UNIVERSITY OF MINNESOTA

ST. ANTHONY FALLS HYDRAULIC LABORATORY

External Memorandum No. 159

HYDROLOGIC INVESTIGATIONS OF SELECTED WATERSHEDS IN COPPER-NICKEL REGION OF NORTHEASTERN MINNESOTA

by

Charles S. Savard, A. Juliann Gray,
and C. Edward Bowers

Prepared for

MINNESOTA ENVIRONMENTAL QUALITY BOARD
MINNESOTA STATE PLANNING AGENCY
COPPER-NICKEL PROJECT

August 1978

Minneapolis, Minnesota

External Memorandum No. 159

HYDROLOGIC INVESTIGATIONS OF SELECTED WATERSHEDS IN COPPER-NICKEL REGION OF NORTHEASTERN MINNESOTA

by

Charles S. Savard, A. Juliann Gray,
and C. Edward Bowers

Prepared for

Minnesota Environmental Quality Council
Minnesota State Planning Agency
Copper-Nickel Project

August 1978
Minneapolis, Minnesota

ABSTRACT

The study reported herein was performed for the Minnesota Environmental Quality Board, Minnesota State Planning Agency, by the St. Anthony Falls Hydraulic Laboratory, Department of Civil and Mineral Engineering, University of Minnesota. The Principal Investigator was C. Edward Bowers, Professor of Civil Engineering. Mr. Alan Wald of the Department of Natural Resources and Mr. Daryle Thingvold of the Minnesota Environmental Quality Board provided the primary liason on the study. This assistance is sincerely appreciated.

The study involved the fitting of the simulation model SSARR (Streamflow Synthesis and Reservoir Regulation) and the TR-20 to 3 selected watersheds in the Copper-Nickel area of Northeastern Minnesota (see SAFHL External Memorandum No. 155). This was followed by the application and further fitting of the SSARR model to the 1200 square mile Kawishiwi River Basin above Winton and the 291 square mile St. Louis River Basin above Aurora. The SSARR was developed in a cooperative effort by the North Pacific Division of the Corps of Engineers and the National Weather Service in the Columbia Basin. The TR-20 was developed by the Soil Conservation Service.

Information on possible water appropriations and loss of watershed area, both due to possible copper-nickel mining development, was provided by the Regional Copper-Nickel Study Group. The TR-20 model was used to compute the changes in runoff due to the mining developments in specific areas. The runoff changes and the water appropriations were then incorporated in the SSARR runs to determine regional hydrologic effects, peak flow characteristics and runoff volumes. Of special interest were low-flow effects.

With the maximum mining effect, there would be a decrease in the 120-day low flow of the Kawishiwi River at Winton on the order of 15 percent and a corresponding decrease in the 120-day low flow of the St. Louis River at Aurora of 31 percent. At the conclusion of mining, with restoration of the mining areas, the 120-day low flow volume would be slightly increased over the present condition. These values are based on an initial set of appropriation data. See Appendix H for the results of a second set of data.

Relative to peak flows, the 100-year rain storm flood of the Kawishiwi River at Winton would be decreased about 6 percent. The post mining peak would be about 3 percent larger than current conditions.

The SSARR model was used to generate flood hydrographs for snowmelt and rainstorm floods with recurrence intervals of 100-, 25-, and 2-years. Very good agreement was obtained between the snowmelt floods and a frequency analysis of annual floods of the Kawishiwi River near Winton. The 100-year rain storm floods were well below the snowmelt floods, as expected.

The 100-year snowmelt floods of the St. Louis River near Aurora, by the SSARR, were well below the frequency analysis of annual floods. This can probably be improved by incorporating more severe floods in the fitting process of the Partridge and St. Louis Rivers.

Due to the wide spacing of weather stations in Northeastern Minnesota, considerable difficulty was encountered in fitting the SSARR and TR20 for rainstorm floods, and for low flow. This resulted because many summer storms are much smaller than the spacing between stations. Snow accumulation and melt had much less variability between stations and generally were easier to model.

The authors wish to thank Mr. Howard Midge and his associates in the Soil Conservation Service for assistance relative to the TR-20 program. Their assistance is sincerely appreciated.

The assistance of Dr. Curtis Larson and Francis I. Idike on predicting initial moisture conditions in runoff analysis and Dr. Kenneth Brooks on the SSARR model is also sincerely appreciated.

TABLES

1. Station Number List.

2. Listing of Adjacent Stations and Area Percentage.

3. Calibration Periods for Subwatersheds.

4. Weather Station List for Calibration Purposes.

5. TSBII Parameter Values for the Watersheds.

6. Conceptual Reservoir Design Parameters.

7. River Reach Characteristics.

8. Listing of Watershed Units, Mining Developments, Total Watershed Area Lost, and Appropriation Rates.

9. Percentage of Index Station to Create Low Flow Impacted Mining Condition Hydrograph.

10. Comparison of Observed Flows and Computed Flows with No Mining, Mining and Post Mining Conditions, for 120 Day Duration or Average.

11. Total Appropriation Amounts for 1976 During Mining Operations.

12. Calculated Peak Flows (cfs) for 100 Year Rain Event.

13. Peak Flows - Kawishiwi River at Winton.

14. Peak Flows - St. Louis River at Aurora

Appendix A

A-I. Magnitude and Frequency of Annual Flows at Continuous-Record Gaging Stations.

A-II. Low Flow Discharges for Selected Years, for Durations of 1 Day to 365 Days.

A-III. Low Flow Frequency Data for 1960 and 1976.

Appendix B

B-I. Input Parameters for TR-20.

B-II. Peak Flows.

FIGURES

1. Kawishiwi and St. Louis River Watersheds.

2. St. Louis River System.

3. Kawishiwi River System.

4. Rain Basin Soil Moisture Indexes.

5. Snow Basin Soil Moisture Indexes .

6. Rain Basin Baseflow Infiltration Indexes.

7. Snow Basin Baseflow Infiltration Indexes.

8. Rain Basin Surface-Subsurface Separation Curves.

9. Snow Basin Surface-Subsurface Separation Curves.

10. Melt Rate Functions.

11. Snow Covered Area as a Function of Water Equivalent in the Snowpack.

12. Effectiveness of Evapotranspiration Index During Rain Events.

13. Area vs. Time of Concentration Times No. of Reservoirs.

14. St. Louis River at Aurora, 1975 Calibration Run.

15. Stony River, 1960 Calibration Run.

16. Stony River, 1961 Calibration Run.

17. Dunka River, 1960 Calibration Run.

18. Dunka River, 1961 Calibration Run.

19. Kawishiwi at Winton, 1960 Calibration Run.

20. Kawishiwi at Winton, 1961 Calibration Run.

21. Schematic of Mining Developments Included in the Kawishiwi River System, Low Flow Events.

22. Schematic of Mining Development Included in the St. Louis River System, Low Flow Events.

FIGURES (Cont.)

23. Schematic of Kawishiwi Mining Development for Rain Event Analysis.

24. Schematic of St. Louis Mining Development for Rain Event Analysis.

25. Schematic of Kawishiwi Watershed for Low Flow Event During Post Mining Conditions.

26. Schematic of St. Louis Watershed for Low Flow Events During Post Mining Conditions.

27. Schematic of Kawishiwi Watershed for High Flow Events During Post Mining Conditions.

28. Schematic of St. Louis Watershed for High Flow Events During Post Mining Conditions.

29. Kawishiwi River at Winton, 1976 Low Flow, Hydrographs of Mining and Post Mining Conditions.

30. Kawishiwi River at Winton, 1960 Low Flow, Hydrographs of Mining and Post Mining Conditions.

31. St. Louis River at Aurora, 1976 Low Flow, Hydrographs of Mining and Post Mining Conditions.

32. St. Louis River at Aurora, 1960 Low Flow, Hydrographs of Mining and Post Mining Conditions.

33. Kawishiwi River at Winton, 100 Year Rain Event, Hydrographs of No Mining, Post Mining and Mining Conditions.

34. St. Louis River at Aurora, 100 Year Rain Event, Hydrographs of No Mining, Post Mining and Mining Conditions.

35. Frequency of Maximum Water Equivalent of March Snow Cover.

36. Frequency Analysis of Annual Floods, Kawishiwi River at Winton.

37. Frequency Analysis of Annual Floods, Partridge River Near Aurora.

38. Frequency Analysis of Annual Floods, St. Louis River Near Aurora.

Appendix A

A-1 Low Flow Analysis, Kawishiwi River Near Winton.

A-2 Low Flow Analysis, St. Louis River Near Aurora.

A-3 Kawishiwi River Near Winton, Low Flow Data.

A-4 St. Louis River Near Aurora, Low Flow Data.

Appendix B

B-1 Mining Area in Filson Creek, Present and Restored Condition Hydrographs of Proposed Mining Areas.

B-2 Mining Area in Stony River, Present and Restored Condition Hydrographs of Proposed Mining Areas.

B-3 Mining Area in Birch Lake, Present and Restored Condition Hydrographs of Proposed Mining Areas.

B-4 Mining Area in Partridge River, Present and Restored Condition Hydrographs of Proposed Mining Areas.

B-5 Mining Area in Dunka River Watershed.

B-6 Analysis of Area vs. Time of Concentration.

Hydrologic Investigations of Selected Watersheds in Copper-Nickel Region of Northeastern Minnesota

INTRODUCTION

The alteration of watershed runoff will be one of the environmental impacts of the proposed copper-nickel mining development in Northeastern Minnesota. The purpose of the study was to provide the methodology for evaluating regional hydrologic effects of mining development and to analyze the impact of specified mining conditions and appropriation rates.

The Streamflow Synthesis and Reservoir Regulation (SSARR) watershed and river system model was selected to analyze the regional hydrologic impacts. The SSARR had been successfully used to model runoff for the Stony, Partridge, and Filson Creek watersheds (Savard, Nelson, Bowers, 1978) and had been judged suitable for modeling larger watersheds.

The Soil Conservation Service TR-20 model was also found useful for evaluating the changes in runoff from mining operation areas.

The SSARR was calibrated and fitted for the Kawishiwi River above Winton and the St. Louis River above Aurora (Fig. 1). The calibration included developing the conceptual watershed parameters, such as the soil moisture index and baseflow infiltration index for the major subwatersheds: Kawishiwi, Isabella, Stony, Dunka, Bear Island, Partridge, and St. Louis. Also the routing parameters for the major watersheds were developed.

The Regional Copper-Nickel Study provided the general location and size of proposed mining developments. The proposed developments were incorporated in the TR-20 and SSARR. The regional hydrologic impacts were then investigated. Selected high flow events such as the 100 year snowcover and 100 year rainstorm, and selected low flow events such as the flows for 1960 and 1976, were analyzed and compared at the watershed outlets for pre-mining, mining, and post-mining conditions.

The two primary areas associated with possible copper-nickel developments are the Kawishiwi River and Upper St. Louis River watersheds. This report

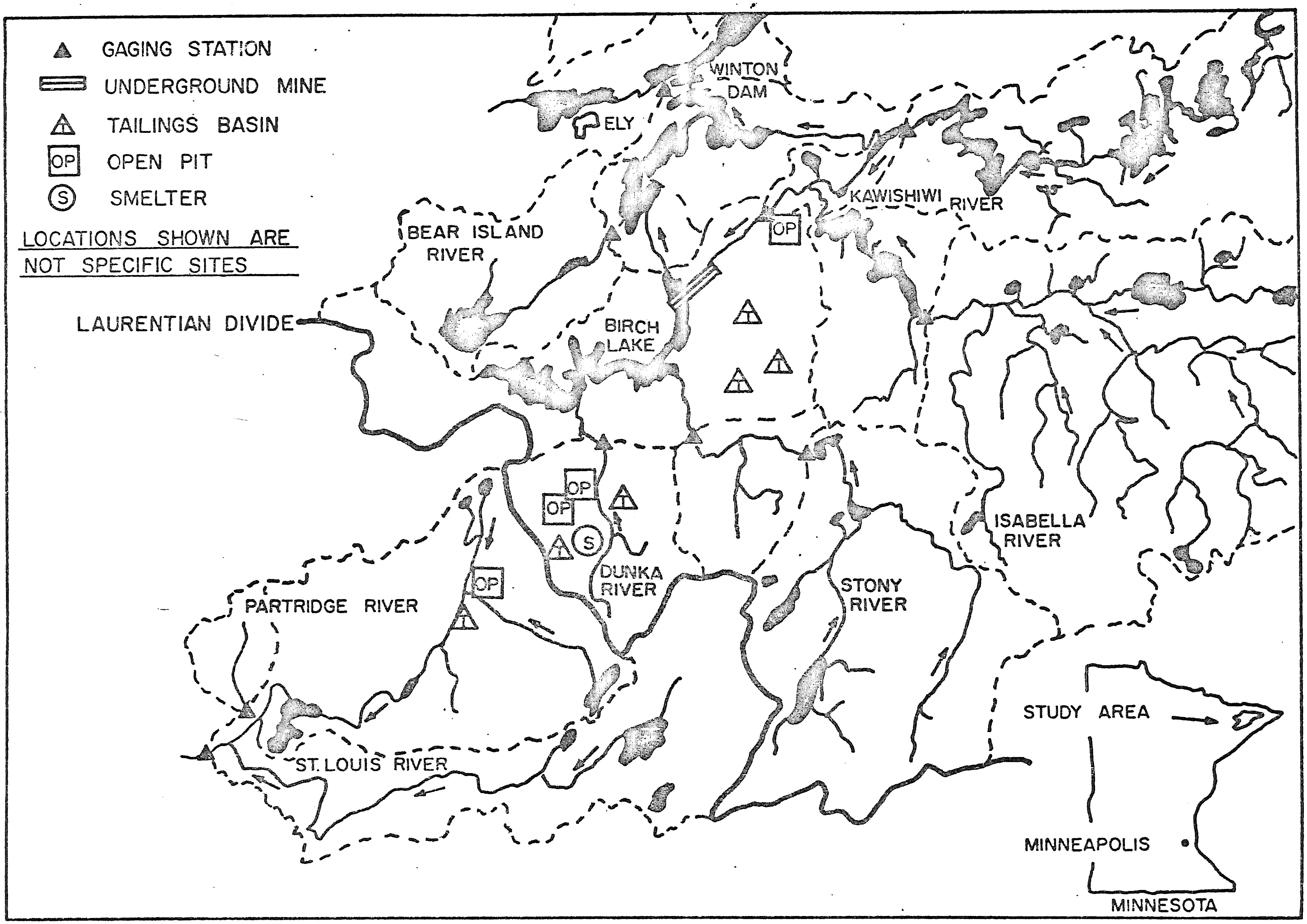

GAGING STATION
UNDERGROUND MINE
TAILINGS BASIN
OPEN PIT
SMELTER
LOCATIONS SHOWN ARE NOT SPECIFIC SITES
LAURENTIAN DIVIDE
WINTON DAM
ELY
BEAR ISLAND RIVER
KAWISHIWI RIVER
BIRCH LAKE
OP
S
DUNKA RIVER
ISABELLA RIVER
STONY RIVER
PARTRIDGE RIVER
ST. LOUIS RIVER
STUDY AREA
MINNEAPOLIS
MINNESOTA

Fig. 1

contains a brief description of these watersheds followed by these subjects:

1. Application of the SSARR to selected sub-watersheds.
2. Analysis of possible mining developments.
3. Use of the TR-20 program to evaluate mining effects.
4. Use of the SSARR to determine mining impacts at Winton and Aurora.

WATERSHED DESCRIPTIONS

Both the Kawishiwi and St. Louis River watersheds are forested, with many lakes and swampy areas, resulting in considerable storage. The Kawishiwi, with an area of approximately 1200 square miles lies to the north of the Laurentian Divide. The St. Louis lies to the south of the divide and drains 312 square miles.

The bedrock in the watersheds is crystalline, consisting mainly of Precambrian gabbros, granites, and quartzite, with some medisedimentary and sedimentary rocks. Outcrops are extensive in certain areas and cause high runoff due to their low permeabilities. Deep groundwater aquifers do not exist in the study area. However, shallow aquifers exist locally in the extensive glacial deposits of the watersheds. The aquifers consist of bouldery till and outwash deposits of sand and gravel. These local deposits are very important to the hydrologic response of small areas. The glacial deposits are generally thin, 0-50 feet, but many reach depths of more than 100 feet. The local aquifers act as small storage reservoirs for interflow during wet periods, and the runoff is released slowly after the precipitation event. The region also has extensive peat and marsh like areas. Along with the numerous lakes, these have a tendency to reduce peak flows and lengthen the time of concentration for single runoff events in the watersheds.

The Kawishiwi River system contains 5 major tributaries: the Kawishiwi, Isabella, Stony, Dunka, and Bear Island Rivers. The Kawishiwi splits into two branches in the north central part of watershed. The north branch flows westward towards Farm and Garden Lakes. The south branch flows southwesterly towards Birch Lake. The Isabella River goes through Bald Eagle and Gabbro Lakes before joining the south branch. The Stony and Dunka Rivers also empty into Birch Lake. The outflow from Birch Lake flows into White Iron Lake. The Bear Island River also flows into White Iron Lake. From White Iron the flow goes into Farm and Garden Lakes where the branches rejoin. The Kawishiwi River system then goes through the watershed outlet at the Winton Dam.

The St. Louis River system has two major subwatersheds: the Partridge and St. Louis. The Partridge River joins the St. Louis River just above the St. Louis River at Aurora gauge.

Extensive iron ore mining operations at the present time do exist in the Partridge and Dunka River subwatersheds. The effects of iron mining were ignored in the Dunka watershed since the operations were not running during the calibration years. The Partridge River flow was affected during the calibration period. A correction factor had to be applied to the observed flows for pumpage to and from the river. How the correction factor was applied is discussed in the Appendix and the first report. The correction factor that was applied to the Partridge observed flows was also carried downstream to the St. Louis observed flows.

SSARR WATERSHED AND RIVER SYSTEM DESCRIPTION

The SSARR watersheds generate runoff volumes from the conceptual watershed parameters such as the soil moisture index. The volume is then routed through a conceptual reservoir system and a simulated watershed outflow is generated (Fig. 2). The basic routing method is then used to route the generated flows through river reaches, lakes, and reservoirs to the outlet point. A listing of the stations and schematic maps of the watersheds is given in Table I and Figs. 1, 2, and 3.

The subwatersheds used to generate flow in the model correspond to the gauged subwatersheds in the watersheds. A description of how the runoff volume is found and the outflow hydrographs generated can be found in the first report [1].

The river systems consisted of transfer points, river reaches, and lake-reservoirs. The transfer points were used as either summing points or as an adjacent station.

St. Louis River System

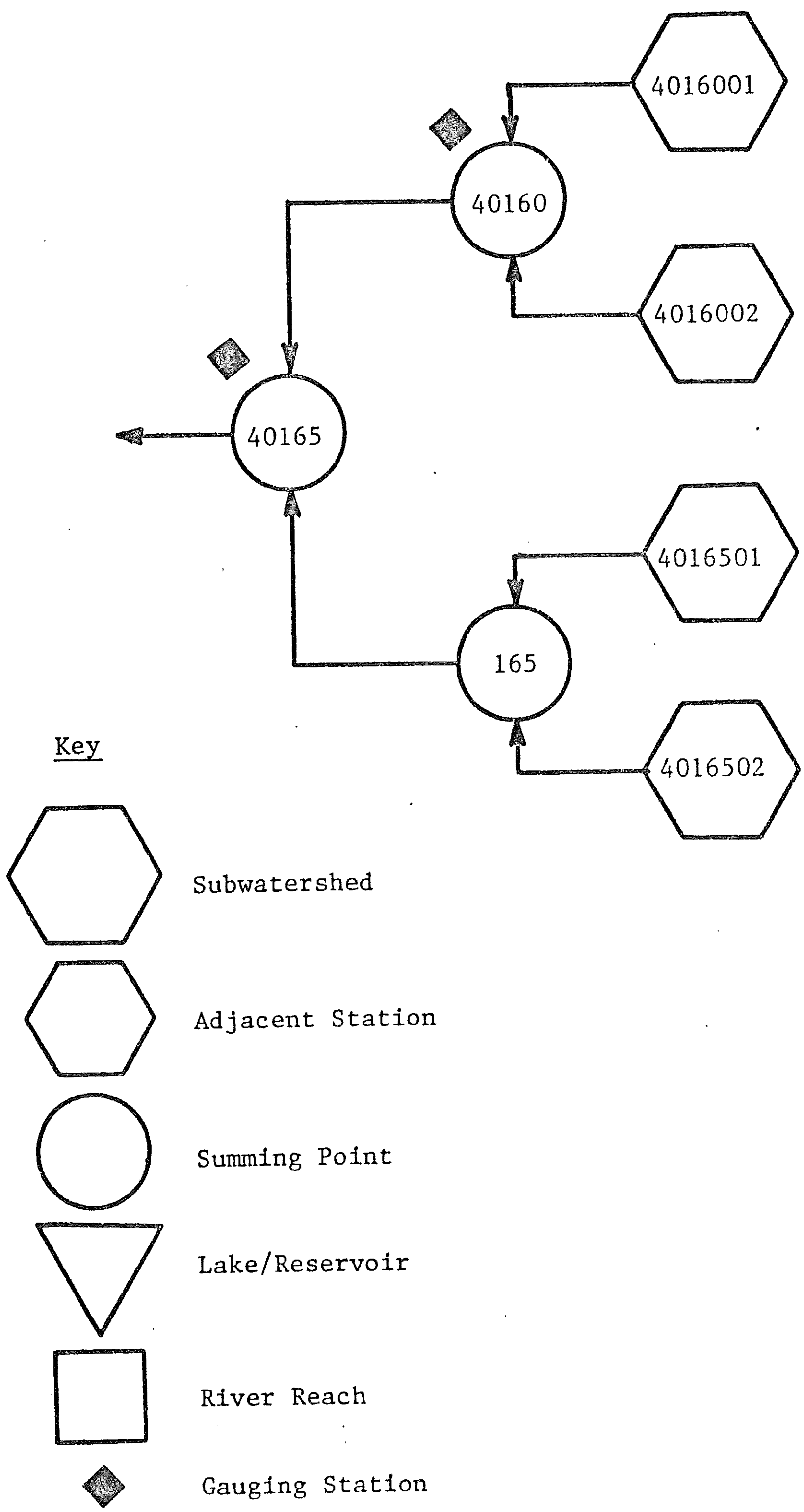
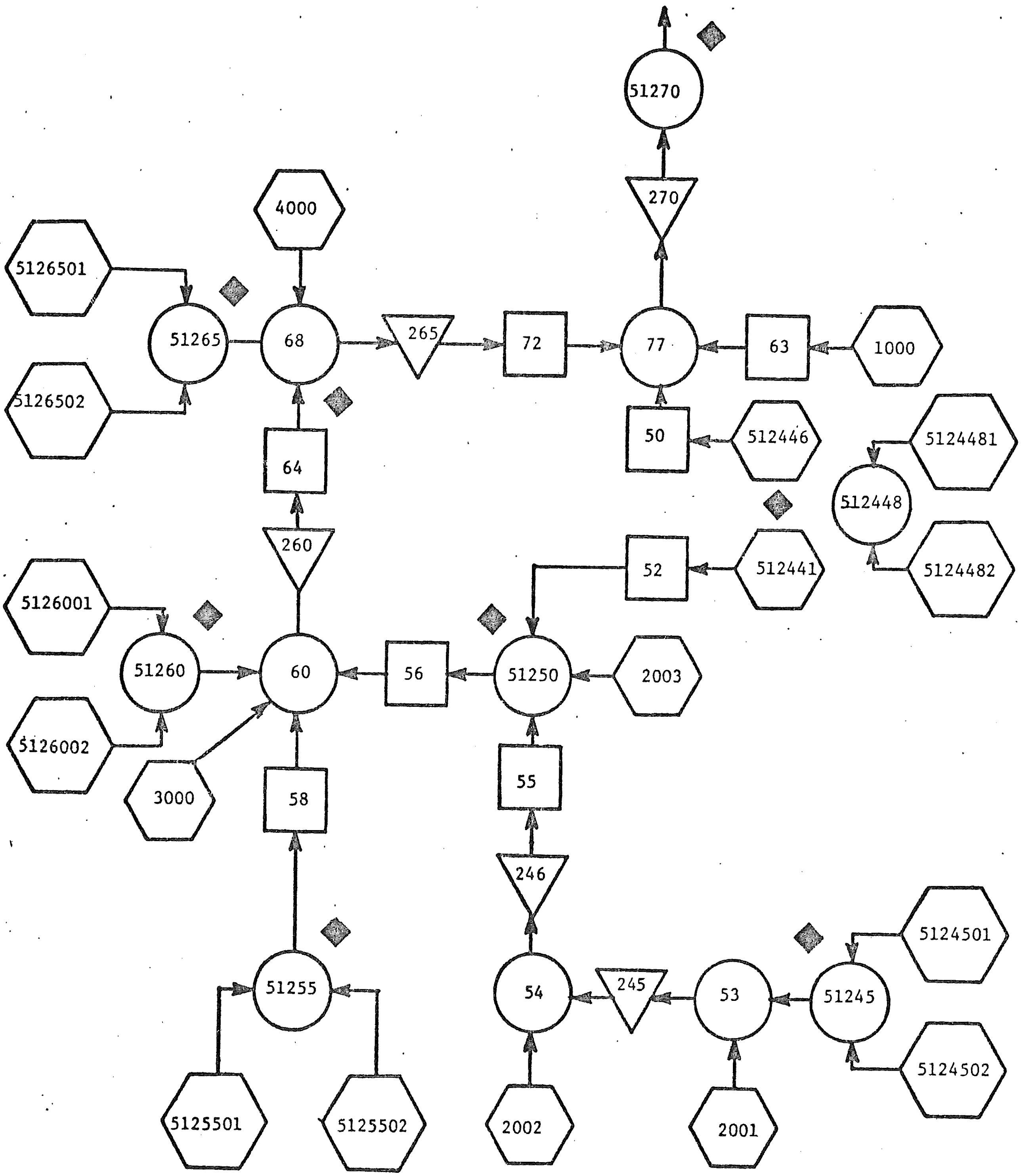


Fig. 2



KAWISHIWI RIVER SYSTEM

Fig. 3

TABLE I - STATION NUMBER LIST

Kawishiwi River System

Subwatersheds:

5124481	Kawishiwi Snow Basin
5124482	Kawishiwi Rain Basin
5124501	Isabella Snow Basin
5124502	Isabella Rain Basin
5125501	Stony Snow Basin
5125502	Stony Rain Basin
5126001	Dunka Snow Basin
5126002	Dunka Rain Basin
5126501	Bear Island Snow Basin
5126502	Bear Island Rain Basin

Adjacent Stations:

512446	North Split Kawishiwi
512441	South Split Kawishiwi
1000	Local Inflow North Kawishiwi
2001	Local Inflow Bald Eagle
2002	Local Inflow Gabbro
2003	Local Inflow South Kawishiwi
3000	Local Inflow Birch
4000	Local Inflow White Iron

Lakes and Reservoirs:

245	Bald Eagle
246	Gabbro
260	Birch
265	White Iron
270	Winton

Summing Points:

512448	Calculated Outflow Kawishiwi
51245	Calculated Outflow Isabella
51255	Calculated Outflow Stony
51260	Calculated Outflow Dunka
51265	Calculated Outflow Bear Island
51250	Calculated Flow South Kawishiwi
53	Inflow to Bald Eagle
54	Inflow to Gabbro
60	Inflow to Birch
68	Inflow to White Iron
77	Inflow to Winton
51270	Outflow From Winton

TABLE I - STATION NUMBER LIST (Cont.)

River Reaches:

50	North Kawishiwi
52	Kawishiwi Split to South Kawishiwi
55	Gabbro to South Kawishiwi
56	South Kawishiwi to Birch
58	Stony to Birch
64	Birch to White Iron
72	White Iron to Winton
63	North Kawishiwi to Winton

Gauging Stations:

5124480	Kawishiwi Near Ely (253 Sq. Mi.)
5124500	Isabella Near Isabella (341 Sq. Mi.)
5125000	South Kawishiwi Near Ely
5125500	Stony Near Isabella (180 Sq. Mi.)
5125550	Stony Near Babbitt
5126000	Dunka Near Babbitt (53 Sq. Mi.)
5126210	South Kawishiwi Above White Iron
5126500	Bear Island Near Ely (68.5 Sq. Mi.)
5127000	Kawishiwi Near Winton (1200 Sq. Mi. approximately)

St. Louis River System

Subwatershed:

4016001	Partridge Snow Basin
4016002	Partridge Rain Basin
4016501	Upper St. Louis Snow Basin
4016502	Upper St. Louis Rain Basin

Summing Points:

40160	Calculated Outflow Partridge
165	Calculated Outflow Upper St. Louis
40165	Calculated Flow St. Louis

Gauging Stations:

4016000	Corrected Partridge River (156 Sq. Mi.)
4016500	Corrected St. Louis River (312 Sq. Mi.)

Summing points were used throughout both large watersheds. They were used to add together snow and rain basin outflows to obtain subwatershed discharge, to find the total inflow into lakes and reservoirs, and for computing the total flow past a gauging station.

The adjacent station provision of the SSARR was used for local inflows and for splitting the Kawishiwi River into the north and south branches. The adjacent station feature computes a flow that is a function of another flow. The function can be defined as a flow relationship or a percentage of the index station discharge. The SSARR users manual describes the actual computer format for the provision [2].

At the split of the Kawishiwi Rivers, Bowers and Gutschick [3] found approximately 60 percent goes into the south branch and 40 percent into the north branch. Using the upper Kawishiwi watershed as the index station, 60 percent of the flow was put into the south branch and the remaining 40 percent into the north branch.

The adjacent station feature was also used for local inflow calculations. For illustration, the local flow into Bald Eagle Lake will be discussed. The watershed model was used to calculate the discharge up to the Isabella gauge, but the local inflow from 58 square miles adjacent to Bald Eagle Lake had to be calculated and added to the Isabella outflow before routing through Bald Eagle Lake. The local inflow was calculated using the ratio of the local area to the area of the nearest watershed and multiplying it by the discharge of the watershed. The equation for the calculation was

$$Q_{Local} = \left[\frac{\text{Local Area}}{\text{Isabella Area}}\right] Q_{Isabella} .$$

Thus the ratio value was found to be 58/340 = .17.

For the other adjacent stations in the Kawishiwi, the index station and ratio are listed in Table II. The straight ratio was taken since low flow conditions were of importance to the study. If only peak flows were of importance, the ratio would have been raised to the 1.6 power (Guetzkow 4).

TABLE II - LISTING OF ADJACENT STATIONS AND AREA PERCENTAGE.

Adjacent Station	Index Station Outflow for Calculation	Percentage of Index Station Discharge
512441	512448	60
512446	512448	40
1000	512448	13
2001	51245	17
2002	51245	4
2003	51245	9
3000	51255	91
4000	51265	39

The routing technique in the SSARR for lake, reservoir and river reaches uses the basic storage equation

$$I - 0 = ds/dt$$

where

I	-	Inflow
0	-	Outflow
ds/dt	-	The change in storage with respect to time.

How the equation is utilized in the SSARR is covered by the SSARR users manual.

There are five lake/reservoirs in the Kawishiwi River system which were routed through. They are Bald Eagle, Gabbro, Birch, White Iron, and Farm and Garden Lakes. Using an iterative procedure, the SSARR solves the routing problem. An elevation, discharge, storage table is supplied by the user for each lake/reservoir. For the five lake/reservoirs, the tables were taken from Bowers and Gutschick [3].

For river reaches, the length of river is divided into short sections. Each section corresponds to one phase for the storage equation and is approximately 5 miles long. The basic storage relation was derived in the equation

$$0_2 = [(I_m - 0_1)/((KTS/Q^n) + t/2)]\ t + 0_1$$

where

0_2	-	the river reach outflow at the end of the time period
I_m	-	mean inflow
0_1	-	outflow at beginning of period
KTS	-	constant
Q	-	discharge
n	-	coefficient
t	-	period length

The user supplies the variables n and KTS. Values of $n = 0.2$ were used in the Columbia River Basin and were also used in the present study. The KTS parameter was found using a nomograph in the SSARR users manual. To use the nomograph, an n value must be specified together with the average discharge and the time of storage per phase or the T_s. The T_s is found by dividing the number of phases along the reach by the travel time of the reach.

Calibration Procedure

The calibration procedure involves fitting the SSARR parameters for both the watershed and river system sections of the model. The years which were used for calibration are given in Table III. Unfortunately, all stations in the Kawishiwi watershed were only gauged together during 1976. The other years were used to calibrate parts of the system that pertained. For the Kawishiwi watershed, the upper Kawishiwi near Ely subwatershed gauge was fitted. Once the fit was achieved, the remainder of the system was fitted.

A discussion of the adjustment procedure for the watershed parameters, soil moisture index (SMI), baseflow infiltration index (BII), surface-subsurface separation curve (S-SS), time delay (TSBII), melt rate function (M-R), snow covered area (SCA), effectiveness of evapotranspiration (KE), and the conceptual reservoir designs, is given in the first report [1].

During calibration, the following weather stations, Isabella, Winton, Gunflint Lake, Babbitt, Hoyt Lakes, Tower, and Brimson, were used for precipitation input. Table IV displays the subwatersheds and associated thiessen polygon weights used during the calibration. Several times during the calibration period a precipitation station did not have a record. If the period of no record was short, one week to a month, the nearest station record was substituted. If the missing record period was longer, one year, the thiessen polygon weights for the watershed were redefined.

The temperature stations used for snowmelt calculations were Isabella and Babbitt. The snowcover data was taken from snowcover-water-equivalent depths on maps put out by the Corps of Engineers. The streamflow data was taken from the U.S. Geological Survey and Minnesota Department of Natural Resources water resources files.

TABLE III - CALIBRATION PERIODS FOR SUBWATERSHEDS

Watershed	Calibration Years
Kawishiwi	1968-1970, 1972, 1976
Isabella	1959-61, 1976
Stony	1959-64, 1976
Dunka	1959-61, 1976
Bear Island	1959-61, 1976
Partridge	1961-64, 1975
St. Louis	1961-64, 1975

TABLE IV - WEATHER STATION LIST FOR CALIBRATION

Watershed	Rain Station	Thiessen Weight
Kawishiwi	Isabella	35 %
	Winton	20
	Gunflint Lake	45
Isabella	Isabella	99
	Winton	1
Stony	Isabella	85
	Babbit	15
Dunka	Babbitt	100
Bear Island	Babbitt	67
	Winton	21
	Tower	12
Partridge	Hoyt Lakes	66
	Babbitt	34
St. Louis	Hoyt Lakes	45
	Babbitt	39
	Brimson	16

Although the SSARR is designed to model all flows, both high and low, the input data is not always representative of the actual events that occurred. This is usually associated with inadequate precipitation data. Thus the model does not always accurately reproduce discharges. Since the input data may be low or high and the resultant output low or high, during calibration over prediction and under prediction of similar magnitude is sought. Because one of the main objectives of the study was to determine mining impacts on low flows, the calibration was geared toward fitting low flow events. High flow events were important also, but if a calibration fitted low events better than high events, the low fit was chosen to be more important.

The fitted parameters presented here and used in the model represent what the authors feel is the best fit to date. As more data become available, and the working knowledge of SSARR by the users increases, the fitted parameters should become better defined.

The rain basin SMI curves shown in Fig. 4 all show the expected trend of increasing runoff with increasing soil moisture. Extrapolation of the curves should be used with caution because during the calibration period the model was not adequately fitted in the high moisture index due to lack of data. The snow basin SMI curves in Fig. 5 are approximately the same except in one small portion of the soil moisture zone. Better defined curves could be generated if snowcover data were of better quality. Also, since the SSARR uses only one water equivalent number for the snow depth for an entire watershed, the natural variance is smoothed and well-defined SMI curves unattainable.

The BII rain-and snow-basin curves show considerable variation between watersheds (Figs. 6 and 7). The Kawishiwi subwatershed shows much more baseflow contribution to runoff than the other watersheds. This may be because the soil types and structure of the local hydrologic system have more baseflow going through them. Another possibility is that the storage effects of the lakes in the subwatershed are being handled as a long baseflow response by the user and model.

At the present time correlation between the soil types or soil depths, unconsolidated material in the watersheds has not been related to the BII curves. Further study of the baseflow characteristics and baseflow sources within the watersheds may help in determining more precise BII curves.

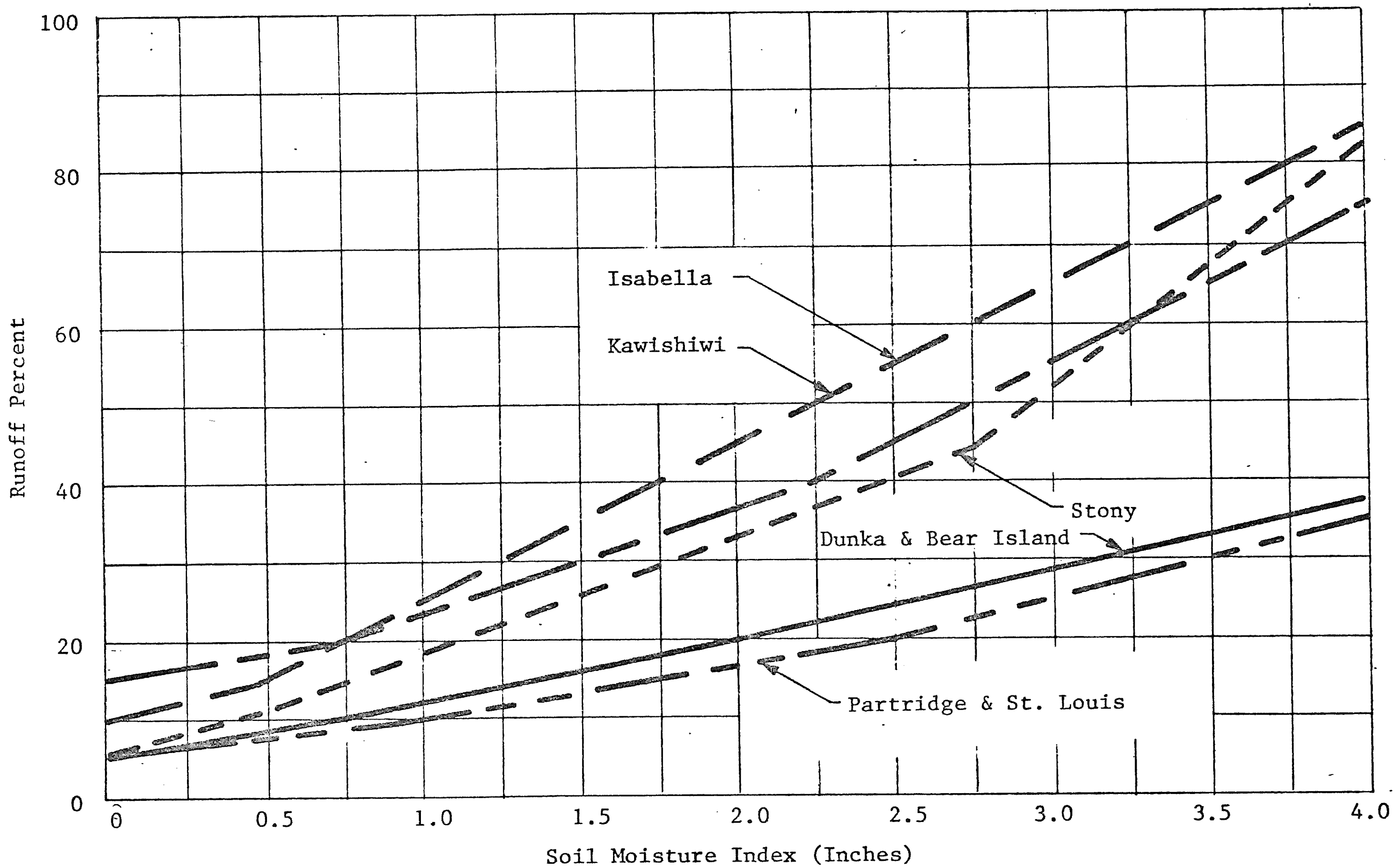


Fig. 4 - Rain Basin Soil Moisture Indexes.

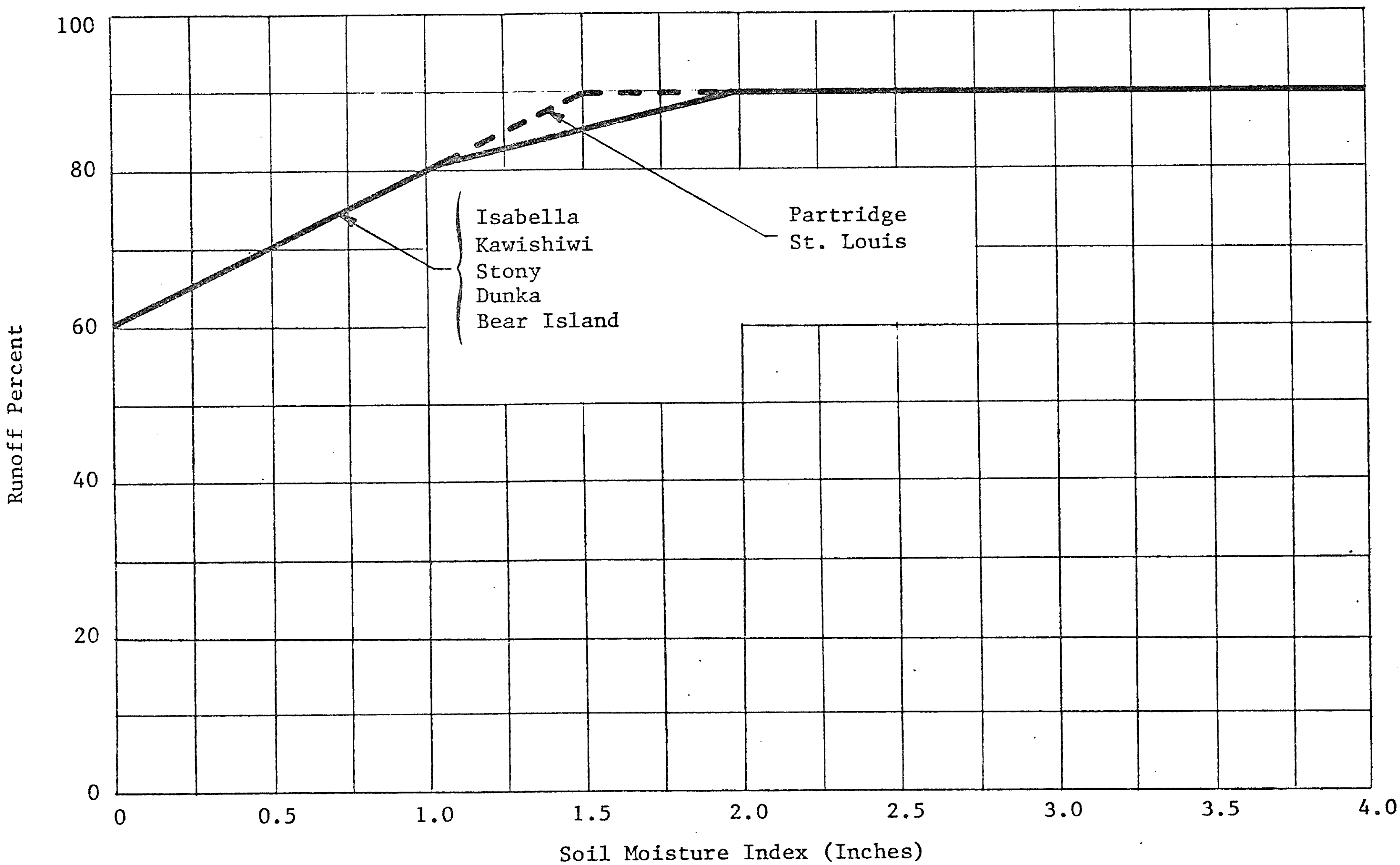


Fig. 5 - Snow Basin Soil Moisture Indexes.

