.56	28.94	29.57	93.62	94.00
61	97.44	97.88	93.58	93.85	72.82	73.67	15.94	16.55	28.71	29.25	93.43	93.58
62	98.16	99.09	94.41	95.13	72.82	73.67	15.94	16.56	28.94	29.57	93.62	94.00
63	97.97	98.45	93.90	94.40	72.82	73.67	15.94	16.56	28.79	29.57	93.49	94.00
64	97.94	98.28	94.05	94.33	72.82	73.67	15.94	16.56	28.94	29.57	93.48	94.00
65	97.93(d)	99.75(d)	94.04(d)	95.38(d)	73.67	77.92(d)	16.56	21.98(d)	28.36(d)	30.24(d)	93.98(d)	94.22(d)
66	98.89	1300.76(d)	94.93	95.50(d)	73.67	77.92(d)	16.56	21.34(d)	28.53(d)	29.57	93.42(d)	94.00
67	98.00	1299.07(d)	94.12	94.81	72.00(d)	74.34(d)	16.22	18.66(d)	28.37(d)	29.57	93.27(d)	94.00
68	98.14	98.31	93.90	94.47	72.82	73.67	15.94	16.56	28.94	29.57	93.49	94.00

Note: (d) Indicates a daily max. or min., not a monthly average

Table 8 (Cont.)

Low Flow Plan - High and Low Elevations from May 1 to Sept. 30: Reservoirs

	Winni		Leech		Pokegama		Sandy		Pine		Gull	
	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
1969	98.44	99.92(d)	94.59	95.26(d)	73.50(d)	77.92(d)	16.38	21.41(d)	28.37(d)	29.57	93.28(d)	94.00
70	97.90	99.43(d)	94.02	94.85	72.90(d)	74.98(d)	15.75	16.95(d)	28.37(d)	29.57	93.40(d)	94.00
71	97.86	98.89(d)	94.10(d)	94.51(d)	73.51	77.92(d)	16.48	21.39(d(	28.35(d)	29.57	93.28(d)	94.00
72	98.35	99.44(d)	94.42(d)	95.01(d)	73.55	77.21(d)	16.56	21.36(d)	28.38(d)	29.57	93.36(d)	94.00
73	97.53	98.06	93.71	93.99	72.54	73.67	15.94	16.56	28.89	29.57	93.62	94.00
74	98.44	99.95(d)	94.56(d)	95.65(d)	73.67	77.67(d)	16.56	21.30(d)	28.36(d)	29.57	93.35(d)	94.00
75	98.61(d)	1300.08(d)	94.48(d)	95.37	73.67	77.92(d)	16.46	21.74(d)	29.21(d)	29.57	94.00	94.00
1976	97.38	1298.76	93.68	94.43	72.82	73.67	14.67	15.56	26.58	28.74	92.60	93.41

Note: (d) Indicates a daily max. or min., not a monthly average

Table 9

LOW FLOW PLAN: High Flow at Aitkin (May-Sept.), Monthly Ave. Low Flow at Anoka (Annual)

		AITKIN		ANOKA	
YEAR	DATE	MAY-SEPT. HIGH FLOW (cfs)	MAY-SEPT. HIGH ELEV. (ft.)	DATE	MONTHLY AVE. ANNUAL LOW FLOW (cfs)
1932	May	2,772	1189.3	Dec.	1600
33	"	2,695	89.2	"	1467
34	"	1,864	87.95	Aug.	744
35	"	2,715	89.2	Jan.	1243
36	"	4,825	91.9	Feb.	1600
37	"	3,787	90.65	Jan.	1493
38	May 14	9,299	96.25	"	1601
39	June	2,471	88.9	Dec.	1944
1940	May	3,326	90.05	Jan/Feb.	1601
41	May 1	8,193	95.3	Jan	2,821
42	May	4,848	91.95	"	3,568
43	June 4	9,580	96.5	Dec.	3,979
44	June 6	9,224	96.2	Jan.	4,349
45	May 1	6,369	93.55	"	4,276
46	June	6,102	93.3	Sept.	3,625
47	"	6,064	93.25	"	3,295
48	May 2	11,723	98.25	Oct.	2,199
49	July	5,544	92.7	Sept.	2,616
1950	May 18	20,025	1203.9	Feb.	3,629
51	May	3,832	1190.7	Jan.	4,241
52	May 25	6,991	94.2	Oct.	3,974
53	Aug. 10	10,887	97.55	Jan.	4,832
54	May 7	11,836	98.35	Dec.	4,055
55	June	3,610	90.45	Nov.	3,149
56	May 1	8,874	95.9	Oct.	2,606
57	July	4,843	91.95	Jan.	3,006
58	"	1,983	88.1	Aug.	2,518
59	June	3,794	90.65	March	2,283

Table 9 (Cont.)

LOW FLOW PLAN: High Flow at Aitkin (May-Sept.)

Monthly Ave. Low Flow at Anoka (Annual)

	AITKIN			ANOKA	
YEAR	DATE	MAY-SEPT. HIGH FLOW (cfs)	MAY-SEPT. HIGH ELEV. (ft.)	DATE	MONTHLY AVE. ANNUAL LOW FLOW (cfs)
1960	May	5,056	92.2	Aug.	1,977
61	"	3,118	89.8	"	1,642
62	"	7,705	94.85	March	2,391
63	June	5,365	92.55	Dec.	2,924
64	May	6,710	93.9	Aug.	2,571
65	June 8	11,419	98.0	Feb.	3,481
66	May 5	9,588	96.5	Dec.	4,904
67	May 21	6,304	93.5	Nov.	2,234
68	June	5,333	92.5	Jan.	3,171
69	May 1	12,682	99.0	Sept.	2,863
1970	May 12	8,747	95.8	"	1,858
71	May 2	9,402	96.35	"	3,126
72	May 25	8,716	95.75	Feb.	6,734
73	June	2,842	89.4	July	4,609
74	May 23	9,379	96.3	Sept.	3,203
75	May 7	15,710	1201.1	Feb.	3,819
1976	June	1,533	1187.4	Oct.	1,645

Table 10

HIGH FLOW RUN: High and Low Elevations from May 1 to Sept. 30: Reservoirs

	Winni		Leech		Pokegama		Sandy		Pine		Gull	
	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
1932	1290.42	1291.10	1292.05	1292.74	1270.18	1272.56	1212.87	1215.06	1228.58	1229.17	1192.65	1193.48
33	91.35	92.18	91.87	92.98	70.27	73.06	09.60	12.42	28.73	29.57	93.18	94.00
34	90.54	91.18	91.52	92.38	69.02	70.42	09.45	10.43	24.73	28.29	92.43	92.99
35	91.46	92.89	92.36	93.08	70.71	72.97	11.62	15.60	26.76	28.20	93.42	94.00
36	93.07	93.73	91.81	93.06	70.58	73.55	14.06	16.56	28.70	29.56	93.00	93.91
37	91.58	93.54	92.93	93.26	72.78	73.67	11.82	14.78	28.88	29.57	93.62	94.00
38	92.80(d)	96.63	93.27(d)	94.31	71.66	76.81(d)	09.91(d)	18.74(d)	28.31(d)	29.57	93.34(d)	94.71(d)
39	93.37	93.99	92.87	93.49	71.50	73.37	12.04	14.32	28.69	29.49	93.38	93.91
1940	92.71	93.80	92.78	93.32	71.02	73.64	10.65	12.46	28.88	29.50	93.53	93.77
41	93.13(d)	94.98	93.69(d)	94.07	72.47	74.94(d)	16.56	17.07(d)	28.34(d)	29.57	93.41(d)	94.00
42	93.81	95.59	93.72	94.65	72.20	73.67	12.63	16.56	28.94	29.57	93.62	94.00
43	95.52	99.23	94.09	95.18(d)	73.26	74.65(d)	12.94	21.16(d)	28.94	29.88(d)	93.62	94.17(d)
44	93.96	98.88	93.80	95.18(d)	72.73	74.73(d)	13.67	21.31(d)	28.94	29.63(d)	93.62	94.44(d)
45	95.25(d)	97.45	94.42(d)	94.61	70.64(d)	73.67	15.68(d)	16.56	28.34(d)	29.57	93.27(d)	94.00
46	94.88	96.22	94.28	94.90	72.31	73.67	11.76	16.56	28.72	29.57	93.54	94.00
47	94.84	97.59	94.26	94.75	73.29	73.90	13.52	16.45	28.94	29.57	93.89	94.00
48	95.11(d)	95.86	94.33	94.63(d)	73.52(d)	77.72(d)	16.41	20.26(d)	29.12(d)	29.57	93.34(d)	94.00
49	93.80	98.64	93.48	94.82	72.17	73.67	10.91	14.88	28.87	29.57	93.62	94.00
1950	94.81(d)	1301.06(d)	94.29(d)	96.05(d)	73.67	77.92(d)	16.23	23.97(d)	29.57	30.45(d)	93.74	94.67(d)
51	98.05	99.44	94.70	95.05	73.28	73.67	13.74	16.78	28.94	29.57	93.62	94.00
52	96.13(d)	98.37(d)	94.54(d)	95.19(d)	73.53(d)	77.51(d)	16.53(d)	21.50(d)	28.38(d)	29.57	93.28(d)	94.14(d)
53	94.67	99.20	94.05	95.13(d)	72.86	77.23(d)	14.07	21.47(d)	28.94	29.57	93.62	94.00
54	95.40(d)	97.88	94.59(d)	95.18(d)	73.65(d)	77.92(d)	16.56	20.60(d)	28.38(d)	29.57	93.27(d)	94.00
55	94.53	96.00	93.93	94.38	73.17	73.67	10.92	16.56	28.62	29.57	93.32	94.00
56	94.05(d)	94.90	93.63	93.99(d)	73.66	74.37(d)	16.49	18.02(d)	28.35(d)	29.57	93.26(d)	94.00
57	93.84	97.60	94.00	94.80	73.46	73.67	13.10	16.56	28.88	29.57	93.52	94.00
58	93.78	94.17	93.13	93.46	70.27	73.03	08.13	14.86	27.97	28.91	93.34	93.99
59	93.03	94.49	93.06	93.79	70.02	73.67	10.01	16.56	28.54	29.57	93.56	94.00
1960	93.21	93.90	93.80	94.26	72.77	73.67	13.93	16.56	28.94	29.57	93.62	94.00
61	92.85	93.18	93.03	93.31	72.67	73.60	11.45	13.55	28.71	29.25	93.43	93.58
62	93.92	99.29	94.25	94.90	72.51	73.67	12.59	16.56	28.94	29.57	93.62	94.00
63	94.35	95.84	93.78	94.28	73.42	73.67	11.60	16.56	28.79	29.57	93.49	94.00
64	93.39	94.72	93.56	93.86	73.34	73.67	13.60	16.56	28.94	29.57	93.48	94.00
65	93.67(d)	96.80	93.94(d)	95.27(d)	73.67	77.92(d)	16.56	21.31(d)	28.32(d)	30.24(d)	93.98(d)	94.22(d)
66	96.71(d)	99.49	94.72(d)	95.56(d)	73.15	77.92(d)	16.56	21.10(d)	28.53(d)	29.57	93.42(d)	94.00
67	95.54(d)	98.17	94.07	94.90	71.87(d)	73.67(d)	16.22	17.66(d)	28.37(d)	29.57	93.27(d)	94.00
68	94.41	96.69	94.00	94.56	73.07	73.67	12.12	16.56	28.94	29.57	93.49	94.00
69	95.60(d)	98.52	94.54	95.18(d)	73.33(d)	77.92(d)	16.38	21.31(d)	28.37(d)	29.57	93.28(d)	94.00

Note: (d) means value is a daily max. or min., not a monthly average.

Table 10 (Cont.)

HIGH FLOW RUN: High and Low Elevations from May 1 to Sept. 30: Reservoirs

	Winni		Leech		Pokegama		Sandy		Pine		Gull	
	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
1970	95.11(d)	97.44	93.97	94.82	72.07(d)	73.85(d)	13.59(d)	16.56	28.37(d)	29.57	93.40(d)	94.00
71	95.35(d)	96.97	94.46(d)	94.86	73.51	77.92(d)	16.48	20.72(d)	28.35(d)	29.57	93.28(d)	94.00
72	95.42(d)	97.47	94.47(d)	94.97(d)	73.67	76.54(d)	16.56	19.97(d)	38.38(d)	29.57	93.36(d)	94.00
73	94.55	95.37	93.78	94.06	72.34	73.67	11.44	16.56	28.89	29.57	93.62	94.00
74	95.16(d)	98.38	94.47(d)	95.42(d)	73.67	76.83(d)	16.56	19.57(d)	28.36(d)	29.57	93.35(d)	94.00
75	95.49(d)	99.44	94.62(d)	95.33(d)	73.66	77.92(d)	16.46	21.32(d)	29.21(d)	29.57	94.00	94.05(d)
76	94.12	94.64	93.28	94.12	71.00	72.72	10.50	11.47	27.91	28.74	92.60	93.41

Note: (d) means value is a daily max. or min., not a monthly average.