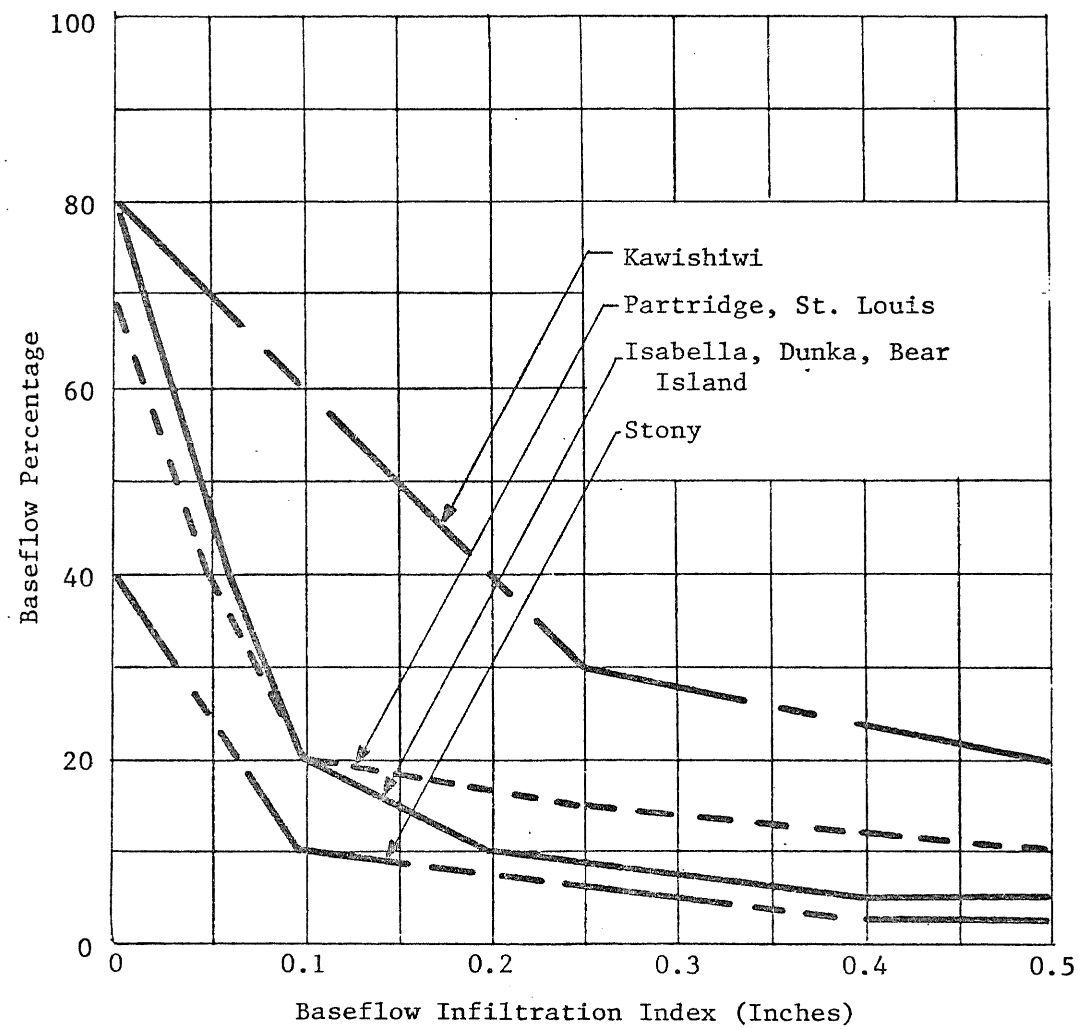


Fig. 6 - Rain Basin Baseflow Infiltration Indexes.

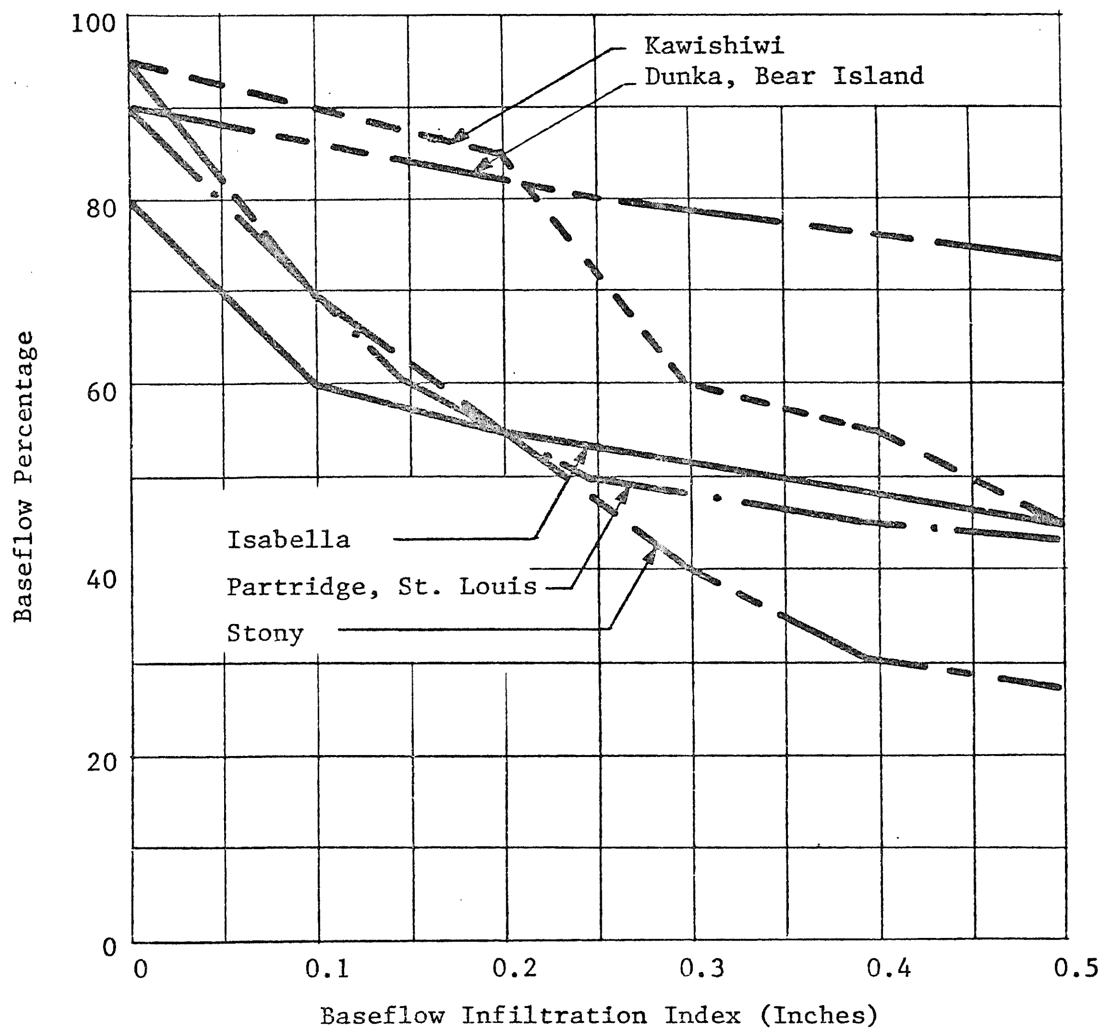


Fig. 7 - Snow Basin Baseflow Infiltration Indexes.

The S-SS curves shown in Figs. 8 and 9 for the rain and snow basins show the same general trend; as the input rate increases, the subsurface component becomes constant and only the surface component increases. Caution should be exercised in the high input rates, above 0.03 inches/hour, since very few events were modeled in that region of the curves. Also, at the high input rates the actual runoff process in forested watersheds is not fully understood nor interpretable from precipitation records. Summer storms of short duration and long spring rains of low intensities may provide the rain gauges with the same amount of precipitation. The SSARR has provisions for SMI curve families to be used as a function of intensity, but the data were not available for this study. Thus the S-SS curves at high input rates, as well as some low input rates, are not well defined.

The MR curves in Fig. 10 show varied values for the different watersheds. This can be interpreted as some function of physical characteristics within the watersheds, such as forest cover.

The snow covered area as a function of water equivalent in the snow pack are generally the same for all watersheds (Fig. 11). More actual data is needed for better definition of the curves.

The effectiveness of the evapotranspiration index during rain events (Fig. 12) has not been optimized. Similar values have been used for all watersheds. The parameter is a minor parameter in the model.

The temporary storage parameters (TSBII) values shown in Table V do not have a great variation. The value of 40 hours was chosen as an average value and used in the majority of watersheds. The 60 and 44 hour values represent minor optimization for a better fit in a watershed.

The designs of the conceptual reservoir systems, as shown in Table VI, are the results of fitting. Preliminary investigation into the relationship between the product of time of concentration and the number of reservoirs with watershed area have shown no conclusive correlations (Fig. 13). Additional investigation into correlations between the design and other watershed runoff indexes may provide improved design guidelines for future usage of the SSARR.

During the calibration periods, it was necessary to select initial values of elevation and discharge. With the simulation periods beginning before

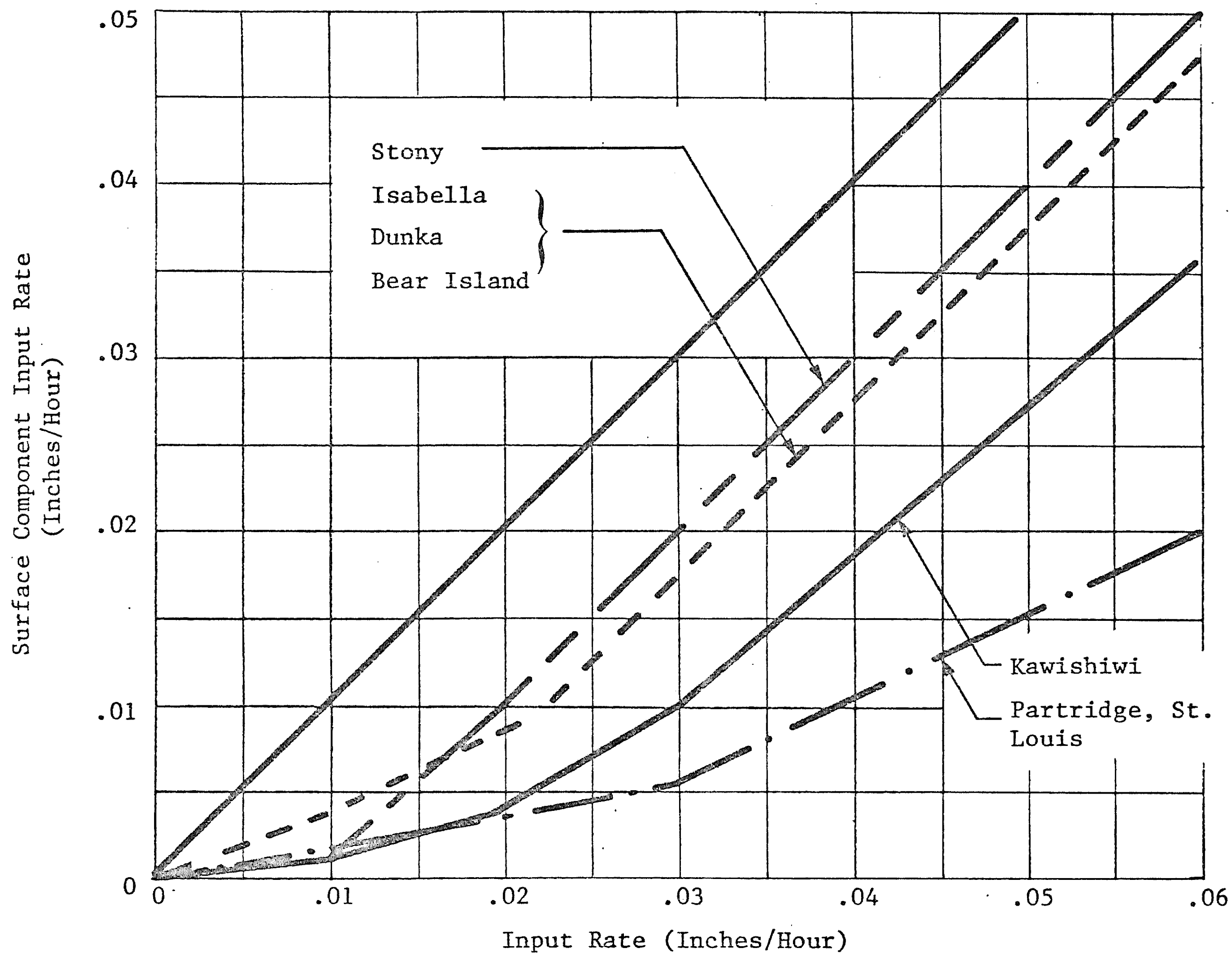


Fig. 8 - Rain Basin Surface-Subsurface Separation Curves.

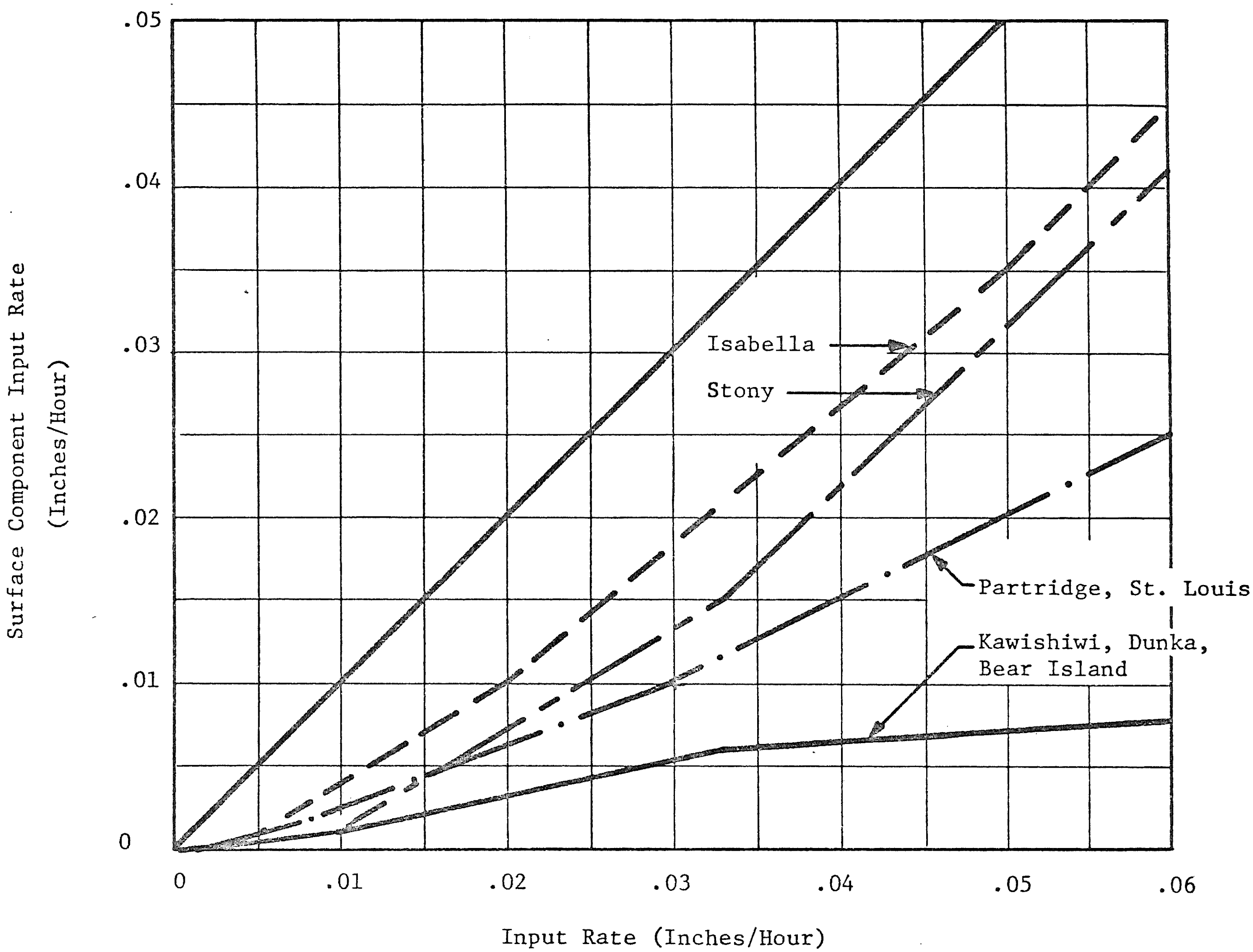


Fig. 9 - Snow Basin Surface-Subsurface Separation Curves

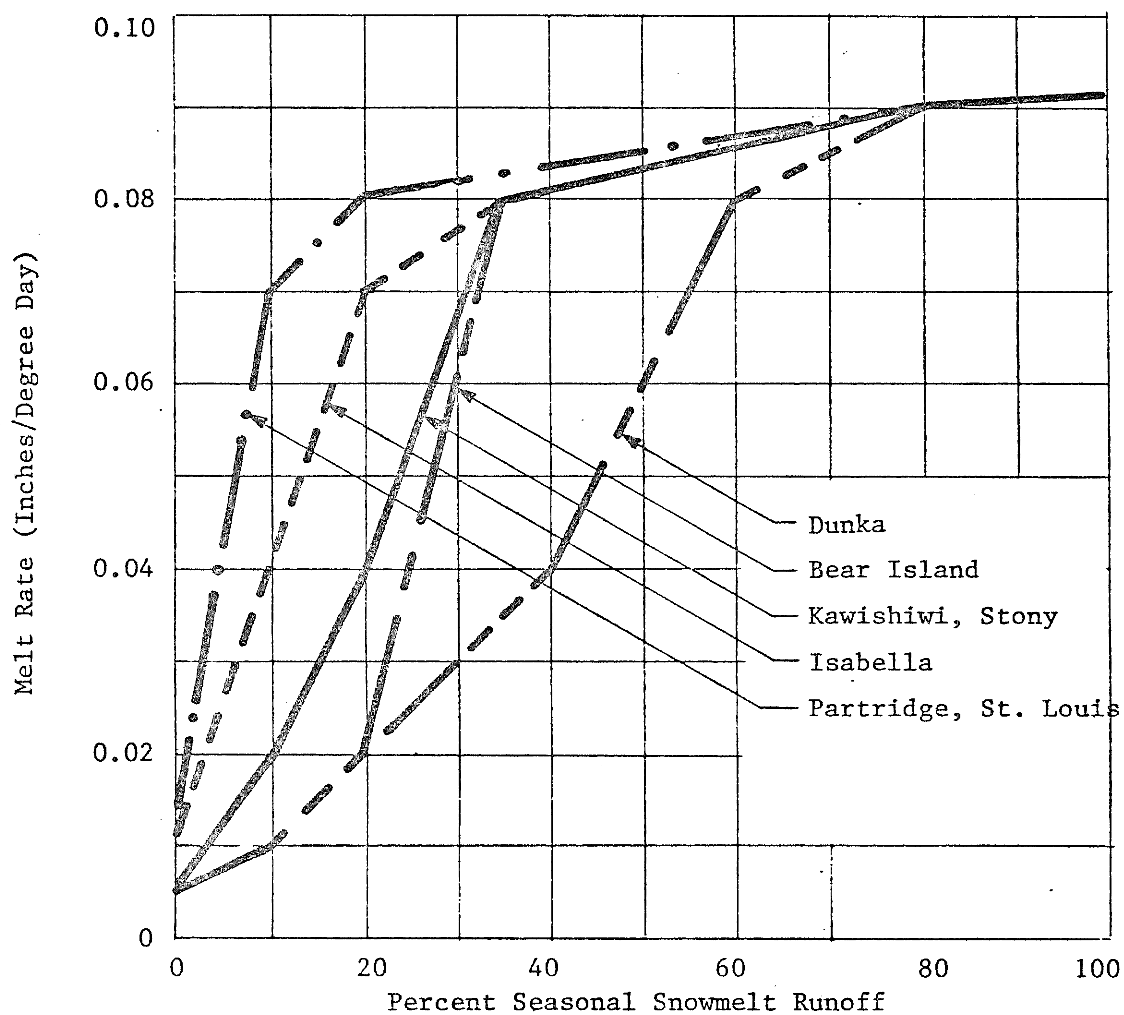


Fig. 10 - Melt Rate Functions.

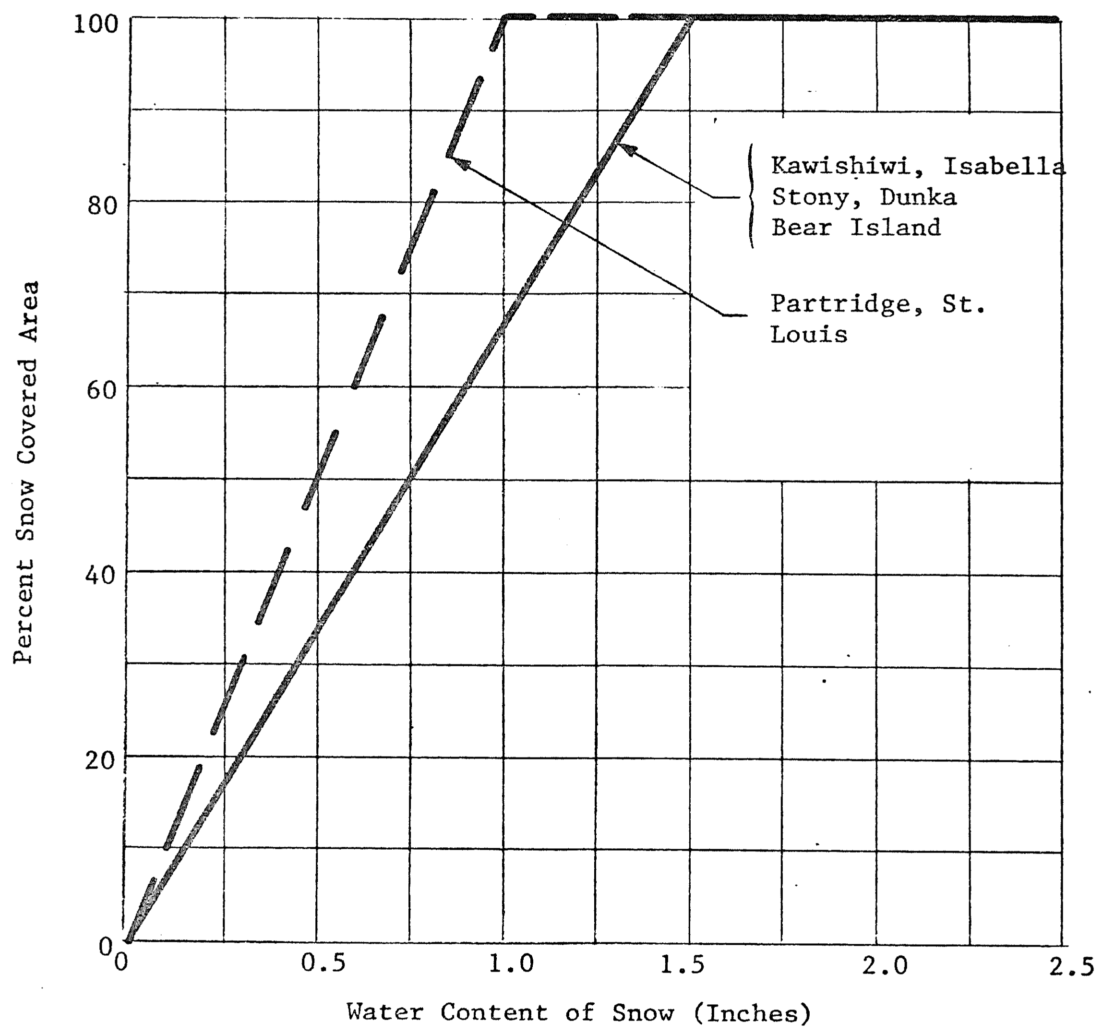


Fig. 11 - Snow Covered Area as a Function of Water Equivalent in the Snowpack.

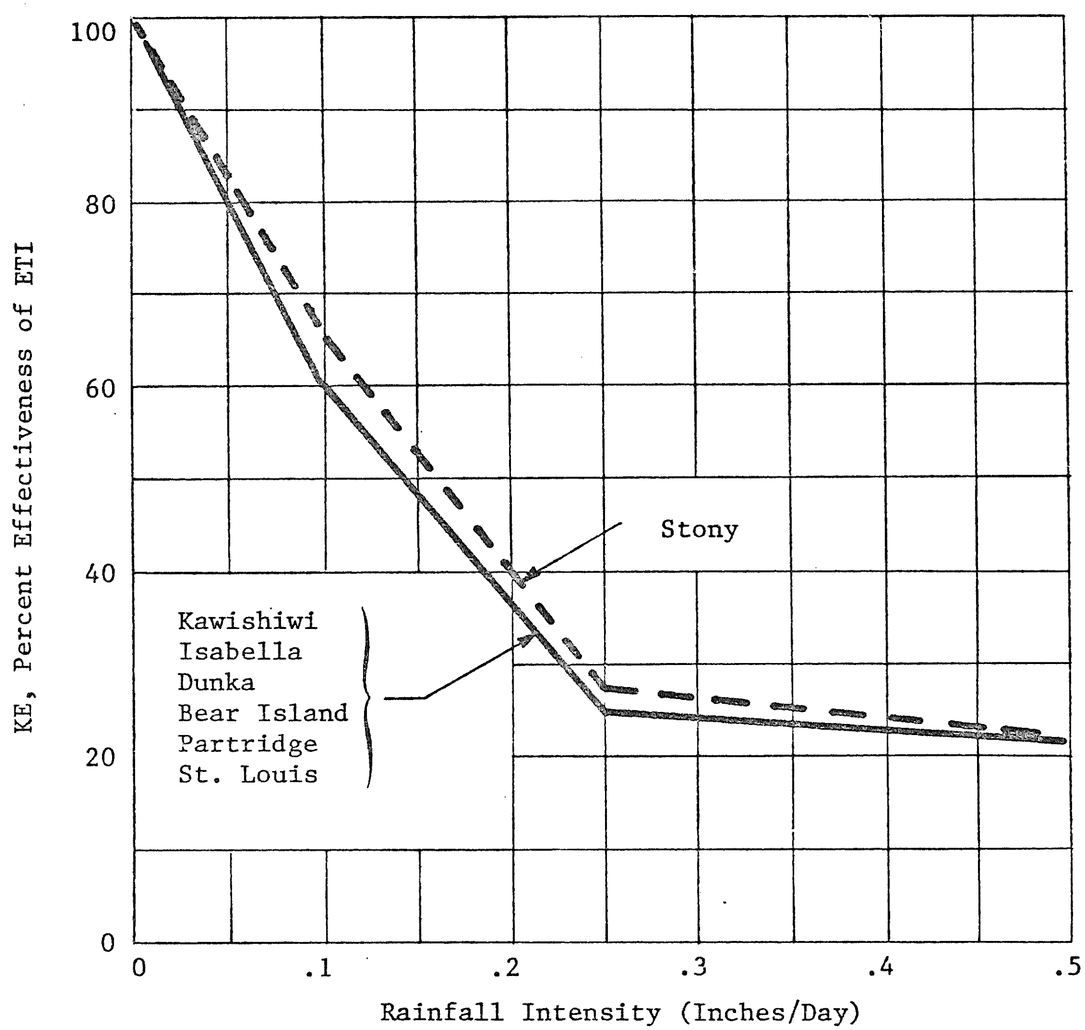


Fig. 12 - Effectiveness of Evapotranspiration Index During Rain Events.

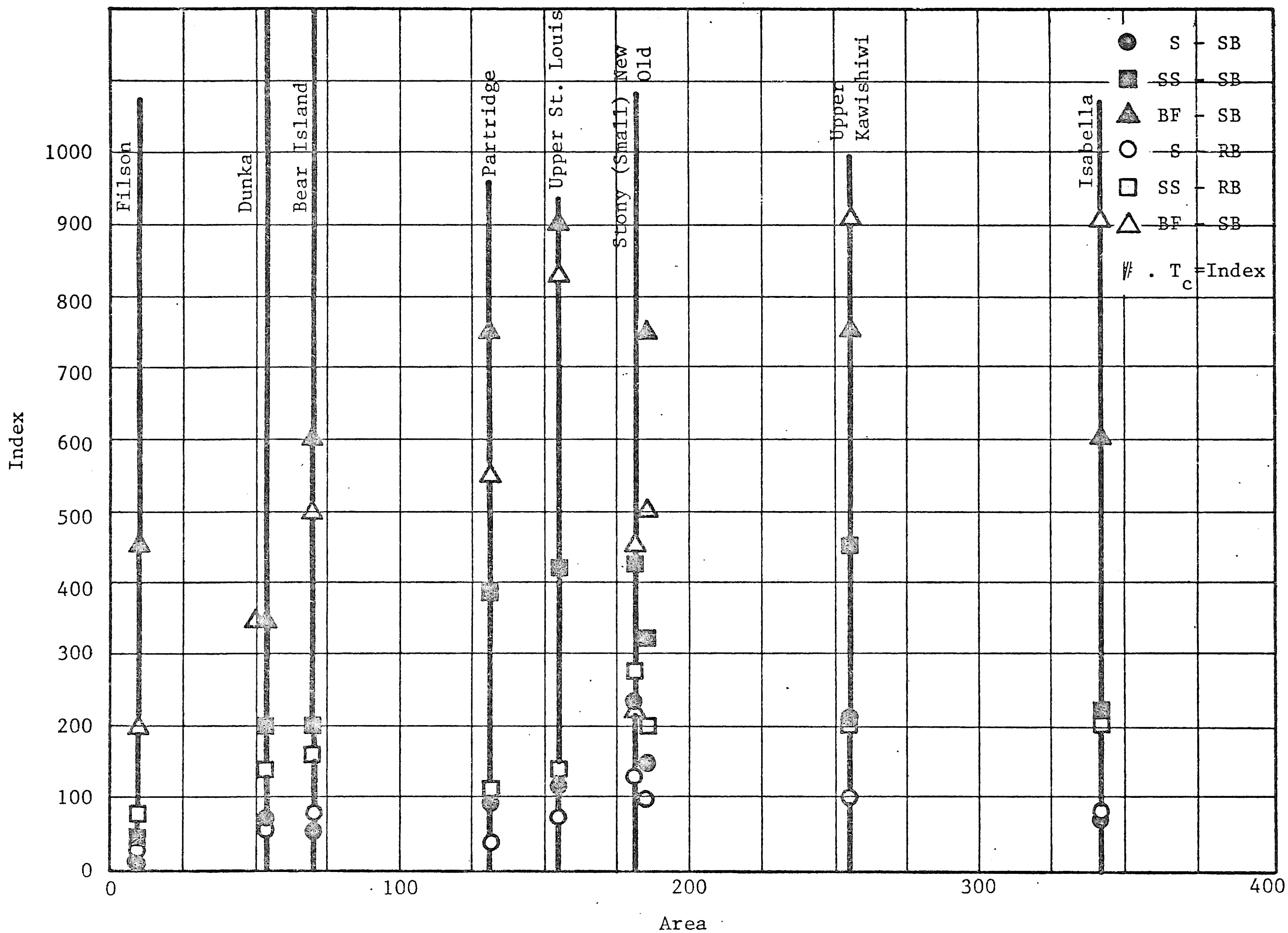


Fig. 13 - Area vs. Time of Concentration Times Number of Reservoirs.

TABLE V - TSBII PARAMETER VALUES FOR THE WATERSHEDS

Watershed		Rising Limb TSBII (Hours)	Falling Limb TSBII (Hours)
Kawishiwi	Snow	40	40
	Rain	40	40
Isabella	Snow	40	40
	Rain	40	40
Stony	Snow	40	40
	Rain	44	60
Dunka	Snow	40	40
	Rain	40	40
Bear Island	Snow	40	40
	Rain	40	40
Partridge	Snow	40	60
	Rain	40	60
St. Louis	Snow	40	60
	Rain	40	60

TABLE VI - CONCEPTUAL RESERVOIR DESIGN PARAMETERS

	Snow Basin			Rain Basin			
	Surface	Sub Surface	Baseflow	Surface	Sub Surface	Baseflow	
Kawishiwi (253)	6 35	6 75	3 250	4 25	4 50	3 300	Number Time of Conc
Isabella (340)	5 15	4 55	2 300	4 20	5 40	3 300	" "
Stony (180)	6 25	5 65	3 250	6 22	5 55	1 225	" "
Dunka (53)	5 15	4 35	2 175	4 15	4 50	2 300	" "
Bear Island (69)	4 15	4 50	2 300	4 20	4 40	2 250	" "
Partridge (130)	5 20	6 65	3 250	4 10	3 35	2 275	" "
St. Louis (156)	6 20	6 70	3 300	5 15	4 35	3 275	" "

spring runoff and ending in December, low values were used. It was assumed that during the winter months the lakes/reservoirs were drained to low elevations just above their lowest possible elevation. As the simulation progressed, the calculated values merged with the appropriate values. Thus, modulation between the calculated and observed values at the beginning of the simulation was ignored.

The values obtained for the river reaches are given in Table VII. The procedure for choosing the values is given in the SSARR manual. Since travel times within the watersheds are small, very little calibration was performed with the recommended values; results were satisfactory.

Several hydrographs for the Stony and Dunka subwatersheds and the basin outflow points at the St. Louis and Winton gauges are included in the report for illustrative purposes. The hydrographs are copies of the SSARR output.

In Fig. 14 the SSARR calculated gauge value, St. Louis at Aurora, underpredicts during the snowmelt event in April and May. During rain events, it underpredicts in June, overpredicts in September, and predicts well the remainder of the year. The low flow periods show good agreement between calculated and observed values.

There is a very substantial disagreement in June. In the opinion of the authors this is caused primarily by inadequate precipitation data. Throughout this study, the single most significant data problem involved inadequate precipitation data. As a result, the SSARR model would sometimes indicate a flood when none existed and in other cases would not indicate a flood when one did exist. This resulted because the spacing of rain gauges was much larger than the area covered by some summer storms. In many cases there were no rain gauges in a subwatershed. In some cases the subwatershed might be several miles from the nearest gauge. As a result, the average precipitation determined by Thiessen relationships may be seriously in error. There should be a minimum of one rain gauge per subwatershed. In long watersheds, such as the North Kawishiwi, the Isabella, the Stony, and the Partridge Rivers, several gauges should be provided.

The Stony River calculations (Fig. 15) for 1960 show good agreement for all parts of the year including snow and rain events and low flow periods. Again

TABLE VII - RIVER REACH CHARACTERISTICS

Reach	Station Number	Number of Routing Phases	n	KTS
Upper Kawishiwi to Winton, North Branch	50	1	.2	50
Local N. Kawishiwi to Winton	63	1	.2	26
Upper Kawishiwi to South Kawishiwi	52	2	.2	40
Gabbro Lake to South Kawishiwi	55	3	.2	9
South Kawishiwi to Birch Lake	56	1	.2	8
Stony River to Birch Lake	58	1	.2	5
Birch Lake to White Iron	64	1	.2	7
White Iron to Winton	72	1	.2	5

PLOT CHARACTER	STATION NAME	STATION NUMBER	CONTROL
*	CORRECTED ST LOUIS	401650.0	Q
X	CALCULATED AT ST LOUIS GAUGE	4016.5	Q
L	CALCULATED ST LOUIS	16.5	Q
P	CALCULATED FLOW,PARTRIDGE ABOVE SECOND	4016.0	Q

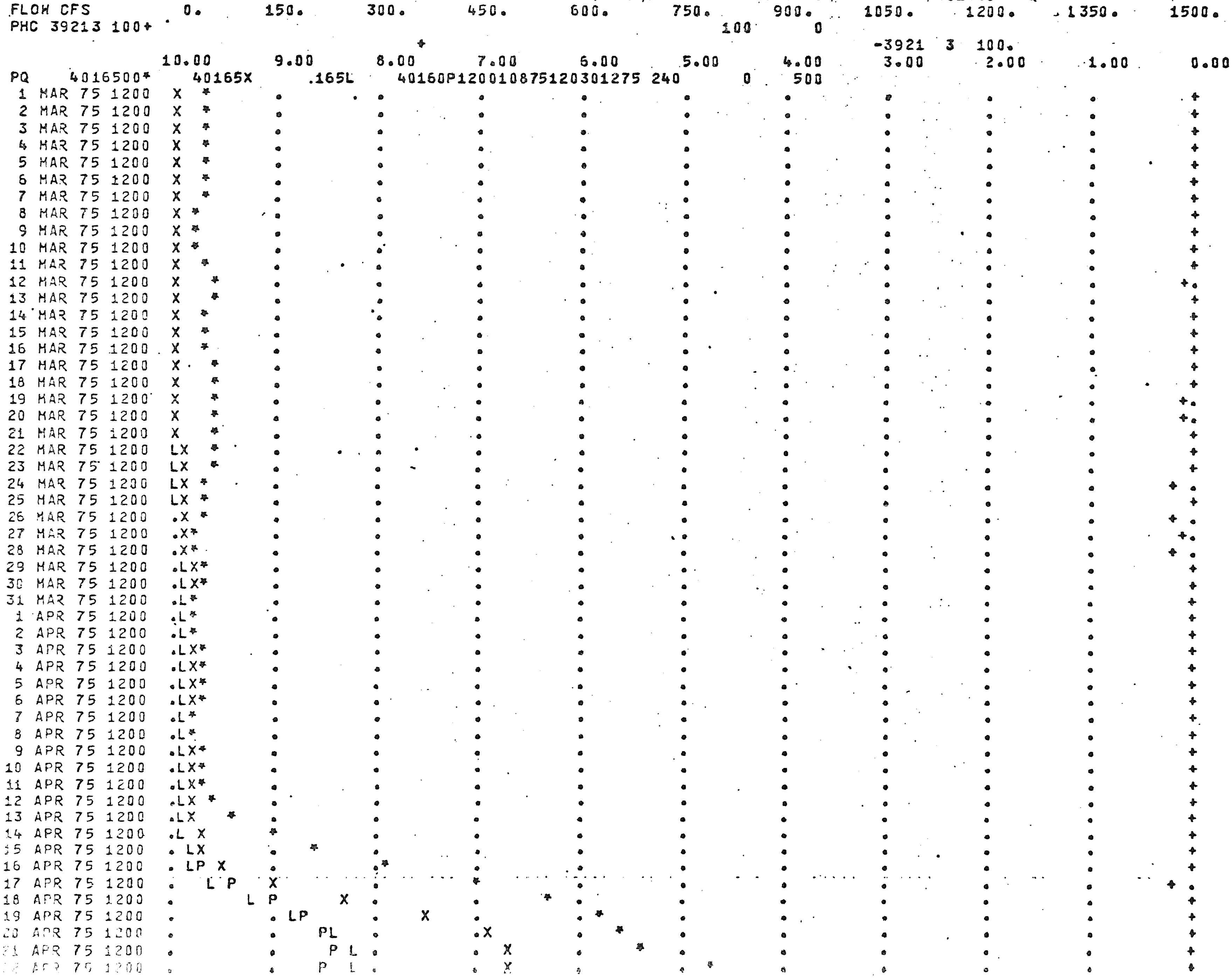


Fig. 14a

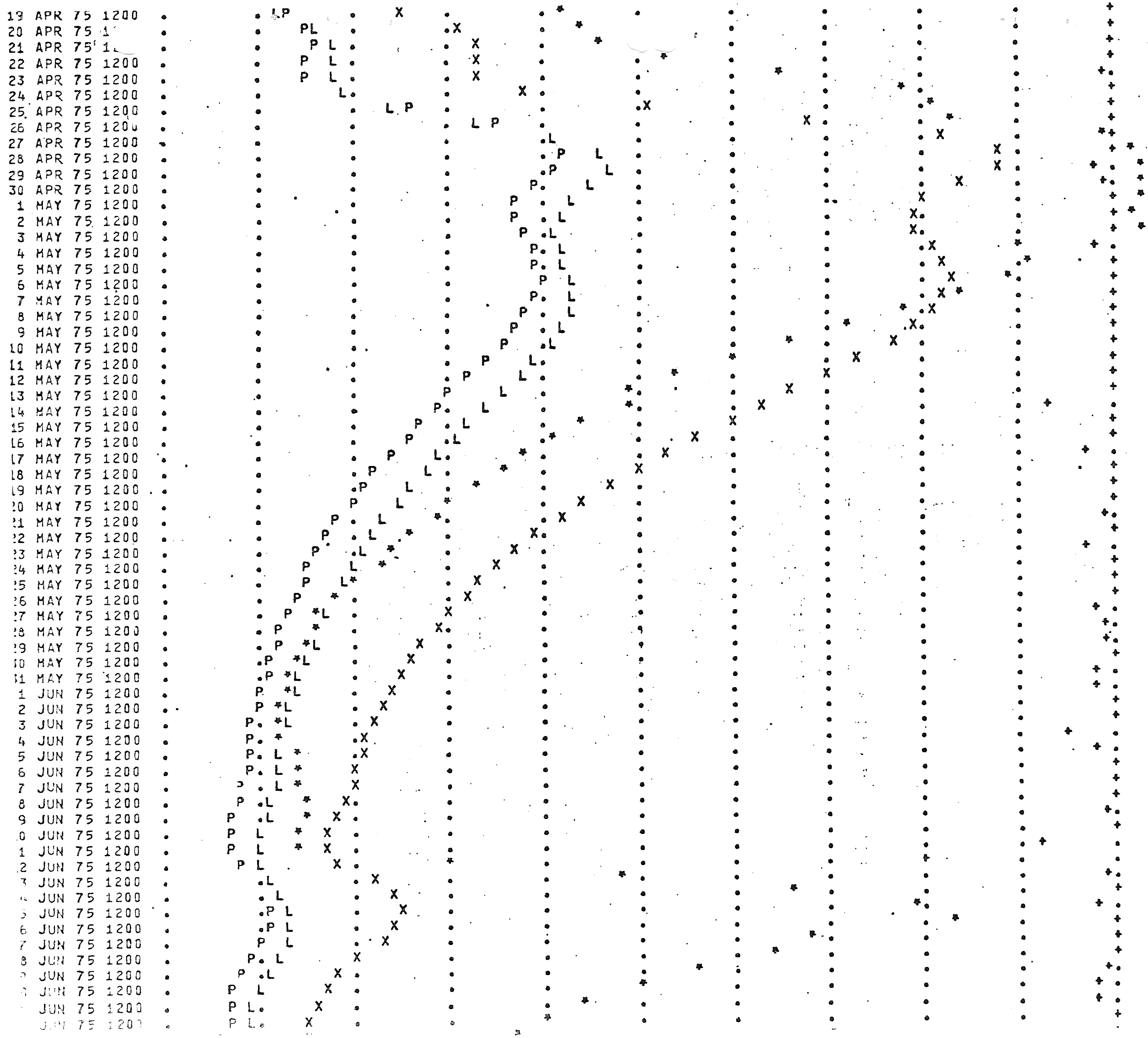

19 APR 75 1200
20 APR 75 1200
21 APR 75 1200
22 APR 75 1200
23 APR 75 1200
24 APR 75 1200
25 APR 75 1200
26 APR 75 1200
27 APR 75 1200
28 APR 75 1200
29 APR 75 1200
30 APR 75 1200
1 MAY 75 1200
2 MAY 75 1200
3 MAY 75 1200
4 MAY 75 1200
5 MAY 75 1200
6 MAY 75 1200
7 MAY 75 1200
8 MAY 75 1200
9 MAY 75 1200
10 MAY 75 1200
11 MAY 75 1200
12 MAY 75 1200
13 MAY 75 1200
14 MAY 75 1200
15 MAY 75 1200
16 MAY 75 1200
17 MAY 75 1200
18 MAY 75 1200
19 MAY 75 1200
20 MAY 75 1200
21 MAY 75 1200
22 MAY 75 1200
23 MAY 75 1200
24 MAY 75 1200
25 MAY 75 1200
26 MAY 75 1200
27 MAY 75 1200
28 MAY 75 1200
29 MAY 75 1200
30 MAY 75 1200
31 MAY 75 1200
1 JUN 75 1200
2 JUN 75 1200
3 JUN 75 1200
4 JUN 75 1200
5 JUN 75 1200
6 JUN 75 1200
7 JUN 75 1200
8 JUN 75 1200
9 JUN 75 1200
10 JUN 75 1200
11 JUN 75 1200
12 JUN 75 1200
13 JUN 75 1200
14 JUN 75 1200
15 JUN 75 1200
16 JUN 75 1200
17 JUN 75 1200
18 JUN 75 1200
19 JUN 75 1200
20 JUN 75 1200
21 JUN 75 1200
22 JUN 75 1200

Fig. 14b

198838

```
23 JUN 75 1200  .     P L .      X
24 JUN 75 1200  .     P L .     X     .         .  *      .         .         .         .         .         .         +
25 JUN 75 1200  .     P L .     X     .      *  .         .         .         .         .         .         .        +.
26 JUN 75 1200  .     P L .   X       .   *     .         .         .         .         .         .         .         +
27 JUN 75 1200  .    P L   . X       . *        .         .         .         .         .         .         .         +
28 JUN 75 1200  .    P L   . X       *          .         .         .         .         .         .         .         +
29 JUN 75 1200  .    P L   .X       *.          .         .         .         .         .         .         .         +
30 JUN 75 1200  .     PL   . X     *  .         .         .         .         .         .         .    +    .
 1 JUL 75 1200  .     PL   .  X     *.          .         .         .         .         .         .         .        +.
 2 JUL 75 1200  .         L.       X .          .*        .         .         .         .         .         .  +      .
 3 JUL 75 1200  .          . LP      .     X    .    *    .         .         .         .         .        +.         +
 4 JUL 75 1200  .          .  P L    .        X .      *  .         .         .         .         .         .         +
 5 JUL 75 1200  .          . P  L    .        X .      *  .         .         .         .         .         .   +     .
 6 JUL 75 1200  .          .  P  L   .         X.       *..         .         .         .         .         .         +
 7 JUL 75 1200  .          .     L   .          . X     *.          .         .         .         .   +     .         +
 8 JUL 75 1200  .          .        LP          .        X.  *      .         .         .         .         .         +
 9 JUL 75 1200  .          .         P L        .        .X *       .         .         .         .         .         +
10 JUL 75 1200  .          .       P . L        .       *X          .         .         .         .         .         +
11 JUL 75 1200  .          .    P     L         .    *   .          .         .         .         .         .         +
12 JUL 75 1200  .          .  P    L .          X*       .          .         .         .         .         .         +
13 JUL 75 1200  .          P    L      .     X *.        .          .         .         .         .         .         +
14 JUL 75 1200  .        P .  L        .X  *    .        .          .         .         .         .         .         +
15 JUL 75 1200  .       P  .L      X     *      .        .          .         .         .         .         .         +
16 JUL 75 1200  .      P  L.     X      .*      .        .          .         .         .         .         .         +
17 JUL 75 1200  .     P  L .  X       *.        .        .          .         .         .         .         .         +
18 JUL 75 1200  .     P L  . X     *   .        .        .          .         .         .         .         .         +
19 JUL 75 1200  .    P L   .X     *    .        .        .          .         .         .         .         .         +
20 JUL 75 1200  .    P L.  X *         .        .        .          .         .         .         .         .         +
21 JUL 75 1200  .    PL    X*          .        .        .          .         .         .         .         .        +.
22 JUL 75 1200  .    PL   X. *         .        .        .          .         .         .         .         .         +
23 JUL 75 1200  .    PL   X.*          .        .        .          .         .         .         .         .         +
24 JUL 75 1200  .     L    X*          .        .        .          .         .         .         .         .    +    .
25 JUL 75 1200  .     PL   *           .        .        .          .         .         .         .         .         +
26 JUL 75 1200  .     PL  *.X          .        .        .          .         .         .         .         .         +
27 JUL 75 1200  .     PL  *.X          .        .        .          .         .         .         .         .     +   .
28 JUL 75 1200  .    P L *  .X         .        .        .          .         .         .         .         .         +
29 JUL 75 1200  .    P L*   X          .        .        .          .         .         .         .         .         +
30 JUL 75 1200  .    P L* X.           .        .        .          .         .         .         .         .         +
31 JUL 75 1200  .   P *   X.           .        .        .          .         .         .         .         .         +
 1 AUG 75 1200  .   P L* X .           .        .        .          .         .         .         .         .        +.

* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

                                        PLOT       STATION NAME                                          STATION
                                       CHARACTER                                                          NUMBER CONTROL

                                          *-CORRECTED ST LOUIS                                           401650.0    Q
                                          X-CALCULATED AT ST LOUIS GAUGE                                   4016.5    Q
                                          L-CALCULATED ST LOUIS                                              16.5    Q
                                          P-CALCULATED FLOW,PARTRIDGE ABOVE SECOND                         4016.0    Q
FLOW CFS           0.        50.       100.      150.      200.      250.      300.      350.      400.      450.      500.
PHC 39213 100+                                                            100       0
                                                                                     -3921  3  100.
                10.00        9.00       8.00      7.00      6.00      5.00      4.00      3.00      2.00      1.00      0.00
END
    END OF FILE ON INPUT DECK

 1 AUG 75 1200  .         P    L    *.   X    .         .         .         .         .         .         .        +.
 2 AUG 75 1200  .        P.   L   *  .  X     .         .         .         .         .         .         .         +
 3 AUG 75 1200  .        P.  L    *  .  X     .         .         .         .         .         .         .         +
 4 AUG 75 1200  .        P.  L      *.  X     .         .         .         .         .         .         .        +.
 5 AUG 75 1200  .         P   L    * .  X     .         .         .         .         .         .         .        +.
 6 AUG 75 1200  .        P.   L    * .  X     .         .         .         .         .         .         .         +
 7 AUG 75 1200  .        P.   L *    . X      .         .         .         .         .         .         .         +
 8 AUG 75 1200  .       P .  L *    .X        .         .         .         .         .         .         .         +
```

Fig. 14c

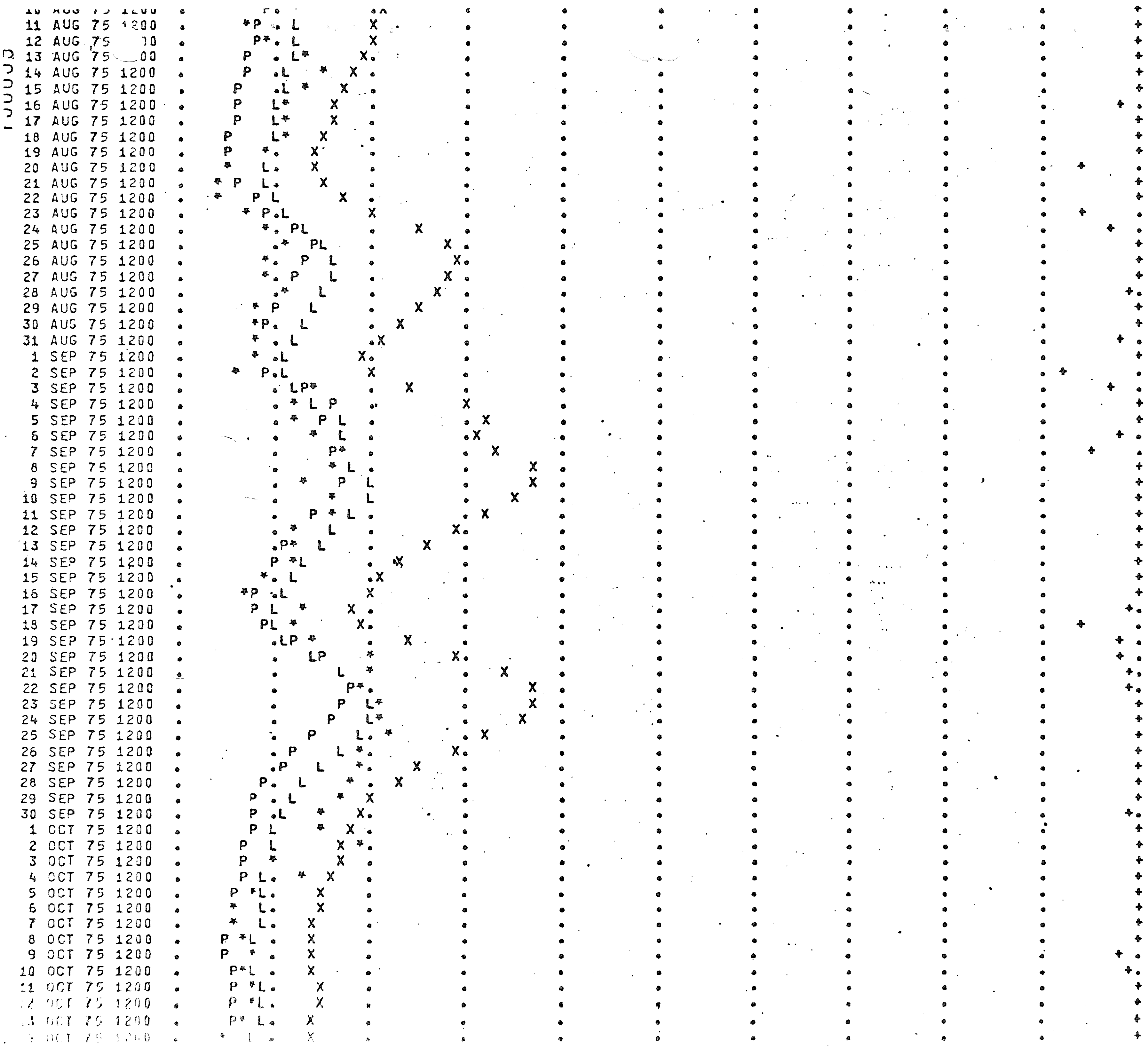

11 AUG 75 1200
12 AUG 75
13 AUG 75
14 AUG 75 1200
15 AUG 75 1200
16 AUG 75 1200
17 AUG 75 1200
18 AUG 75 1200
19 AUG 75 1200
20 AUG 75 1200
21 AUG 75 1200
22 AUG 75 1200
23 AUG 75 1200
24 AUG 75 1200
25 AUG 75 1200
26 AUG 75 1200
27 AUG 75 1200
28 AUG 75 1200
29 AUG 75 1200
30 AUG 75 1200
31 AUG 75 1200
1 SEP 75 1200
2 SEP 75 1200
3 SEP 75 1200
4 SEP 75 1200
5 SEP 75 1200
6 SEP 75 1200
7 SEP 75 1200
8 SEP 75 1200
9 SEP 75 1200
10 SEP 75 1200
11 SEP 75 1200
12 SEP 75 1200
13 SEP 75 1200
14 SEP 75 1200
15 SEP 75 1200
16 SEP 75 1200
17 SEP 75 1200
18 SEP 75 1200
19 SEP 75 1200
20 SEP 75 1200
21 SEP 75 1200
22 SEP 75 1200
23 SEP 75 1200
24 SEP 75 1200
25 SEP 75 1200
26 SEP 75 1200
27 SEP 75 1200
28 SEP 75 1200
29 SEP 75 1200
30 SEP 75 1200
1 OCT 75 1200
2 OCT 75 1200
3 OCT 75 1200
4 OCT 75 1200
5 OCT 75 1200
6 OCT 75 1200
7 OCT 75 1200
8 OCT 75 1200
9 OCT 75 1200
10 OCT 75 1200
11 OCT 75 1200
12 OCT 75 1200
13 OCT 75 1200

Fig. 14d

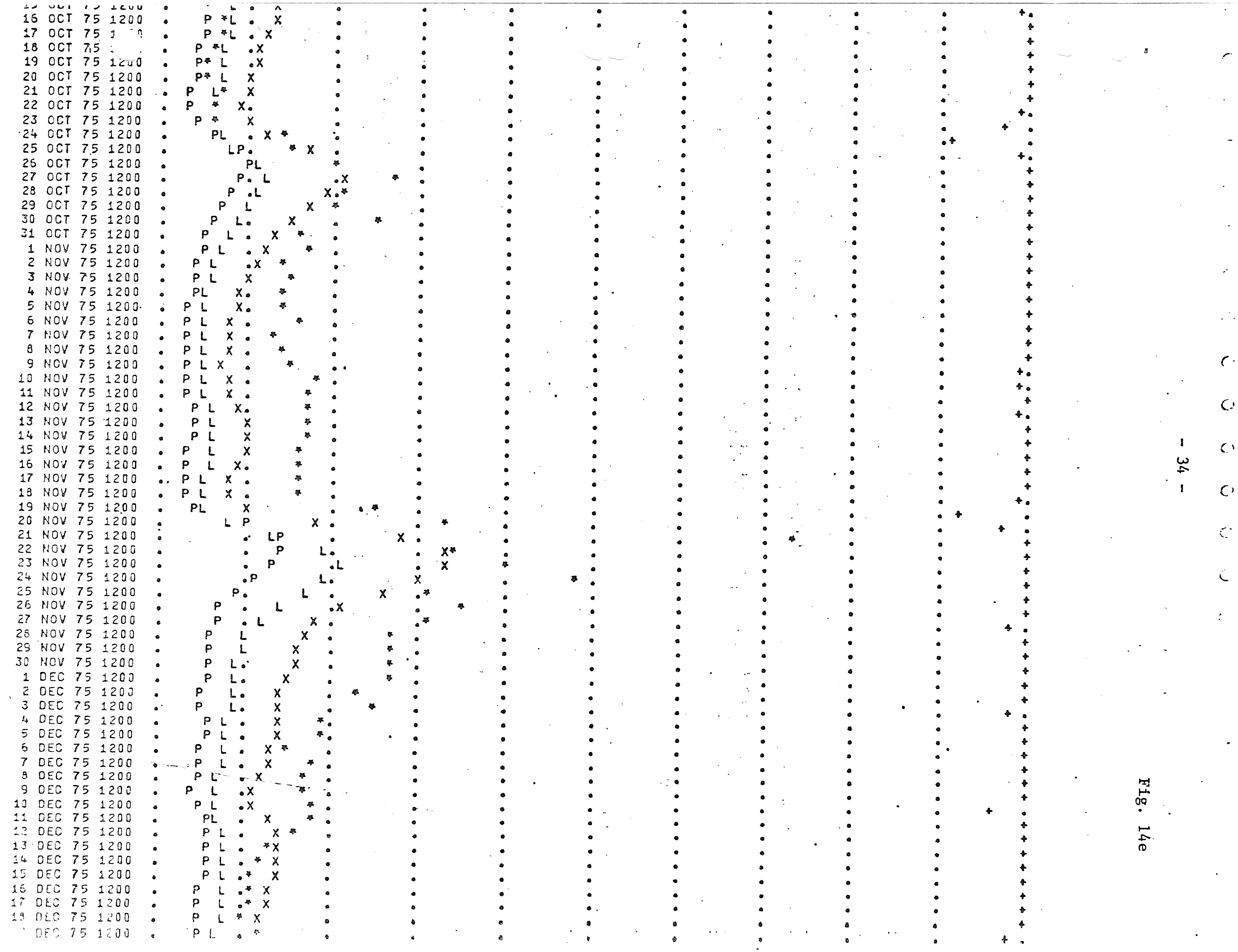

16 OCT 75 1200
17 OCT 75
18 OCT 75
19 OCT 75
20 OCT 75 1200
21 OCT 75 1200
22 OCT 75 1200
23 OCT 75 1200
24 OCT 75 1200
25 OCT 75 1200
26 OCT 75 1200
27 OCT 75 1200
28 OCT 75 1200
29 OCT 75 1200
30 OCT 75 1200
31 OCT 75 1200
1 NOV 75 1200
2 NOV 75 1200
3 NOV 75 1200
4 NOV 75 1200
5 NOV 75 1200
6 NOV 75 1200
7 NOV 75 1200
8 NOV 75 1200
9 NOV 75 1200
10 NOV 75 1200
11 NOV 75 1200
12 NOV 75 1200
13 NOV 75 1200
14 NOV 75 1200
15 NOV 75 1200
16 NOV 75 1200
17 NOV 75 1200
18 NOV 75 1200
19 NOV 75 1200
20 NOV 75 1200
21 NOV 75 1200
22 NOV 75 1200
23 NOV 75 1200
24 NOV 75 1200
25 NOV 75 1200
26 NOV 75 1200
27 NOV 75 1200
28 NOV 75 1200
29 NOV 75 1200
30 NOV 75 1200
1 DEC 75 1200
2 DEC 75 1200
3 DEC 75 1200
4 DEC 75 1200
5 DEC 75 1200
6 DEC 75 1200
7 DEC 75 1200
8 DEC 75 1200
9 DEC 75 1200
10 DEC 75 1200
11 DEC 75 1200
12 DEC 75 1200
13 DEC 75 1200
14 DEC 75 1200
15 DEC 75 1200
16 DEC 75 1200
17 DEC 75 1200
18 DEC 75 1200
DEC 75 1200

Fig. 14e

148861

```
21 DEC 75 ·200  .    P  L. *   X    .    .    .    .    .    .    .    .    +
22 DEC 75    00  .    P  *  .   X    .    .    .    .    .    .    .    .    +
23 DEC 75  _00  .    P  *  .  X     .    .    .    .    .    .    .    .    +
24 DEC 75 1200  .   P  L* .  X     .    .    .    .    .    .    .    .    +
25 DEC 75 1200  .    P *   .  X     .    .    .    .    .    .    .    .    +
26 DEC 75 1200  .    P *   .  X     .    .    .    .    .    .    .    .    +
27 DEC 75 1200  .   P   *  .X      .    .    .    .    .    .    .    .    +
28 DEC 75 1200  .   P   *  .X      .    .    .    .    .    .    .    .    +
29 DEC 75 1200  .   P   *  X       .    .    .    .    .    .    .    .    +
30 DEC 75 1200  .  P  L*   X       .    .    .    .    .    .    .    .    +
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
```


Fig. 14f

787699

CHARACTER

STATION NUMBER CONTROL

CHARACTER	STATION NUMBER	CONTROL
*-OBSERVED FLOW STONY	512550.0	Q
X-CALCULATED FLOW STONY	5125.5	Q
S-SNOW BASIN STONY	512550.1	Q
R-STONY RAIN BASIN	512550.2	Q

FLOW CFS 0. 150. 300. 450. 600. 750. 900. 1050. 1200. 1350. 1500.

PHC 40683 100+ 100 0

10.00 9.00 8.00 7.00 6.00 5.00 4.00 3.00 2.00 1.00 0.00

-4068 3 100.

PQ 5126000* 51260X 5126001S 5126002R 120010660 240 0 500

1 JAN 60 1200	X *
2 JAN 60 1200	RX*
3 JAN 60 1200	RX*
4 JAN 60 1200	R *
5 JAN 60 1200	R *
6 JAN 60 1200	R *X
7 JAN 60 1200	.R*X
8 JAN 60 1200	.R*SX
9 JAN 60 1200	.R*SX
10 JAN 60 1200	.R*SX
11 JAN 60 1200	.R* SX
12 JAN 60 1200	.R* SX
13 JAN 60 1200	.R* SX
14 JAN 60 1200	.R* SX
15 JAN 60 1200	.R* SX
16 JAN 60 1200	.R* SX
17 JAN 60 1200	.R* SX
18 JAN 60 1200	.R* SX
19 JAN 60 1200	.R* SX
20 JAN 60 1200	.R* SX
21 JAN 60 1200	.R* SX
22 JAN 60 1200	.R* X
23 JAN 60 1200	.R* X
24 JAN 60 1200	.R*SX
25 JAN 60 1200	.R*SX
26 JAN 60 1200	.R*SX
27 JAN 60 1200	.R*SX
28 JAN 60 1200	R *X
29 JAN 60 1200	R *X
30 JAN 60 1200	R *X
31 JAN 60 1200	R *X
1 FEB 60 1200	R *X
2 FEB 60 1200	R*SX
3 FEB 60 1200	R*SX
4 FEB 60 1200	R*X
5 FEB 60 1200	R*X
6 FEB 60 1200	R*X
7 FEB 60 1200	R*X
8 FEB 60 1200	R*X
9 FEB 60 1200	R*X
10 FEB 60 1200	R*X
11 FEB 60 1200	R*X
12 FEB 60 1200	R*X
13 FEB 60 1200	R*X
14 FEB 60 1200	R*
15 FEB 60 1200	R*
16 FEB 60 1200	R*
17 FEB 60 1200	R*
18 FEB 60 1200	R*
19 FEB 60 1200	R*
20 FEB 60 1200	R*
21 FEB 60 1200	R*
22 FEB 60 1200	R*

Fig. 15a

787700

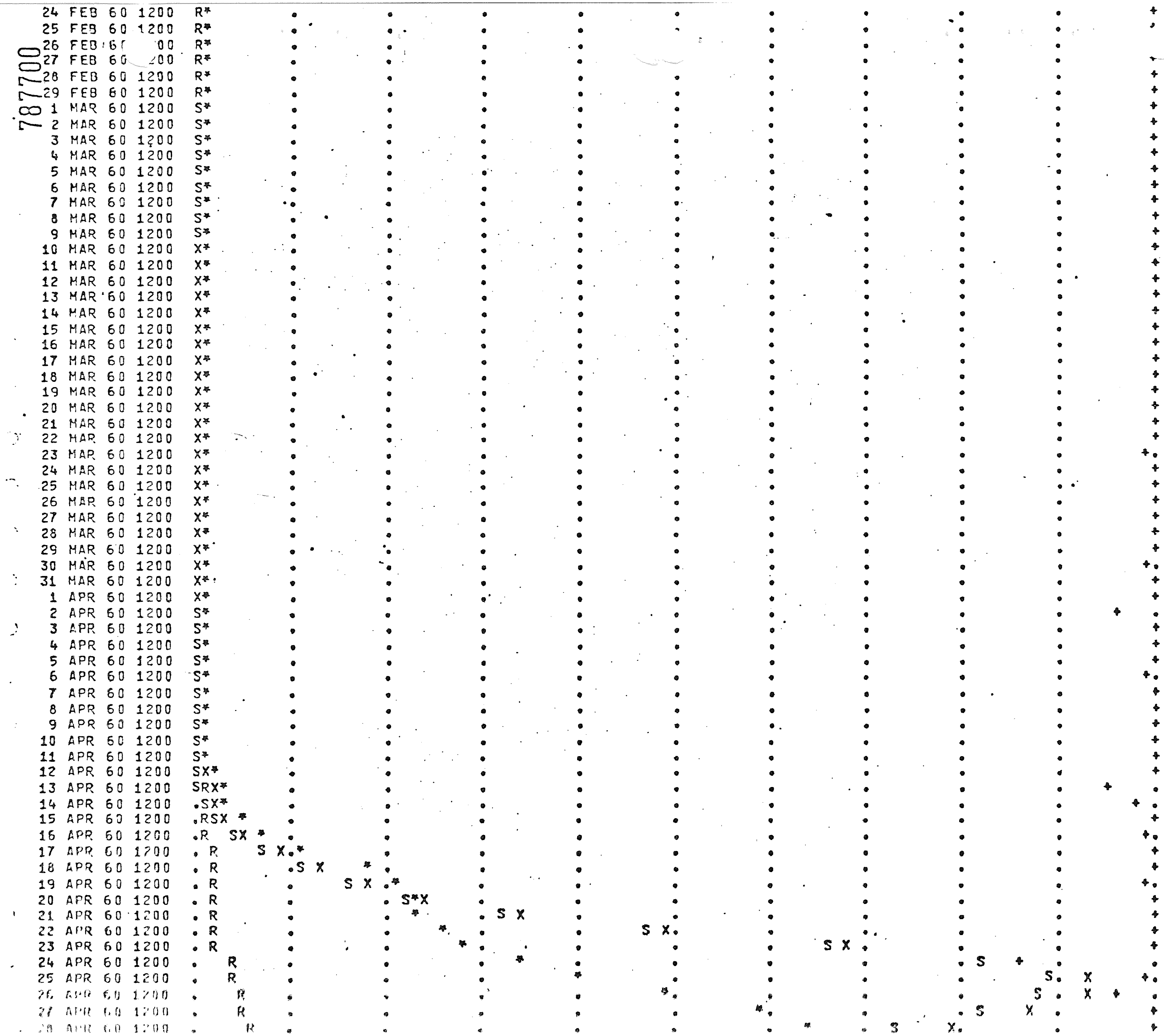


Fig. 15b

- 37 -

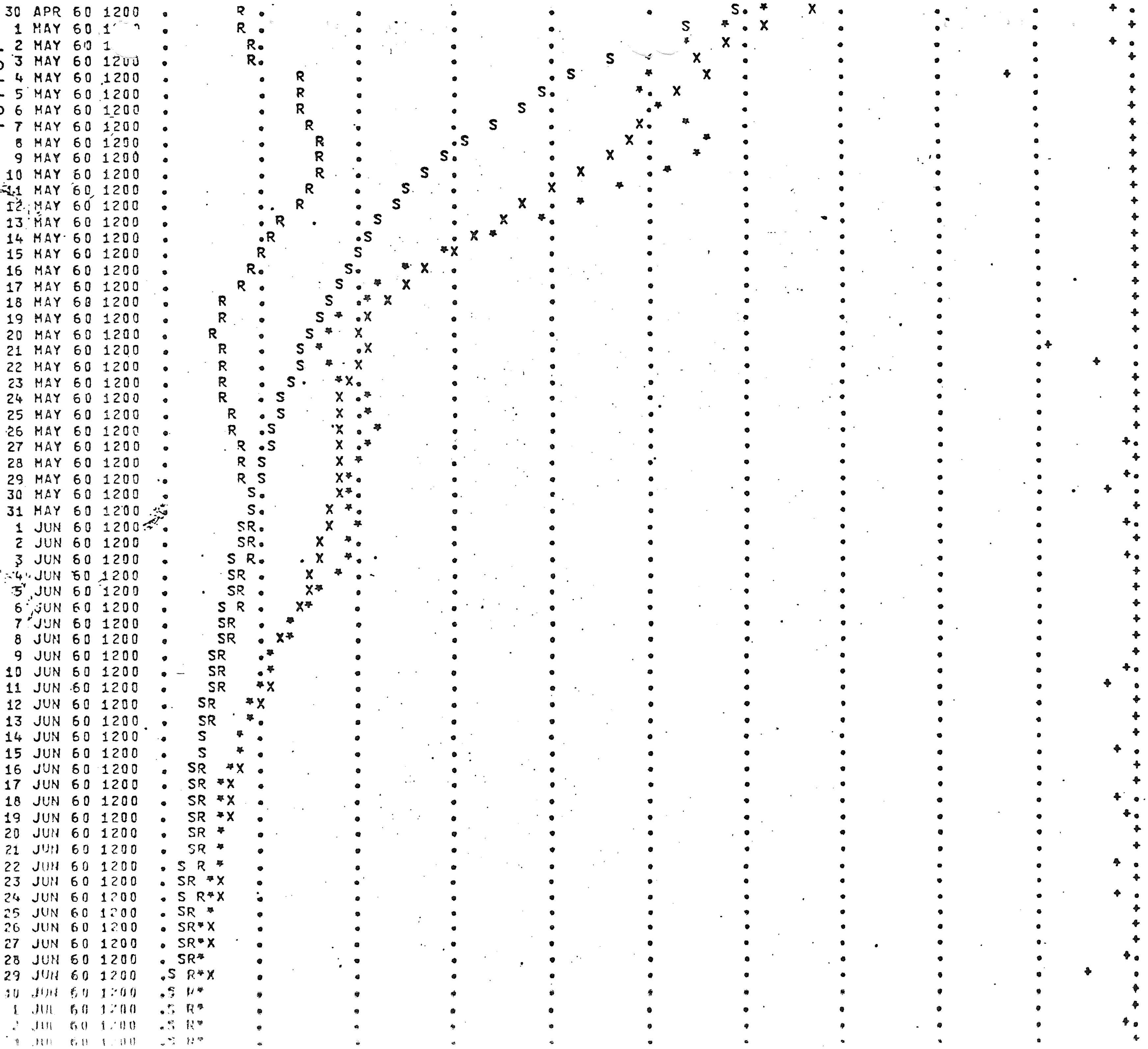

30 APR 60 1200
1 MAY 60
2 MAY 60 1
3 MAY 60 1200
4 MAY 60 1200
5 MAY 60 1200
6 MAY 60 1200
7 MAY 60 1200
8 MAY 60 1200
9 MAY 60 1200
10 MAY 60 1200
11 MAY 60 1200
12 MAY 60 1200
13 MAY 60 1200
14 MAY 60 1200
15 MAY 60 1200
16 MAY 60 1200
17 MAY 60 1200
18 MAY 60 1200
19 MAY 60 1200
20 MAY 60 1200
21 MAY 60 1200
22 MAY 60 1200
23 MAY 60 1200
24 MAY 60 1200
25 MAY 60 1200
26 MAY 60 1200
27 MAY 60 1200
28 MAY 60 1200
29 MAY 60 1200
30 MAY 60 1200
31 MAY 60 1200
1 JUN 60 1200
2 JUN 60 1200
3 JUN 60 1200
4 JUN 60 1200
5 JUN 60 1200
6 JUN 60 1200
7 JUN 60 1200
8 JUN 60 1200
9 JUN 60 1200
10 JUN 60 1200
11 JUN 60 1200
12 JUN 60 1200
13 JUN 60 1200
14 JUN 60 1200
15 JUN 60 1200
16 JUN 60 1200
17 JUN 60 1200
18 JUN 60 1200
19 JUN 60 1200
20 JUN 60 1200
21 JUN 60 1200
22 JUN 60 1200
23 JUN 60 1200
24 JUN 60 1200
25 JUN 60 1200
26 JUN 60 1200
27 JUN 60 1200
28 JUN 60 1200
29 JUN 60 1200
30 JUN 60 1200
1 JUL 60 1200

Fig. 15c

787702

```
 4 JUL 60 1200 .S R*
 5 JUL 60 1200 .SRX*
 6 JUL 60 1200 .SR*
 7 JUL 60 1200 .SR*
 8 JUL 60 1200 .SR*
 9 JUL 60 1200 .SR*
10 JUL 60 1200 .SX*
11 JUL 60 1200 .SX*
12 JUL 60 1200 .S*
13 JUL 60 1200 .S*
14 JUL 60 1200 .X*
15 JUL 60 1200 SX*
16 JUL 60 1200 S *
17 JUL 60 1200 S X*
18 JUL 60 1200 S R*
19 JUL 60 1200 S  *
20 JUL 60 1200 S  X*
21 JUL 60 1200 S  X*
22 JUL 60 1200 S    X*
23 JUL 60 1200 S    X*
24 JUL 60 1200 S    *
25 JUL 60 1200 S      *X
26 JUL 60 1200 S      *
27 JUL 60 1200 S      *
28 JUL 60 1200 S      *
29 JUL 60 1200 S      *
30 JUL 60 1200 S      *  X
31 JUL 60 1200 S      *X
 1 AUG 60 1200 S      *X
 2 AUG 60 1200 S      *X
 3 AUG 60 1200 S      *X
 4 AUG 60 1200 S      *X
 5 AUG 60 1200 S    *RX
 6 AUG 60 1200 S    *X
 7 AUG 60 1200 S    *X
 8 AUG 60 1200 S    *X
 9 AUG 60 1200 S    *X
10 AUG 60 1200 S    *
11 AUG 60 1200 S   *X
12 AUG 60 1200 S   *X
13 AUG 60 1200 S   *
14 AUG 60 1200 S   *
15 AUG 60 1200 S *X
16 AUG 60 1200 S *X
17 AUG 60 1200 S *
18 AUG 60 1200 S *
19 AUG 60 1200 S *
20 AUG 60 1200 S *
21 AUG 60 1200 S *
22 AUG 60 1200 SR*
23 AUG 60 1200 SX*
24 AUG 60 1200 SX*
25 AUG 60 1200 SX*
26 AUG 60 1200 SX*
27 AUG 60 1200 S*
28 AUG 60 1200 S*
29 AUG 60 1200 S*
30 AUG 60 1200 S*
31 AUG 60 1200 *X
 1 SEP 60 1200 S*
 2 SEP 60 1200 S*
 3 SEP 60 1200 S*
 4 SEP 60 1200 S*
 5 SEP 60 1200 S*
 6 SEP 60 1200 S*
```

Fig. 15d

```
 8 SEP 60 1200 S*
 9 SEP 60 1200 S*
10 SEP 60 1200 S*
11 SEP 60 1200 S*
12 SEP 60 1200 S*
13 SEP 60 1200 S*
14 SEP 60 1200 S*
15 SEP 60 1200 S*
16 SEP 60 1200 S*
17 SEP 60 1200 S*
18 SEP 60 1200 S*
19 SEP 60 1200 S*
20 SEP 60 1200 X*
21 SEP 60 1200 X*
22 SEP 60 1200 X*
23 SEP 60 1200 X*
24 SEP 60 1200 S*
25 SEP 60 1200 S*
26 SEP 60 1200 S*
27 SEP 60 1200 S*
28 SEP 60 1200 S*
29 SEP 60 1200 S*
30 SEP 60 1200 S*
 1 OCT 60 1200 S*
 2 OCT 60 1200 S*
 3 OCT 60 1200 S*
 4 OCT 60 1200 S*
 5 OCT 60 1200 S*
 6 OCT 60 1200 S*
 7 OCT 60 1200 S*
 8 OCT 60 1200 S*
 9 OCT 60 1200 S*
10 OCT 60 1200 X*
11 OCT 60 1200 X*
12 OCT 60 1200 X*
13 OCT 60 1200 S*
14 OCT 60 1200 S*
15 OCT 60 1200 S*
16 OCT 60 1200 S*
17 OCT 60 1200 S*
18 OCT 60 1200 S*
19 OCT 60 1200 S*
20 OCT 60 1200 S*
21 OCT 60 1200 S*
22 OCT 60 1200 S*
23 OCT 60 1200 S*
24 OCT 60 1200 S*
25 OCT 60 1200 S*
26 OCT 60 1200 S*
27 OCT 60 1200 S*
28 OCT 60 1200 S*
29 OCT 60 1200 S*
30 OCT 60 1200 S*X
31 OCT 60 1200 S*X
 1 NOV 60 1200 S* X
 2 NOV 60 1200 S*  X
 3 NOV 60 1200 S*  X
 4 NOV 60 1200 S*   X
 5 NOV 60 1200 S*   X
 6 NOV 60 1200 S*    X
 7 NOV 60 1200 S *   X
 8 NOV 60 1200 S *   X
 9 NOV 60 1200 S *   X
10 NOV 60 1200 S  *  X
11 NOV 60 1200 S  *    X
```

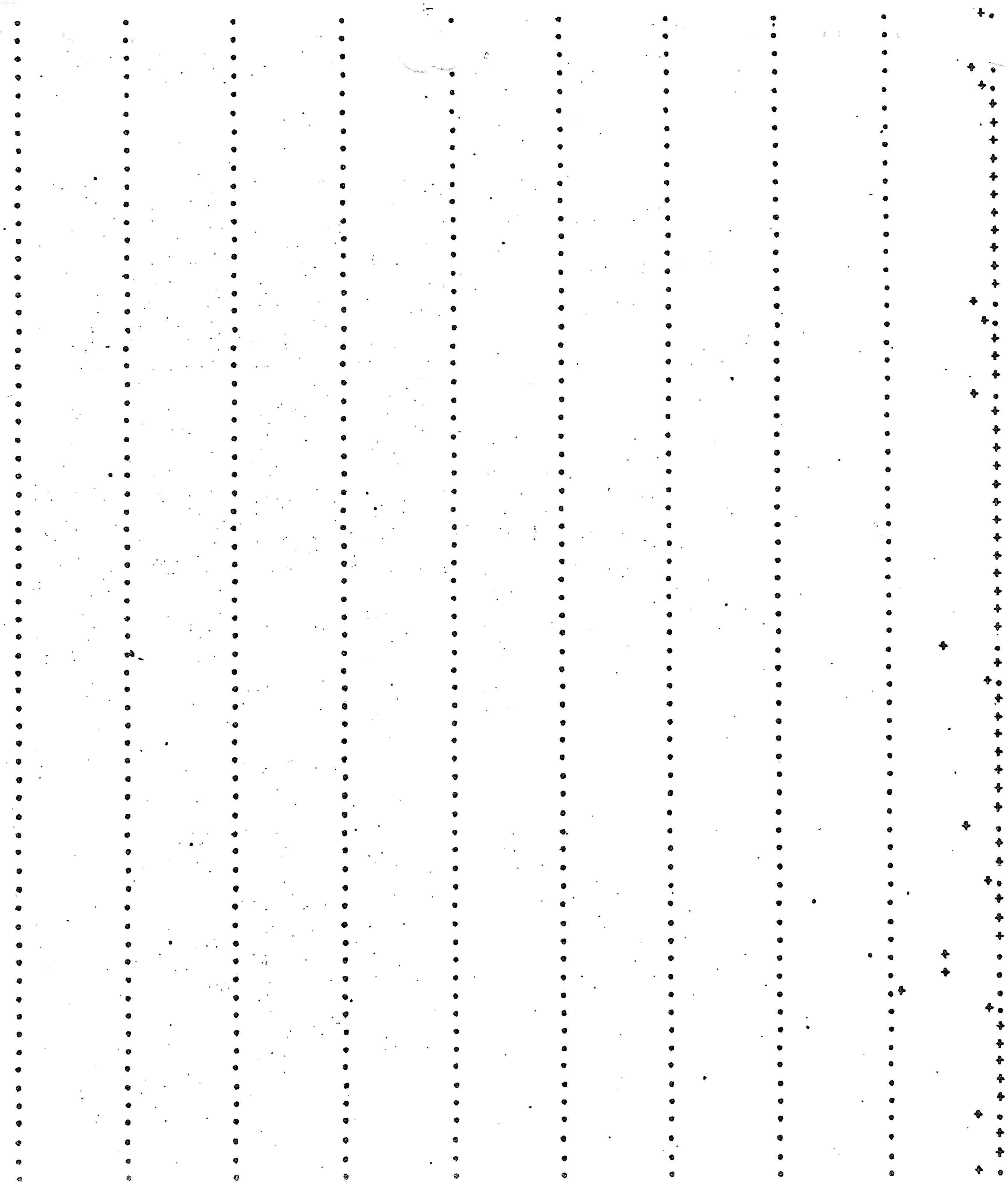


Fig. 15e

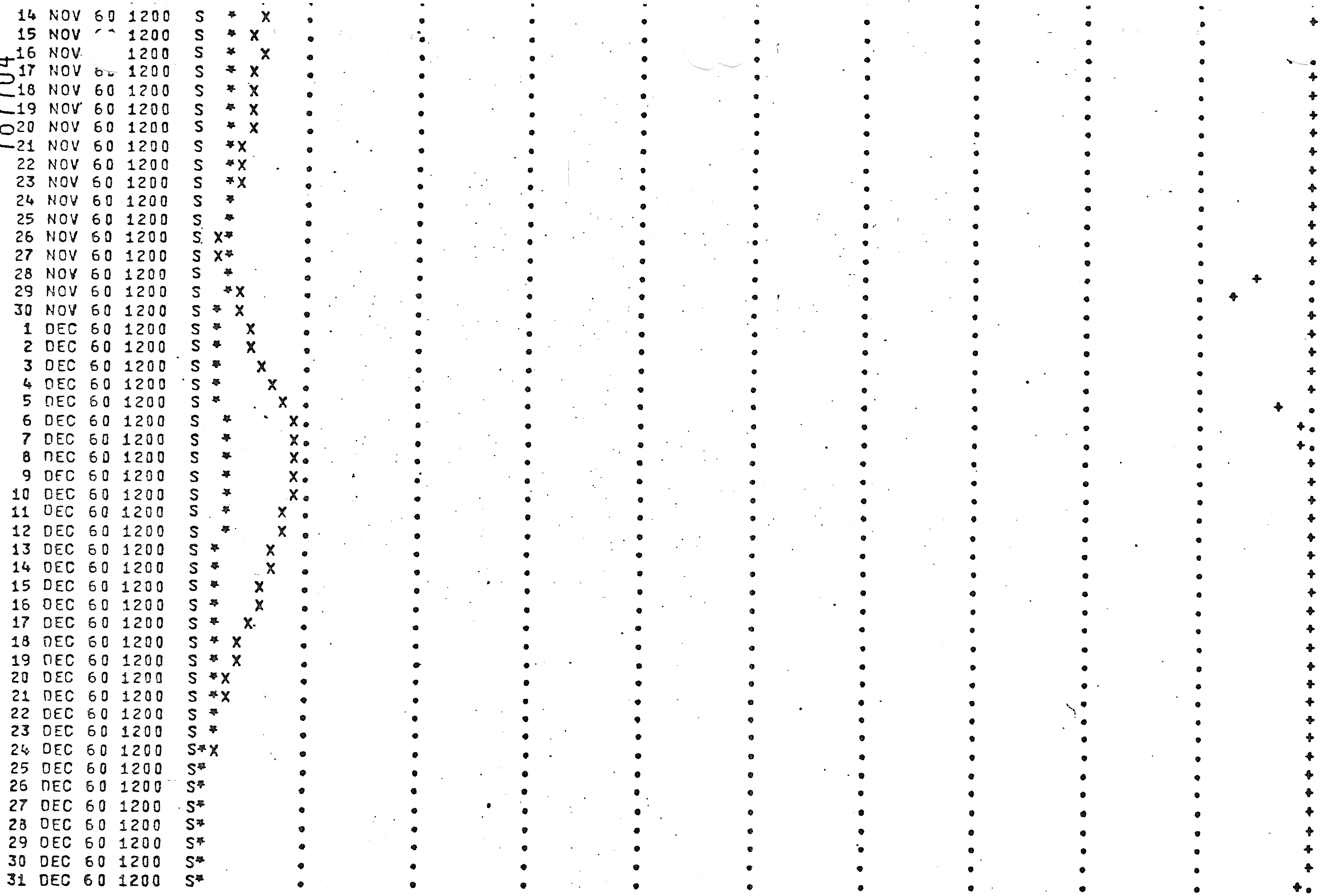

14 NOV 60 1200 S
15 NOV 1200 S
16 NOV 1200 S
17 NOV 1200 S
18 NOV 60 1200 S
19 NOV 60 1200 S
20 NOV 60 1200 S
21 NOV 60 1200 S
22 NOV 60 1200 S
23 NOV 60 1200 S
24 NOV 60 1200 S
25 NOV 60 1200 S
26 NOV 60 1200 S
27 NOV 60 1200 S
28 NOV 60 1200 S
29 NOV 60 1200 S
30 NOV 60 1200 S
1 DEC 60 1200 S
2 DEC 60 1200 S
3 DEC 60 1200 S
4 DEC 60 1200 S
5 DEC 60 1200 S
6 DEC 60 1200 S
7 DEC 60 1200 S
8 DEC 60 1200 S
9 DEC 60 1200 S
10 DEC 60 1200 S
11 DEC 60 1200 S
12 DEC 60 1200 S
13 DEC 60 1200 S
14 DEC 60 1200 S
15 DEC 60 1200 S
16 DEC 60 1200 S
17 DEC 60 1200 S
18 DEC 60 1200 S
19 DEC 60 1200 S
20 DEC 60 1200 S
21 DEC 60 1200 S
22 DEC 60 1200 S
23 DEC 60 1200 S
24 DEC 60 1200 S
25 DEC 60 1200 S
26 DEC 60 1200 S
27 DEC 60 1200 S
28 DEC 60 1200 S
29 DEC 60 1200 S
30 DEC 60 1200 S
31 DEC 60 1200 S

Fig. 15f

in 1961 (Fig. 16) the calculated Stony is a good fit for all periods except for a segment in September. Again it is assumed that rainfall data are inadequate.