Table 11

HIGH FLOW PLAN: Aitkin High Flow (May-Sept.), Anoka Monthly Ave. Low Flow (Annual)

	AITKIN			ANOKA	
YEAR	DATE	MAY-SEPT. HIGH FLOW (cfs)	MAY-SEPT. HIGH ELEV. (ft.)	DATE	MONTHLY AVE. ANNUAL LOW FLOW (cfs)
1932	May	2,292	1188.6	Sept.	1,170
33	"	2,610	89.1	"	862
34	"	1,595	87.5	July	892
35	"	2,614	89.1	Jan.	856
36	"	3,895	90.8	July	827
37	"	3,643	90.45	Jan.	1,590
38	May 14	9,299	96.25	"	1,938
39	May	2,340	88.7	Oct.	1,850
1940	"	2,929	89.55	Sept.	1,324
41	May 1	8,205	95.3	Aug.	2,827
42	May	4,006	90.9	Jan.	3,096
43	June 29	8,802	95.8	Sept.	4,007
44	June 7	9,604	96.5	Jan.	3,897
45	May 1	6,904	94.1	Dec.	4,849
46	June	4,010	90.9	Sept.	3,625
47	May	5,002	92.1	Aug.	2,923
48	May 1	12,685	99.0	Oct.	2,062
49	July	3,434	90.2	Sept.	2,356
1950	May 13	20,025	1203.9	Aug.	2,540
51	May	5,822	93.0	Jan.	4,797
52	July 22	9,893	96.75	Oct.	4,305
53	Aug. 9	10,093	96.9	Jan.	5,056
54	May 7	10,511	97.25	Dec.	4,030
55	Aug.	3,379	90.15	"	4,077
56	May 3	8,781	95.8	Oct.	2,357
57	July	3,757	90.6	Jan.	3,015
58	June	1,508	87.3	Aug.	2,471
59	"	2,817	89.35	Aug.	2,540

Table 11 (Cont.)

HIGH FLOW PLAN: Aitkin High Flow (May-Sept.)

Anoka Monthly Ave. Low Flow (Annual)

	AITKIN			ANOKA	
YEAR	DATE	MAY-SEPT. HIGH FLOW (cfs)	MAY-SEPT. HIGH ELEV. (ft.)	DATE	MONTHLY AVE. ANNUAL LOW FLOW (cfs)
1960	May	4,551	91.6	Aug.	1,977
61	"	2,738	89.25	"	1,632
62	"	4,751	91.85	March	2,523
63	June	3,495	90.3	Oct.	2,935
64	May	5,505	92.65	Aug.	2,521
65	June 9	10,605	97.35	March	2,911
66	May 4	12,595	98.9	Dec.	4,407
67	May 1	8,132	95.25	Oct.	2,340
68	June	3,487	90.3	Jan.	2,708
69	May 1	11,102	97.75	Sept.	2,464
1970	May 1	8,742	95.8	"	1,858
71	"	9,993	96.85	"	3,126
72	May 9	9,393	96.35	Dec.	6,447
73	Aug.	2,585	89.05	July	4,479
74	May 14	9,206	96.2	Oct.	3,144
75	May 11	13,885	99.9	Aug.	4,228
1976	May	1,071	86.45	Sept.	1,109

period 1932-76. (Stages and releases for actual flow conditions are summarized in Appendix E.) These tables should assist in comparing the 4 plans without reference to the complete set of curves. The curves, although extremely beneficial, were included in the Appendices because of their large number.

Plates 79 to 83 show a comparison of 1932-1976 water surface elevations in Winnibigoshish Reservoir with the 4 operating plans. In the top portion of the plates a comparison can be made between the Present Operating Plan, Low Flow Plan, and Natural Flow. As a fourth curve on this portion of the graph would have caused problems, the High Flow Plan was placed on the lower half of the graph with the Present Operating Plan added for comparison.

As may be noted on Plate 79, the water surface of Winnibigoshish Reservoir was quite low from 1932 to 1937 with the Present Operating Plan. Thereafter, it was quite close to the desired summer range except for 1943 and 1950, when it was quite high. The Low Flow Plan levels were somewhat below the Present Operating Plan levels in other years. The Low Flow Plan does not have a significant effect on the reservoirs except for several years in the 1930's.

The Natural Flow Plan levels for Winnibigoshish Reservoir are about 10 feet below the Present Operating Plan for most of the 45 year period. Natural levels result with no dams.

The High Flow Plan results in a water surface in Winnibigoshish Reservoir that is frequently 3 feet below that for the Present Operating Plan. This occurs because the Reservoir must be maintained at a lower level under the plan to reserve space for storing floods. The lake level frequently operates 2 to 4 feet below the desired summer range, in order to provide the required flood storage space.

Plates 84 to 88 show a similar comparison of water-surface elevations for Leech Lake Reservoir. Referring to Plate 84, it may be noted that the Natural Flow curve is much closer to the Present Operating Plan for Leech Lake Reservoir than it was for Winnibigoshish Reservoir. (The difference is about 2.5 feet for Leech as compared to about 10 feet for Winnibigoshish.) This presumably results because the normal operating levels for Leech Lake are much closer to the natural flow sill. The Low Flow Plan for Leech is again quite close to the Present Operating Plan. The High Flow Plan is again below the Present Operating Plan but much closer for Leech than for Winnibigoshish.

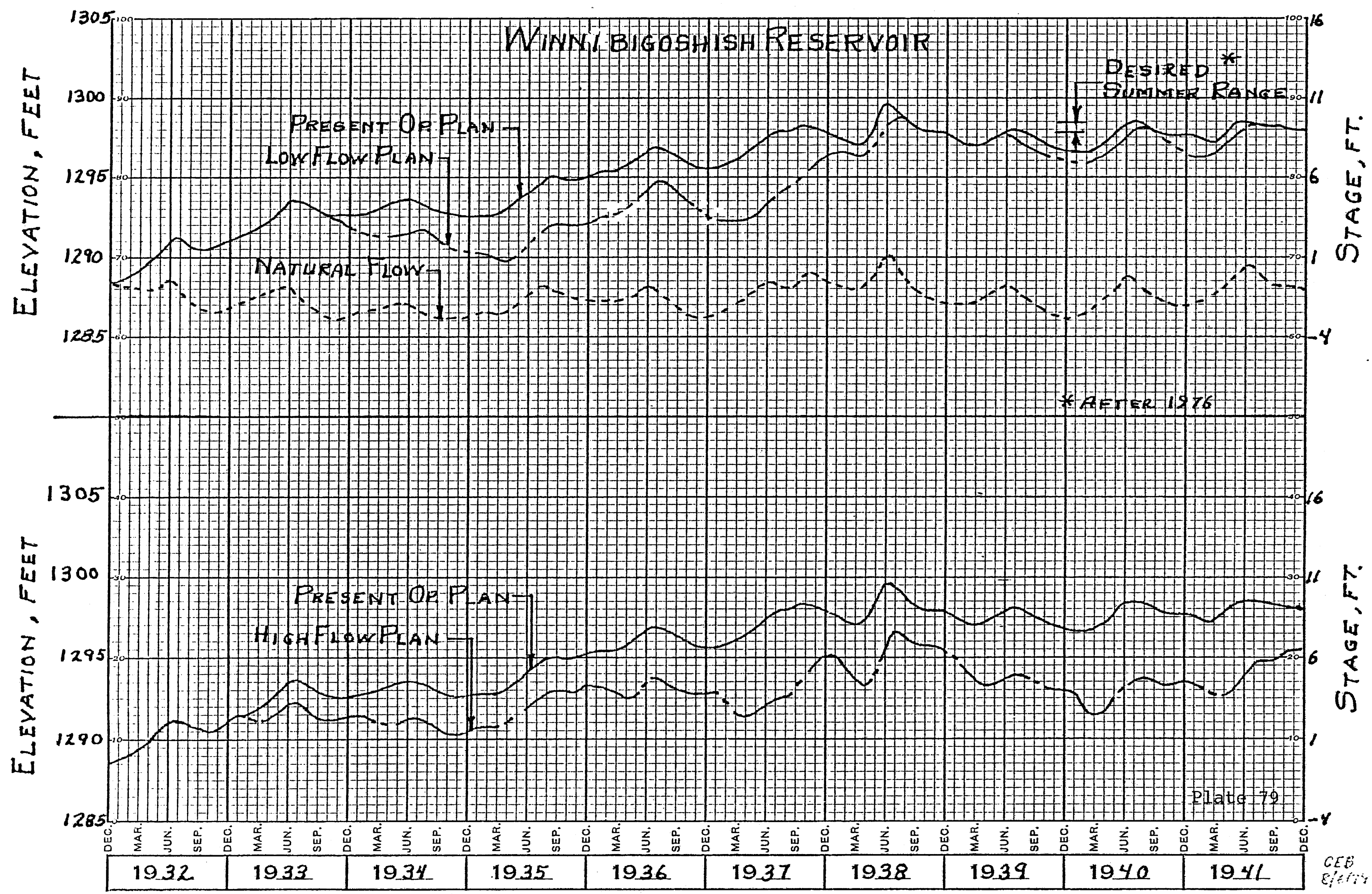
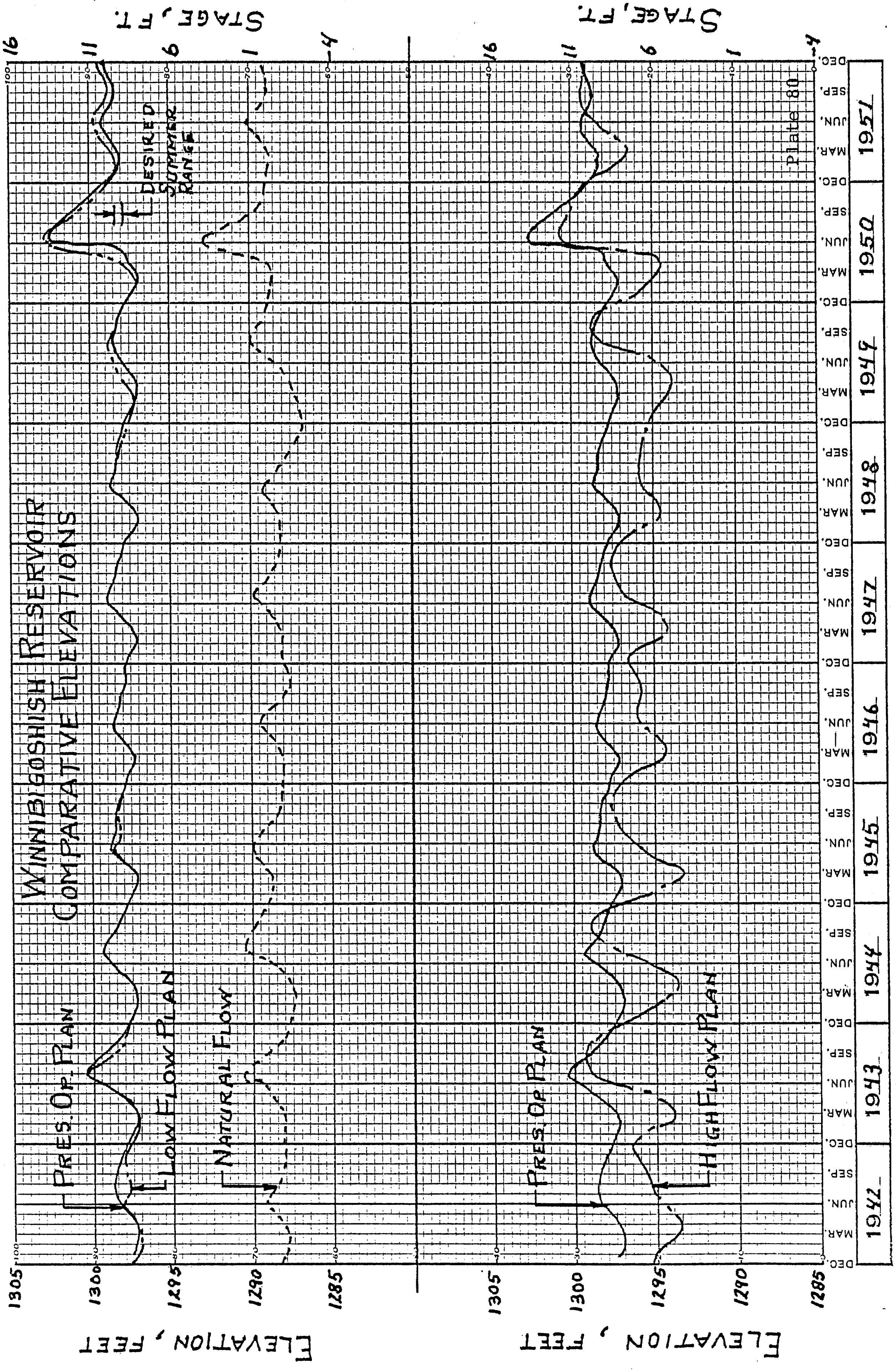

WINNIBIGOSHISH RESERVOIR
ELEVATION, FEET
STAGE, FT.
1305
1300
1295
1290
1285
16
11
6
1
-4
PRESENT OP PLAN
LOW FLOW PLAN
NATURAL FLOW
DESIRED SUMMER RANGE *
* AFTER 1976
HIGH FLOW PLAN
DEC. MAR. JUN. SEP.
1932
1933
1934
1935
1936
1937
1938
1939
1940
1941

Plate 79


Winnibigoshish Reservoir
Comparative Elevations
Pres. Op. Plan
Low Flow Plan
Natural Flow
Pres. Op. Plan
High Flow Plan
Desired Summer Range
Plate 80
Stage, Ft.
Elevation, Feet
1942
1943
1944
1945
1946
1947
1948
1949
1950
1951

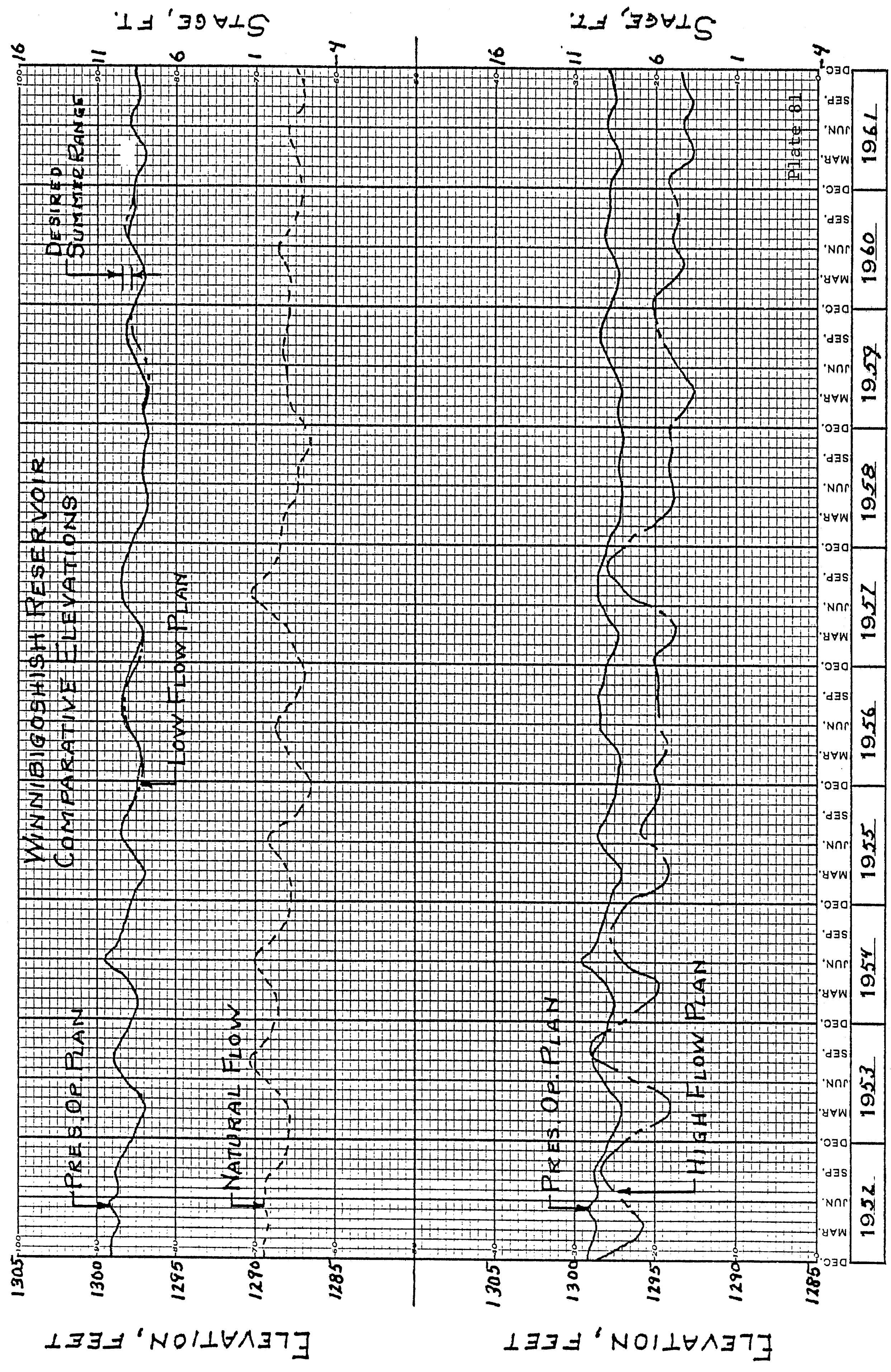

WINNIBIGOSHISH RESERVOIR
COMPARATIVE ELEVATIONS
DESIRED SUMMER RANGE
PRES. OP. PLAN
NATURAL FLOW
LOW FLOW PLAN
PRES. OP. PLAN
HIGH FLOW PLAN
STAGE, FT.
STAGE, FT.
ELEVATION, FEET
ELEVATION, FEET
1952
1953
1954
1955
1956
1957
1958
1959
1960
1961

Plate 81

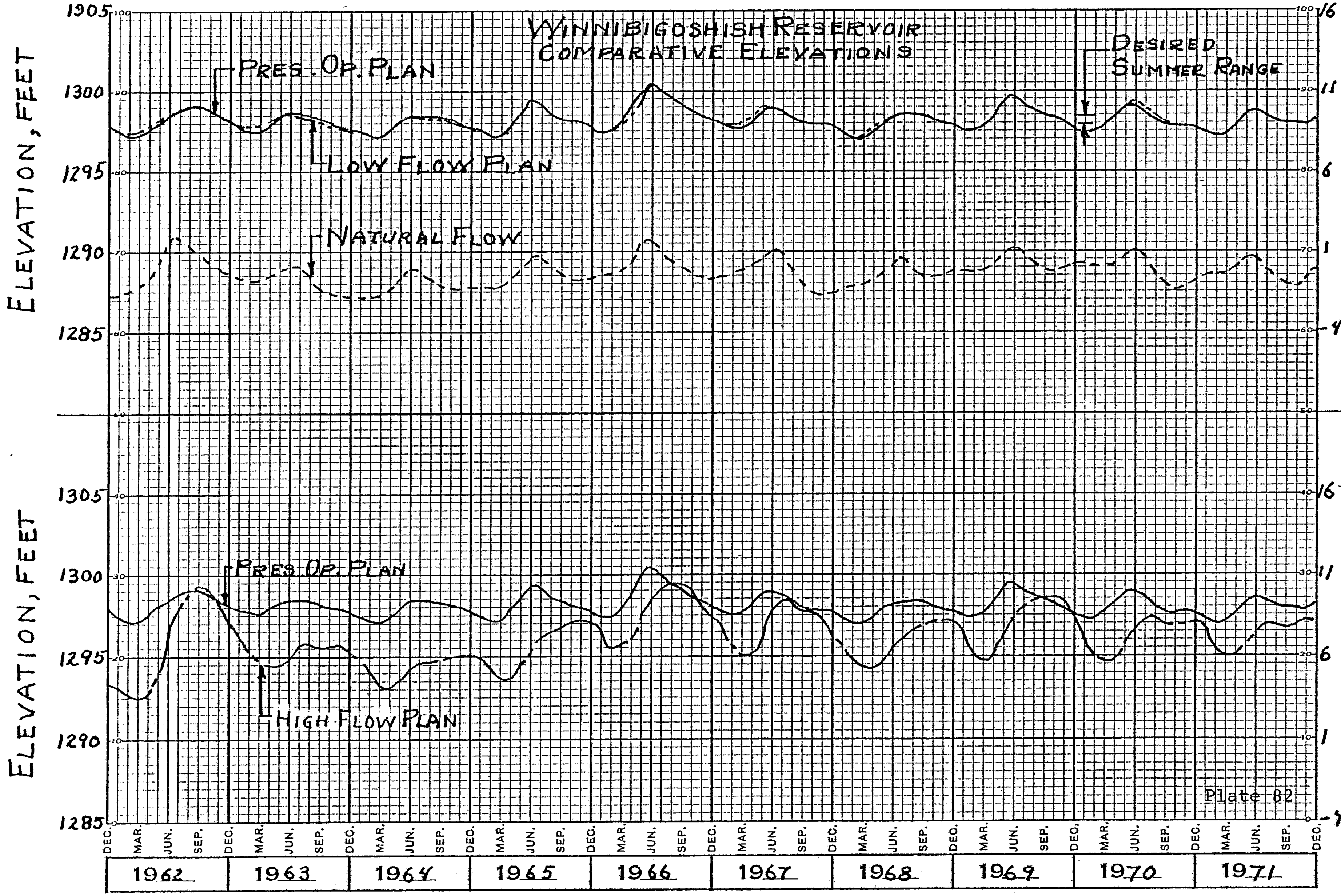

WINNIBIGOSHISH RESERVOIR
COMPARATIVE ELEVATIONS
PRES. OP. PLAN
LOW FLOW PLAN
NATURAL FLOW
DESIRED SUMMER RANGE
HIGH FLOW PLAN
ELEVATION, FEET
STAGE, FT.
1305
1300
1295
1290
1285
16
11
6
1
-4
DEC. MAR. JUN. SEP.
1962
1963
1964
1965
1966
1967
1968
1969
1970
1971

Plate 82

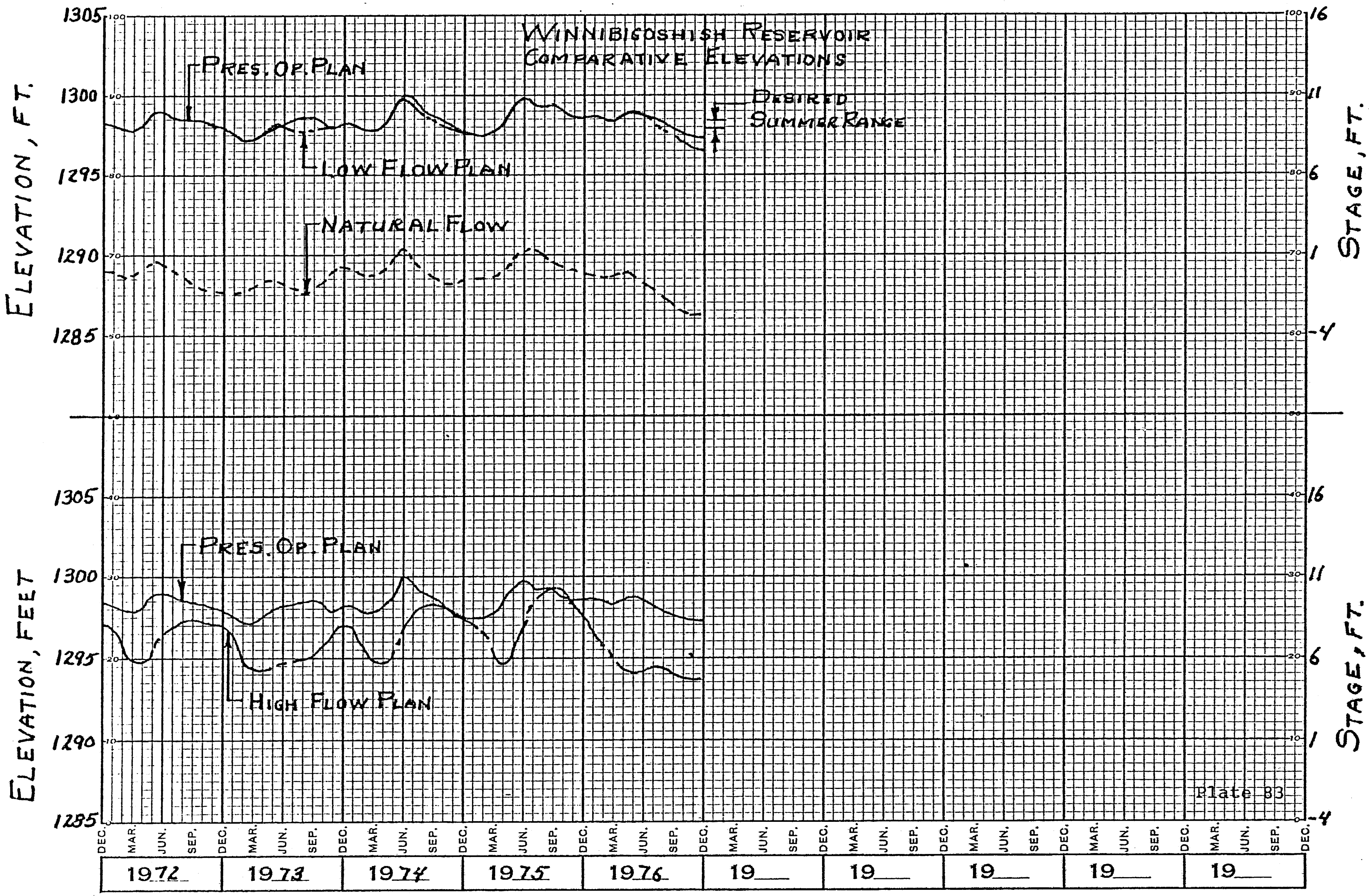

WINNIBIGOSHISH RESERVOIR
COMPARATIVE ELEVATIONS
PRES. OP. PLAN
LOW FLOW PLAN
NATURAL FLOW
DESIRED SUMMER RANGE
HIGH FLOW PLAN
ELEVATION, FT.
STAGE, FT.
ELEVATION, FEET
1305
1300
1295
1290
1285
16
11
6
1
-4
DEC. MAR. JUN. SEP.
1972
1973
1974
1975
1976
19__