The calculated data for the Dunka (Fig. 17) overpredicted snow runoff and underpredicted spring rains in 1960. The remaining low flow period for the rest of the year showed good agreement. In 1961 (Fig. 18) the calculated Dunka was underpredicted for snowmelt events and also for spring rains. The remaining part of the year was fitted very well for rain events and low flow periods. If time permits, additional fitting runs will be performed.

At the Kawishiwi watershed outlet at Winton for 1960 (Fig. 19) the computed snowmelt event peaked a little faster than the observed. The remaining part of the year was modeled fairly well except for November and December. The latter difference was caused by a failure of the SSARR to store the snowfall in November and December when the temperature is usually below 32°F or 0°C. While it does store snowfall in the winter and early spring, adding it to the snowpack it does not do so in the fall and early winter. As a result, it shows surface runoff when none occurs. The observed data at Winton must be taken as a general trend. The Winton Dam is just above the Gauging station and at flows below 1000 cfs; the river flow is regulated by man instead of by natural conditions. For 1961 (Fig. 20) the snowmelt flood is overpredicted and spring rain flows underpredicted. Except for overpredicting a September rain event, the remaining portion of the year showed good agreement especially for low flow periods.

MINING DEVELOPMENT DESCRIPTION

The Regional Copper-Nickel Study provided a mining development scheme for the St. Louis and Kawishiwi River watersheds. The proposed developments were designated for subwatershed areas and local inflow areas. The general locations can be seen in Fig. 1.

The developments included underground and open pit mines, stockpiles of overburden, waste rock, and lean ores, processing plants, smelter/refinery, and tailing ponds. In Table VIII the subwatershed unit and associated development are listed.

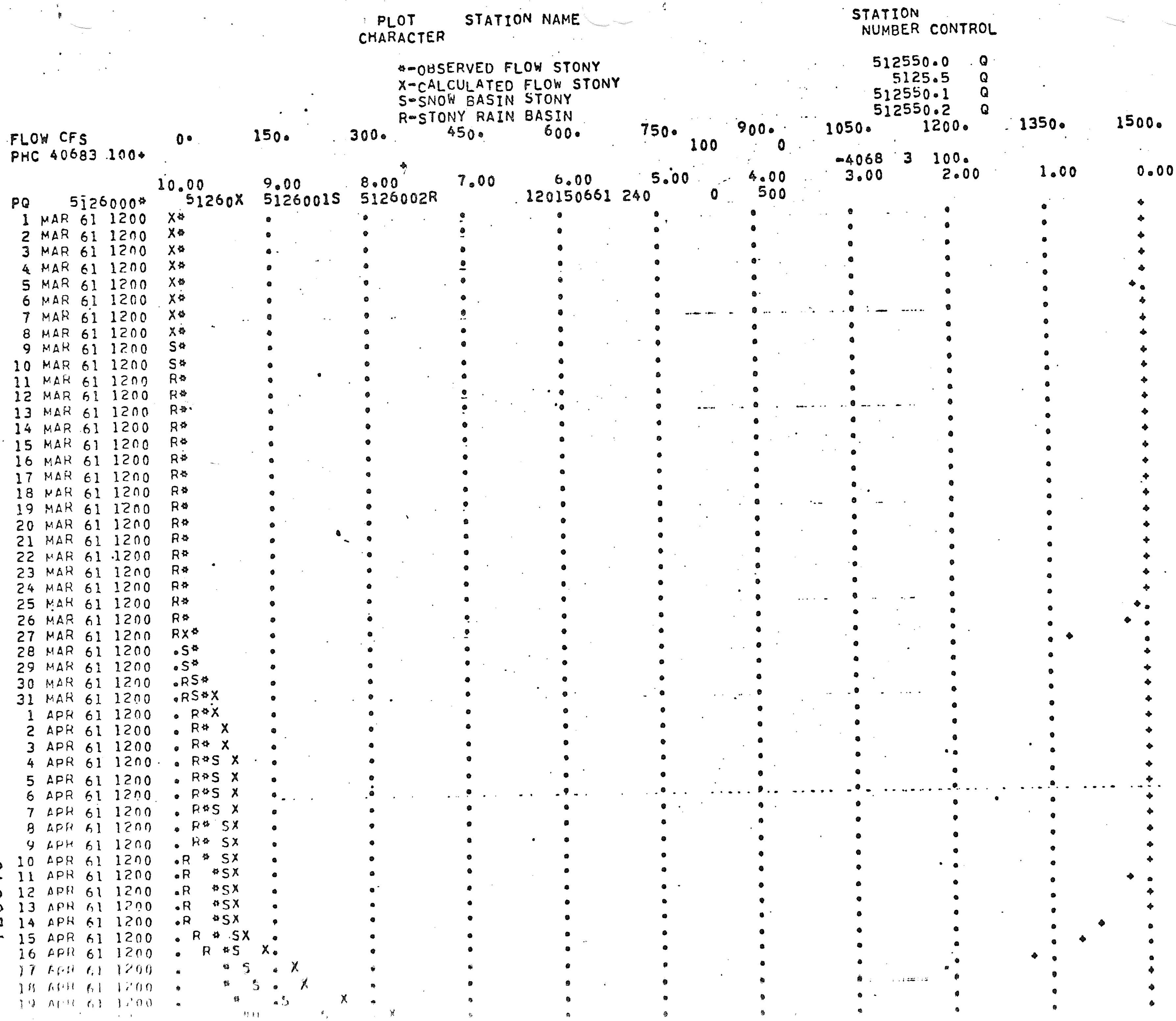

PLOT CHARACTER
STATION NAME
STATION NUMBER CONTROL
*-OBSERVED FLOW STONY 512550.0 Q
X-CALCULATED FLOW STONY 5125.5 Q
S-SNOW BASIN STONY 512550.1 Q
R-STONY RAIN BASIN 512550.2 Q
FLOW CFS 0. 150. 300. 450. 600. 750. 900. 1050. 1200. 1350. 1500.
PHC 40683 100+
10.00 9.00 8.00 7.00 6.00 5.00 4.00 3.00 2.00 1.00 0.00
PQ 5126000* 51260X 5126001S 5126002R 120150661 240 0 500
1 MAR 61 1200
31 MAR 61 1200
1 APR 61 1200
16 APR 61 1200

Fig. 16a

123643

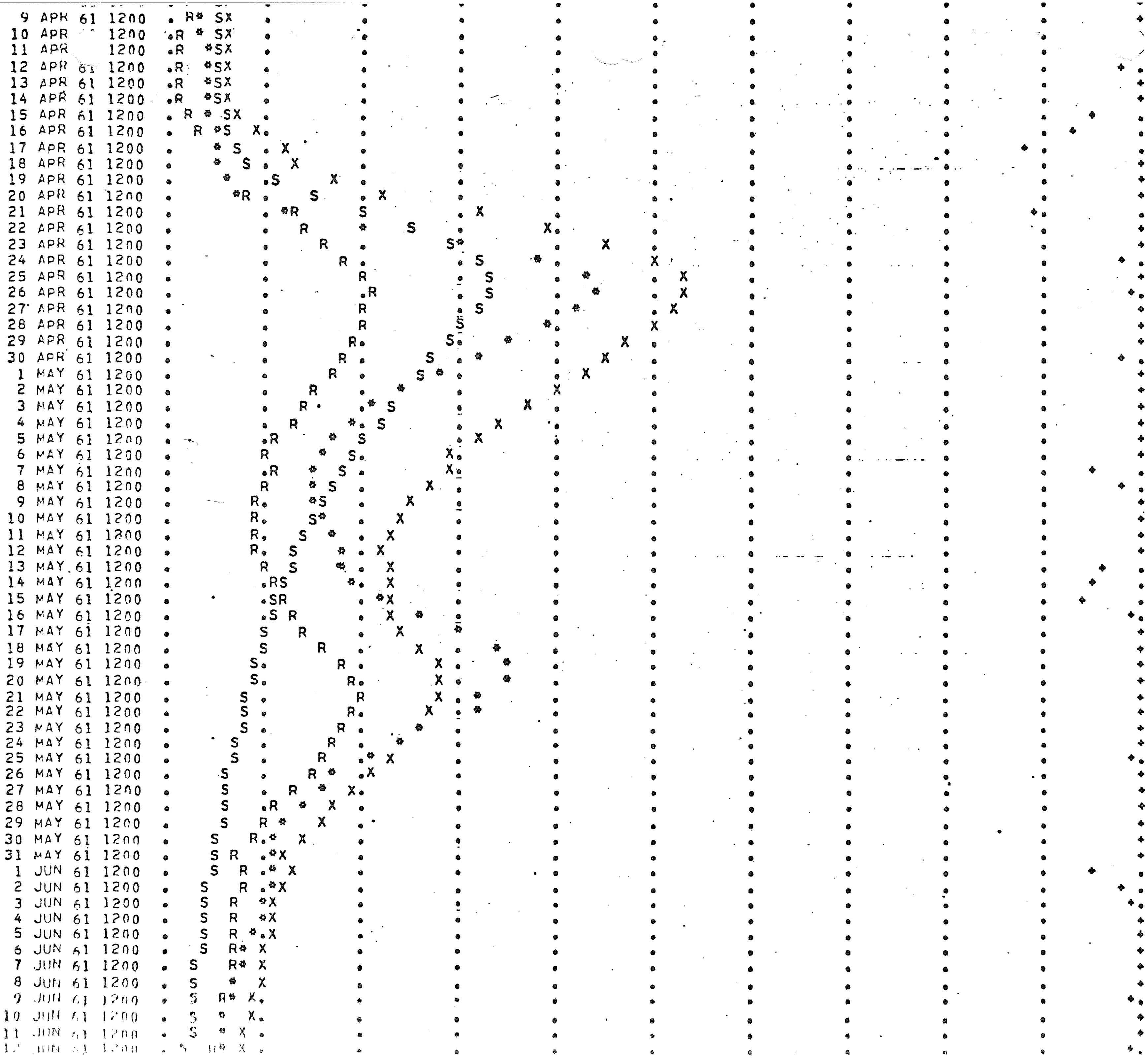


Fig. 16b

123644

12 JUN 61	1200	. S R* X
13 JUN 61	1200	. S * X
14 JUN [illegible]	1200	. S * X
15 JUN [illegible]	1200	. S R*X
16 JUN 61	1200	. S R*X
17 JUN 61	1200	. S *X
18 JUN 61	1200	. SR*X
19 JUN 61	1200	. SR*
20 JUN 61	1200	. SR*
21 JUN 61	1200	.SR *
22 JUN 61	1200	.SR*
23 JUN 61	1200	.SR*
24 JUN 61	1200	.SR*
25 JUN 61	1200	.SX*
26 JUN 61	1200	.SX*
27 JUN 61	1200	.SX*
28 JUN 61	1200	.SX*
29 JUN 61	1200	.S*
30 JUN 61	1200	.S*
1 JUL 61	1200	.X*
2 JUL 61	1200	.X*
3 JUL 61	1200	.X*
4 JUL 61	1200	.X*
5 JUL 61	1200	.X*
6 JUL 61	1200	.X*
7 JUL 61	1200	SX*
8 JUL 61	1200	S*
9 JUL 61	1200	S*
10 JUL 61	1200	S*
11 JUL 61	1200	S*
12 JUL 61	1200	S*
13 JUL 61	1200	S*
14 JUL 61	1200	S*
15 JUL 61	1200	SX*
16 JUL 61	1200	SX*
17 JUL 61	1200	S*
18 JUL 61	1200	S*
19 JUL 61	1200	SX*
20 JUL 61	1200	S*
21 JUL 61	1200	S*
22 JUL 61	1200	S*
23 JUL 61	1200	S*
24 JUL 61	1200	SR*
25 JUL 61	1200	SR*
26 JUL 61	1200	S*X
27 JUL 61	1200	S*X
28 JUL 61	1200	S*X
29 JUL 61	1200	S*X
30 JUL 61	1200	S*X
31 JUL 61	1200	S*X
1 AUG 61	1200	S*X
2 AUG 61	1200	S*X
3 AUG 61	1200	S*X
4 AUG 61	1200	S*
5 AUG 61	1200	S*
6 AUG 61	1200	S*
7 AUG 61	1200	S*
8 AUG 61	1200	S*
9 AUG 61	1200	S*
10 AUG 61	1200	S*
11 AUG 61	1200	S*
12 AUG 61	1200	S*
13 AUG 61	1200	S*
14 AUG 61	1200	S*
15 AUG 61	1200	S*
16 AUG 61	1200	*

Fig. 16c

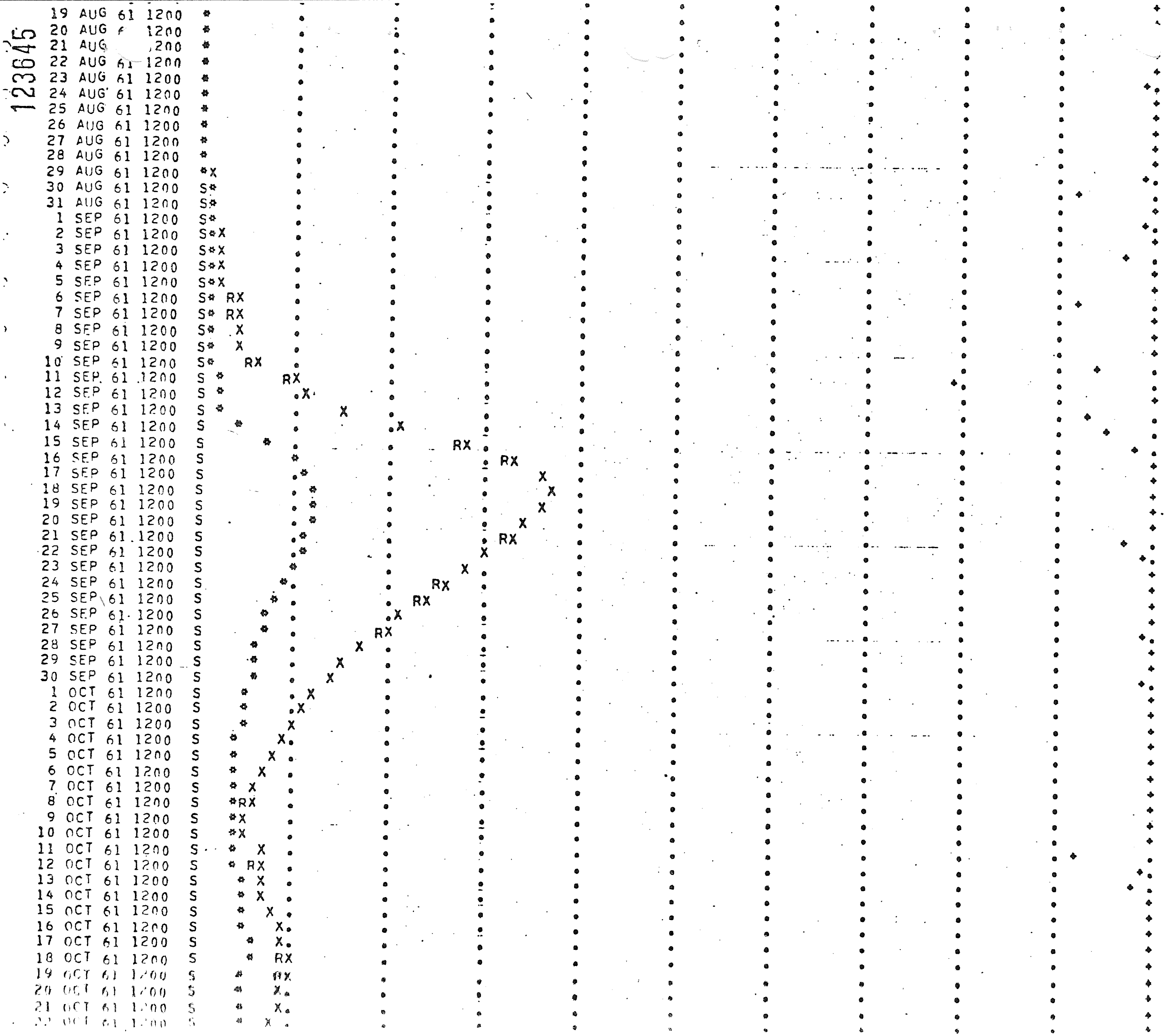

123645
19 AUG 61 1200
20 AUG 1200
21 AUG 200
22 AUG 61 1200
23 AUG 61 1200
24 AUG 61 1200
25 AUG 61 1200
26 AUG 61 1200
27 AUG 61 1200
28 AUG 61 1200
29 AUG 61 1200
30 AUG 61 1200
31 AUG 61 1200
1 SEP 61 1200
2 SEP 61 1200
3 SEP 61 1200
4 SEP 61 1200
5 SEP 61 1200
6 SEP 61 1200
7 SEP 61 1200
8 SEP 61 1200
9 SEP 61 1200
10 SEP 61 1200
11 SEP 61 1200
12 SEP 61 1200
13 SEP 61 1200
14 SEP 61 1200
15 SEP 61 1200
16 SEP 61 1200
17 SEP 61 1200
18 SEP 61 1200
19 SEP 61 1200
20 SEP 61 1200
21 SEP 61 1200
22 SEP 61 1200
23 SEP 61 1200
24 SEP 61 1200
25 SEP 61 1200
26 SEP 61 1200
27 SEP 61 1200
28 SEP 61 1200
29 SEP 61 1200
30 SEP 61 1200
1 OCT 61 1200
2 OCT 61 1200
3 OCT 61 1200
4 OCT 61 1200
5 OCT 61 1200
6 OCT 61 1200
7 OCT 61 1200
8 OCT 61 1200
9 OCT 61 1200
10 OCT 61 1200
11 OCT 61 1200
12 OCT 61 1200
13 OCT 61 1200
14 OCT 61 1200
15 OCT 61 1200
16 OCT 61 1200
17 OCT 61 1200
18 OCT 61 1200
19 OCT 61 1200
20 OCT 61 1200
21 OCT 61 1200

Fig. 16d

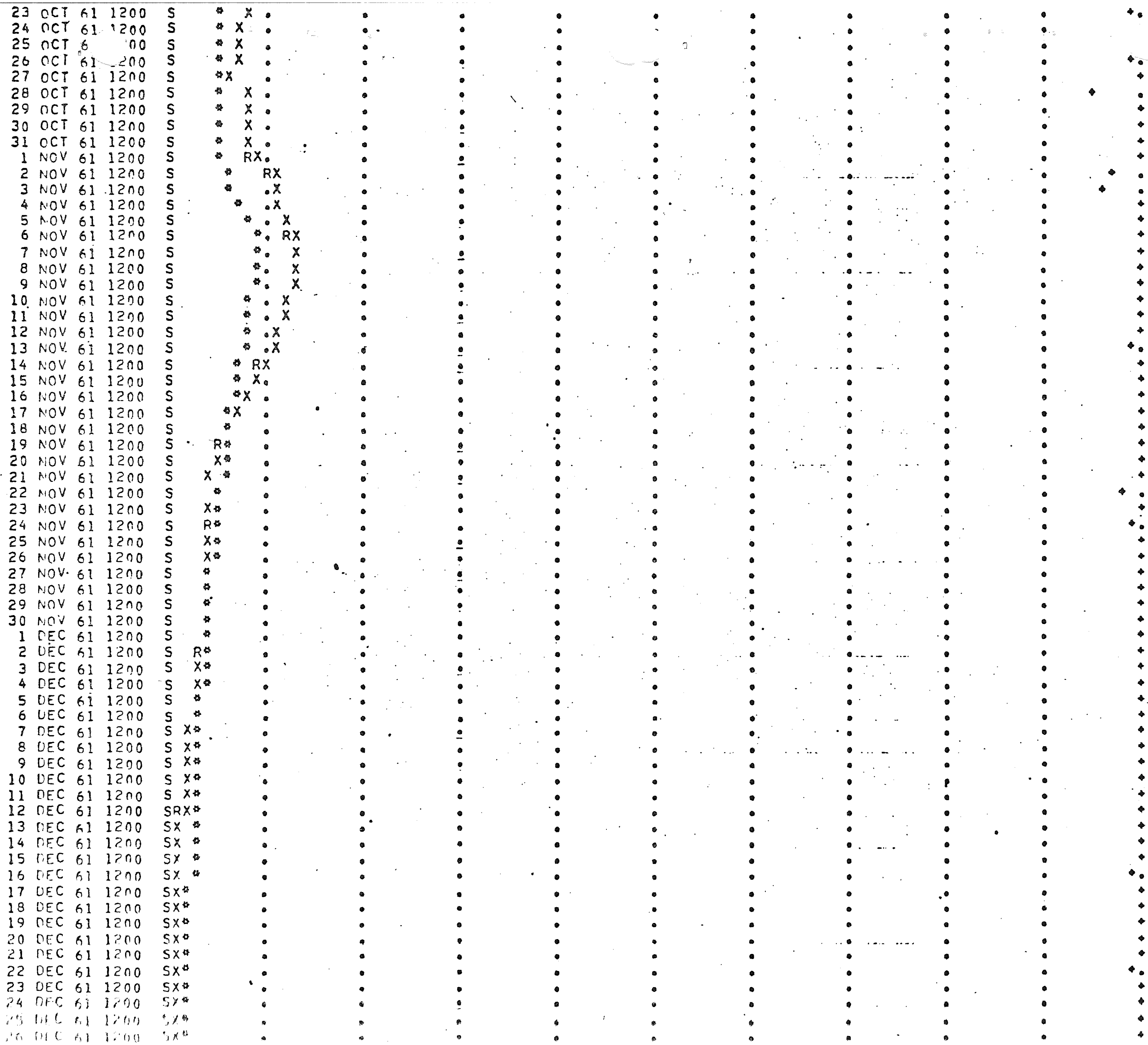

23 OCT 61 1200 S
24 OCT 61 1200 S
25 OCT 6 00 S
26 OCT 61 200 S
27 OCT 61 1200 S
28 OCT 61 1200 S
29 OCT 61 1200 S
30 OCT 61 1200 S
31 OCT 61 1200 S
1 NOV 61 1200 S
2 NOV 61 1200 S
3 NOV 61 1200 S
4 NOV 61 1200 S
5 NOV 61 1200 S
6 NOV 61 1200 S
7 NOV 61 1200 S
8 NOV 61 1200 S
9 NOV 61 1200 S
10 NOV 61 1200 S
11 NOV 61 1200 S
12 NOV 61 1200 S
13 NOV 61 1200 S
14 NOV 61 1200 S
15 NOV 61 1200 S
16 NOV 61 1200 S
17 NOV 61 1200 S
18 NOV 61 1200 S
19 NOV 61 1200 S
20 NOV 61 1200 S
21 NOV 61 1200 S
22 NOV 61 1200 S
23 NOV 61 1200 S
24 NOV 61 1200 S
25 NOV 61 1200 S
26 NOV 61 1200 S
27 NOV 61 1200 S
28 NOV 61 1200 S
29 NOV 61 1200 S
30 NOV 61 1200 S
1 DEC 61 1200 S
2 DEC 61 1200 S
3 DEC 61 1200 S
4 DEC 61 1200 S
5 DEC 61 1200 S
6 DEC 61 1200 S
7 DEC 61 1200 S
8 DEC 61 1200 S
9 DEC 61 1200 S
10 DEC 61 1200 S
11 DEC 61 1200 S
12 DEC 61 1200 S
13 DEC 61 1200 S
14 DEC 61 1200 S
15 DEC 61 1200 S
16 DEC 61 1200 S
17 DEC 61 1200 S
18 DEC 61 1200 S
19 DEC 61 1200 S
20 DEC 61 1200 S
21 DEC 61 1200 S
22 DEC 61 1200 S
23 DEC 61 1200 S
24 DEC 61 1200 S
25 DEC 61 1200 S
26 DEC 61 1200 S

Fig. 16e

787705

```
                                        PLOT      STATION NAME                              STATION
                                      CHARACTER                                              NUMBER CONTROL

                                           *-OBSERVED FLOW DUNKA                            512600.0    Q
                                           X-CALCULATED FLOW DUNKA                            5126.0    Q
                                           S-SNOW BASIN DUNKA RIVER                         512600.1    Q
                                           R-DUNKA RAIN BASIN                               512600.2    Q
 FLOW CFS            0.        50.       100.      150.      200.      250.      300.      350.      400.      450.      500.
 PHC 03903 100+                                                                 100      0
                                          +                                                  -390  3  100.
                     10.00     9.00      8.00      7.00      6.00      5.00      4.00      3.00      2.00      1.00      0.00
 PQ     5126000*      51260X   5126001S  5126002R12001066012031126O 240       0     250
  1 JAN 60 1200   R*       X.        .         .         .         .         .         .         .         .         +
  2 JAN 60 1200   R*       X.        .         .         .         .         .         .         .         .       + .
  3 JAN 60 1200   R*       X.        .         .         .         .         .         .         .         .        +.
  4 JAN 60 1200   R*       X.        .         .         .         .         .         .         .         .         +
  5 JAN 60 1200   R*      X .        .         .         .         .         .         .         .         .         +
  6 JAN 60 1200   R*      X .        .         .         .         .         .         .         .         .         +
  7 JAN 60 1200   R*      X .        .         .         .         .         .         .         .         .       + .
  8 JAN 60 1200   R*     X  .        .         .         .         .         .         .         .         .         +
  9 JAN 60 1200   R*     X  .        .         .         .         .         .         .         .         .       + .
 10 JAN 60 1200   R*    X   .        .         .         .         .         .         .         .         .         +
 11 JAN 60 1200   R*    X   .        .         .         .         .         .         .         .         .         +
 12 JAN 60 1200   R*   X    .        .         .         .         .         .         .         .         .         +
 13 JAN 60 1200   R*   X    .        .         .         .         .         .         .         .         .        +.
 14 JAN 60 1200   R*   X    .        .         .         .         .         .         .         .         .         +
 15 JAN 60 1200   R*  X     .        .         .         .         .         .         .         .         .         +
 16 JAN 60 1200   R*  X     .        .         .         .         .         .         .         .         .         +
 17 JAN 60 1200   R* X      .        .         .         .         .         .         .         .         .         +
 18 JAN 60 1200   R* X      .        .         .         .         .         .         .         .         .         +
 19 JAN 60 1200   R* X      .        .         .         .         .         .         .         .         .         +
 20 JAN 60 1200   R* X      .        .         .         .         .         .         .         .         .         +
 21 JAN 60 1200   R*X       .        .         .         .         .         .         .         .         .         +
 22 JAN 60 1200   R*X       .        .         .         .         .         .         .         .         .         +
 23 JAN 60 1200   R*X       .        .         .         .         .         .         .         .         .         +
 24 JAN 60 1200   R*X       .        .         .         .         .         .         .         .         .         +
 25 JAN 60 1200   R*X       .        .         .         .         .         .         .         .         .        +.
 26 JAN 60 1200   R*        .        .         .         .         .         .         .         .         .         +
 27 JAN 60 1200   R*        .        .         .         .         .         .         .         .         .         +
 28 JAN 60 1200   R*        .        .         .         .         .         .         .         .         .         +
 29 JAN 60 1200   R*        .        .         .         .         .         .         .         .         .         +
 30 JAN 60 1200   R*        .        .         .         .         .         .         .         .         .         +
 31 JAN 60 1200   R*        .        .         .         .         .         .         .         .         .         +
  1 FEB 60 1200   R*        .        .         .         .         .         .         .         .         .         +
  2 FEB 60 1200   R*        .        .         .         .         .         .         .         .         .         +
  3 FEB 60 1200   R*        .        .         .         .         .         .         .         .         .         +
  4 FEB 60 1200   R*        .        .         .         .         .         .         .         .         .         +
  5 FEB 60 1200   X*        .        .         .         .         .         .         .         .         .         +
  6 FEB 60 1200   X*        .        .         .         .         .         .         .         .         .         +
  7 FEB 60 1200   X*        .        .         .         .         .         .         .         .         .         +
  8 FEB 60 1200   X*        .        .         .         .         .         .         .         .         .         +
  9 FEB 60 1200    *        .        .         .         .         .         .         .         .         .         +
 10 FEB 60 1200    *        .        .         .         .         .         .         .         .         .         +
 11 FEB 60 1200    *        .        .         .         .         .         .         .         .         .         +
 12 FEB 60 1200    *        .        .         .         .         .         .         .         .         .         +
 13 FEB 60 1200    *        .        .         .         .         .         .         .         .         .         +
 14 FEB 60 1200    *        .        .         .         .         .         .         .         .         .         +
 15 FEB 60 1200    *        .        .         .         .         .         .         .         .         .         +
 16 FEB 60 1200    *        .        .         .         .         .         .         .         .         .         +
 17 FEB 60 1200    *        .        .         .         .         .         .         .         .         .         +
 18 FEB 60 1200    *        .        .         .         .         .         .         .         .         .         +
 19 FEB 60 1200    *        .        .         .         .         .         .         .         .         .         +
 20 FEB 60 1200    *        .        .         .         .         .         .         .         .         .         +
 21 FEB 60 1200    *        .        .         .         .         .         .         .         .         .        +.
 22 FEB 60 1200    *        .        .         .         .         .         .         .         .         .         +
```


Fig. 17a

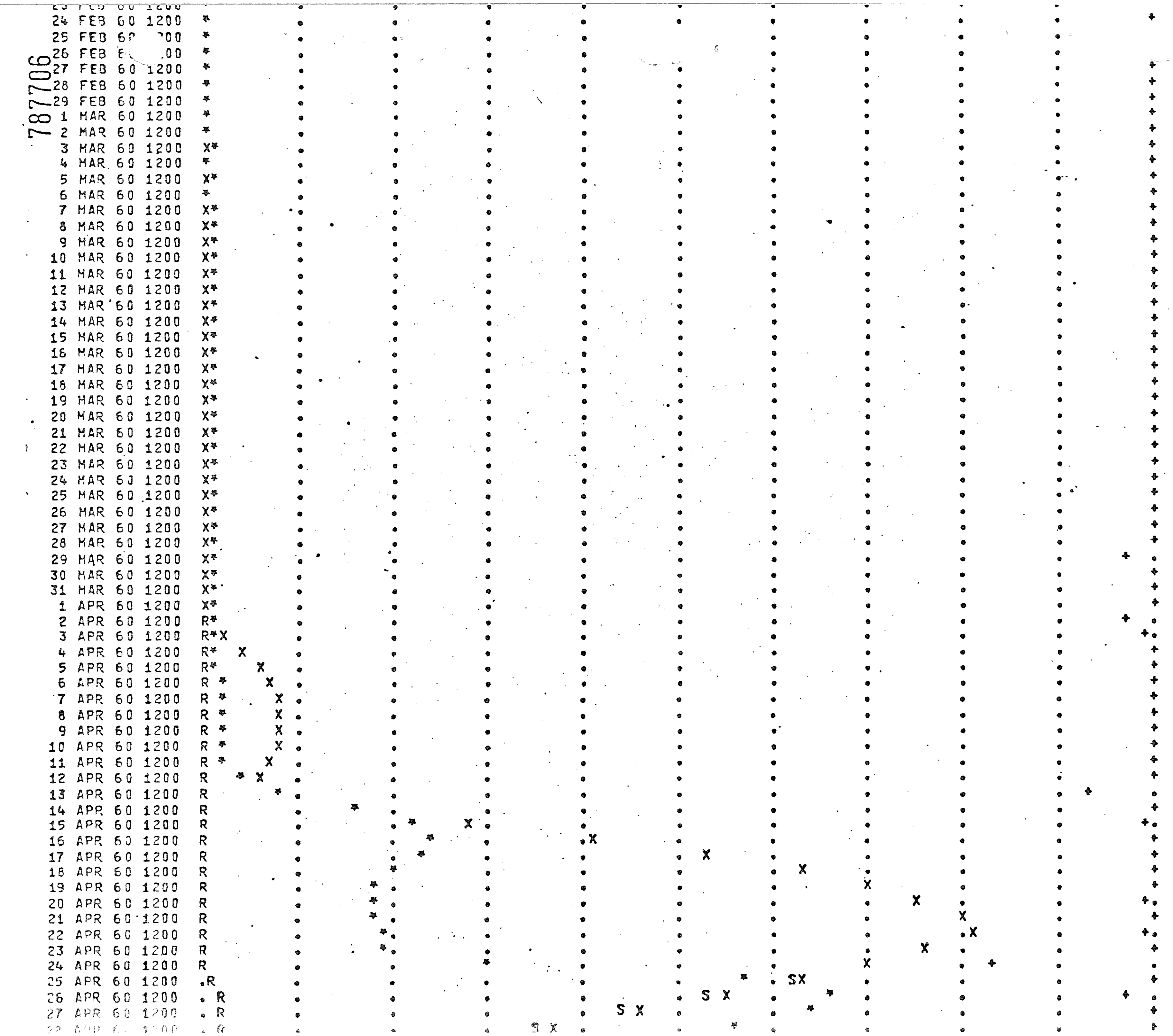

787706
23 FEB 60 1200
24 FEB 60 1200
25 FEB 60 1200
26 FEB 60 1200
27 FEB 60 1200
28 FEB 60 1200
29 FEB 60 1200
1 MAR 60 1200
2 MAR 60 1200
3 MAR 60 1200
4 MAR 60 1200
5 MAR 60 1200
6 MAR 60 1200
7 MAR 60 1200
8 MAR 60 1200
9 MAR 60 1200
10 MAR 60 1200
11 MAR 60 1200
12 MAR 60 1200
13 MAR 60 1200
14 MAR 60 1200
15 MAR 60 1200
16 MAR 60 1200
17 MAR 60 1200
18 MAR 60 1200
19 MAR 60 1200
20 MAR 60 1200
21 MAR 60 1200
22 MAR 60 1200
23 MAR 60 1200
24 MAR 60 1200
25 MAR 60 1200
26 MAR 60 1200
27 MAR 60 1200
28 MAR 60 1200
29 MAR 60 1200
30 MAR 60 1200
31 MAR 60 1200
1 APR 60 1200
2 APR 60 1200
3 APR 60 1200
4 APR 60 1200
5 APR 60 1200
6 APR 60 1200
7 APR 60 1200
8 APR 60 1200
9 APR 60 1200
10 APR 60 1200
11 APR 60 1200
12 APR 60 1200
13 APR 60 1200
14 APR 60 1200
15 APR 60 1200
16 APR 60 1200
17 APR 60 1200
18 APR 60 1200
19 APR 60 1200
20 APR 60 1200
21 APR 60 1200
22 APR 60 1200
23 APR 60 1200
24 APR 60 1200
25 APR 60 1200
26 APR 60 1200
27 APR 60 1200

Fig. 17b

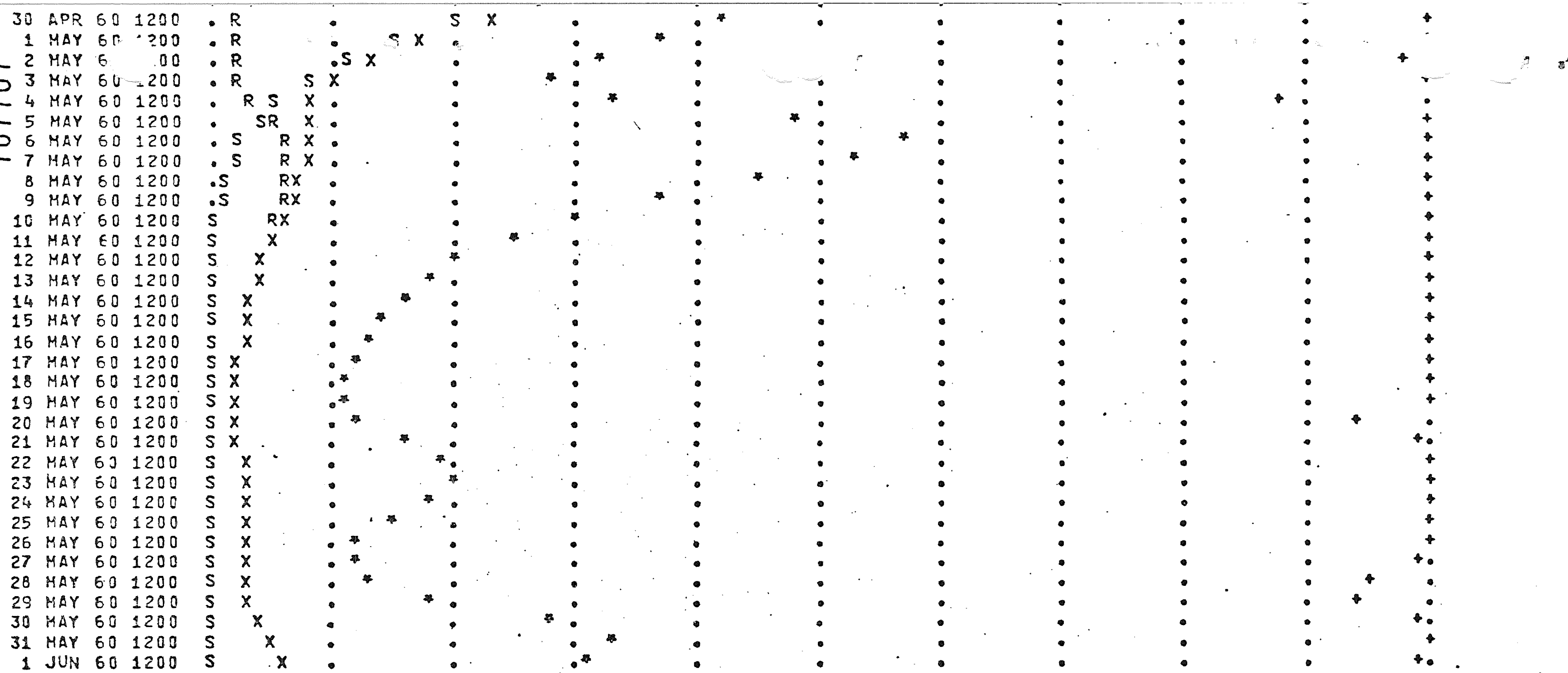

30 APR 60 1200
1 MAY 60 1200
2 MAY 60 1200
3 MAY 60 1200
4 MAY 60 1200
5 MAY 60 1200
6 MAY 60 1200
7 MAY 60 1200
8 MAY 60 1200
9 MAY 60 1200
10 MAY 60 1200
11 MAY 60 1200
12 MAY 60 1200
13 MAY 60 1200
14 MAY 60 1200
15 MAY 60 1200
16 MAY 60 1200
17 MAY 60 1200
18 MAY 60 1200
19 MAY 60 1200
20 MAY 60 1200
21 MAY 60 1200
22 MAY 60 1200
23 MAY 60 1200
24 MAY 60 1200
25 MAY 60 1200
26 MAY 60 1200
27 MAY 60 1200
28 MAY 60 1200
29 MAY 60 1200
30 MAY 60 1200
31 MAY 60 1200
1 JUN 60 1200

Fig. 17c

787708

PLOT CHARACTER	STATION NAME	STATION NUMBER	CONTROL
*	-OBSERVED FLOW DUNKA	512600.0	Q
X	-CALCULATED FLOW DUNKA	5126.0	Q
S	-SNOW BASIN DUNKA RIVER	512600.1	Q
R	-DUNKA RAIN BASIN	512600.2	Q