Plate 33

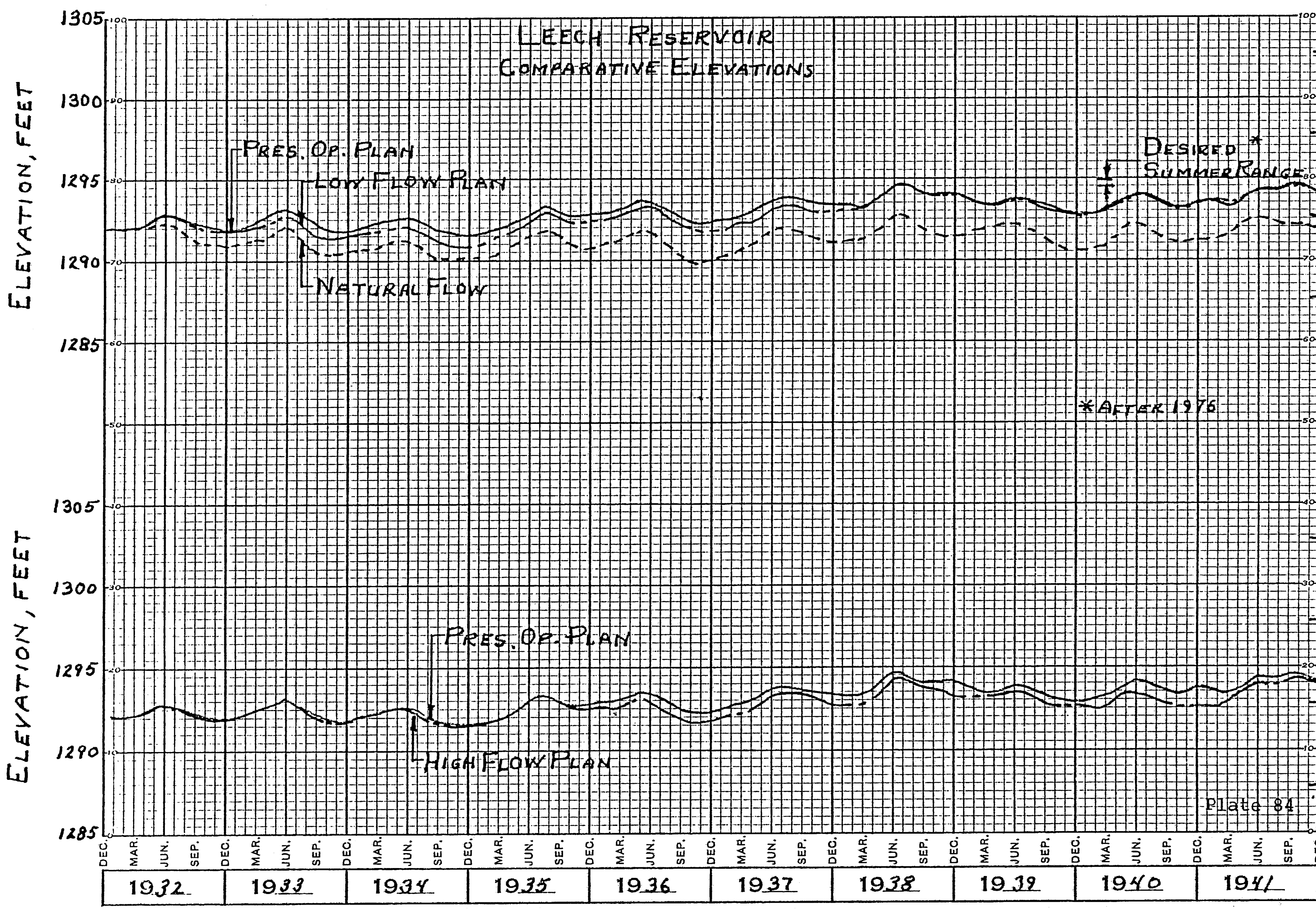
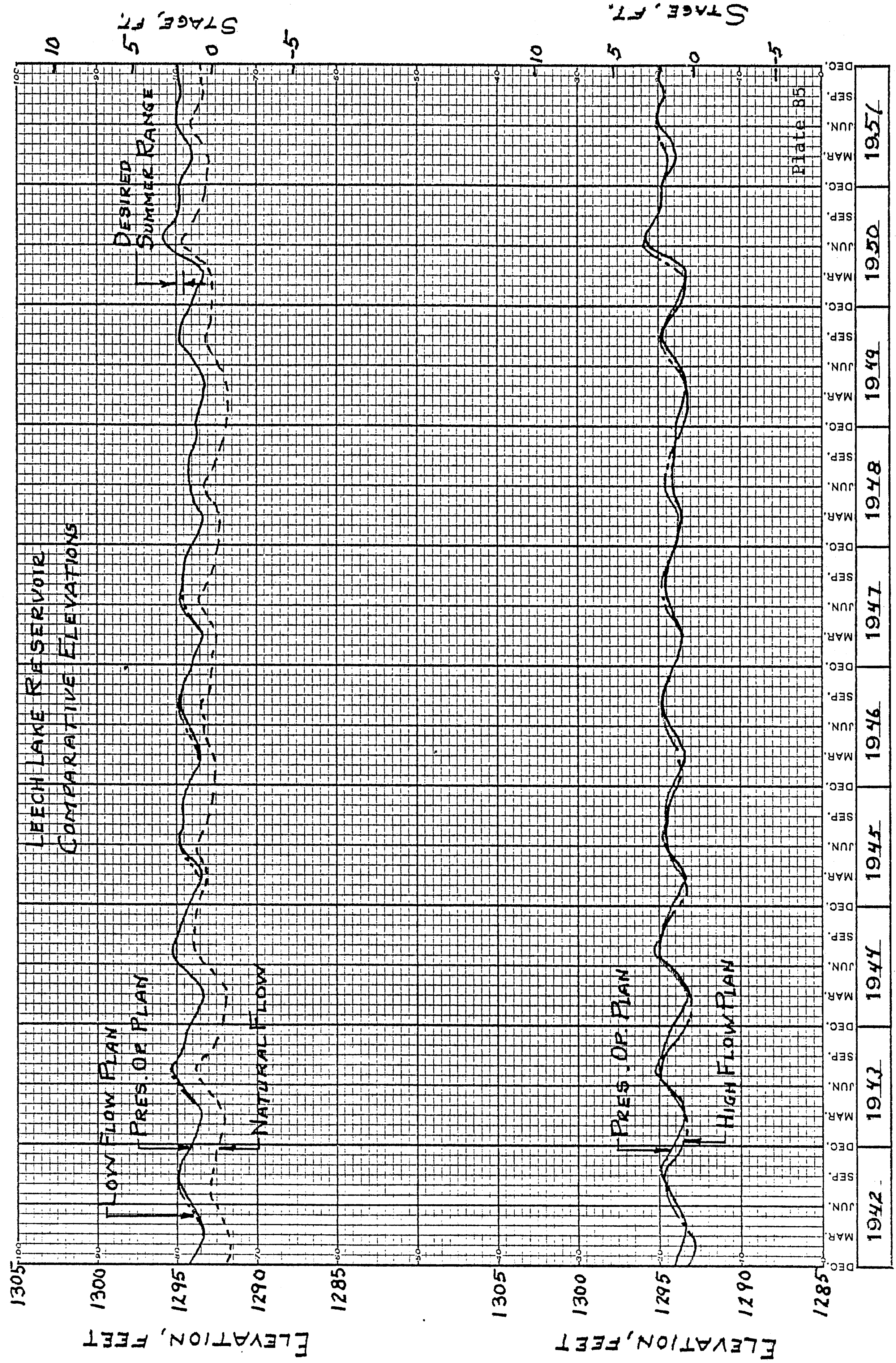

LEECH RESERVOIR
COMPARATIVE ELEVATIONS
PRES. OP. PLAN
LOW FLOW PLAN
NATURAL FLOW
DESIRED *
SUMMER RANGE
*AFTER 1976
PRES. OP. PLAN
HIGH FLOW PLAN
ELEVATION, FEET
STAGE, FT.
1305
1300
1295
1290
1285
10
5
0
-5
1932
1933
1934
1935
1936
1937
1938
1939
1940
1941
DEC.
MAR.
JUN.
SEP.

Plate 84


LEECH LAKE RESERVOIR
COMPARATIVE ELEVATIONS
DESIRED SUMMER RANGE
LOW FLOW PLAN
PRES. OP. PLAN
NATURAL FLOW
PRES. OP. PLAN
HIGH FLOW PLAN
STAGE, FT.
ELEVATION, FEET
1305
1300
1295
1290
1285
10
5
0
-5
DEC. MAR. JUN. SEP.
1942
1943
1944
1945
1946
1947
1948
1949
1950
1951
Plate 35

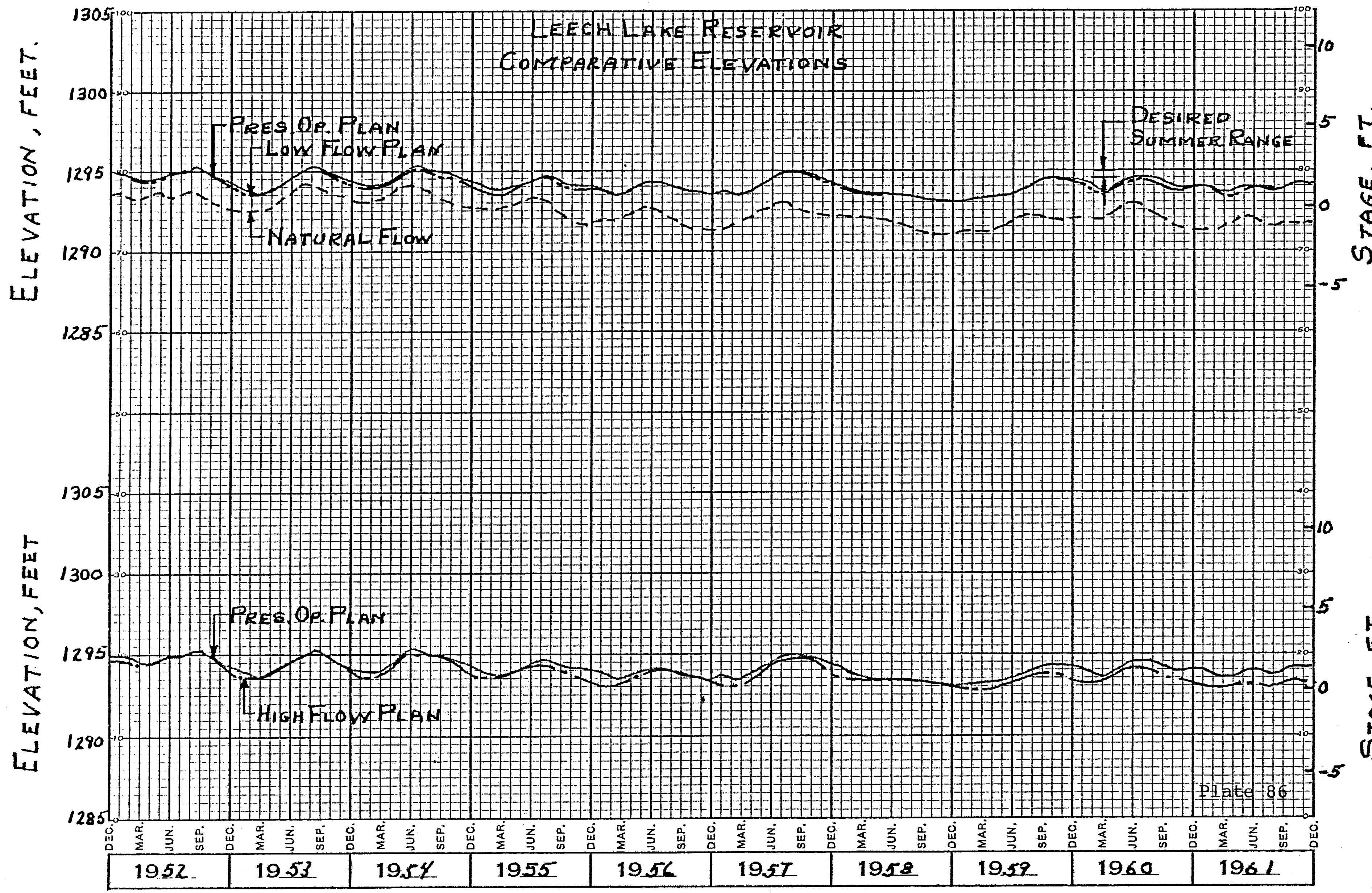

LEECH LAKE RESERVOIR
COMPARATIVE ELEVATIONS
PRES. OP. PLAN
LOW FLOW PLAN
NATURAL FLOW
DESIRED SUMMER RANGE
PRES. OP. PLAN
HIGH FLOW PLAN
ELEVATION, FEET.
ELEVATION, FEET
STAGE, FT.
STAGE, FT.
1305
1300
1295
1290
1285
10
5
0
-5
DEC. MAR. JUN. SEP.
1952
1953
1954
1955
1956
1957
1958
1959
1960
1961

Plate 86

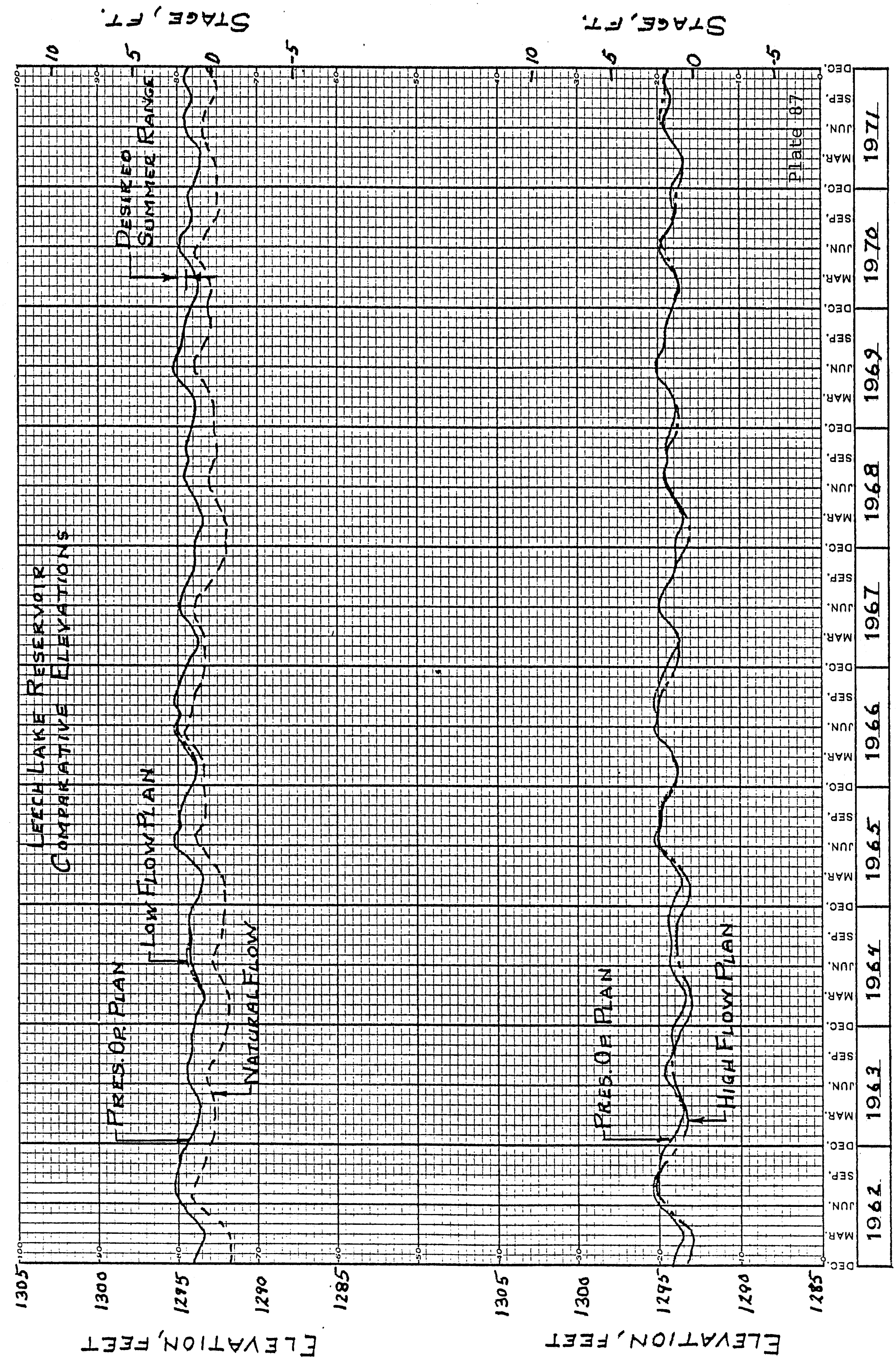

LEECH LAKE RESERVOIR
COMPARATIVE ELEVATIONS
DESIRED SUMMER RANGE
LOW FLOW PLAN
PRES. OP. PLAN
NATURAL FLOW
PRES. OP. PLAN
HIGH FLOW PLAN
STAGE, FT.
STAGE, FT.
ELEVATION, FEET
ELEVATION, FEET
1962
1963
1964
1965
1966
1967
1968
1969
1970
1971

Plate 87

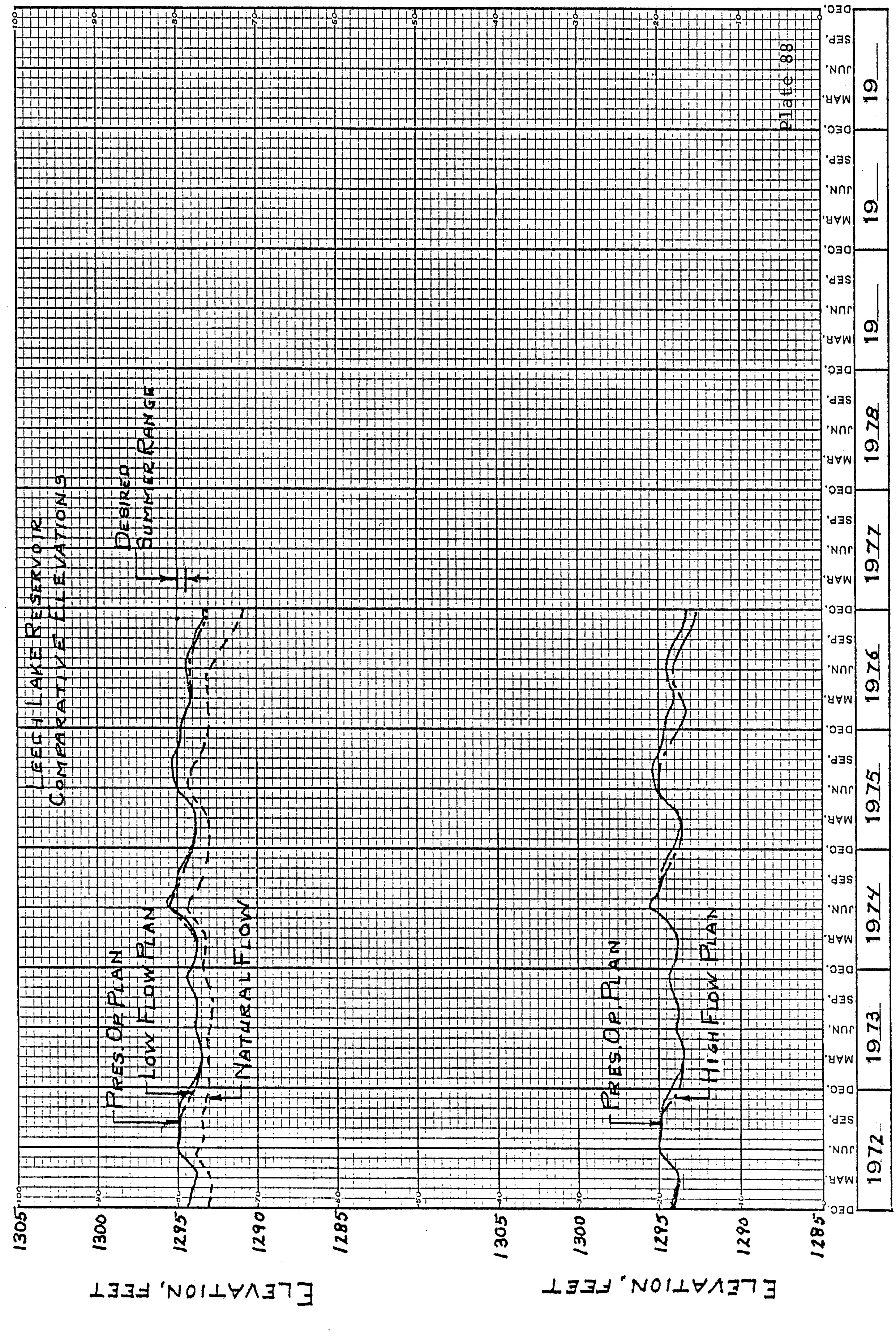

LEECH LAKE RESERVOIR
COMPARATIVE ELEVATIONS
DESIRED SUMMER RANGE
PRES OP PLAN
LOW FLOW PLAN
NATURAL FLOW
PRES OP PLAN
HIGH FLOW PLAN
ELEVATION, FEET
ELEVATION, FEET
1305
1300
1295
1290
1285
1972
1973
1974
1975
1976
1977
1978
MAR. JUN. SEP. DEC.

Plate 88

Comparison curves for the other four reservoirs can be prepared from the primary curves in Appendices A-D.

Plates 89 and 90 show a comparison of monthly flows at Anoka for the Present Operating Plan and the Low Flow Plan for 1932 to 1959 and 1967 to 1976. Of primary interest are the lower discharges (below 4000 cfs). It may be noted that in the 1930's and in 1976 the Low Flow Plan usually results in higher minimum discharges than the Present Operating Plan. However, for the Low Flow Plan, the flow still drops below the desired minimum of 1600 cfs at Anoka on about 8 occasions. As the program should give primary priority to low flow requirements at Anoka and levels in the reservoirs are still above minimum values, it is not clear as to why the flow at Anoka is permitted to drop below 1600 cfs. This should be explored in future runs with HEC-5C.