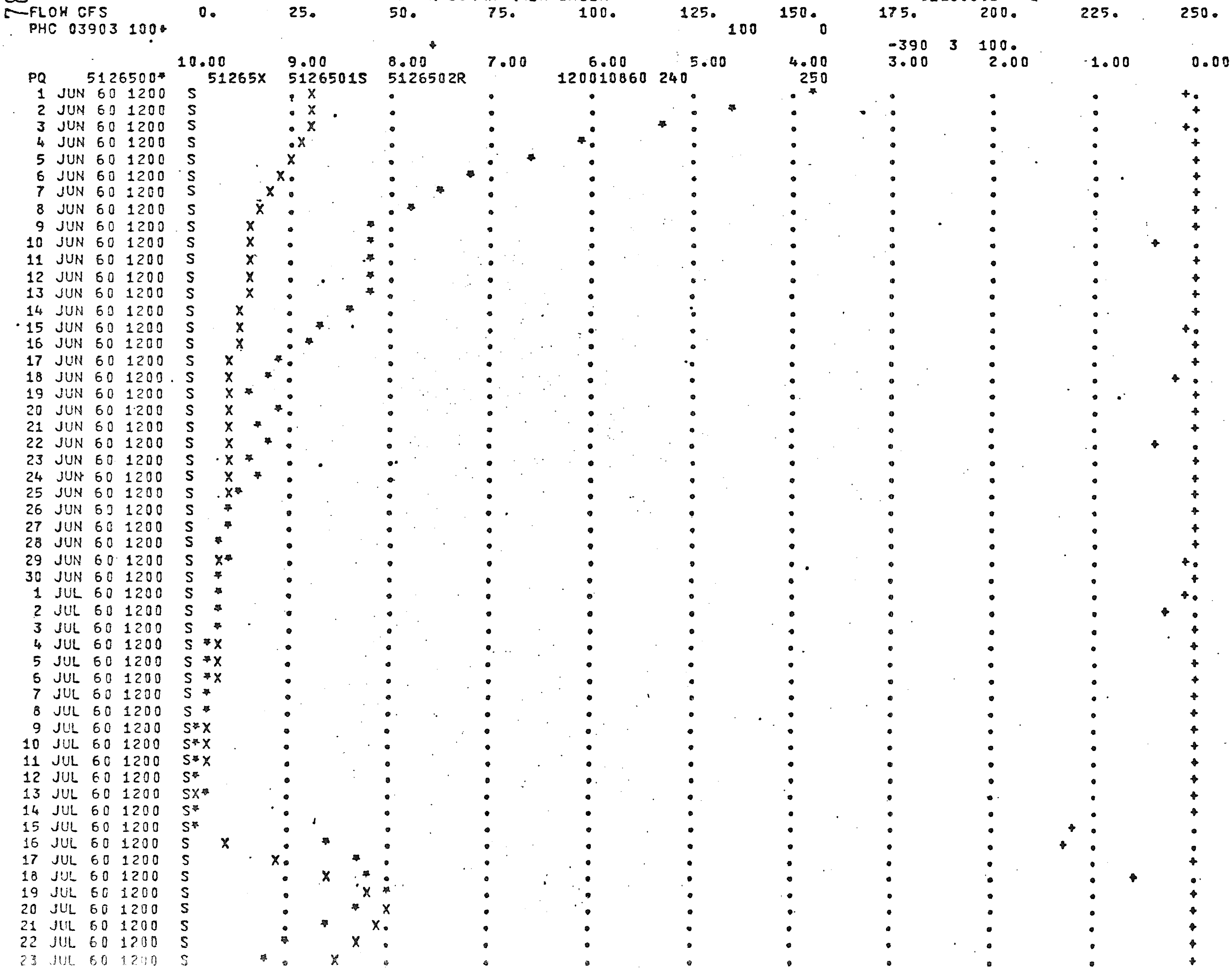
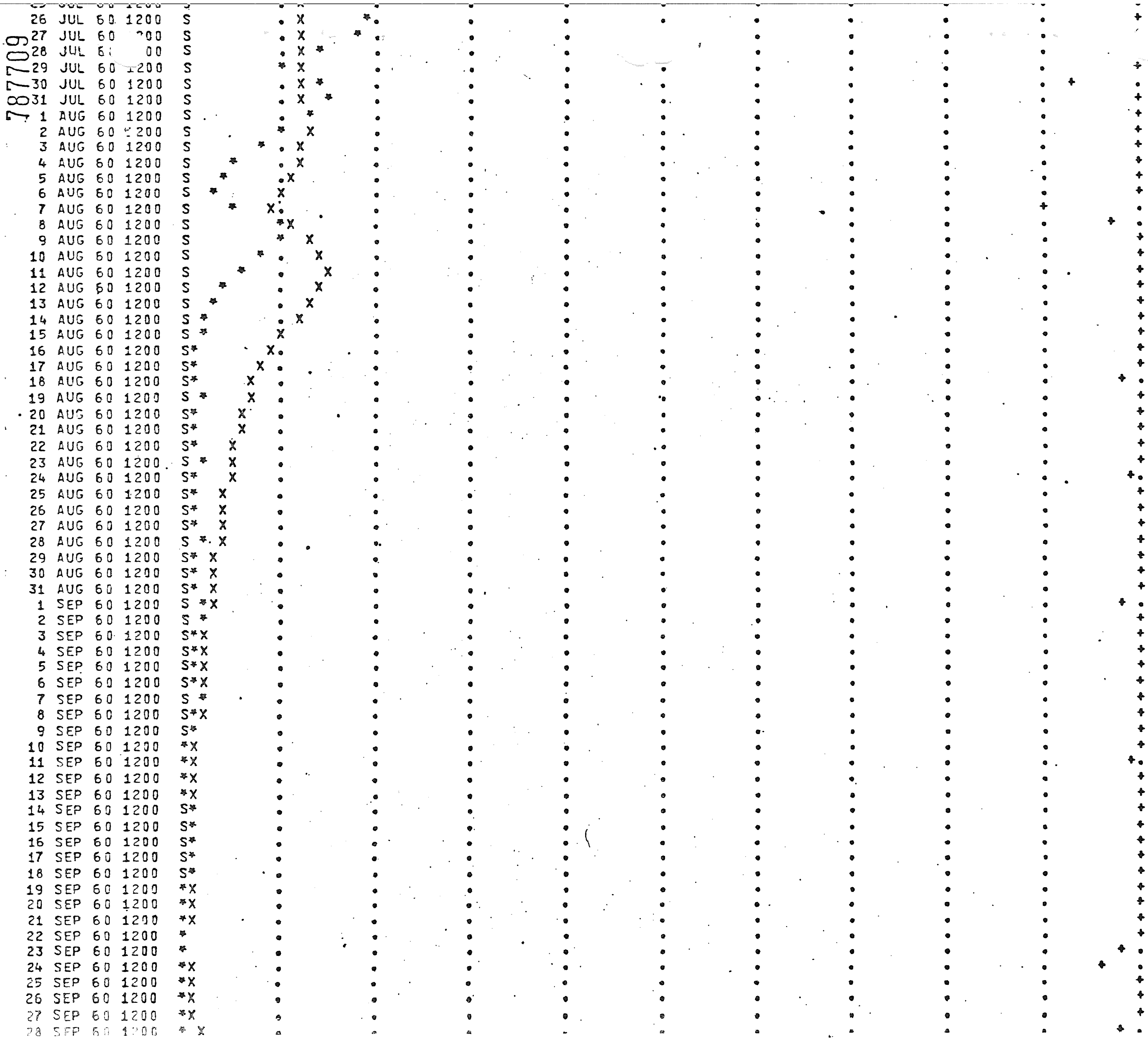


Fig. 17d



787709

Fig. 17e

```
30 SEP 60 1200 S*X
 1 OCT 60 1200 S*X
 2 OCT 60 1200 S*X
 3 OCT 60 1200 SX *
 4 OCT 60 1200 SX *
 5 OCT 60 1200 SX*
 6 OCT 60 1200 SX*
 7 OCT 60 1200 SX*
 8 OCT 60 1200 SX *
 9 OCT 60 1200 SX*
10 OCT 60 1200 SX*
11 OCT 60 1200 SX*
12 OCT 60 1200 S*
13 OCT 60 1200 S*
14 OCT 60 1200 S *
15 OCT 60 1200 S * X
16 OCT 60 1200 S    *X
17 OCT 60 1200 S    *X
18 OCT 60 1200 S  *  X
19 OCT 60 1200 S *   X
20 OCT 60 1200 S * X
21 OCT 60 1200 S * X
22 OCT 60 1200 S *X
23 OCT 60 1200 S *X
24 OCT 60 1200 S * X
25 OCT 60 1200 S * X
26 OCT 60 1200 S *   X
27 OCT 60 1200 S *   X
28 OCT 60 1200 S * X
29 OCT 60 1200 S * X
30 OCT 60 1200 S * X
31 OCT 60 1200 S * X
 1 NOV 60 1200 S   * X
 2 NOV 60 1200 S     *
 3 NOV 60 1200 S     *X
 4 NOV 60 1200 S    *  X
 5 NOV 60 1200 S    *  X
 6 NOV 60 1200 S    * X
 7 NOV 60 1200 S  *   X
 8 NOV 60 1200 S  * X
 9 NOV 60 1200 S  * X
10 NOV 60 1200 S  * X
11 NOV 60 1200 S  * X
12 NOV 60 1200 S  *X
13 NOV 60 1200 S  *X
14 NOV 60 1200 S  *
15 NOV 60 1200 S  X*
16 NOV 60 1200 S  *
17 NOV 60 1200 S  *
18 NOV 60 1200 S X*
19 NOV 60 1200 S X*
20 NOV 60 1200 S X*
21 NOV 60 1200 S X*
22 NOV 60 1200 S *
23 NOV 60 1200 SX*
24 NOV 60 1200 SX*
25 NOV 60 1200 SX*
26 NOV 60 1200 SX*
27 NOV 60 1200 SX*
28 NOV 60 1200 SX*
29 NOV 60 1200 SX*
30 NOV 60 1200 SX*
 1 DEC 60 1200 SX*
 2 DEC 60 1200 SX*
```


Fig. 17f

787711

4	DEC	60	1200	X*
5	DEC	60	1200	SX*
6	DEC	60	1200	SX*
7	DEC	60	1200	SX*
8	DEC	60	1200	SX*
9	DEC	60	1200	SX*
10	DEC	60	1200	SX*
11	DEC	60	1200	SX*
12	DEC	60	1200	SX*
13	DEC	60	1200	SX*
14	DEC	60	1200	SX*
15	DEC	60	1200	SX*
16	DEC	60	1200	SX*
17	DEC	60	1200	SX*
18	DEC	60	1200	SX*
19	DEC	60	1200	SX*
20	DEC	60	1200	S*
21	DEC	60	1200	S*
22	DEC	60	1200	S*
23	DEC	60	1200	X*
24	DEC	60	1200	X*
25	DEC	60	1200	X*
26	DEC	60	1200	X*
27	DEC	60	1200	X*
28	DEC	60	1200	X*
29	DEC	60	1200	X*
30	DEC	60	1200	X*
31	DEC	60	1200	X*

Fig. 17g

PLOT CHARACTER	STATION NAME	STATION NUMBER	CONTROL
*	OBSERVED FLOW DUNKA	512600.0	Q
X	CALCULATED FLOW DUNKA	5126.0	Q
S	SNOW BASIN DUNKA RIVER	512600.1	Q
R	DUNKA RAIN BASIN	512600.2	Q

Dec. 21 - 30 missing

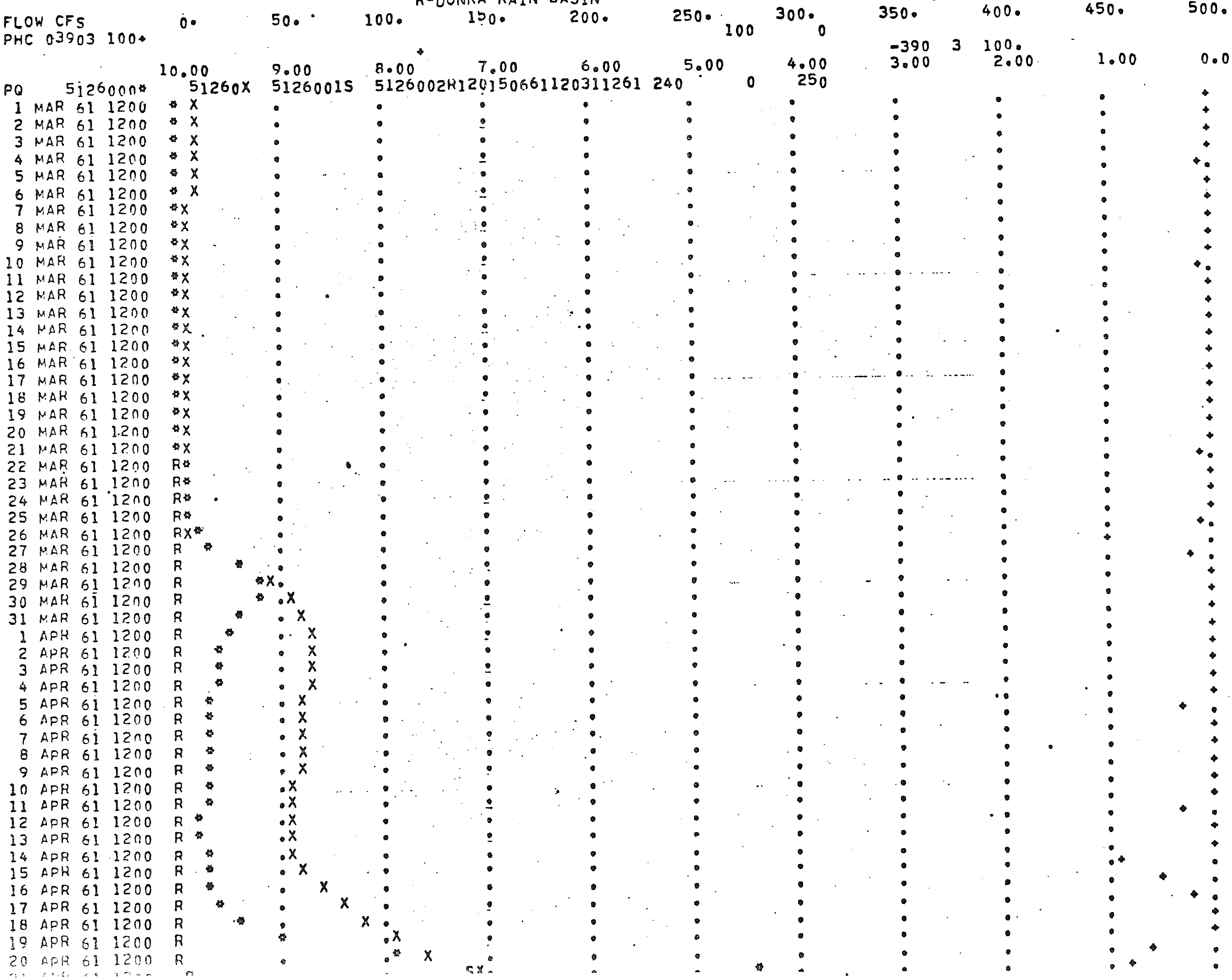
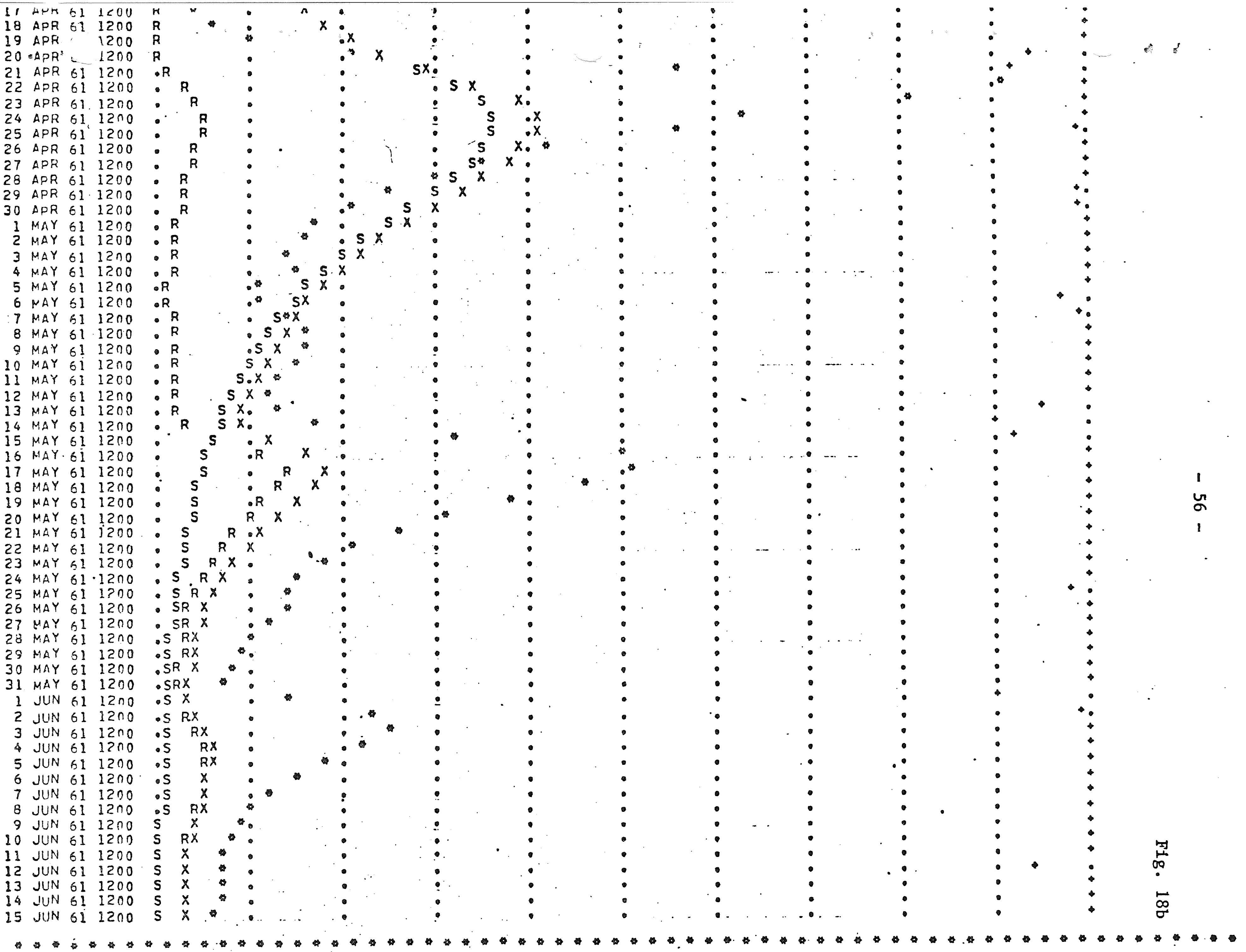


Fig. 18a

123648



PLOT CHARACTER   STATION NAME   STATION NUMBER CONTROL

Fig. 18b

```
                                   O-OBSERVED FLOW DUNKA                           512600.0   Q
                                   X-CALCULATED FLOW DUNKA                           5126.0   Q
                                   S-SNOW BASIN DUNKA RIVF                         512600.1   Q
                                   R-DUNKA RAIN BASIN                              512600.2   Q
123649 FLOW CFS      0.      25.      50.      75.      100.     125.     150.     175.     200.     225.     250.
PHC 03903 100+                                                      100      0
                                                                                 -390  3  100.
                      10.00    9.00     8.00     7.00     6.00     5.00     4.00     3.00     2.00     1.00     0.00
PQ      5126500+      51265X   5126501S 5126502R          120150661 240     0   500
15 JUN 61 1200    .S     RX  . *  .        .        .        .        .        .        .        .        +
16 JUN 61 1200    .S     X   *    .        .        .        .        .        .        .        .        +
17 JUN 61 1200    S      X  *.    .        .        .        .        .        .        .        .        +
18 JUN 61 1200    S     RX * .    .        .        .        .        .        .        .        .        +
19 JUN 61 1200    S     X*   .    .        .        .        .        .        .        .        .        +
20 JUN 61 1200    S    R*    .    .        .        .        .        .        .        .        .        +
21 JUN 61 1200    S    *     .    .        .        .        .        .        .        .        .        +
22 JUN 61 1200    S    *     .    .        .        .        .        .        .        .        .        +
23 JUN 61 1200    S   *X     .    .        .        .        .        .        .        .        .       +.
24 JUN 61 1200    S   *      .    .        .        .        .        .        .        .        .        +
25 JUN 61 1200    S   *      .    .        .        .        .        .        .        .        .        +
26 JUN 61 1200    S *X       .    .        .        .        .        .        .        .        .        +
27 JUN 61 1200    S *X       .    .        .        .        .        .        .        .        .       +.
28 JUN 61 1200    S *X       .    .        .        .        .        .        .        .        .        +
29 JUN 61 1200    S *X       .    .        .        .        .        .        .        .        .        +
30 JUN 61 1200    S *        .    .        .        .        .        .        .        .        .        +
 1 JUL 61 1200    S*X        .    .        .        .        .        .        .        .        .        +
 2 JUL 61 1200    S*X        .    .        .        .        .        .        .        .        .        +
 3 JUL 61 1200    S*X        .    .        .        .        .        .        .        .        .        +
 4 JUL 61 1200    S*X        .    .        .        .        .        .        .        .        .        +
 5 JUL 61 1200    S*X        .    .        .        .        .        .        .        .        .        +
 6 JUL 61 1200    S*         .    .        .        .        .        .        .        .        .        +
 7 JUL 61 1200    S*         .    .        .        .        .        .        .        .        .        +
 8 JUL 61 1200    S*         .    .        .        .        .        .        .        .        .        +
 9 JUL 61 1200    S*         .    .        .        .        .        .        .        .        .        +
10 JUL 61 1200    S*         .    .        .        .        .        .        .        .        .        +
11 JUL 61 1200    S*         .    .        .        .        .        .        .        .        .        +
12 JUL 61 1200    S*         .    .        .        .        .        .        .        .        .        +
13 JUL 61 1200    S*         .    .        .        .        .        .        .        .        .       +.
14 JUL 61 1200    S*         .    .        .        .        .        .        .        .        .       +.
15 JUL 61 1200    S*         .    .        .        .        .        .        .        .        .        +
16 JUL 61 1200    S*         .    .        .        .        .        .        .        .        .        +
17 JUL 61 1200    S*         .    .        .        .        .        .        .        .        .        +
18 JUL 61 1200    S*         .    .        .        .        .        .        .        .        .        +
19 JUL 61 1200    S*         .    .        .        .        .        .        .        .      +         +
20 JUL 61 1200    S*         .    .        .        .        .        .        .        .        .        +
21 JUL 61 1200    S*X        .    .        .        .        .        .        .        .        .       +.
22 JUL 61 1200    S*X        .    .        .        .        .        .        .        .        .       +.
23 JUL 61 1200    S*X        .    .        .        .        .        .        .        .        .        +
24 JUL 61 1200    S *        .    .        .        .        .        .        .        .        .    +   +
25 JUL 61 1200    S *X       .    .        .        .        .        .        .        .        .        +
26 JUL 61 1200    S *X       .    .        .        .        .        .        .        .        .        +
27 JUL 61 1200    S  *       .    .        .        .        .        .        .        .        .       +.
28 JUL 61 1200    S *X       .    .        .        .        .        .        .        .        .        +
29 JUL 61 1200    S *X       .    .        .        .        .        .        .        .        .        +
30 JUL 61 1200    S* X       .    .        .        .        .        .        .        .        .        +
31 JUL 61 1200    S* X       .    .        .        .        .        .        .        .        .        +
 1 AUG 61 1200    S*RX       .    .        .        .        .        .        .        .        .        +
 2 AUG 61 1200    S *        .    .        .        .        .        .        .        .        .       +.
 3 AUG 61 1200    S *        .    .        .        .        .        .        .        .        .        +
 4 AUG 61 1200    S X*       .    .        .        .        .        .        .        .        .        +
 5 AUG 61 1200    S*X        .    .        .        .        .        .        .        .        .        +
 6 AUG 61 1200    S*X        .    .        .        .        .        .        .        .        .        +
 7 AUG 61 1200    S *        .    .        .        .        .        .        .        .        .        +
 8 AUG 61 1200    SR*        .    .        .        .        .        .        .        .        .        +
 9 AUG 61 1200    SX*        .    .        .        .        .        .        .        .        .        +
10 AUG 61 1200    SX*        .    .        .        .        .        .        .        .        .      + .
```


Fig. 18c

123650

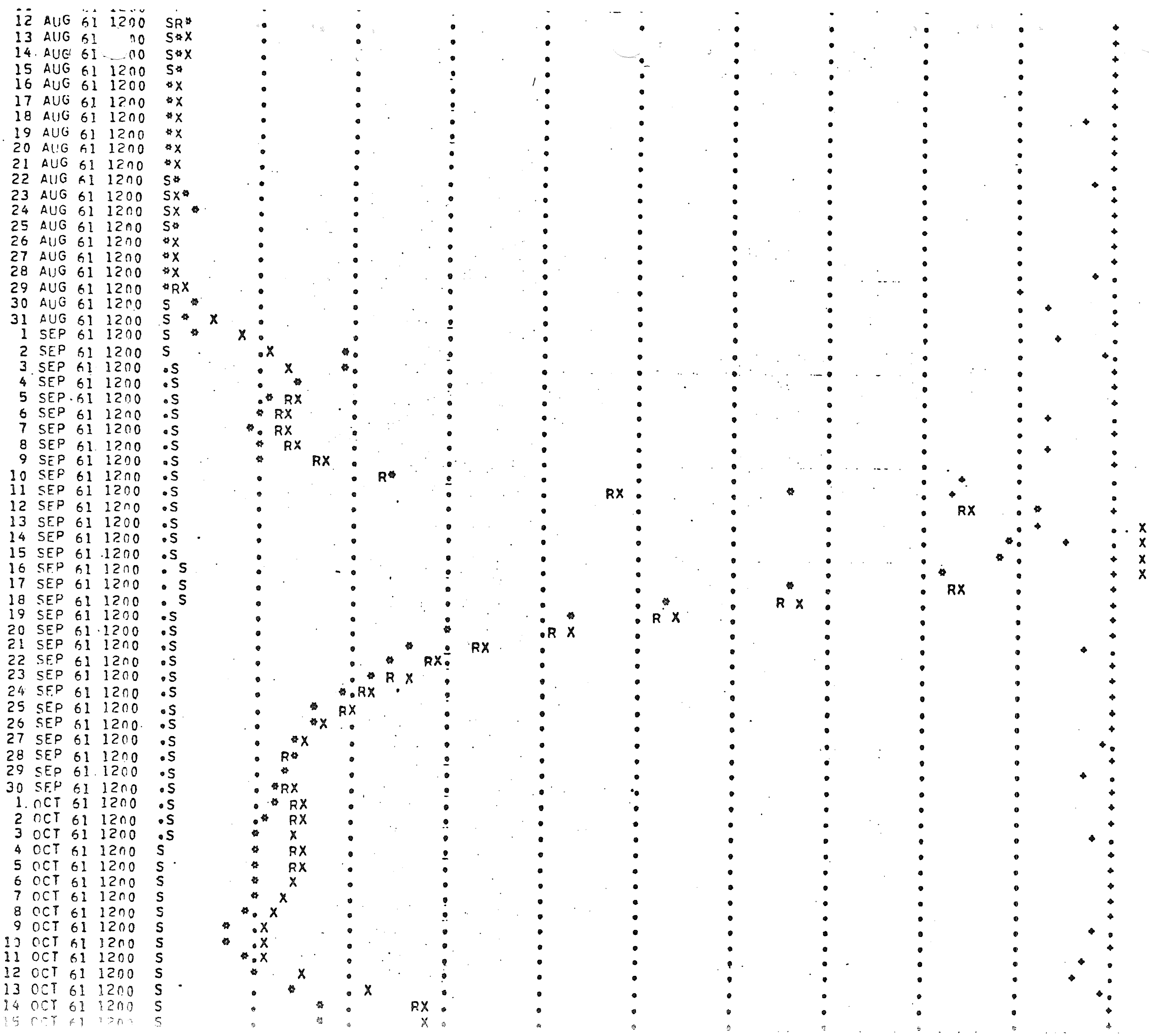


Fig. 18d

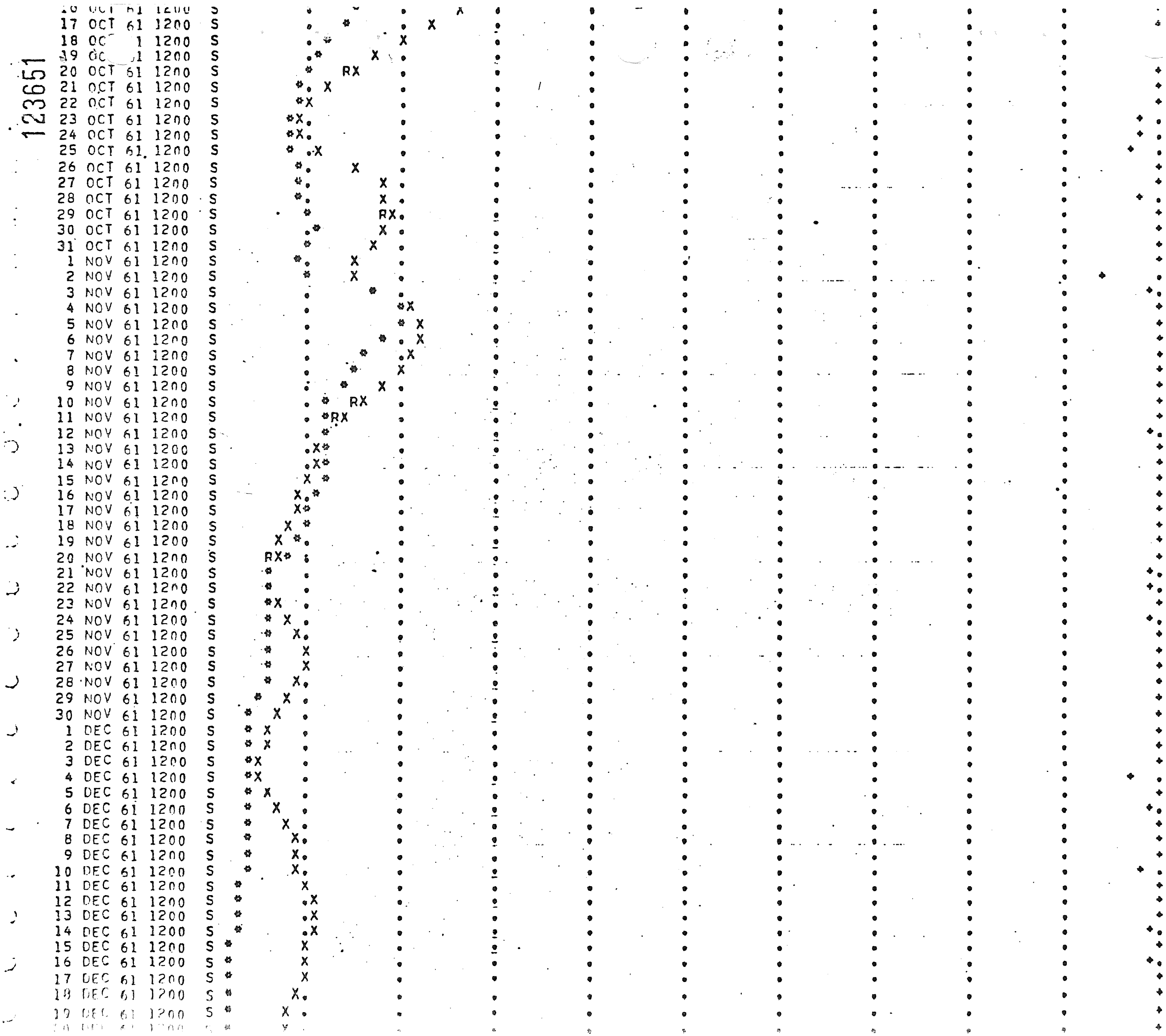

123651
16 OCT 61 1200 S
17 OCT 61 1200 S
18 OCT 61 1200 S
19 OCT 61 1200 S
20 OCT 61 1200 S
21 OCT 61 1200 S
22 OCT 61 1200 S
23 OCT 61 1200 S
24 OCT 61 1200 S
25 OCT 61 1200 S
26 OCT 61 1200 S
27 OCT 61 1200 S
28 OCT 61 1200 S
29 OCT 61 1200 S
30 OCT 61 1200 S
31 OCT 61 1200 S
1 NOV 61 1200 S
2 NOV 61 1200 S
3 NOV 61 1200 S
4 NOV 61 1200 S
5 NOV 61 1200 S
6 NOV 61 1200 S
7 NOV 61 1200 S
8 NOV 61 1200 S
9 NOV 61 1200 S
10 NOV 61 1200 S
11 NOV 61 1200 S
12 NOV 61 1200 S
13 NOV 61 1200 S
14 NOV 61 1200 S
15 NOV 61 1200 S
16 NOV 61 1200 S
17 NOV 61 1200 S
18 NOV 61 1200 S
19 NOV 61 1200 S
20 NOV 61 1200 S
21 NOV 61 1200 S
22 NOV 61 1200 S
23 NOV 61 1200 S
24 NOV 61 1200 S
25 NOV 61 1200 S
26 NOV 61 1200 S
27 NOV 61 1200 S
28 NOV 61 1200 S
29 NOV 61 1200 S
30 NOV 61 1200 S
1 DEC 61 1200 S
2 DEC 61 1200 S
3 DEC 61 1200 S
4 DEC 61 1200 S
5 DEC 61 1200 S
6 DEC 61 1200 S
7 DEC 61 1200 S
8 DEC 61 1200 S
9 DEC 61 1200 S
10 DEC 61 1200 S
11 DEC 61 1200 S
12 DEC 61 1200 S
13 DEC 61 1200 S
14 DEC 61 1200 S
15 DEC 61 1200 S
16 DEC 61 1200 S
17 DEC 61 1200 S
18 DEC 61 1200 S
19 DEC 61 1200 S
20 DEC 61 1200 S

Fig. 18e

PLOT CHARACTER STATION NAME STATION NUMBER CONTROL

*-OBSERVED FLOW WINTON 512700.0 Q
X-CALC FLOW AT WINTON 5127.0 Q

FLOW CFS 0. 600. 1200. 1800. 2400. 3000. 3600. 4200. 4800. 5400. 6000.
PHC 90913 100+ 100 0
-9091 3 100.
10.00 9.00 8.00 7.00 6.00 5.00 4.00 3.00 2.00 1.00 0.00
PQ 5127000* 51270X 12001076012031126O 240 0 1000

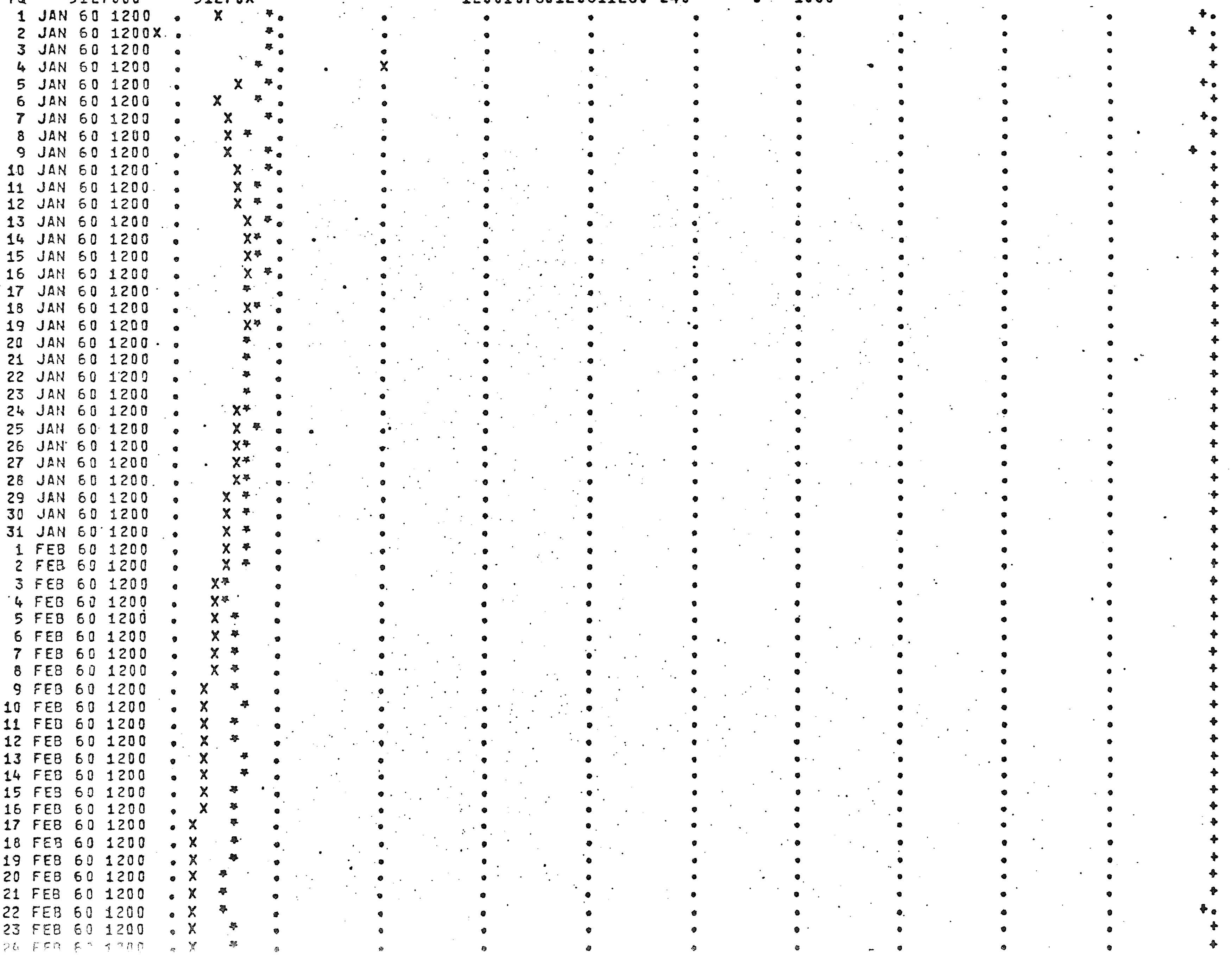


Fig. 19a

787720

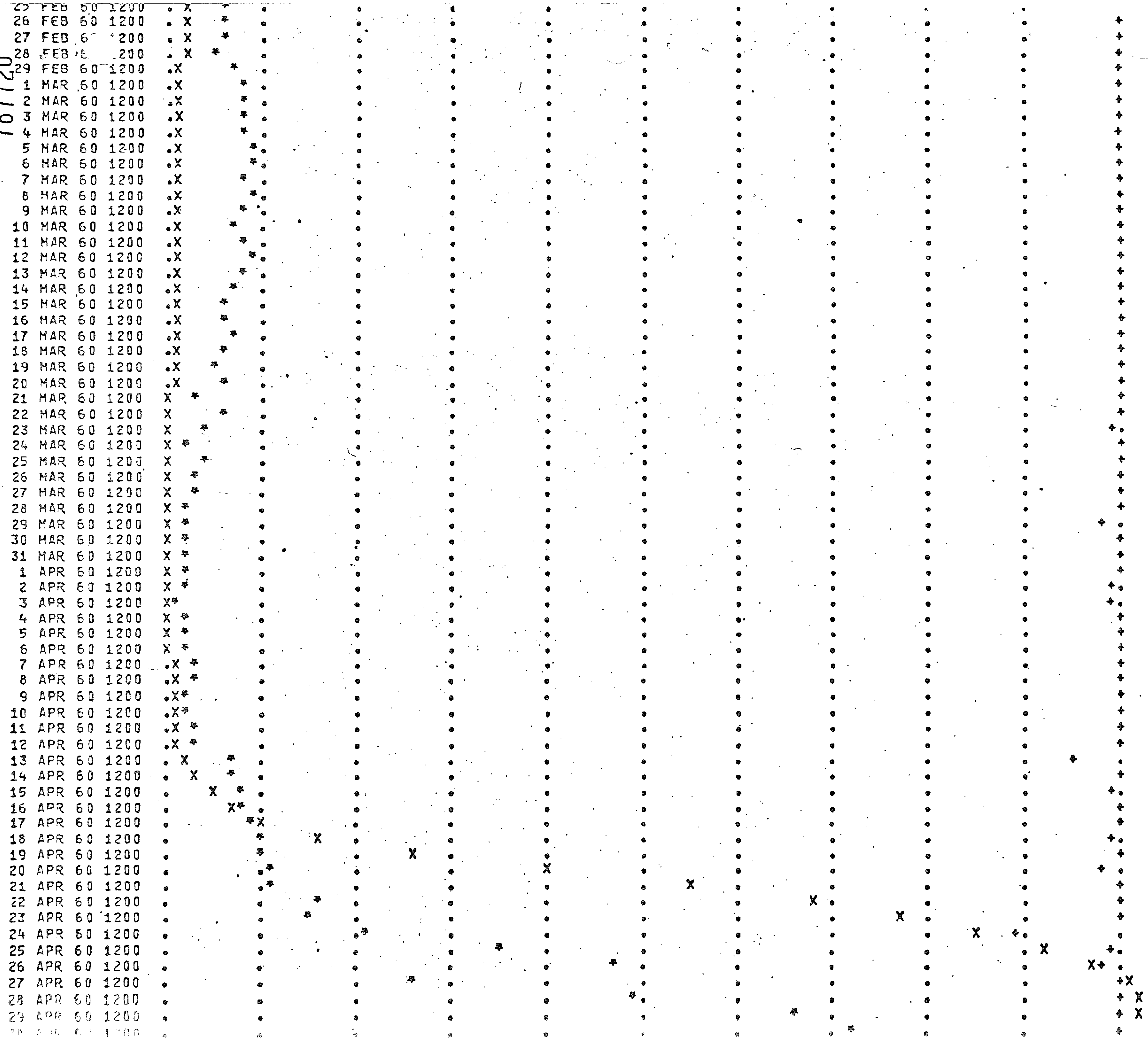


Fig. 19b

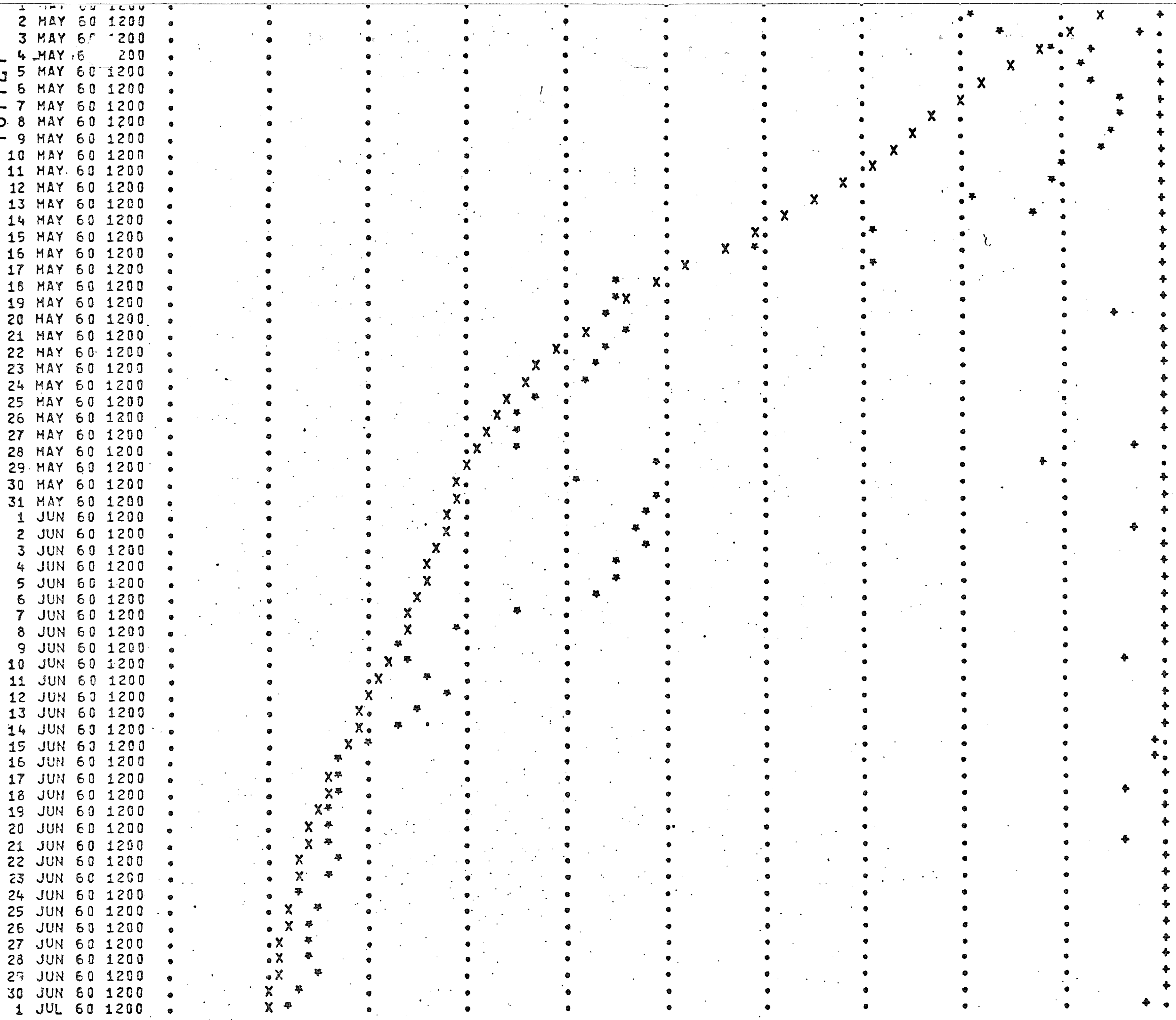

1 MAY 60 1200
2 MAY 60 1200
3 MAY 60 1200
4 MAY 60 1200
5 MAY 60 1200
6 MAY 60 1200
7 MAY 60 1200
8 MAY 60 1200
9 MAY 60 1200
10 MAY 60 1200
11 MAY 60 1200
12 MAY 60 1200
13 MAY 60 1200
14 MAY 60 1200
15 MAY 60 1200
16 MAY 60 1200
17 MAY 60 1200
18 MAY 60 1200
19 MAY 60 1200
20 MAY 60 1200
21 MAY 60 1200
22 MAY 60 1200
23 MAY 60 1200
24 MAY 60 1200
25 MAY 60 1200
26 MAY 60 1200
27 MAY 60 1200
28 MAY 60 1200
29 MAY 60 1200
30 MAY 60 1200
31 MAY 60 1200
1 JUN 60 1200
2 JUN 60 1200
3 JUN 60 1200
4 JUN 60 1200
5 JUN 60 1200
6 JUN 60 1200
7 JUN 60 1200
8 JUN 60 1200
9 JUN 60 1200
10 JUN 60 1200
11 JUN 60 1200
12 JUN 60 1200
13 JUN 60 1200
14 JUN 60 1200
15 JUN 60 1200
16 JUN 60 1200
17 JUN 60 1200
18 JUN 60 1200
19 JUN 60 1200
20 JUN 60 1200
21 JUN 60 1200
22 JUN 60 1200
23 JUN 60 1200
24 JUN 60 1200
25 JUN 60 1200
26 JUN 60 1200
27 JUN 60 1200
28 JUN 60 1200
29 JUN 60 1200
30 JUN 60 1200
1 JUL 60 1200