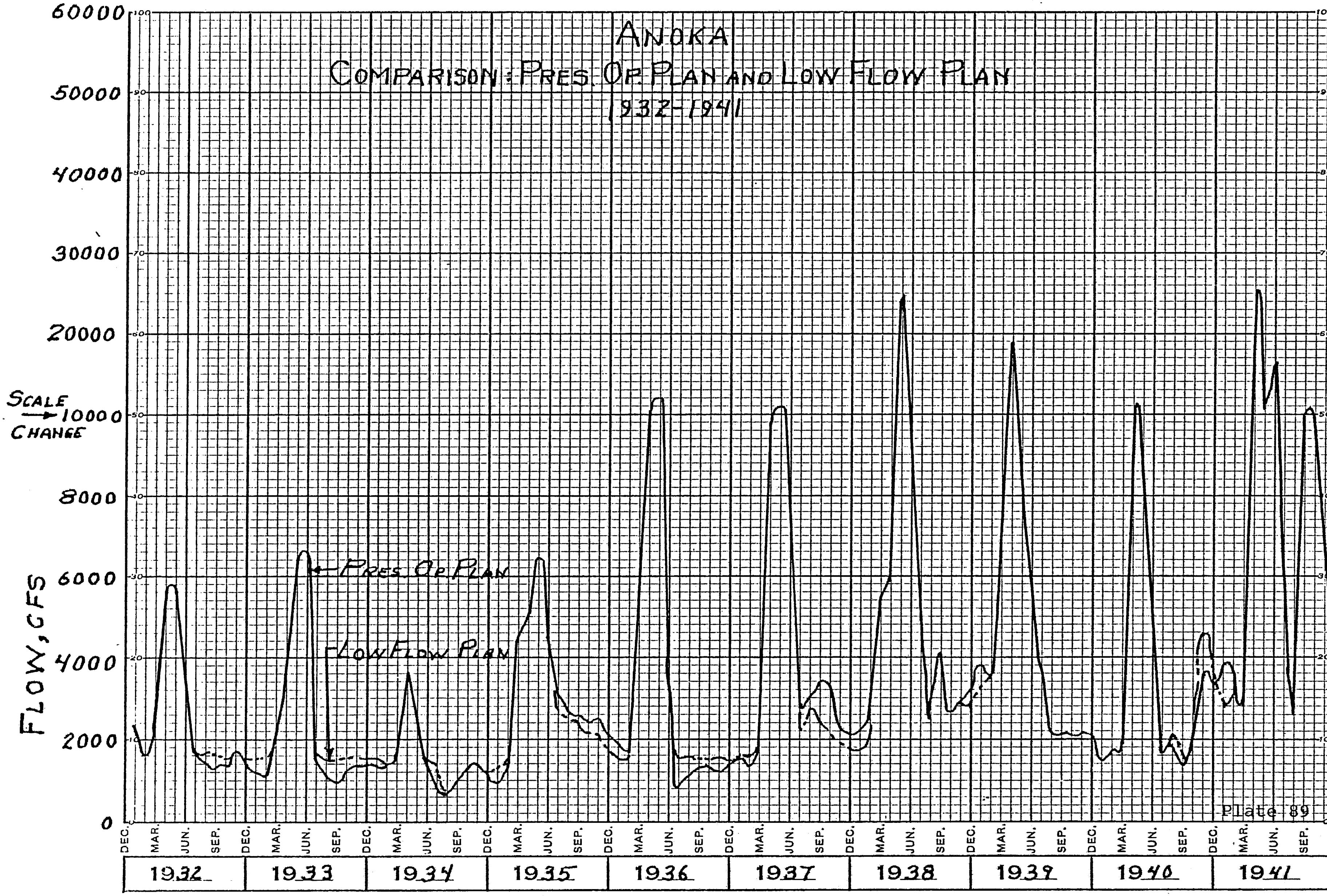
In an attempt to compare the 4 plans, additional comparison graphs were prepared. Plates 91 and 92 show approximate probabilities of water surface elevations in Winnibigoshish and Leech Lake Reservoirs. In Plate 91 the 50 percent probability of high and low elevations have been plotted and labeled "ave". High and low values expected once in 10 years and once in 100 years are also shown.

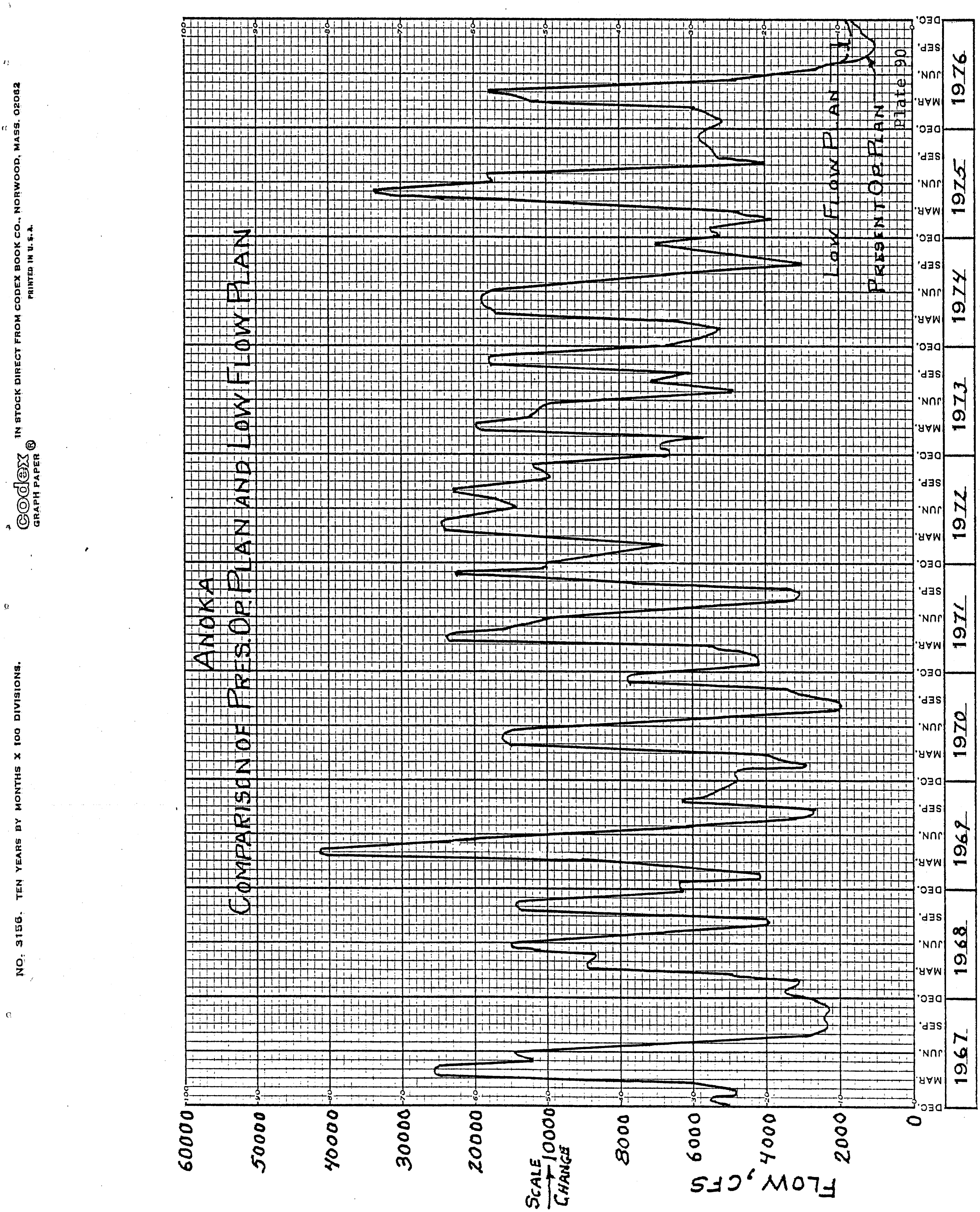
The data for the Natural Flows are quite low, as expected.

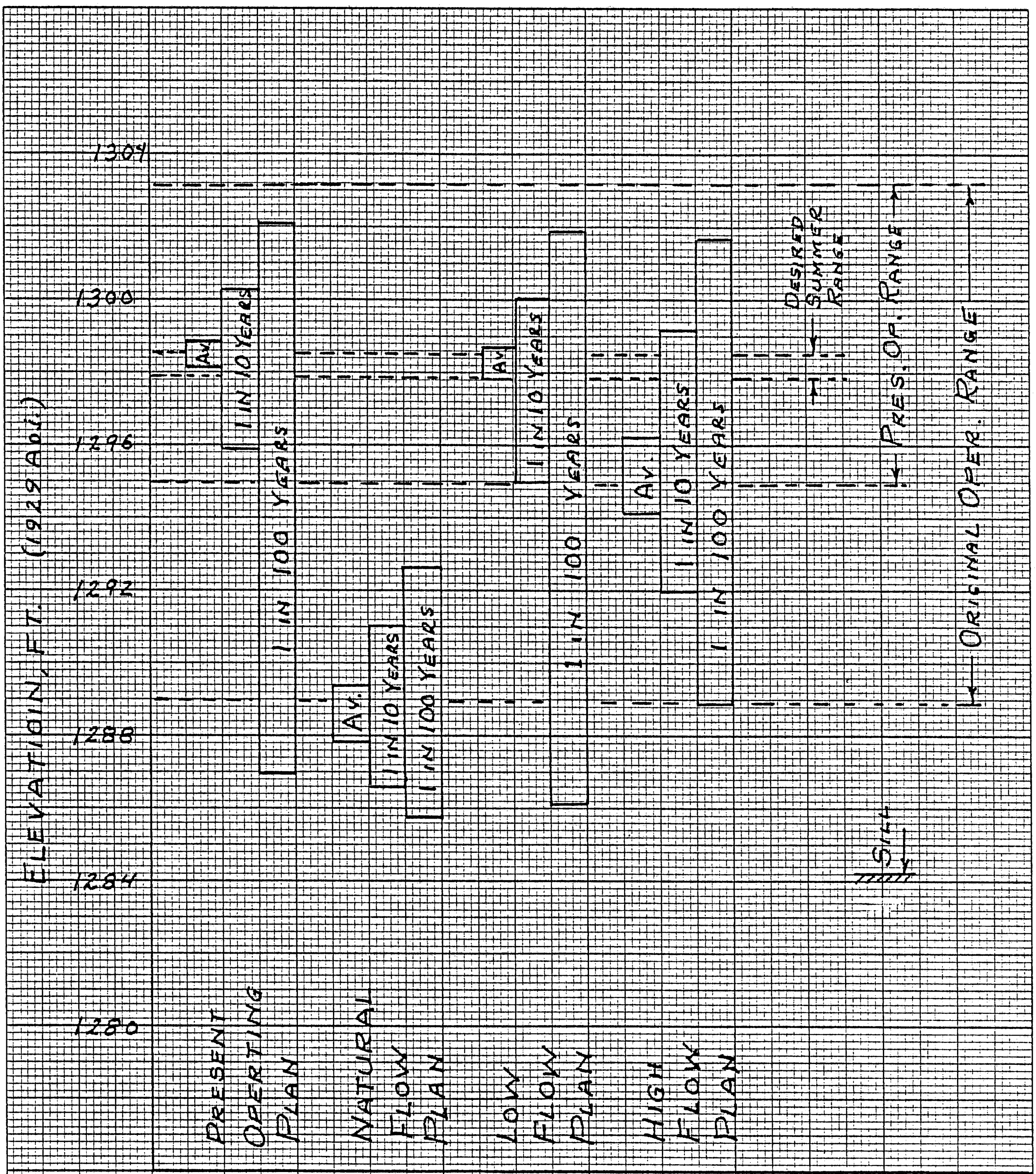
Of special interest is a comparison of the Present Operating Plan and the Low Flow Plan. The comparison shows only minor differences between the two plans relative to water surface elevations in Winnibigoshish and Leech Lake Reservoirs. The 50 percent and 10 percent probabilities for the High Flow Plan are lower than the other two, as expected.

Plate 93 shows the relationship between discharge, stage, and recurrence interval at Aitkin. Plate 94 shows similar data as a function of percent probability, rather than recurrence interval. The plates show that the highest floods would occur with the Natural Flow Plan and that the High Flow Plan results in the lowest floods, as expected. The Low Flow and the Present Operating Plans fall between the other two. All plans result in floods above the flood stage of 15 feet (discharges above 10,500 cfs) for recurrence intervals (above 8 feet).

For a recurrence interval of 10 years the High Flow Plan would have a stage about 0.7 feet below the Present Operating Plan; it would be 2.7 feet below