Fig. 19c

787722

```
                                   PLOT      STATION NAME                                   STATION
                                 CHARACTER                                                   NUMBER CONTROL

                                     *-OBSERVED FLOW WINTON                                  512700.0    Q
                                     X-CALC FLOW AT WINTON                                     5127.0    Q
FLOW CFS           0.        100.      200.      300.      400.      500.      600.      700.      800.      900.      1000.
PHC 90913 100+                                                            100        0
                                          +                                                 -9091  3  100.
               10.00       9.00       8.00      7.00      6.00      5.00      4.00      3.00      2.00      1.00      0.00
END

    END OF FILE ON INPUT DECK
```

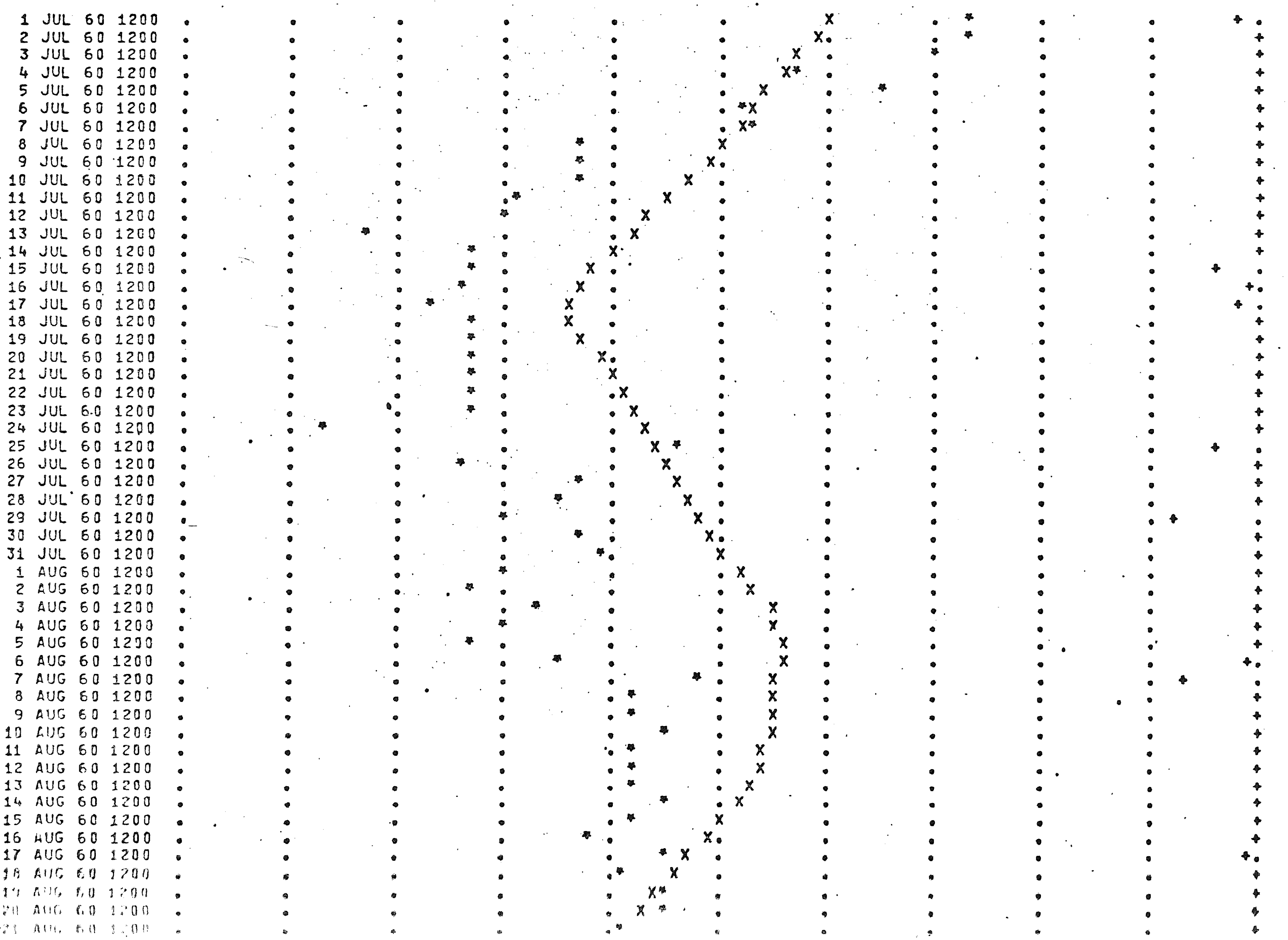
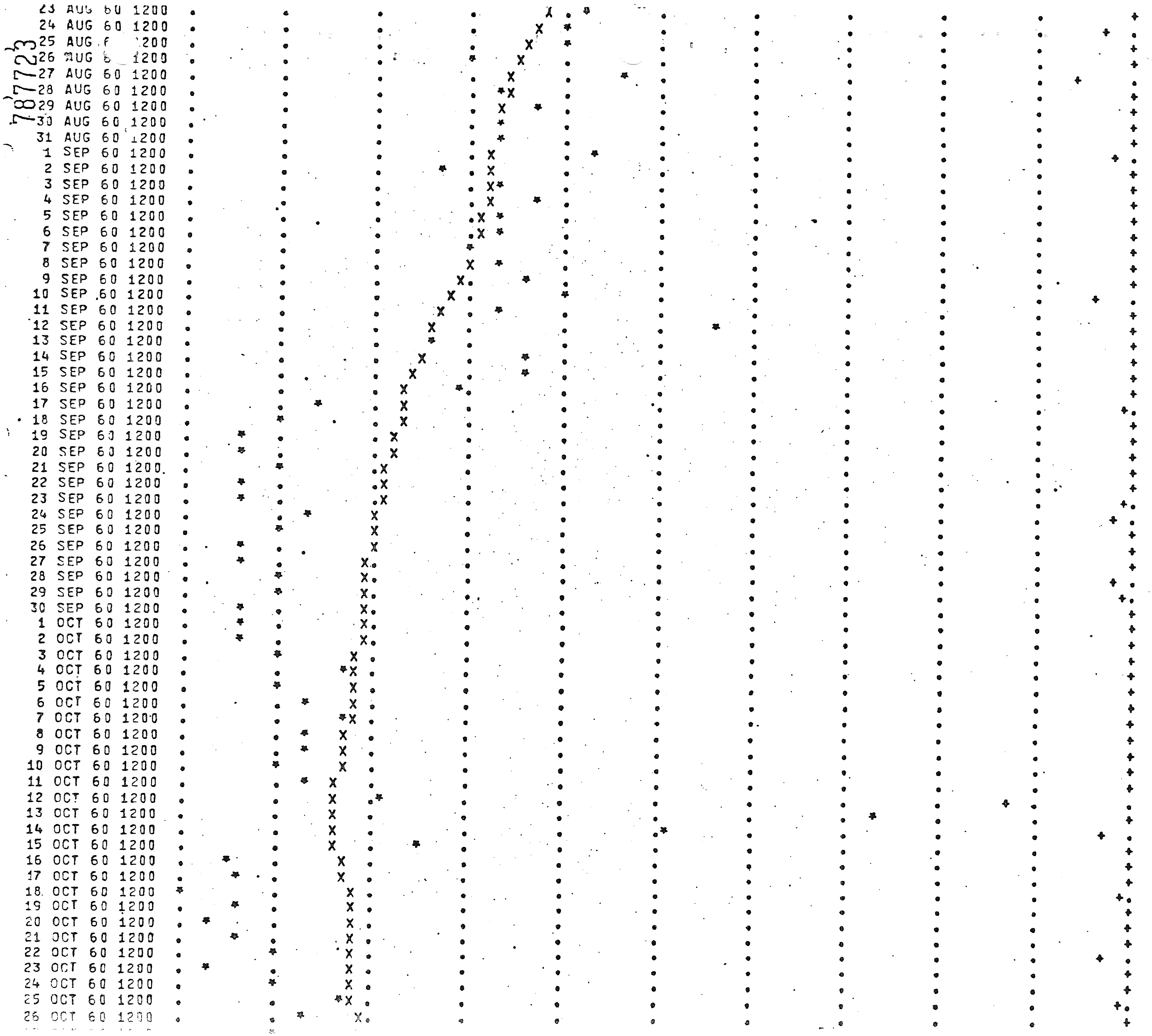


Fig. 19d



23 AUG 60 1200
24 AUG 60 1200
25 AUG 60 1200
26 AUG 60 1200
27 AUG 60 1200
28 AUG 60 1200
29 AUG 60 1200
30 AUG 60 1200
31 AUG 60 1200
1 SEP 60 1200
2 SEP 60 1200
3 SEP 60 1200
4 SEP 60 1200
5 SEP 60 1200
6 SEP 60 1200
7 SEP 60 1200
8 SEP 60 1200
9 SEP 60 1200
10 SEP 60 1200
11 SEP 60 1200
12 SEP 60 1200
13 SEP 60 1200
14 SEP 60 1200
15 SEP 60 1200
16 SEP 60 1200
17 SEP 60 1200
18 SEP 60 1200
19 SEP 60 1200
20 SEP 60 1200
21 SEP 60 1200
22 SEP 60 1200
23 SEP 60 1200
24 SEP 60 1200
25 SEP 60 1200
26 SEP 60 1200
27 SEP 60 1200
28 SEP 60 1200
29 SEP 60 1200
30 SEP 60 1200
1 OCT 60 1200
2 OCT 60 1200
3 OCT 60 1200
4 OCT 60 1200
5 OCT 60 1200
6 OCT 60 1200
7 OCT 60 1200
8 OCT 60 1200
9 OCT 60 1200
10 OCT 60 1200
11 OCT 60 1200
12 OCT 60 1200
13 OCT 60 1200
14 OCT 60 1200
15 OCT 60 1200
16 OCT 60 1200
17 OCT 60 1200
18 OCT 60 1200
19 OCT 60 1200
20 OCT 60 1200
21 OCT 60 1200
22 OCT 60 1200
23 OCT 60 1200
24 OCT 60 1200
25 OCT 60 1200
26 OCT 60 1200

Fig. 19e

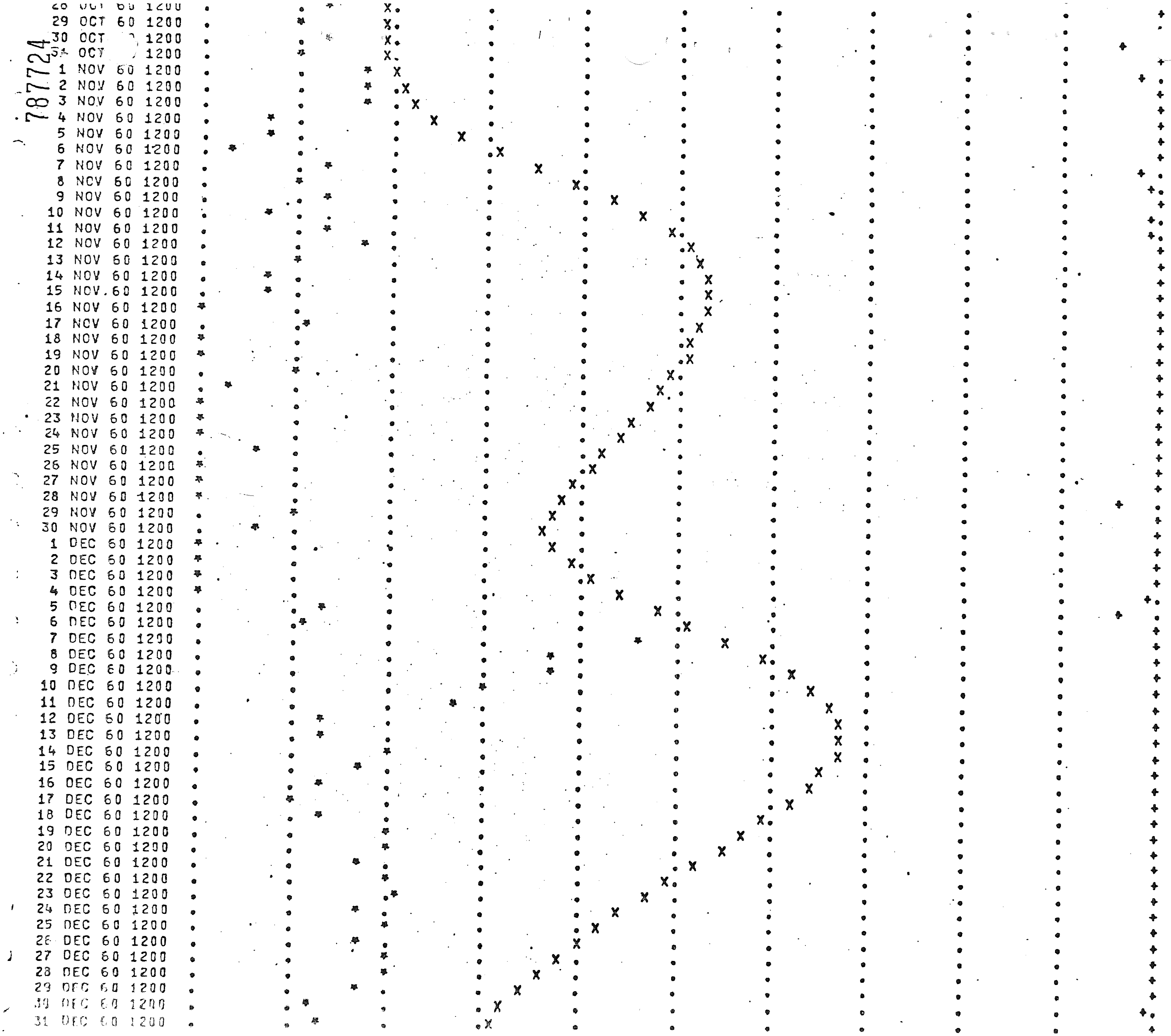

787724
28 OCT 60 1200
29 OCT 60 1200
30 OCT 1200
OCT 1200
1 NOV 60 1200
2 NOV 60 1200
3 NOV 60 1200
4 NOV 60 1200
5 NOV 60 1200
6 NOV 60 1200
7 NOV 60 1200
8 NOV 60 1200
9 NOV 60 1200
10 NOV 60 1200
11 NOV 60 1200
12 NOV 60 1200
13 NOV 60 1200
14 NOV 60 1200
15 NOV 60 1200
16 NOV 60 1200
17 NOV 60 1200
18 NOV 60 1200
19 NOV 60 1200
20 NOV 60 1200
21 NOV 60 1200
22 NOV 60 1200
23 NOV 60 1200
24 NOV 60 1200
25 NOV 60 1200
26 NOV 60 1200
27 NOV 60 1200
28 NOV 60 1200
29 NOV 60 1200
30 NOV 60 1200
1 DEC 60 1200
2 DEC 60 1200
3 DEC 60 1200
4 DEC 60 1200
5 DEC 60 1200
6 DEC 60 1200
7 DEC 60 1200
8 DEC 60 1200
9 DEC 60 1200
10 DEC 60 1200
11 DEC 60 1200
12 DEC 60 1200
13 DEC 60 1200
14 DEC 60 1200
15 DEC 60 1200
16 DEC 60 1200
17 DEC 60 1200
18 DEC 60 1200
19 DEC 60 1200
20 DEC 60 1200
21 DEC 60 1200
22 DEC 60 1200
23 DEC 60 1200
24 DEC 60 1200
25 DEC 60 1200
26 DEC 60 1200
27 DEC 60 1200
28 DEC 60 1200
29 DEC 60 1200
30 DEC 60 1200
31 DEC 60 1200

Fig. 19f

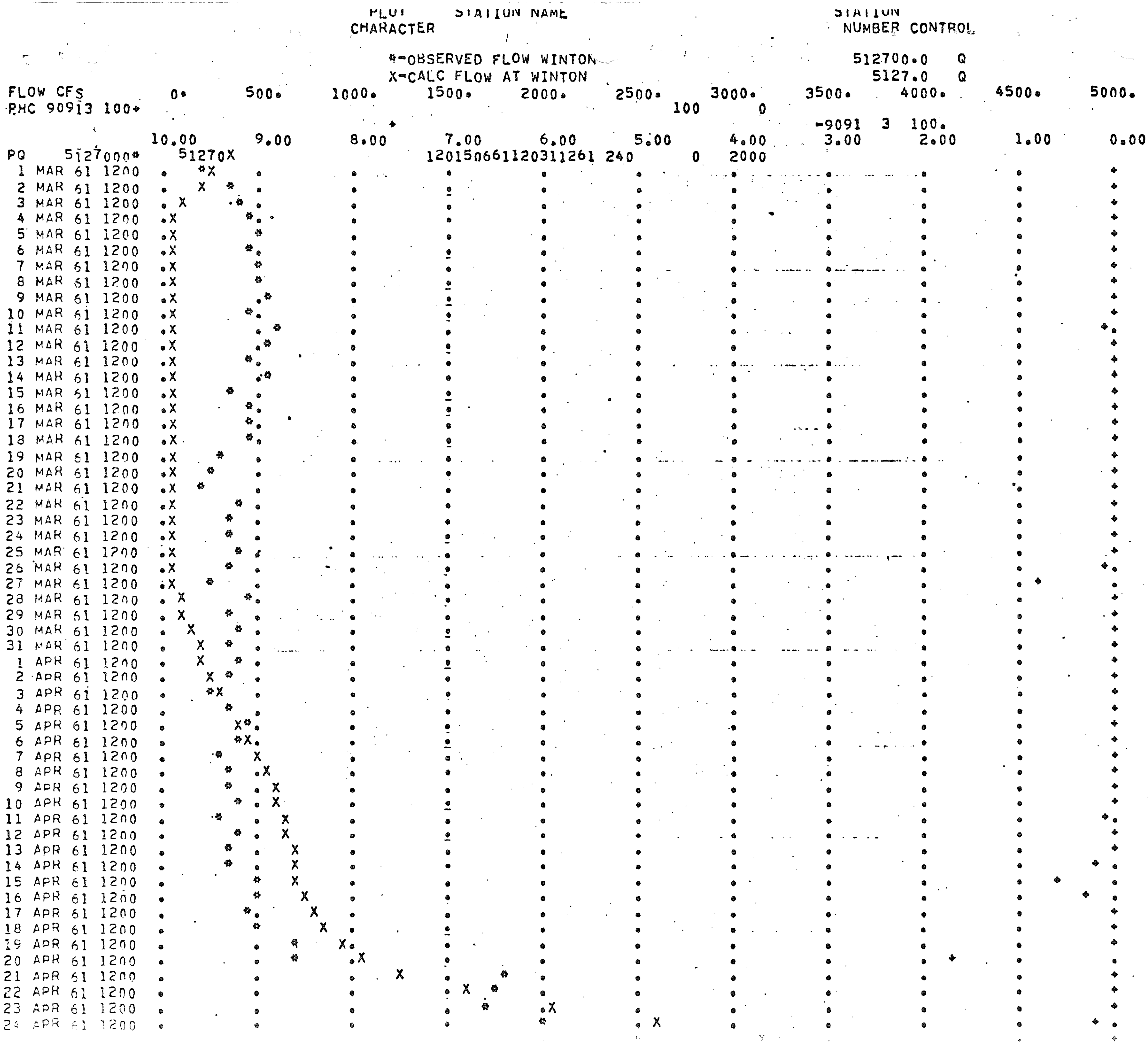


Fig. 20a

123658

123658

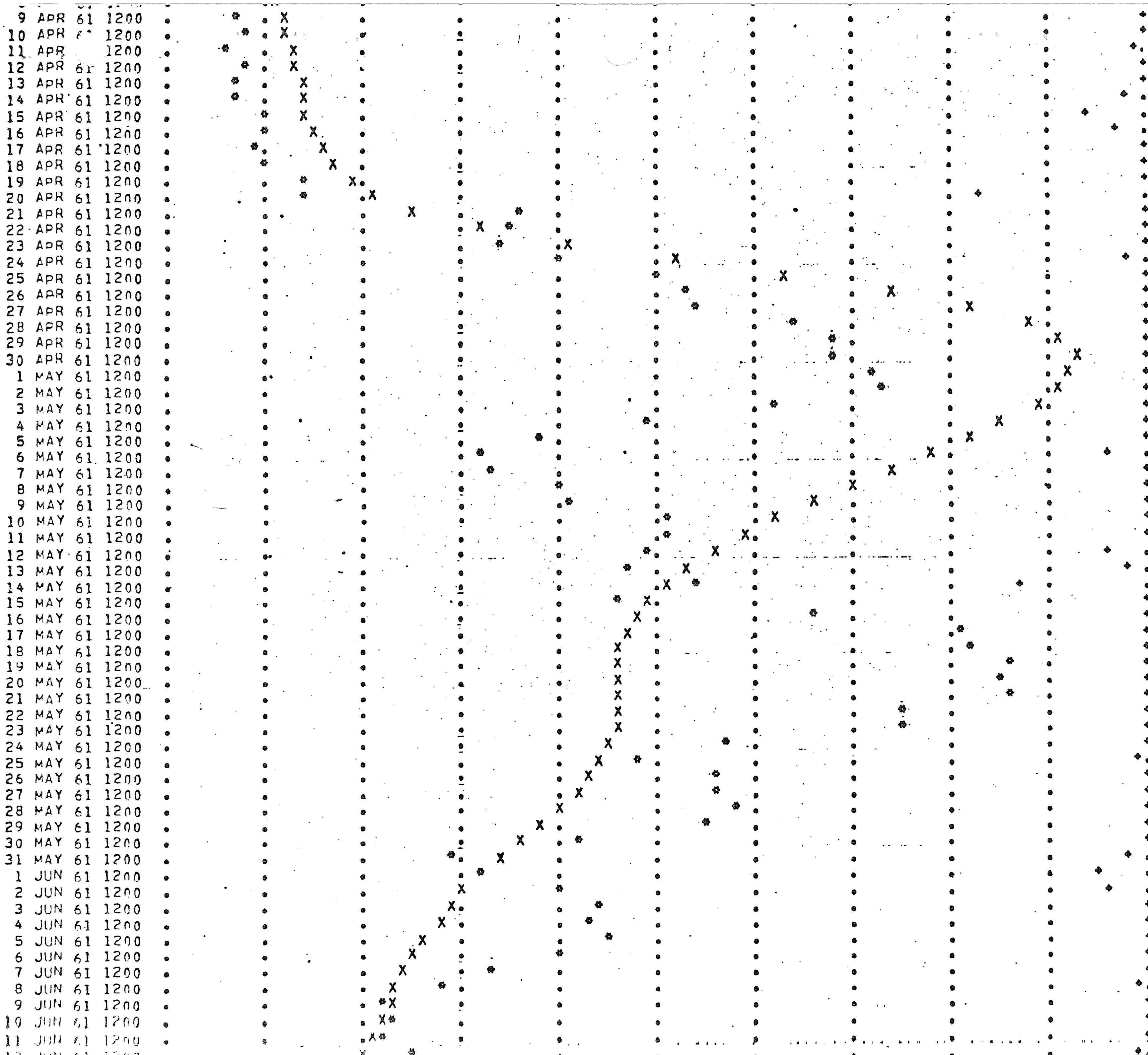


Fig. 20b

123659

14 JUN 61 1200
15 JUN 1200

PLOT CHARACTER   STATION NAME   STATION NUMBER   CONTROL

*-OBSERVED FLOW WINTON   512700.0   Q
X-CALC FLOW AT WINTON   5127.0   Q

FLOW CFS   0.   200.   400.   600.   800.   1000.   1200.   1400.   1600.   1800.   2000.
PHC 90913 100+   100   0
-9091 3 100.
10.00   9.00   8.00   7.00   6.00   5.00   4.00   3.00   2.00   1.00   0.00
END
END OF FILE ON INPUT DECK

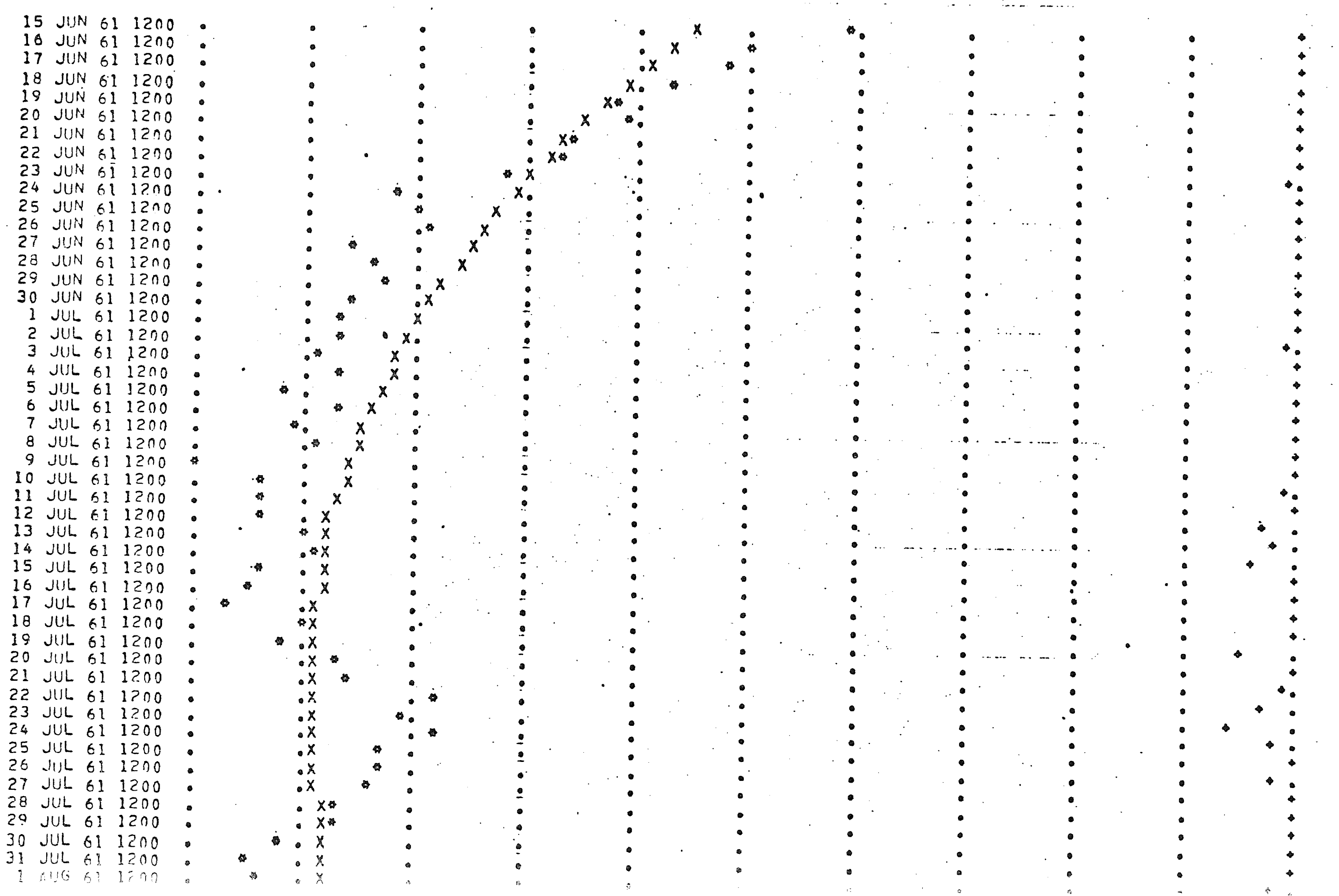


Fig. 20c

123660

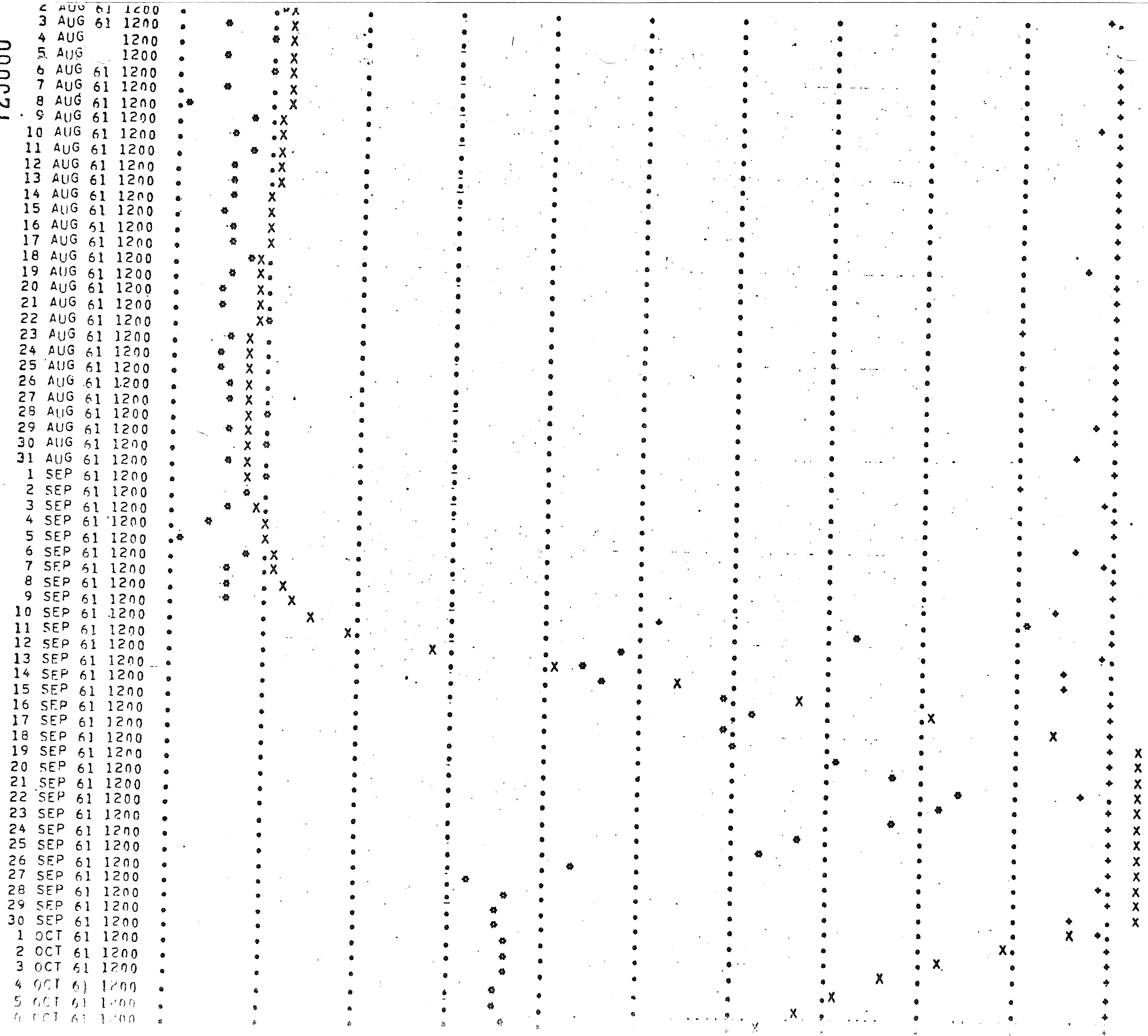


Fig. 20d

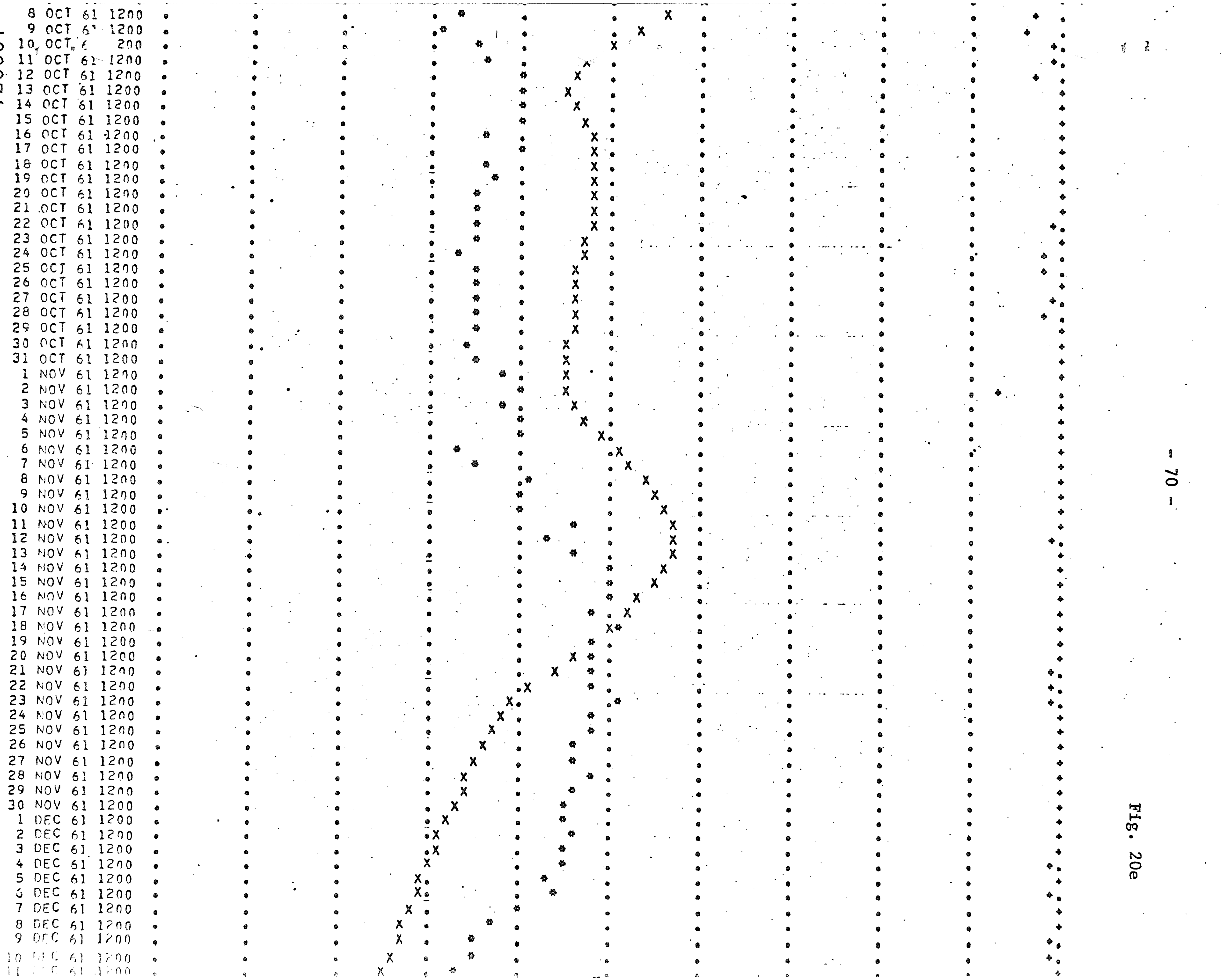

8 OCT 61 1200
9 OCT 61 1200
10 OCT 61 1200
11 OCT 61 1200
12 OCT 61 1200
13 OCT 61 1200
14 OCT 61 1200
15 OCT 61 1200
16 OCT 61 1200
17 OCT 61 1200
18 OCT 61 1200
19 OCT 61 1200
20 OCT 61 1200
21 OCT 61 1200
22 OCT 61 1200
23 OCT 61 1200
24 OCT 61 1200
25 OCT 61 1200
26 OCT 61 1200
27 OCT 61 1200
28 OCT 61 1200
29 OCT 61 1200
30 OCT 61 1200
31 OCT 61 1200
1 NOV 61 1200
2 NOV 61 1200
3 NOV 61 1200
4 NOV 61 1200
5 NOV 61 1200
6 NOV 61 1200
7 NOV 61 1200
8 NOV 61 1200
9 NOV 61 1200
10 NOV 61 1200
11 NOV 61 1200
12 NOV 61 1200
13 NOV 61 1200
14 NOV 61 1200
15 NOV 61 1200
16 NOV 61 1200
17 NOV 61 1200
18 NOV 61 1200
19 NOV 61 1200
20 NOV 61 1200
21 NOV 61 1200
22 NOV 61 1200
23 NOV 61 1200
24 NOV 61 1200
25 NOV 61 1200
26 NOV 61 1200
27 NOV 61 1200
28 NOV 61 1200
29 NOV 61 1200
30 NOV 61 1200
1 DEC 61 1200
2 DEC 61 1200
3 DEC 61 1200
4 DEC 61 1200
5 DEC 61 1200
6 DEC 61 1200
7 DEC 61 1200
8 DEC 61 1200
9 DEC 61 1200
10 DEC 61 1200
11 DEC 61 1200

Fig. 20e

123662

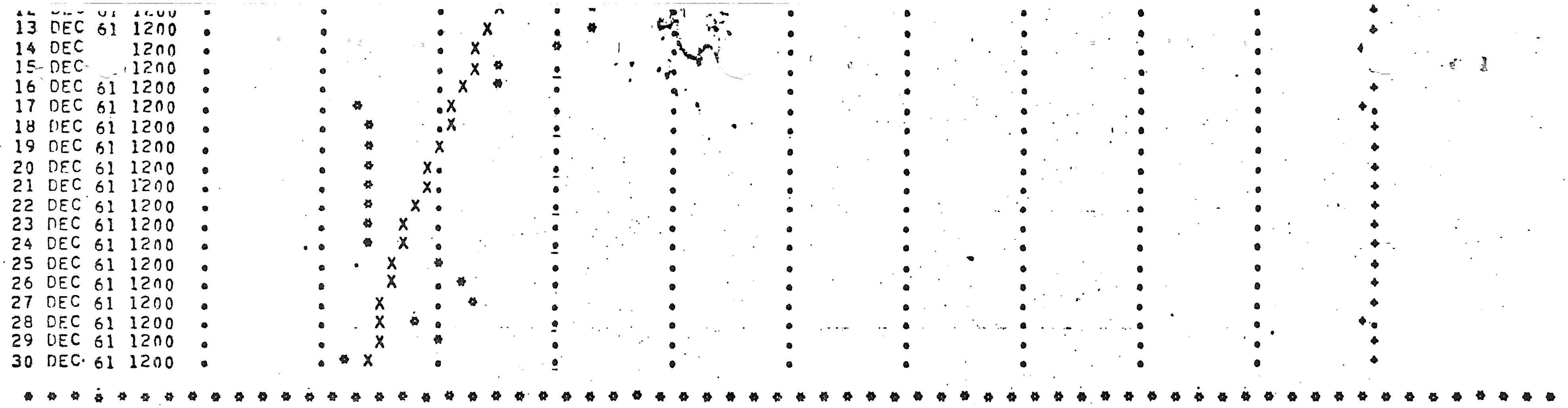


Fig. 20f

TABLE VIII - LISTING OF WATERSHED UNITS, MINE DEVELOPMENTS, TOTAL WATERSHED AREA LOST, AND APPROPRIATION RATES.
(Initial set of appropriation rates)*

Watershed Unit	Development	Total Area Lost (Acres)	Appropriation (cfs)
South Kawishiwi Near Ely (51250)	Open Pit Processing Plant	3124	18.0
Stony River (51255)	Tailings Basins	6324	-
Dunka River (51260)	Open Pits Processing Plant Smelter/ Refinery	14453	24.0
Birch Lake Local Inflow (60)	Underground Mine Processing Plant	3077	14.0
Partridge River (40160)	Open Pit Processing Plant Tailings Basin	7139	18.0

*In a revised set of appropriation data the appropriation of the South Kawishiwi near Ely and of the Partridge River were each reduced from 18 cfs to 9 cfs. Results of runs with these data have been placed in Appendix H. All references to mining effects in the body of the report are based on the data of Table VIII.

The mining and processing of the ores will require the use of water. To obtain the water the mining companies will recover the precipitation and snowmelt in their development area. Thus, a total loss in watershed area is assumed. The loss in watershed area is also listed in Table VIII.

Computations by the Regional Copper-Nickel Study have indicated that the recovered water will not be sufficient to sustain the industry during dry periods. Thus, to supplement the recovered water, appropriation rates were calculated and are also listed in Table VIII.

TECHNIQUES OF INCORPORATING MINING DEVELOPMENT INTO THE SSARR

The hydrologic impact of copper-nickel mining development was investigated using the scheme described earlier in the report for low flow events which occured in 1976 and 1960 and the 100 year rain event for the Kawishiwi and St. Louis watersheds.

Evaluation of low-flow events necessitated the use of observed flows in 1960 and 1976 to determine the severity of the "droughts". In Appendix A the procedure for determining the procedure for evaluating the low flow probability is explained.

Considering the flow of the Kawishiwi River at Winton (for durations of 14, 30, and 120 days) it appears that 1960 has a high probability of occurrence of 50 percent and a corresponding occurrence interval of about 2.0 years. The year 1976 was a much more severe drought with a probability of only 1.3 percent and a recurrence interval of 80 years.

Analysis of the data for the St. Louis River near Aurora indicated a much less severe drought for 1976 than was the case for the Kawishiwi System. The Partridge River is one of the main tributaries of the St. Louis River above Aurora. Extensive mining developments exist in the Partridge River watershed, as noted in an earlier section. Associated with this mining, water is pumped from the mines to the stream and from the stream to processing plants and to storage reservoirs. Some of the pumping rates are well above the low flow discharge for 1976. It is possible that the modifications to flow are too extensive to permit an accurate evaluation of the 1976 low flow frequency. Thus, the data for the Kawishiwi River may be the best index of the 1976 drought in this general area even though the power developments also modify the flow of the Kawishiwi River.

During mining operations, both loss of watershed and flow appropriations had to be included in the SSARR calibrated model. The watershed loss in the area was handled as an adjacent station provision. For low flow events the watershed loss was treated as a percentage loss of the subwatershed outflow. Table IX lists the mining operation and station from which the hydrograph for the lost watershed area was created. The lost watershed hydrograph was then subtracted from the subwatershed outflow creating an impacted hydrograph.