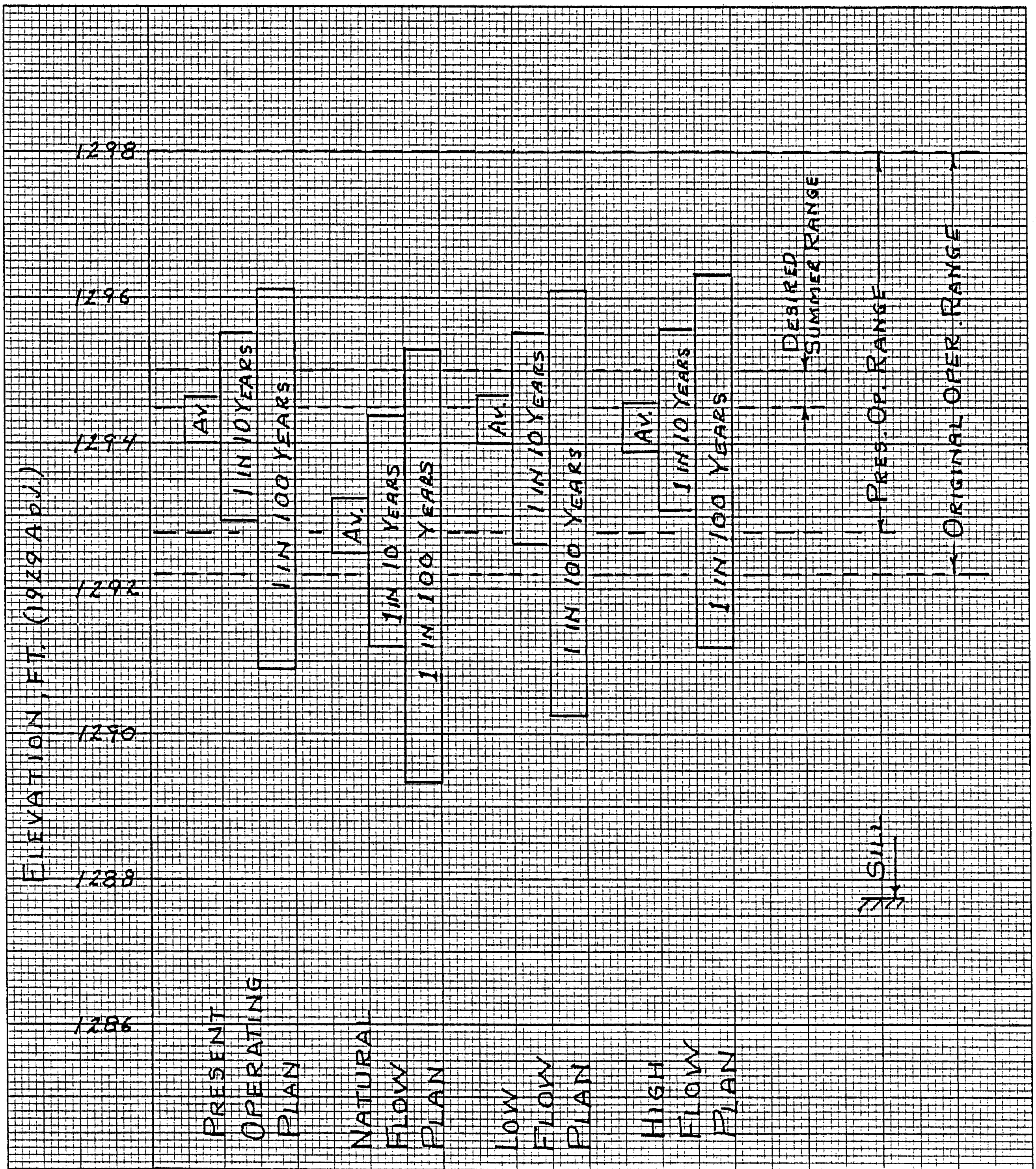

ANOKA
COMPARISON: PRES. OP. PLAN AND LOW FLOW PLAN
1932-1941
FLOW, CFS
60000
50000
40000
30000
20000
SCALE CHANGE 10000
8000
6000
4000
2000
0
PRES. OP. PLAN
LOW FLOW PLAN
DEC. MAR. JUN. SEP.
1932
1933
1934
1935
1936
1937
1938
1939
1940
1941
Plate 89


ANOKA
COMPARISON OF PRES. OP. PLAN AND LOW FLOW PLAN
LOW FLOW PLAN
PRESENT OP. PLAN
Plate 90
1967
1968
1969
1970
1971
1972
1973
1974
1975
1976
DEC. MAR. JUN. SEP.
60000
50000
40000
30000
20000
10000
8000
6000
4000
2000
0
SCALE CHANGE
FLOW, CFS
NO. 3156. TEN YEARS BY MONTHS X 100 DIVISIONS.
Codex GRAPH PAPER
IN STOCK DIRECT FROM CODEX BOOK CO., NORWOOD, MASS. 02062
PRINTED IN U.S.A.



WATER SURFACE ELEVATIONS IN WINNIBIGOSHISH RESERVOIR WITH FOUR OPERATING PLANS

PLATE 91



WATER SURFACE ELEVATIONS IN LEECH LAKE RESERVOIR WITH FOUR OPERATING PLANS

PLATE 92

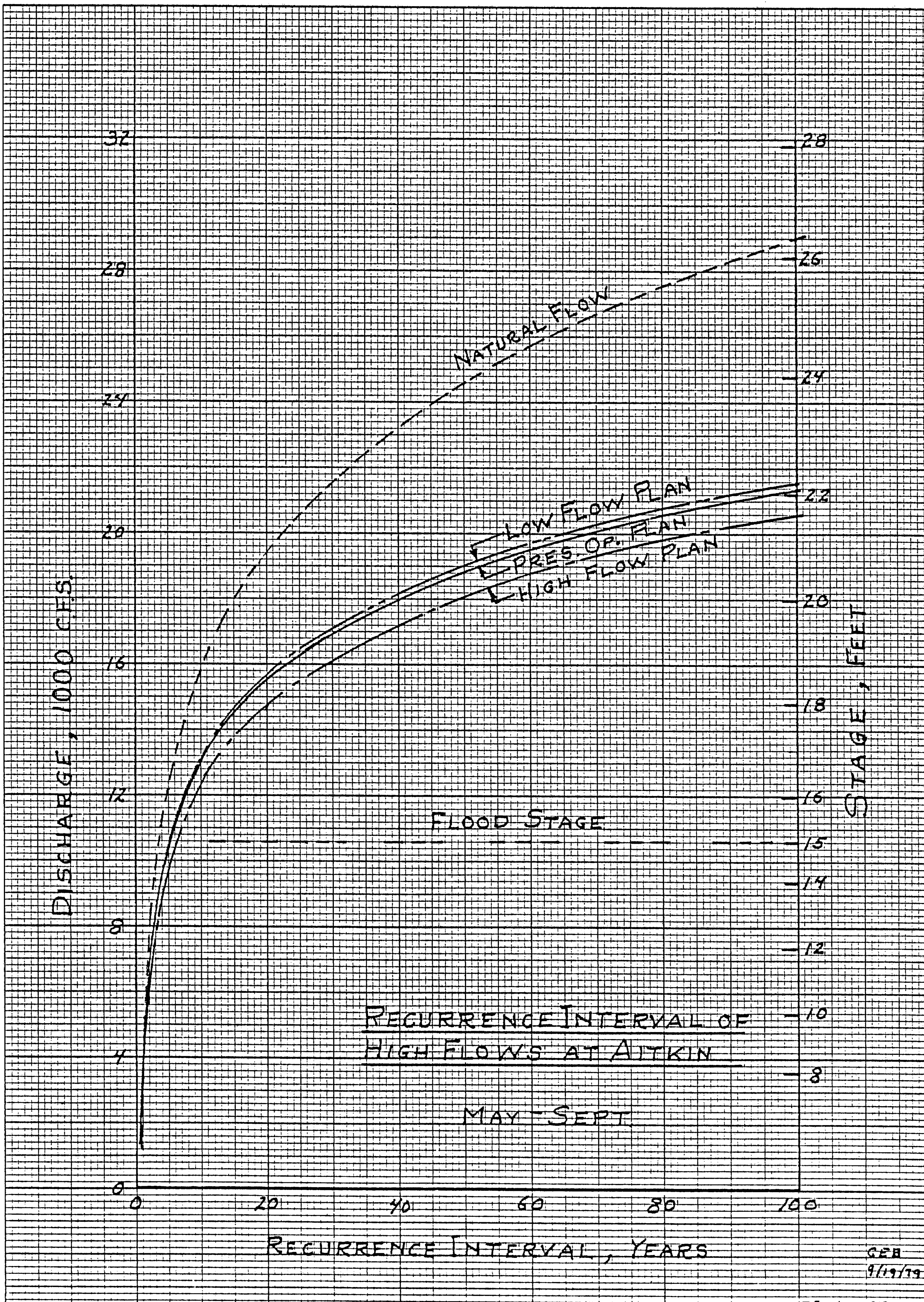
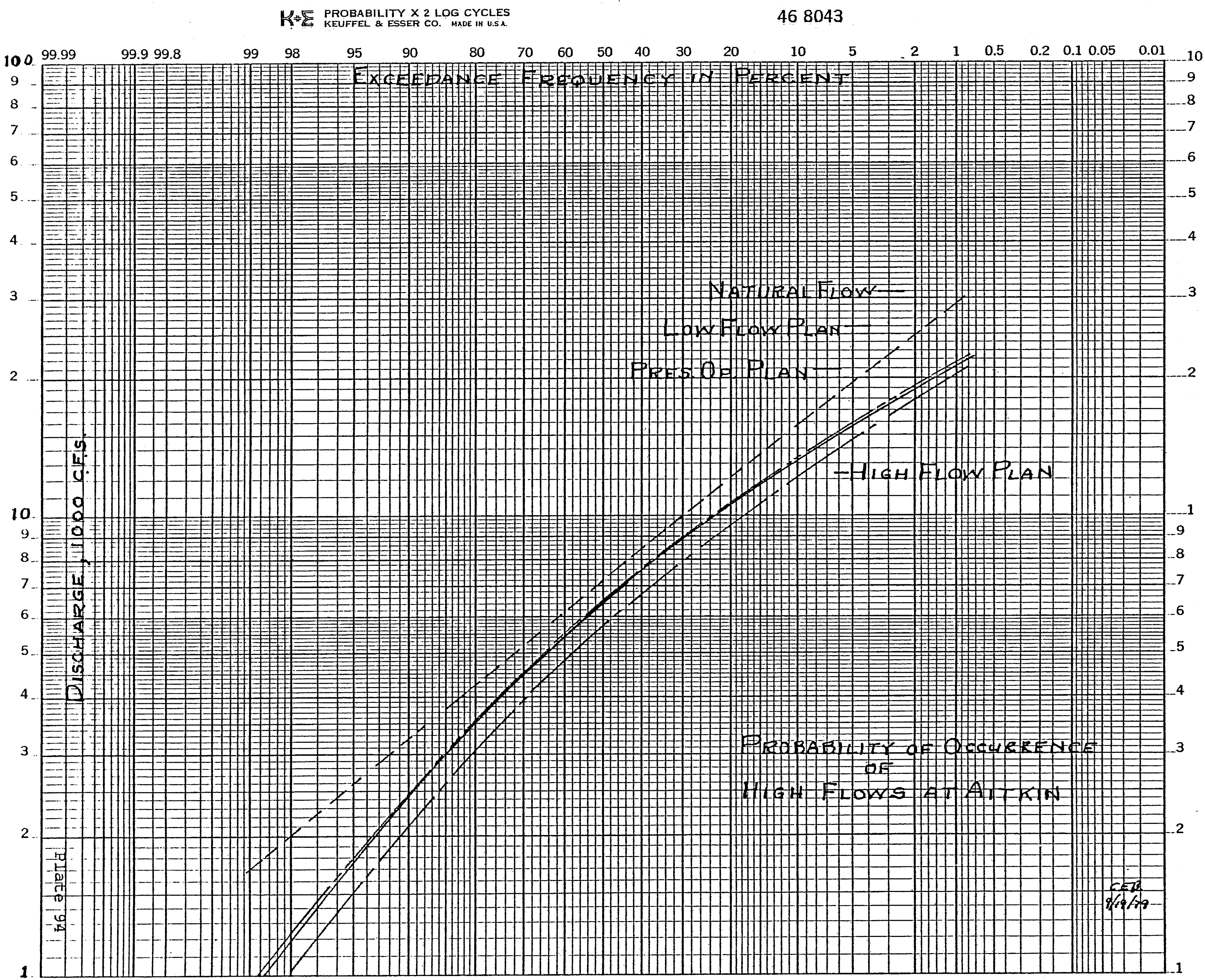

32
28
24
20
16
12
8
4
0
28
26
24
22
20
18
16
15
14
12
10
8
0
20
40
60
80
100
DISCHARGE, 1000 CFS.
STAGE, FEET
NATURAL FLOW
LOW FLOW PLAN
PRES. OP. PLAN
HIGH FLOW PLAN
FLOOD STAGE
RECURRENCE INTERVAL OF
HIGH FLOWS AT AITKIN
MAY - SEPT
RECURRENCE INTERVAL, YEARS
CEB
9/19/79

Plate 93


K+E PROBABILITY X 2 LOG CYCLES
KEUFFEL & ESSER CO. MADE IN U.S.A.
46 8043
EXCEEDANCE FREQUENCY IN PERCENT
DISCHARGE, 1000 C.F.S.
NATURAL FLOW
LOW FLOW PLAN
PRES. OP. PLAN
HIGH FLOW PLAN
PROBABILITY OF OCCURRENCE
OF
HIGH FLOWS AT AITKIN
Plate 94

the Natural Flow Plan. However, all would be above flood stage for the 10-year and larger floods.

Plate 95 shows the relationship between minimum monthly discharge at Anoka and recurrence interval for the 4 plans. Plate 96 shows similar data as a function of probability. Referring to Plate 95, it may be noted that Present Operating Plan, the High Flow Plan, and the Natural Flow Plan are grouped very close together and that the Low Flow Plan is substantially above the other three for recurrence intervals above 10 years. Of interest is the fact that at a recurrence interval of 100 years the Low Flow Plan would have a minimum flow of about 840 cfs as compared to about 400 cfs for the other plans. This is a very substantial difference. Also of interest is the fact that all curves fall below the established minimum Low Flow Plan target of 1600 cfs.

With the Low Flow Plan the minimum monthly flow would be above 1600 cfs for recurrence intervals less than 8 years. For recurrence intervals greater than 8 years the minimum monthly flow would drop below 1600 cfs at some time during the year, with this plan.