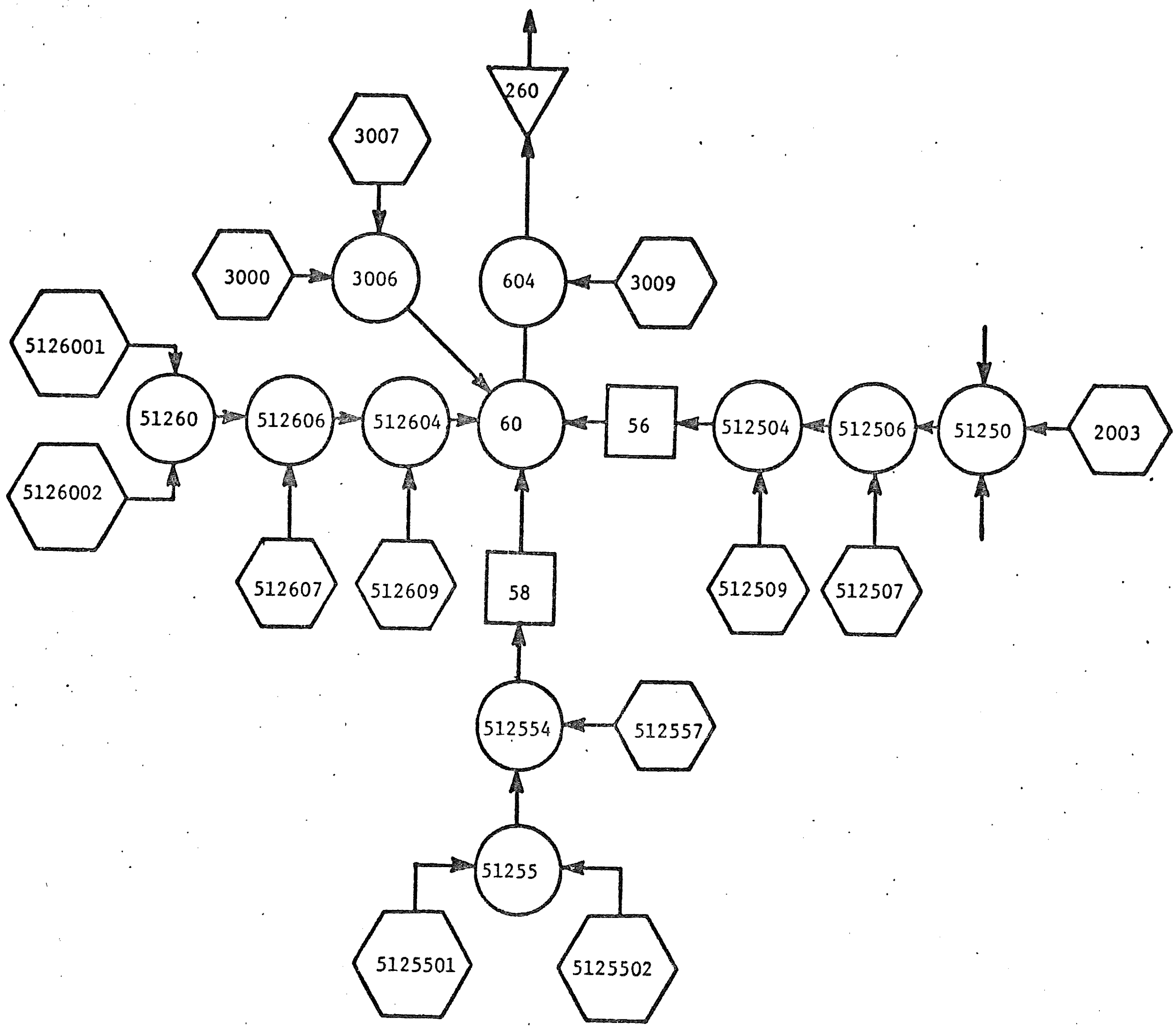
For high flow events the TR-20 was used to create a synthetic hydrograph for the mining areas. The synthetic hydrograph was subtracted from the calculated SSARR watershed hydrograph creating an impacted outflow hydrograph. Appendix B contains the TR-20 hydrographs for high flows.

Also included during mining operations were the appropriations. The appropriations were given a maximum value. If the flow past the appropriation point was less than the maximum value, the appropriation was changed to leave 1 cfs in the river system. An example would be the Dunka where the maximum appropriation was 24 cfs. If the impacted outflow was 10 cfs, then the appropriation was set at 9 cfs. The total new impacted outflow was then calculated for each subwatershed area. Schematic figures of the Kawishiwi and St. Louis watersheds for low flow events are given in Figs. 21 and 22. Figures 23 and 24 show how the system was arranged for determining the mining impact of high flows with the TR-20 results.

To evaluate post operational conditions in the watersheds it was necessary to assume certain runoff conditions were applicable. During high flow events the runoff was calculated from the post mining areas using the TR-20. For low events, where peak flows are not important, an increase in runoff from the area by 25 percent was used. The assumption was based on the fact that the TR-20 calculated a 40 percent increase (in the mine area) in runoff volume for the 2 year storm. Extrapolating towards low flow events, a 25 percent increase was used in the analysis of post mining effects during low flow periods. Schematics of how the watersheds were set up are shown in Figs. 25 and 26.

TABLE IX - PERCENTAGE OF INDEX STATION TO CREATE LOW FLOW IMPACTED MINING CONDITION HYDROGRAPH.

Subwatershed	Area	Index Station	Percent of Index Station
South Kawishiwi 512508	3124	51255	3
Stony 512558	6324	51255	5
Dunka 512608	14453	51260	43
Birch Local 3008	3077	51255	3
Partridge 401605	7139	40160	9



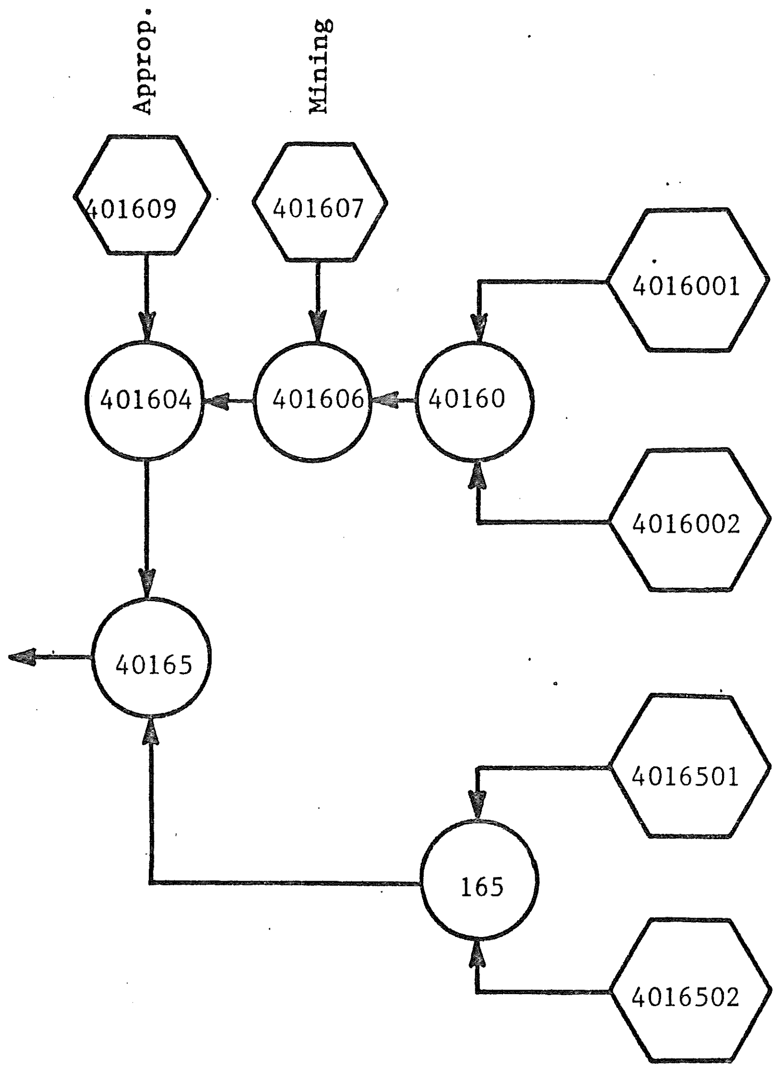
Mining Operations

512507 South Kawishiwi River Locale
512557 Stony River
512607 Dunka River
3007 Birch Lake Locale

Appropriation Stations

512509 South Kawishiwi River Locale
512609 Dunka River
3009 Birch Lake Inflow

Fig. 21 - Schematic of Mining Developments Included in the Kawishiwi River System, Low Flow Events



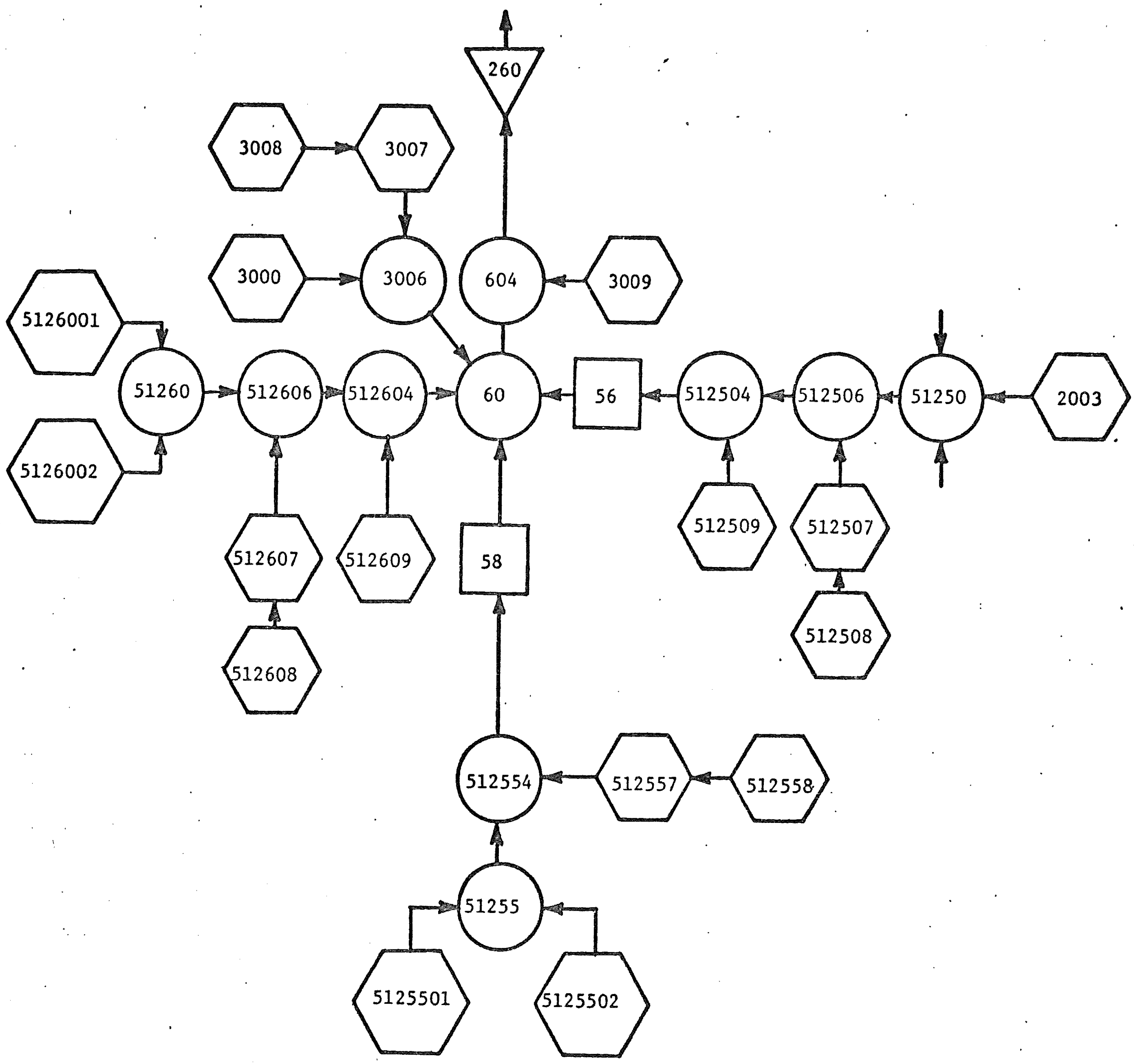
Mining Operation

401607 Partridge River

Appropriation Station

401609 Partridge River

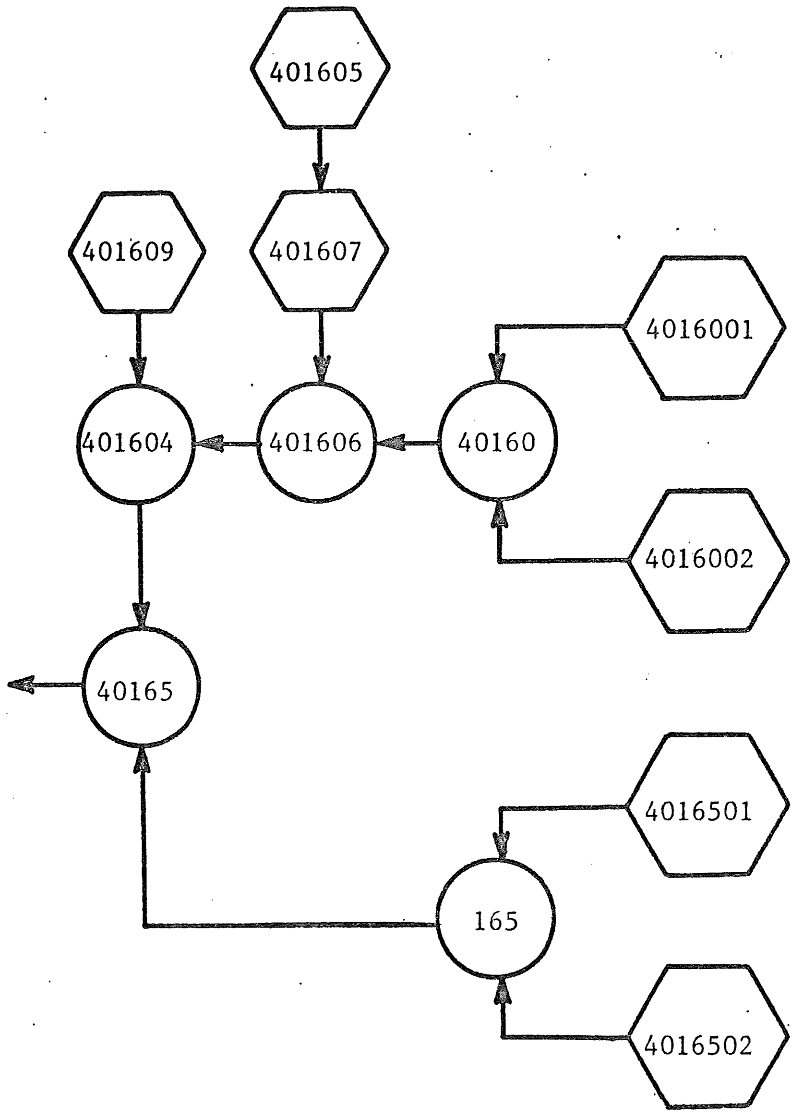
Fig. 22 - Schematic of Mining Development Included in the St. Louis River System, Low Flow Events.



TR-20 Hydrograph Input Stations

512508	South Kawishiwi
512558	Stony
3008	Birch Lake Locale
512608	Dunka

Fig. 23 - Schematic of Kawishiwi Mining Development for Rain Event Analysis



TR-20 Hydrograph Input Station

401605 Partridge

Fig. 24 - Schematic of St. Louis Mining Development for Rain Event Analysis.

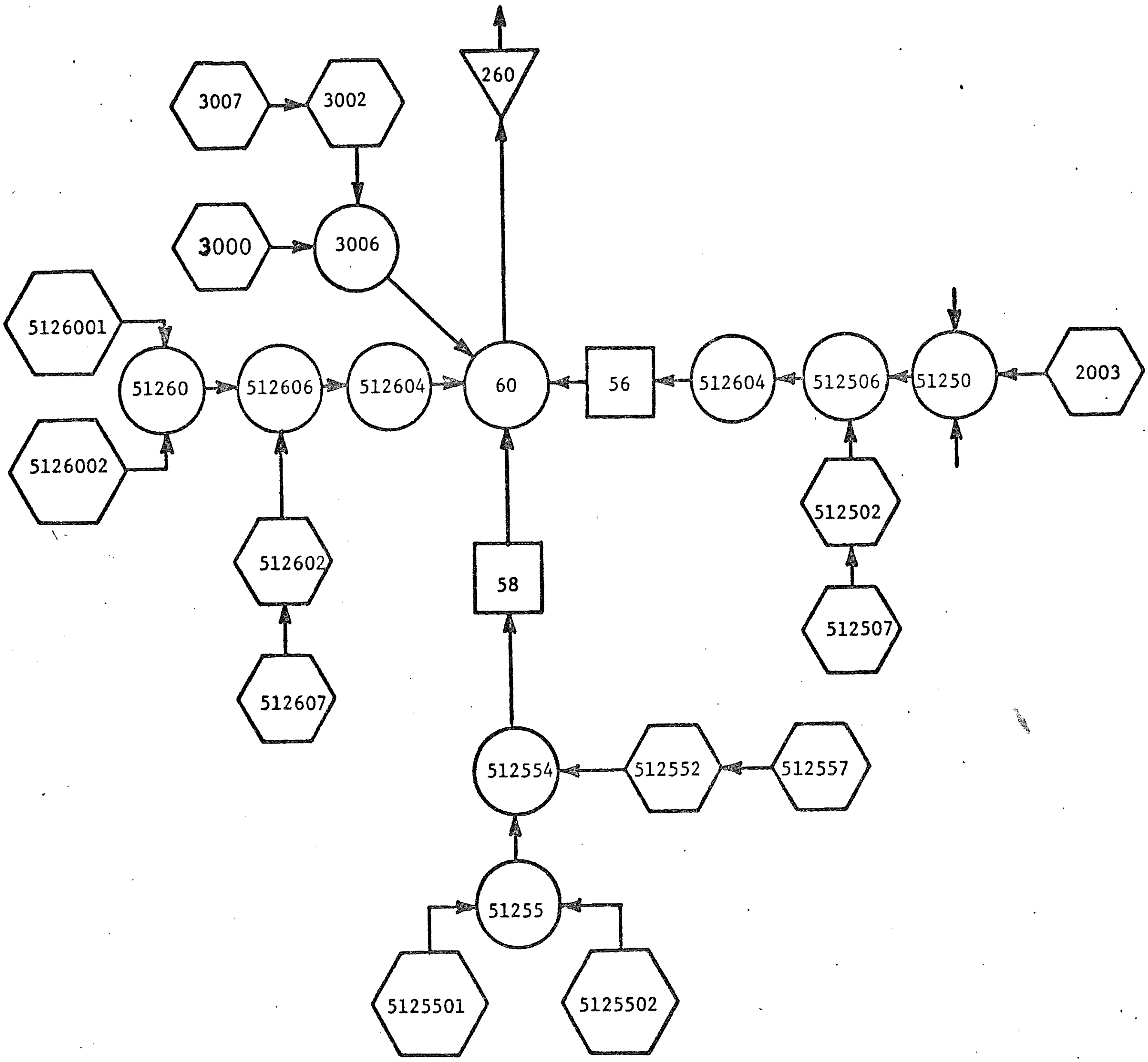


Fig. 25 - Schematic of Kawishiwi Watershed for Low Flow Event During Post Mining Conditions

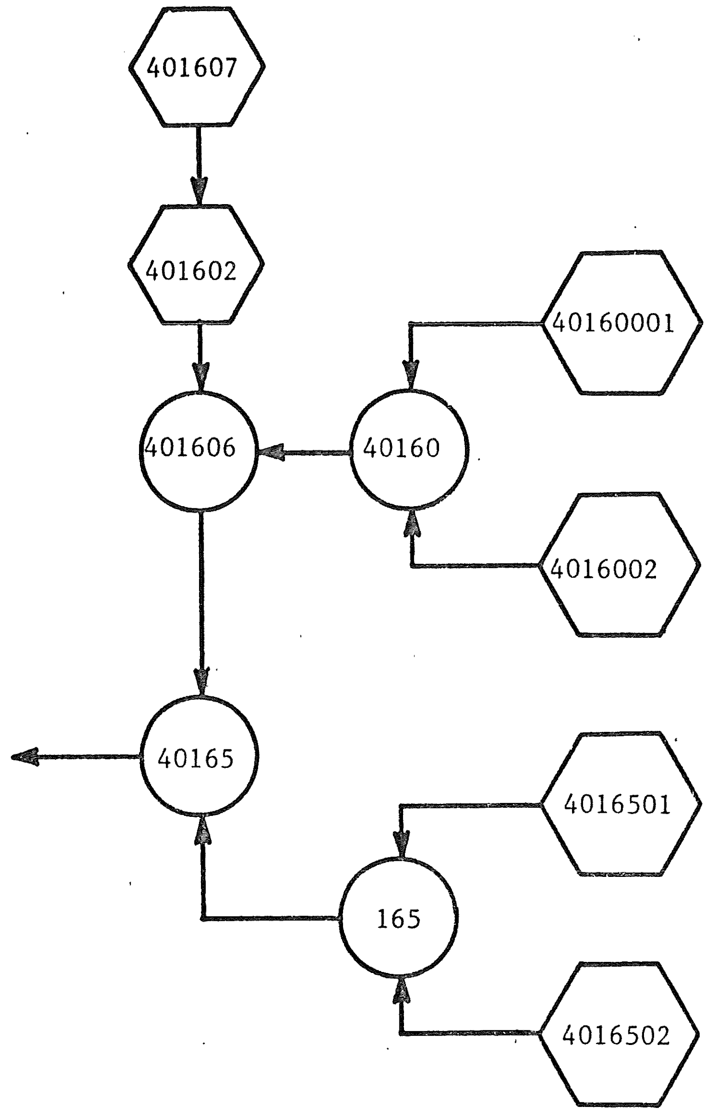


Fig. 26 - Schematic of St. Louis Watershed for Low Flow Events During Post Mining Conditions.

The post mining effect was modeled in the SSARR using the adjacent station provision. For low flows the subwatershed outflow was calculated. Then 25 percent of what would have been subtracted from the calculated flow to simulate mining was added to provide the runoff increase. Post-mining TR-20 hydrographs were added to mining operation calculated hydrograph to simulate high flow events. Schematics of how the watersheds were set up are shown in Figs. 27 and 28.

HYDROLOGIC IMPACTS OF COPPER-NICKEL DEVELOPMENT

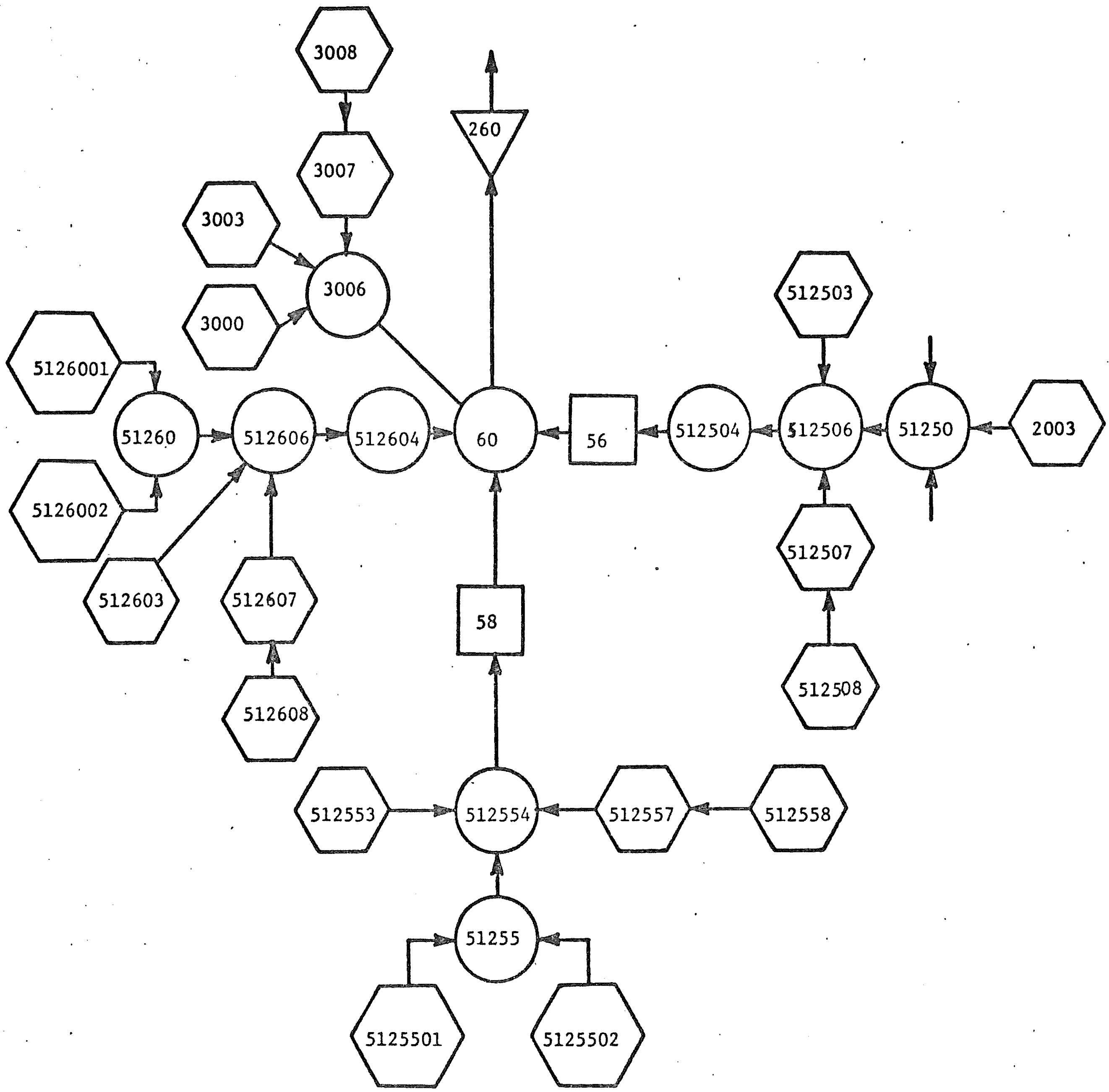
The calibrated SSARR was run with both mining conditions operational and post operational. The hydrographs for the above conditions with the before mining calculated outflow for Winton on the Kawishiwi are given in Figs. 29 and 30 for low flow event years 1976 and 1960. The same years for the St. Louis gauge with the same conditions are given in Figs. 31 and 32.

During the low flow period, August 3 - November 30, 120 days, of 1976 the SSARR calculated an outflow for the Kawishiwi basin (at Winton) of 28017 second foot days (one sec.-ft.-day = two acre ft.). During mining operations the flow was reduced to 23826 SFD, a 15 percent decrease. With post mining conditions, the flow was increased to 28103 SFD (a 0.3 percent increase relative to the initial condition).

For the St. Louis basin the 120 day low flow period of September 3 - December 31, 1976 was calculated at 1605 SFD for the outflow of Aurora. During mining the outflow was reduced to 1105 SFD, a 31 percent decrease. With post-mining conditions, the outflow was increased to 1647, a 3 percent increase over the present or initial conditions.

The period August 3 - November 30 was the period with the minimum observed flow for 1976 at Winton. The minimum computed flow occurred over a later period. Table X shows a comparison of the 120 day low flows for 1960 and 1976,

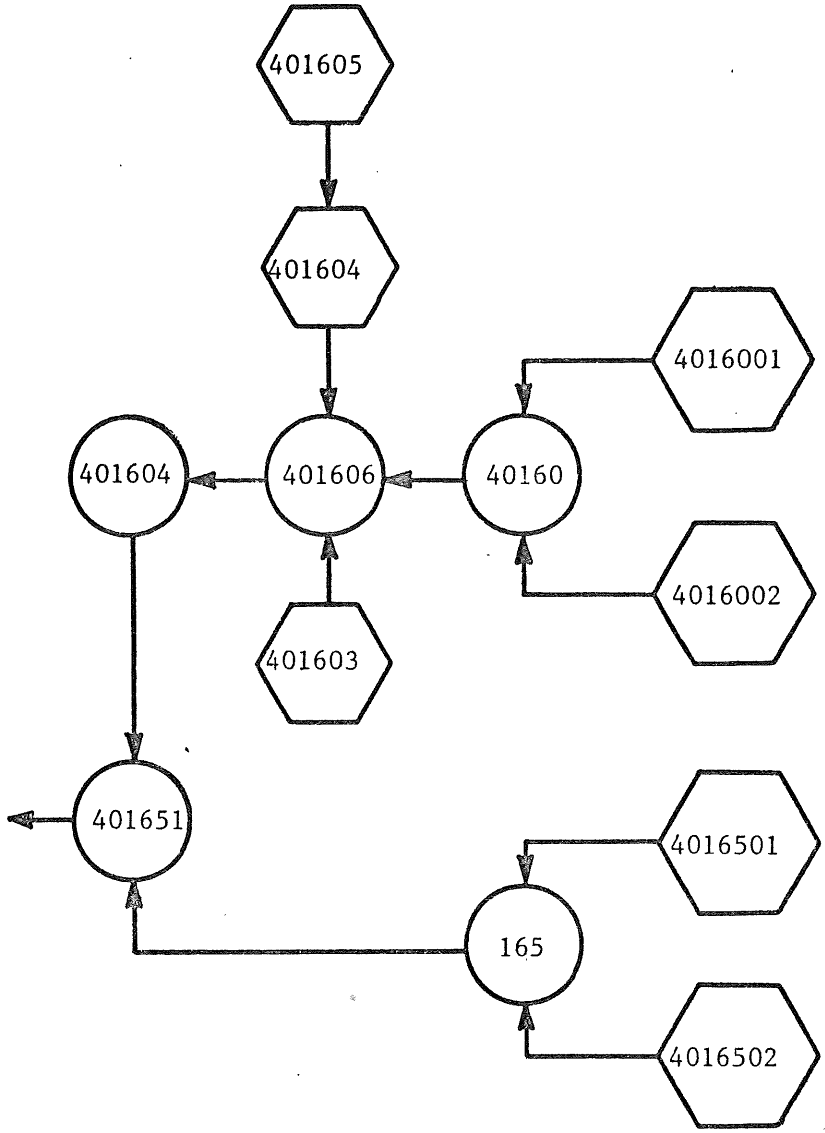
(1) with computed flows for present conditions,
(2) computed flows with the mining condition shown in Tables VIII and IX. (These had a total mining area of 34,117 acres in the



TR-20 Post Mining Hydrograph Stations

512503	South Kawishiwi
512553	Stony
3003	Birch Lake Locale
512603	Dunka

Fig. 27 - Schematic of Kawishiwi Watershed for High Flow Events During Post Mining Conditions



TR-20 Post Mining Hydrograph Station

401603 Partridge

Fig. 28 - Schematic of St. Louis Watershed for High Flow Events During Post Mining Conditions.

PLOT CHARACTER	STATION NAME	STATION NUMBER	CONTROL
$	WINTON POST MINING	51270.1	Q
≠	WINTON WITH MINING	5127.0	Q
X	CALC WINTON NO MINING	512707.5	Q
*	OBSERVED FLOW WINTON	512700.0	Q

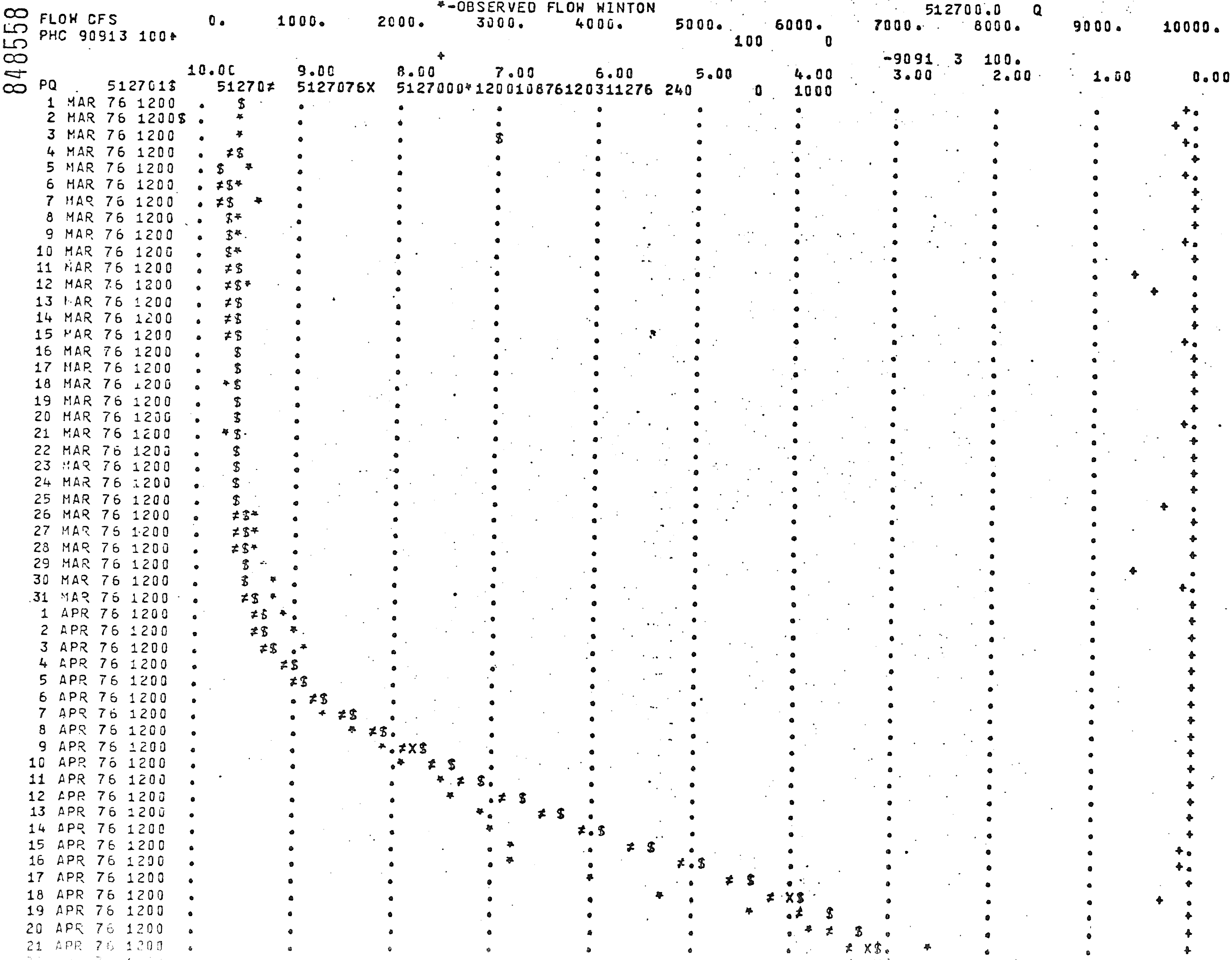


Fig. 29a

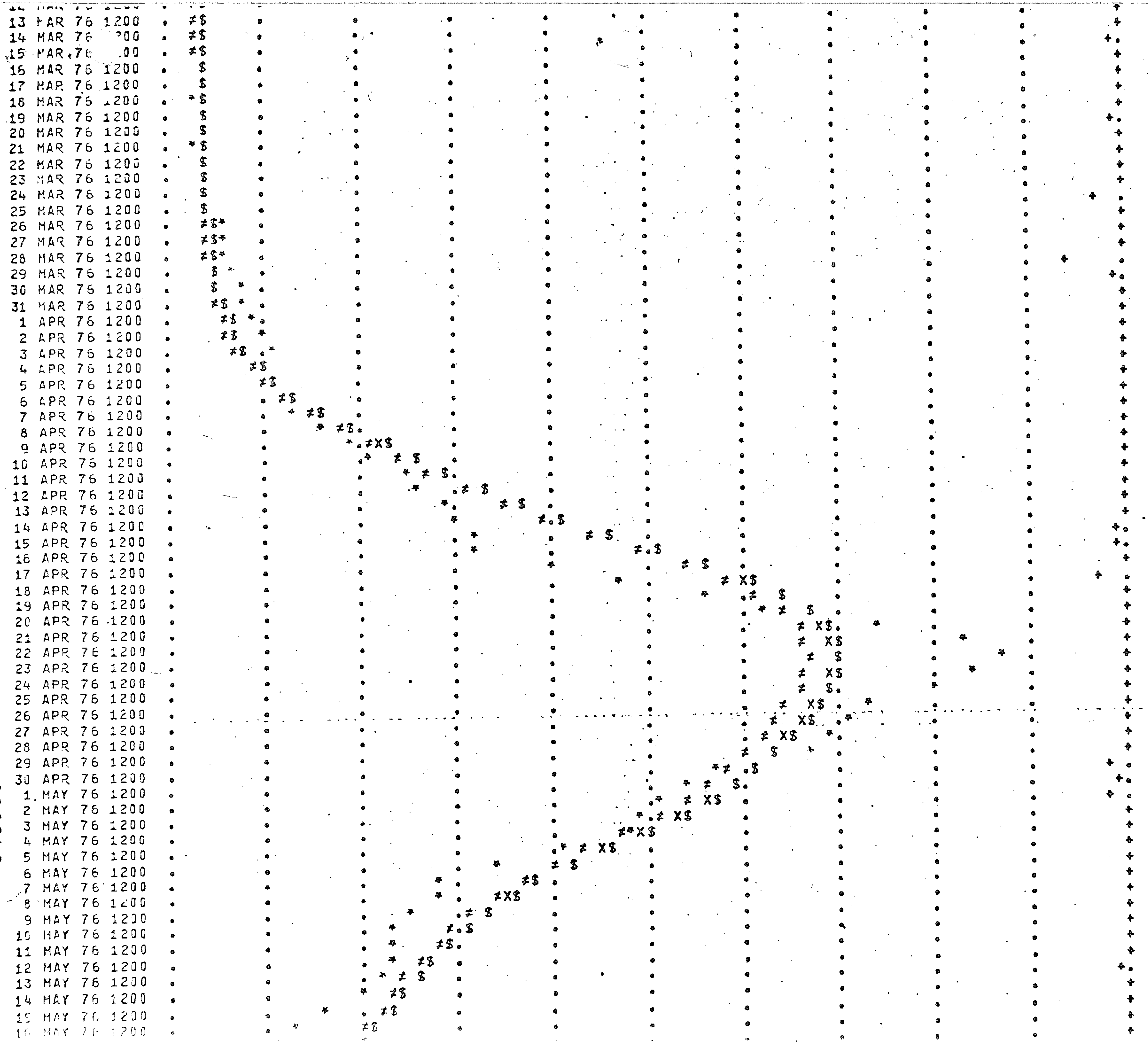
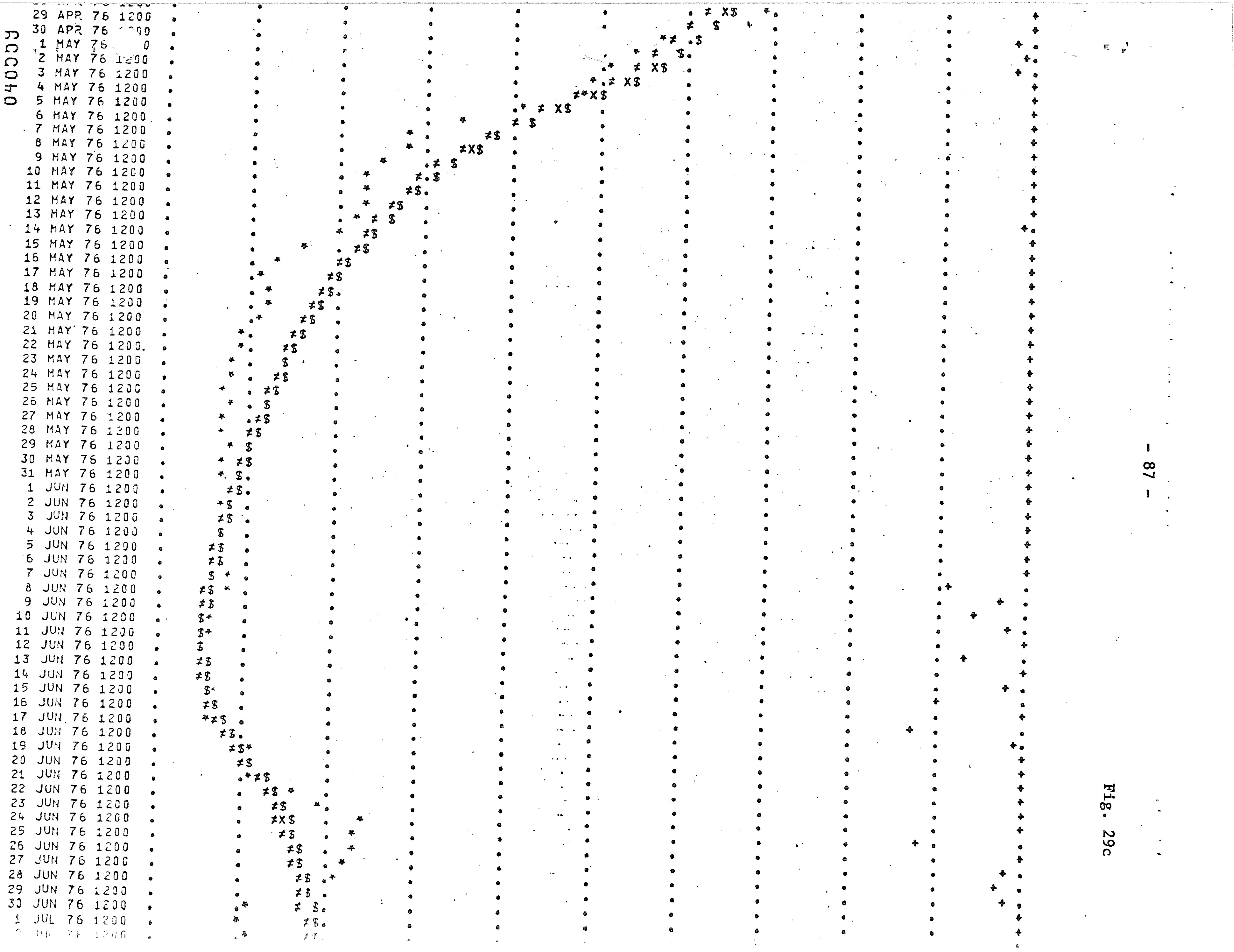