Another way of expressing this would be to say that in a 100-year period about 88 percent of the years would have low flows exceeding 1600 cfs and 12 percent would have at least one month with an average flow below 1600 cfs. From the standpoint of city water supply, the Twin Cities may have to (1) curtail use, (2) store more water in special reservoirs, (3) draw more from groundwater, or (4) release more water from the headwater reservoirs when 1600 cfs were not available.

Damage Summary

Table 12 is a summary of damages in the 6 reservoirs and at Aitkin, plus potential losses in the Twin City area due to flows below 1600 cfs at Anoka. This table, together with Plates 93 and 95, should be of special interest relative to an evaluation of the 4 operating plans. Three subtotals have been provided in the table to assist in evaluating the plans.

If one considers the losses down to and including Aitkin, the Present Operating Plan would have the minimum damage of $757,386 per year as compared to $876,737 for the Low Flow Plan and $894,808 for the High Flow Plan.

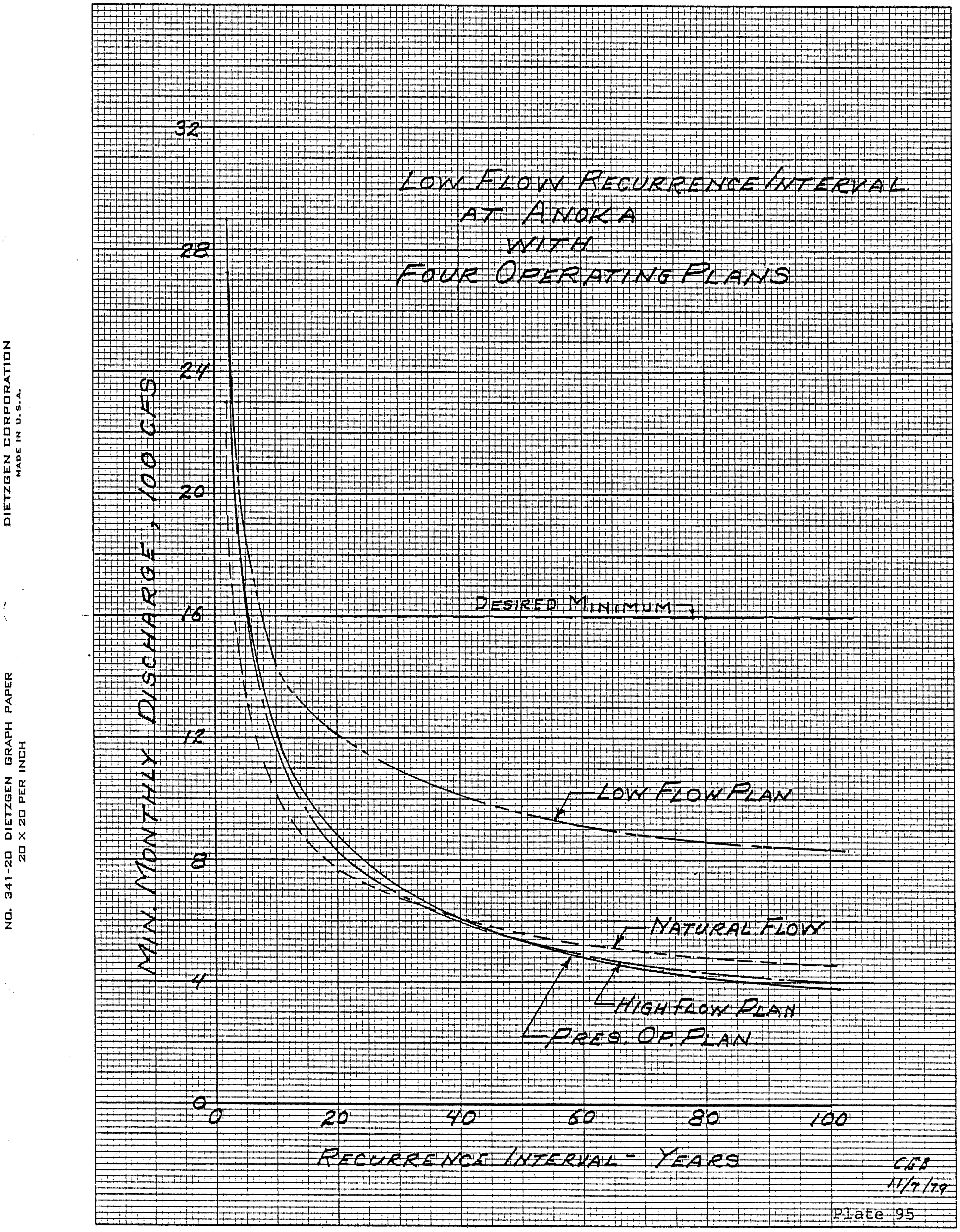
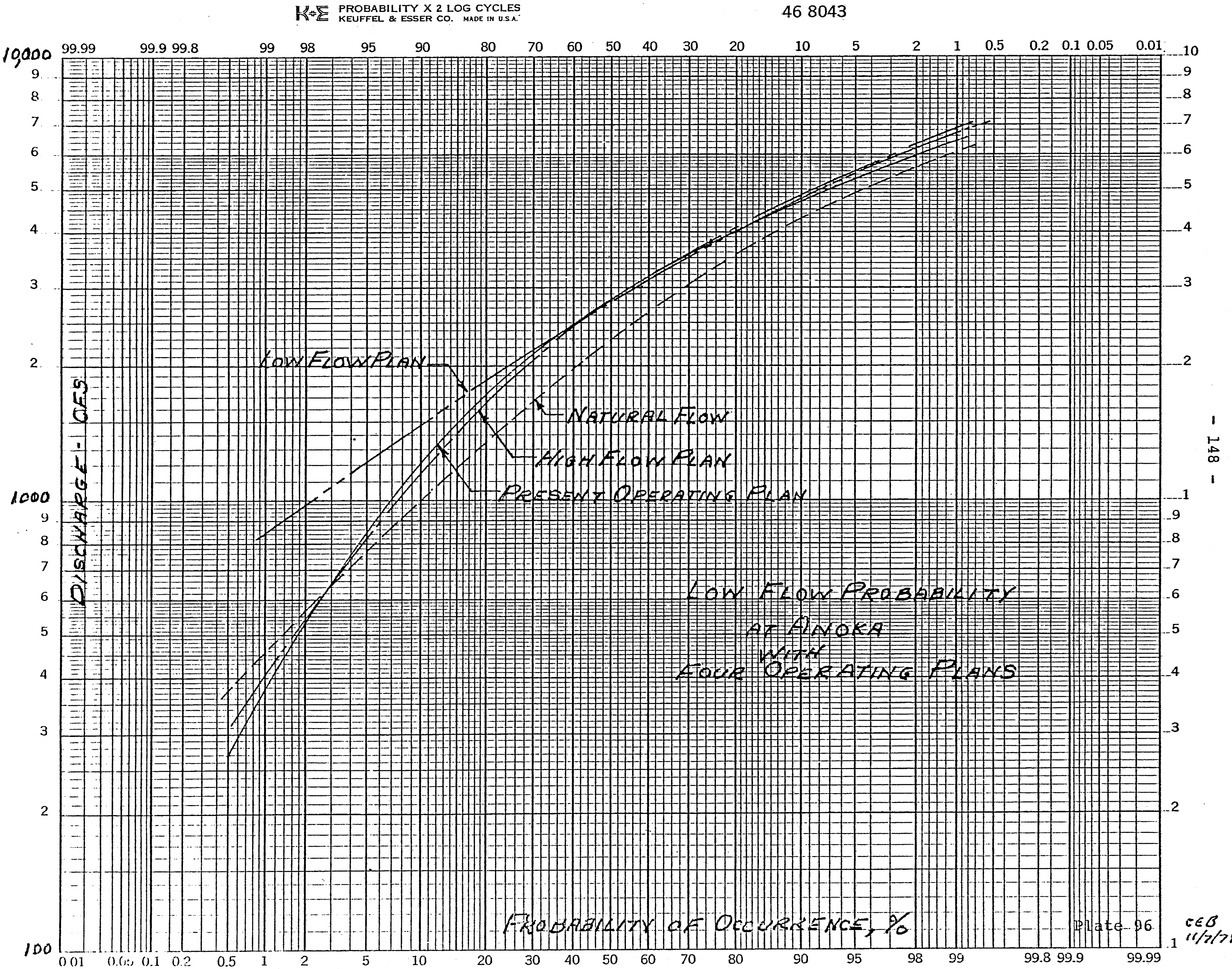

LOW FLOW RECURRENCE INTERVAL
AT ANOKA
WITH
FOUR OPERATING PLANS
MIN. MONTHLY DISCHARGE, 100 CFS
32
28
24
20
16
12
8
4
0
DESIRED MINIMUM
LOW FLOW PLAN
NATURAL FLOW
HIGH FLOW PLAN
PRES. OP. PLAN
0
20
40
60
80
100
RECURRENCE INTERVAL - YEARS
CGB
11/7/79
NO. 341-20 DIETZGEN GRAPH PAPER
20 X 20 PER INCH
DIETZGEN CORPORATION
MADE IN U.S.A.

Plate 95



K&E PROBABILITY X 2 LOG CYCLES
KEUFFEL & ESSER CO. MADE IN U.S.A.
46 8043
LOW FLOW PLAN
NATURAL FLOW
HIGH FLOW PLAN
PRESENT OPERATING PLAN
LOW FLOW PROBABILITY
AT ANOKA
WITH
FOUR OPERATING PLANS
DISCHARGE - CFS
PROBABILITY OF OCCURRENCE, %
10,000
1000
100
CEB
11/7/79

Plate 96

Table 12

Mississippi River Headwater Reservoirs
Dammage Summary

Mean Annual Damage in Dollars[1]

Reservoir or Area	Pres. Op. Plan	Natural Flows	Low Flow	High Flow
Winnibigoshish	32,460	97,440	29,867	72,746
Leech Lake	96,085	499,368	125,096	126,445
Pokegama	68,840	55,845	68,262	65,271
Sandy Lake	96,836	407,848	92,557	196,293
Subtotal[3]	294,221	1,060,501	315,782	460,755
Pine River	33,425	698,303	95,580	33,338
Gull Lake	120,140	443,343	164,855	128,155
Subtotal[4]	447,486	2,202,147	576,217	622,248
Aitkin	309,600	453,760	300,520	272,560
Subtotal[5]	757,386	2,655,907	876,737	894,808
Anoka[2]	4,488,500	6,119,500	1,104,100	3,631,800
TOTAL	5,245,886	8,775,407	1,980,837	4,526,608

(1) Based on May - September, unless noted otherwise.

(2) Based on calendar year (losses due to inadequate water supply or inability to maintain 1600 cfs minimum flow at Anoka).

(3) Total flood and low-water damage for Winnibigoshish, Leech, Pokegama, and Sandy.

(4) Total flood and low-water damage for the six reservoirs.

(5) Total flood and low-water damage for six reservoirs and Aitkin.

Considering the reservoirs, Aitkin and the Twin Cities, the Low Flow Plan is by far the most economical with an annual cost of $1,980,837 as compared to $ 5,245,886 for the Present Operating Plan.

Conclusions

1. On the basis of total damages and losses, the Low Flow Plan is superior to the Present Operating Plan.

2. The High Flow Plan ($4,526,608) is slightly superior to the Present Operating Plan ($5,245,886) for all damages and losses, but 2.5 times less favorable than the Low Flow Plan.

3. Considering variations in the reservoir surface elevations and annual damage, the Low Flow Plan is very similar to the Present Operating Plan.

4. From the standpoint of damage only at Aitkin, the High Flow Plan is superior, with annual damages of $272,560, as compared to $300,520 for the Low Flow Plan and $309,600 for the Present Operating Plan.

5. The HEC-5C Program showed that the Low Flow Plan would provide a minimum flow of about 800 cfs at Anoka for large recurrence intervals, as compared to 400 cfs for the other three plans. However, 800 cfs is well below the specified minimum criteria of 1600 cfs.

6. Future studies involving HEC-5C and this reservoir system should include the following:

    a) further study of the Low Flow Plan to determine whether the minimum flows at Anoka in all cases can be increased (to 1600 cfs) by changing control statements,

    b) tests with low flow minimums other than 1600 cfs,

    c) review of time lag procedures in routing to the Twin Cities,

    d) a comparison of the HEC-5C performance (Present Operating Plan) with current rule curve operation (which HEC-5C can only approximate), and

    e) review of reverse routing procedures for the reservoirs.

7. Approximately 374 graphs were prepared as part of Phase 1 of the study. Ninety-one of these are included in the text; 283 are included in the Appendices. As the Appendices have not been included with most copies of the body of the report, the reader may wish to consult a complete copy for some details of the study.