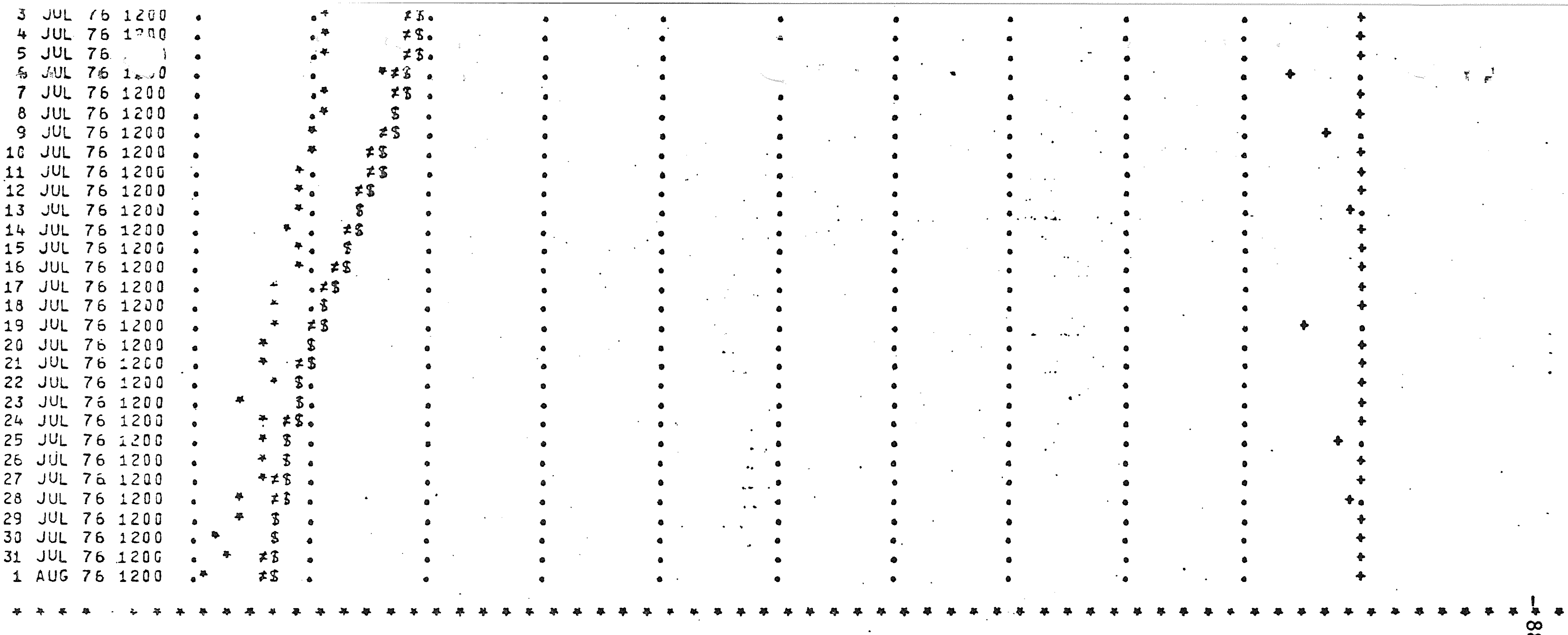
Fig. 29b

848559



29 APR 76 1200
30 APR 76 1200
1 MAY 76 1200
2 MAY 76 1200
3 MAY 76 1200
4 MAY 76 1200
5 MAY 76 1200
6 MAY 76 1200
7 MAY 76 1200
8 MAY 76 1200
9 MAY 76 1200
10 MAY 76 1200
11 MAY 76 1200
12 MAY 76 1200
13 MAY 76 1200
14 MAY 76 1200
15 MAY 76 1200
16 MAY 76 1200
17 MAY 76 1200
18 MAY 76 1200
19 MAY 76 1200
20 MAY 76 1200
21 MAY 76 1200
22 MAY 76 1200
23 MAY 76 1200
24 MAY 76 1200
25 MAY 76 1200
26 MAY 76 1200
27 MAY 76 1200
28 MAY 76 1200
29 MAY 76 1200
30 MAY 76 1200
31 MAY 76 1200
1 JUN 76 1200
2 JUN 76 1200
3 JUN 76 1200
4 JUN 76 1200
5 JUN 76 1200
6 JUN 76 1200
7 JUN 76 1200
8 JUN 76 1200
9 JUN 76 1200
10 JUN 76 1200
11 JUN 76 1200
12 JUN 76 1200
13 JUN 76 1200
14 JUN 76 1200
15 JUN 76 1200
16 JUN 76 1200
17 JUN 76 1200
18 JUN 76 1200
19 JUN 76 1200
20 JUN 76 1200
21 JUN 76 1200
22 JUN 76 1200
23 JUN 76 1200
24 JUN 76 1200
25 JUN 76 1200
26 JUN 76 1200
27 JUN 76 1200
28 JUN 76 1200
29 JUN 76 1200
30 JUN 76 1200
1 JUL 76 1200

Fig. 29c



PLOT CHARACTER	STATION NAME	STATION NUMBER	CONTROL
$	WINTON POST MINING	51270.1	Q
≠	WINTON WITH MINING	5127.0	Q
X	CALC WINTON NO MINING	512707.6	Q
*	OBSERVED FLOW WINTON	512700.0	Q

```
FLOW CFS        0.      100.      200.      300.      400.      500.      600.      700.      800.      900.      1000.
PHC 90913 100+                                                  100        0
                                                                              -9091  3  100.
           10.00      9.00      8.00      7.00      6.00      5.00      4.00      3.00      2.00      1.00      0.00
END
   END OF FILE ON INPUT DECK
```

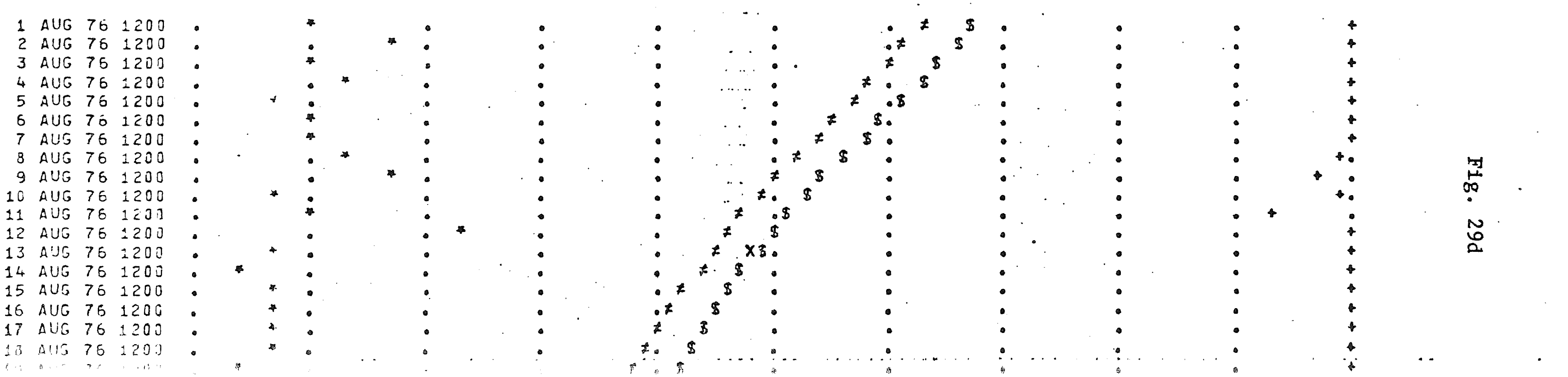


Fig. 29d

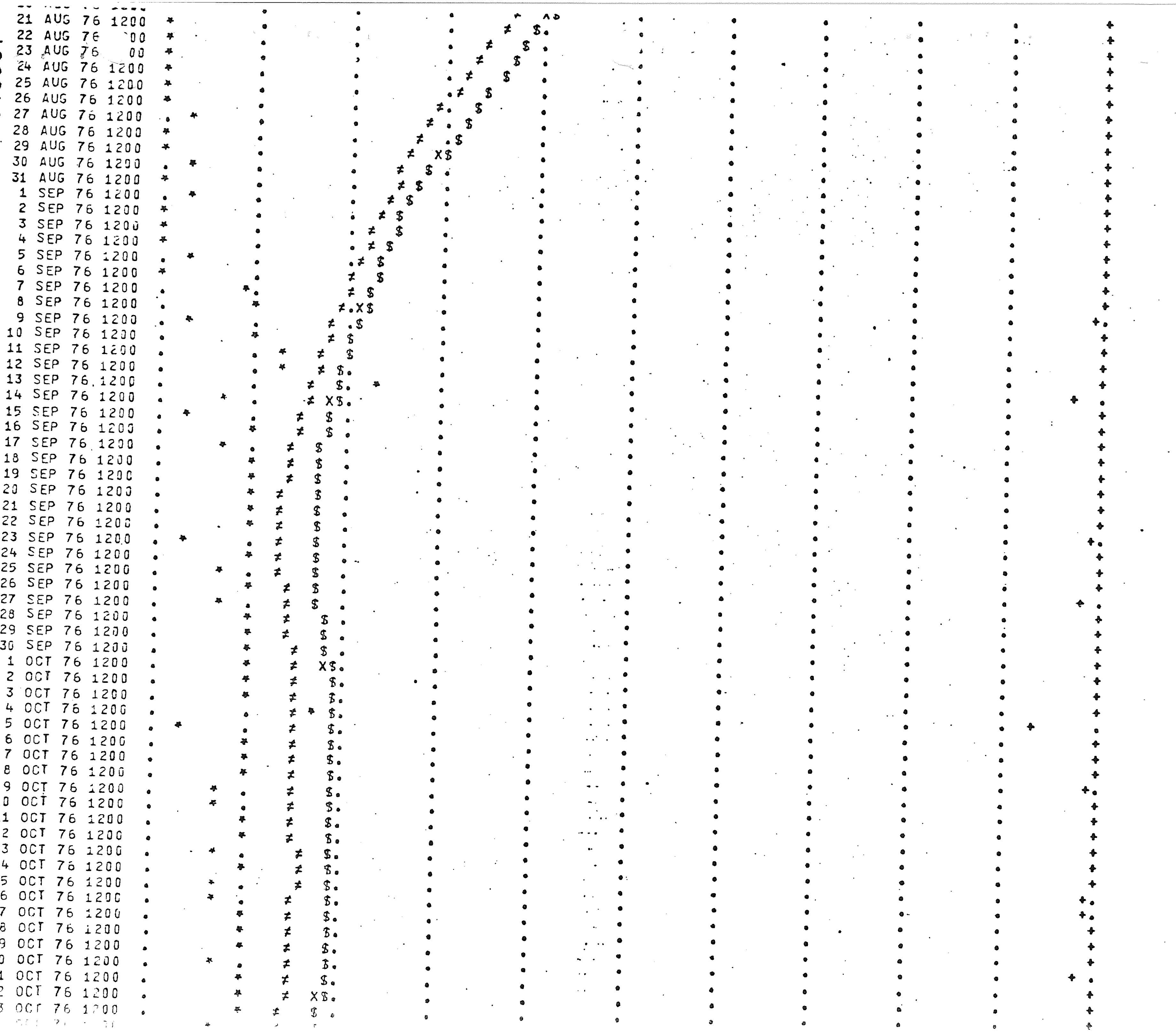

21 AUG 76 1200
22 AUG 76
23 AUG 76
24 AUG 76 1200
25 AUG 76 1200
26 AUG 76 1200
27 AUG 76 1200
28 AUG 76 1200
29 AUG 76 1200
30 AUG 76 1200
31 AUG 76 1200
1 SEP 76 1200
2 SEP 76 1200
3 SEP 76 1200
4 SEP 76 1200
5 SEP 76 1200
6 SEP 76 1200
7 SEP 76 1200
8 SEP 76 1200
9 SEP 76 1200
10 SEP 76 1200
11 SEP 76 1200
12 SEP 76 1200
13 SEP 76 1200
14 SEP 76 1200
15 SEP 76 1200
16 SEP 76 1200
17 SEP 76 1200
18 SEP 76 1200
19 SEP 76 1200
20 SEP 76 1200
21 SEP 76 1200
22 SEP 76 1200
23 SEP 76 1200
24 SEP 76 1200
25 SEP 76 1200
26 SEP 76 1200
27 SEP 76 1200
28 SEP 76 1200
29 SEP 76 1200
30 SEP 76 1200
1 OCT 76 1200
2 OCT 76 1200
3 OCT 76 1200
4 OCT 76 1200
5 OCT 76 1200
6 OCT 76 1200
7 OCT 76 1200
8 OCT 76 1200
9 OCT 76 1200
10 OCT 76 1200
11 OCT 76 1200
12 OCT 76 1200
13 OCT 76 1200
14 OCT 76 1200
15 OCT 76 1200
16 OCT 76 1200
17 OCT 76 1200
18 OCT 76 1200
19 OCT 76 1200
20 OCT 76 1200
21 OCT 76 1200
22 OCT 76 1200
23 OCT 76 1200

Fig. 29e

848562

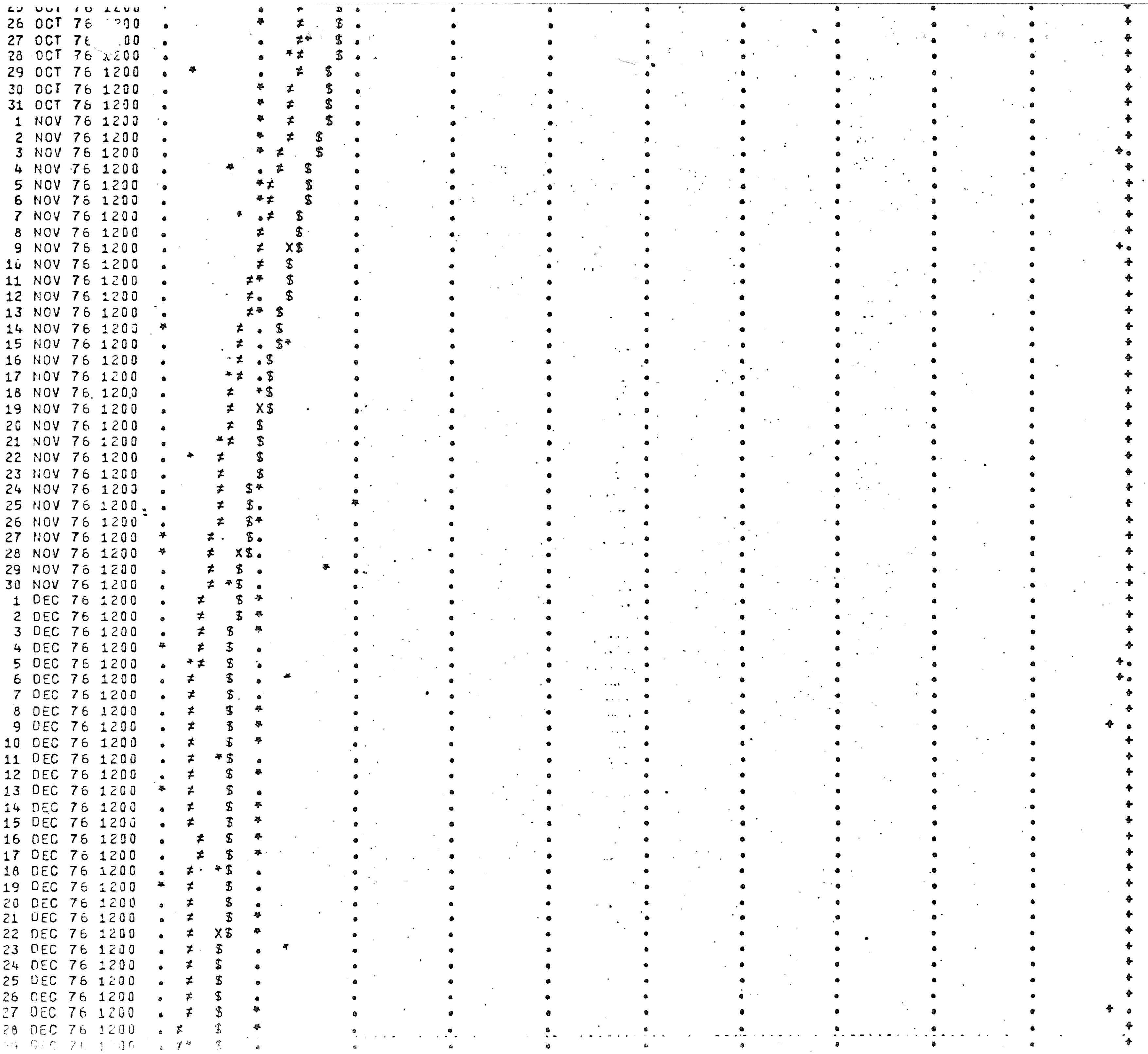
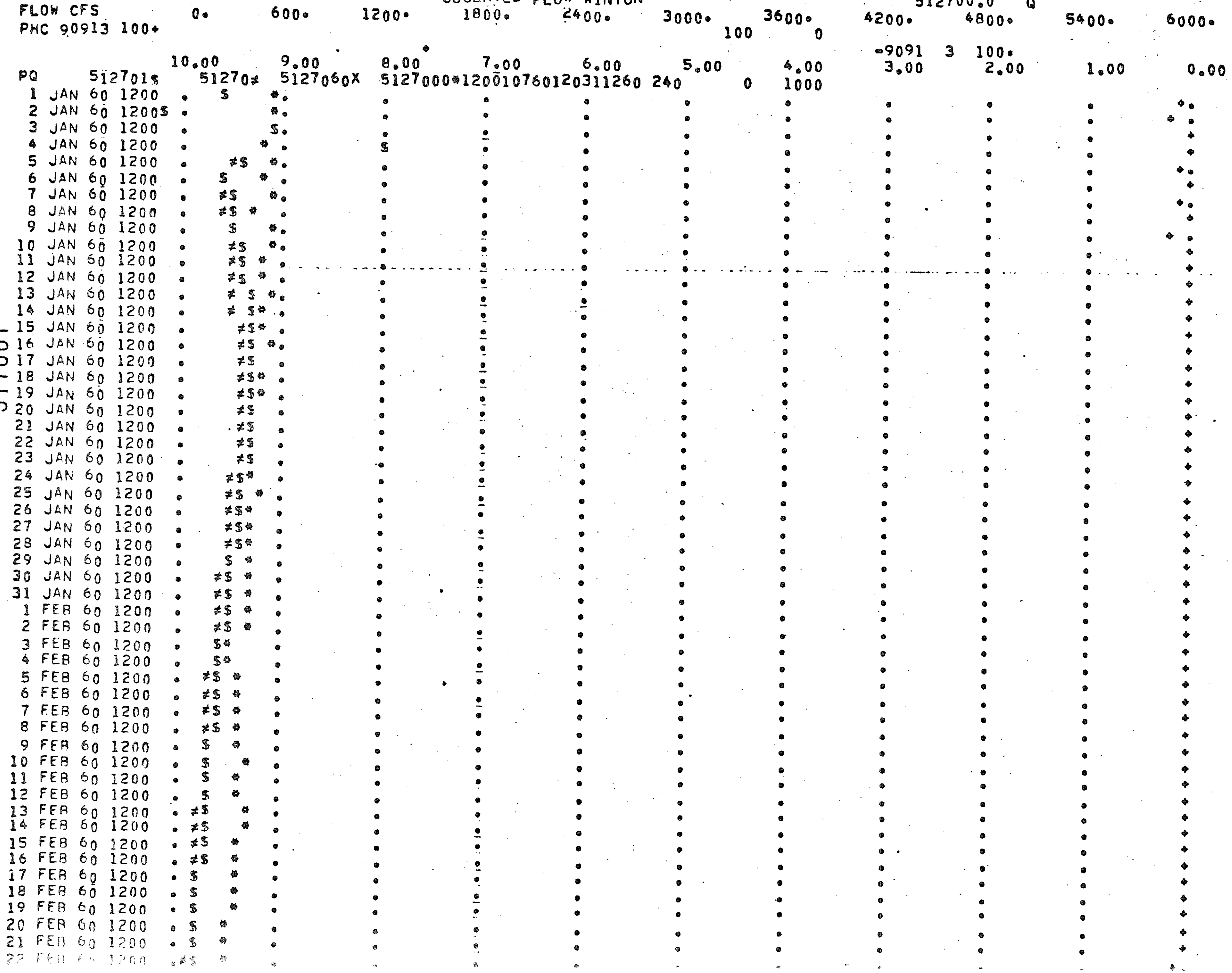


Fig. 29f

PLOT CHARACTER	STATION NAME	STATION NUMBER	CONTROL
$	WINTON POST MINING	51270.1	Q
≠	WINTON WITH MINING	5127.0	Q
X	CALC WINTON NO MINING	512706.0	Q
*	OBSERVED FLOW WINTON	512700.0	Q



517881

Fig. 30a

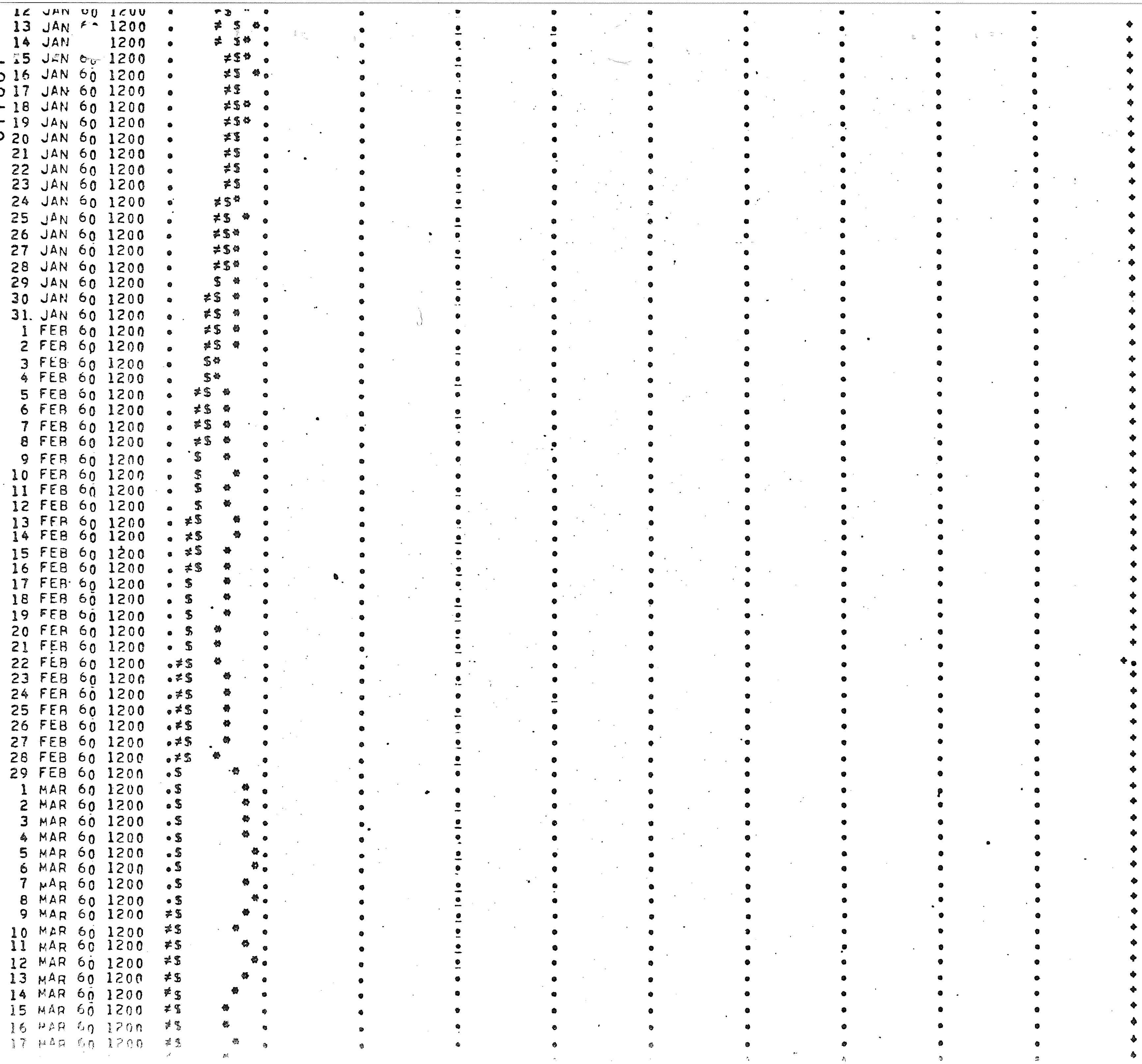

12 JAN 60 1200
13 JAN 60 1200
14 JAN 60 1200
15 JAN 60 1200
16 JAN 60 1200
17 JAN 60 1200
18 JAN 60 1200
19 JAN 60 1200
20 JAN 60 1200
21 JAN 60 1200
22 JAN 60 1200
23 JAN 60 1200
24 JAN 60 1200
25 JAN 60 1200
26 JAN 60 1200
27 JAN 60 1200
28 JAN 60 1200
29 JAN 60 1200
30 JAN 60 1200
31 JAN 60 1200
1 FEB 60 1200
2 FEB 60 1200
3 FEB 60 1200
4 FEB 60 1200
5 FEB 60 1200
6 FEB 60 1200
7 FEB 60 1200
8 FEB 60 1200
9 FEB 60 1200
10 FEB 60 1200
11 FEB 60 1200
12 FEB 60 1200
13 FEB 60 1200
14 FEB 60 1200
15 FEB 60 1200
16 FEB 60 1200
17 FEB 60 1200
18 FEB 60 1200
19 FEB 60 1200
20 FEB 60 1200
21 FEB 60 1200
22 FEB 60 1200
23 FEB 60 1200
24 FEB 60 1200
25 FEB 60 1200
26 FEB 60 1200
27 FEB 60 1200
28 FEB 60 1200
29 FEB 60 1200
1 MAR 60 1200
2 MAR 60 1200
3 MAR 60 1200
4 MAR 60 1200
5 MAR 60 1200
6 MAR 60 1200
7 MAR 60 1200
8 MAR 60 1200
9 MAR 60 1200
10 MAR 60 1200
11 MAR 60 1200
12 MAR 60 1200
13 MAR 60 1200
14 MAR 60 1200
15 MAR 60 1200
16 MAR 60 1200
17 MAR 60 1200

Fig. 30b

517882

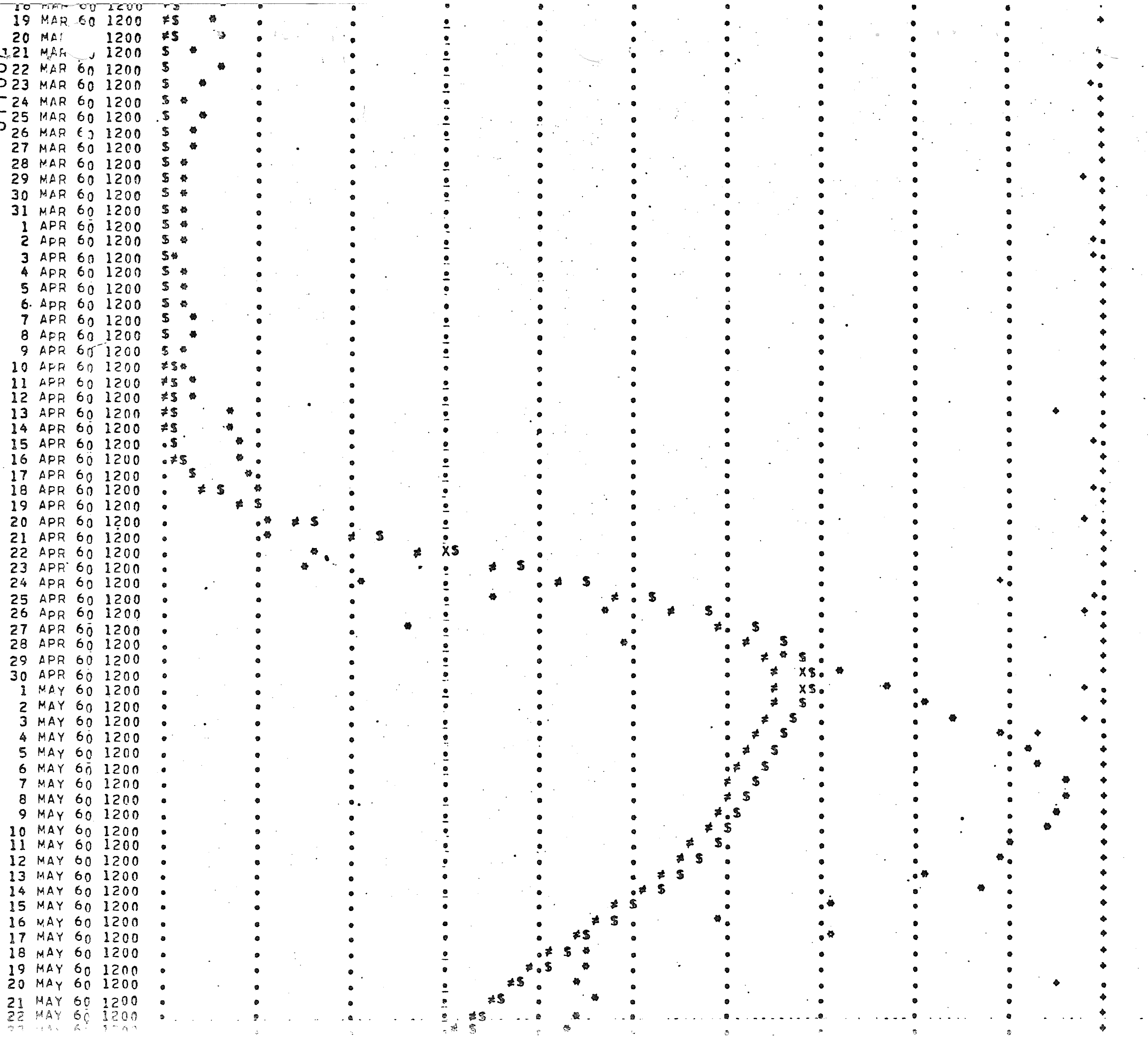
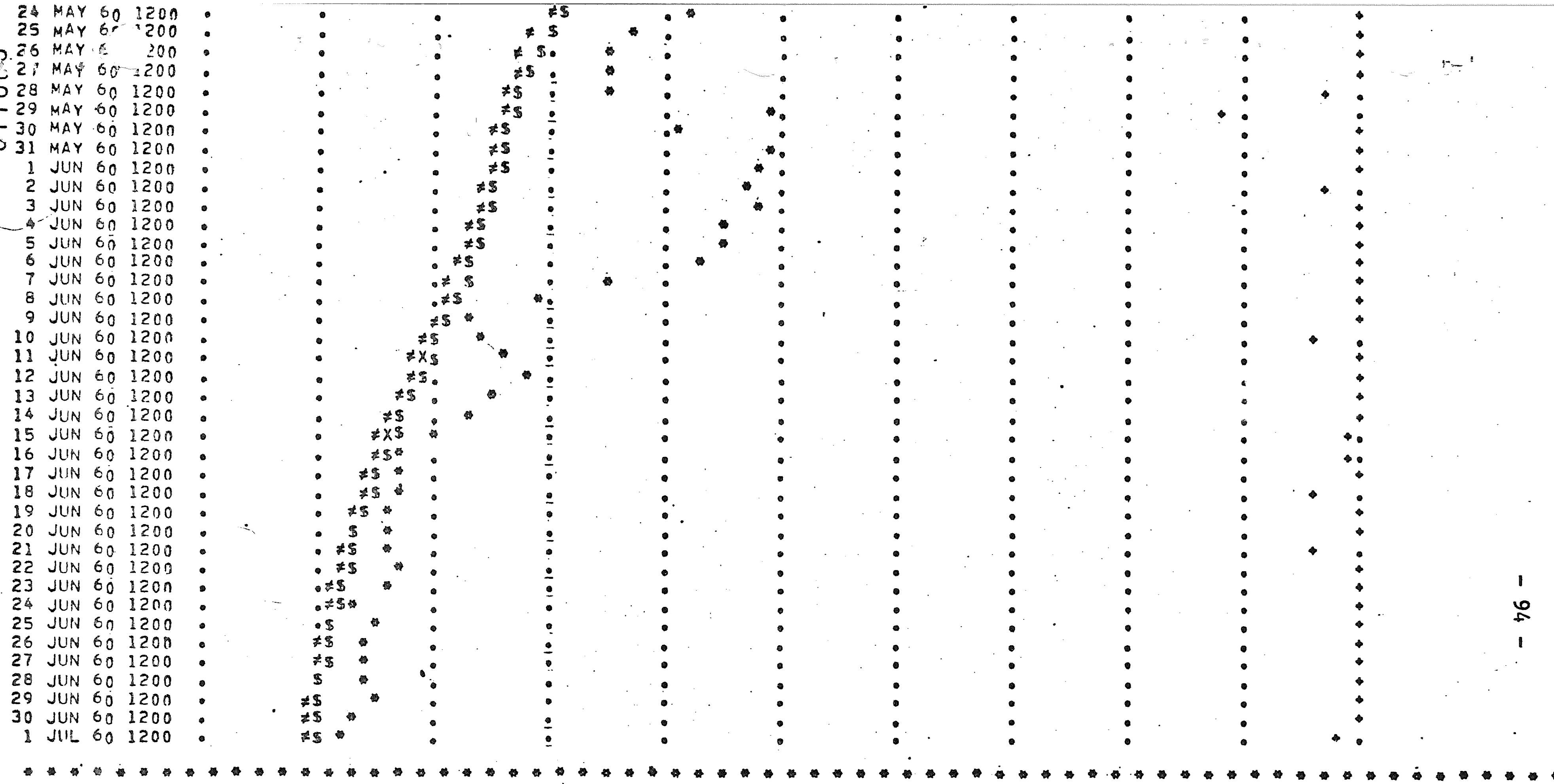


Fig. 30c

517883



PLOT CHARACTER	STATION NAME	STATION NUMBER	CONTROL
$	WINTON POST MINING	51270.1	Q
≠	WINTON WITH MINING	5127.0	Q
X	CALC WINTON NO MINING	512706.0	Q
*	OBSERVED FLOW WINTON	512700.0	Q

FLOW CFS 0. 100. 200. 300. 400. 500. 600. 700. 800. 900. 1000.

PHC 90913 100+ 100 0

-9091 3 100.

10.00 9.00 8.00 7.00 6.00 5.00 4.00 3.00 2.00 1.00 0.00

END

END OF FILE ON INPUT DECK

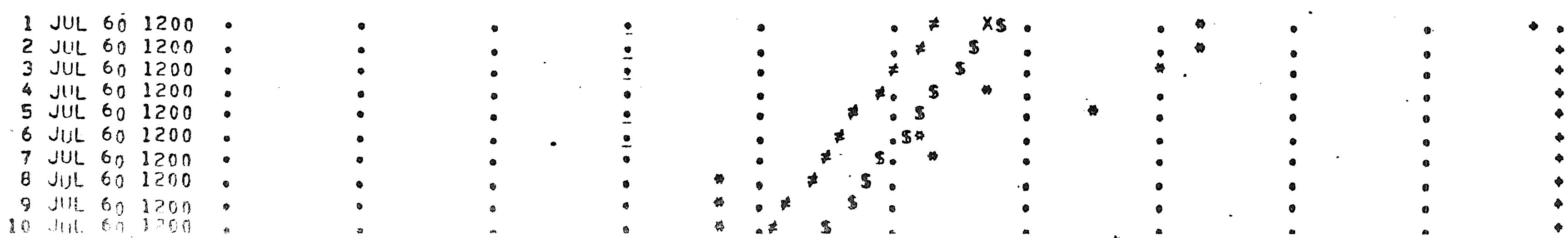
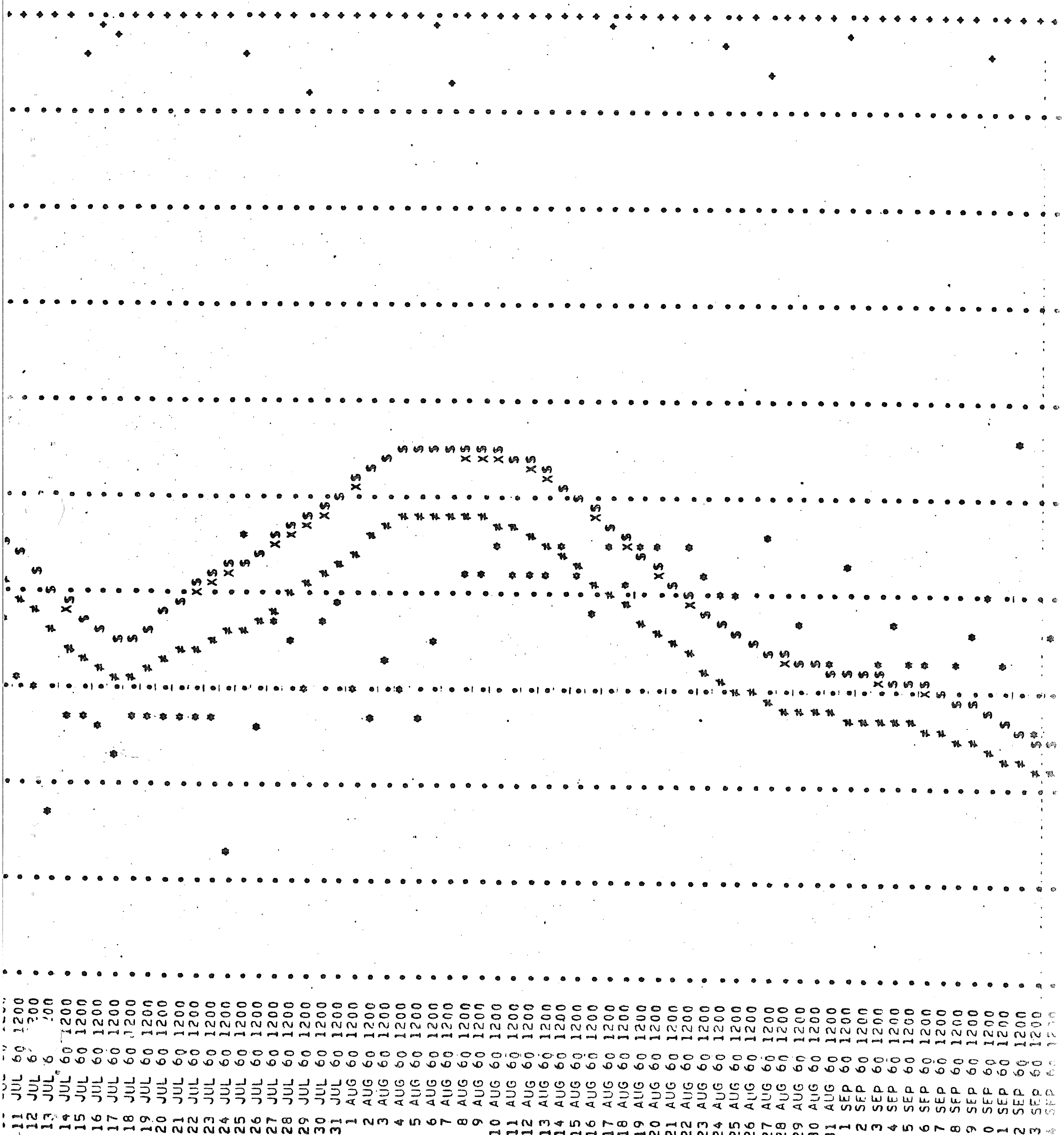


Fig. 30d

Fig. 30e


12 JUL 60 1200
13 JUL 60 1200
14 JUL 60 1200
15 JUL 60 1200
16 JUL 60 1200
17 JUL 60 1200
18 JUL 60 1200
19 JUL 60 1200
20 JUL 60 1200
21 JUL 60 1200
22 JUL 60 1200
23 JUL 60 1200
24 JUL 60 1200
25 JUL 60 1200
26 JUL 60 1200
27 JUL 60 1200
28 JUL 60 1200
29 JUL 60 1200
30 JUL 60 1200
31 JUL 60 1200
1 AUG 60 1200
2 AUG 60 1200
3 AUG 60 1200
4 AUG 60 1200
5 AUG 60 1200
6 AUG 60 1200
7 AUG 60 1200
8 AUG 60 1200
9 AUG 60 1200
10 AUG 60 1200
11 AUG 60 1200
12 AUG 60 1200
13 AUG 60 1200
14 AUG 60 1200
15 AUG 60 1200
16 AUG 60 1200
17 AUG 60 1200
18 AUG 60 1200
19 AUG 60 1200
20 AUG 60 1200
21 AUG 60 1200
22 AUG 60 1200
23 AUG 60 1200
24 AUG 60 1200
25 AUG 60 1200
26 AUG 60 1200
27 AUG 60 1200
28 AUG 60 1200
29 AUG 60 1200
30 AUG 60 1200
31 AUG 60 1200
1 SEP 60 1200
2 SEP 60 1200
3 SEP 60 1200
4 SEP 60 1200
5 SEP 60 1200
6 SEP 60 1200
7 SEP 60 1200
8 SEP 60 1200
9 SEP 60 1200
10 SEP 60 1200
11 SEP 60 1200
12 SEP 60 1200

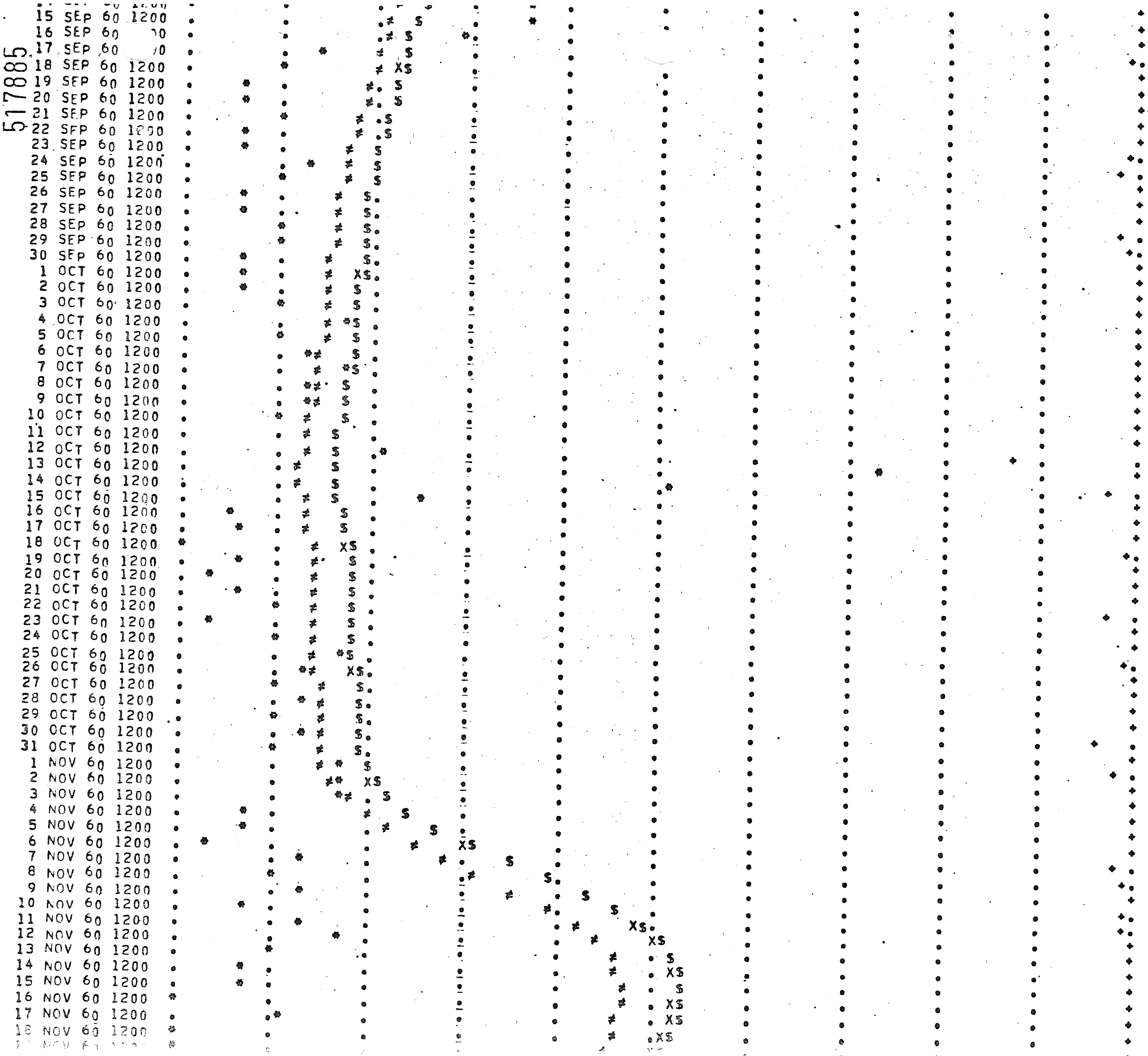
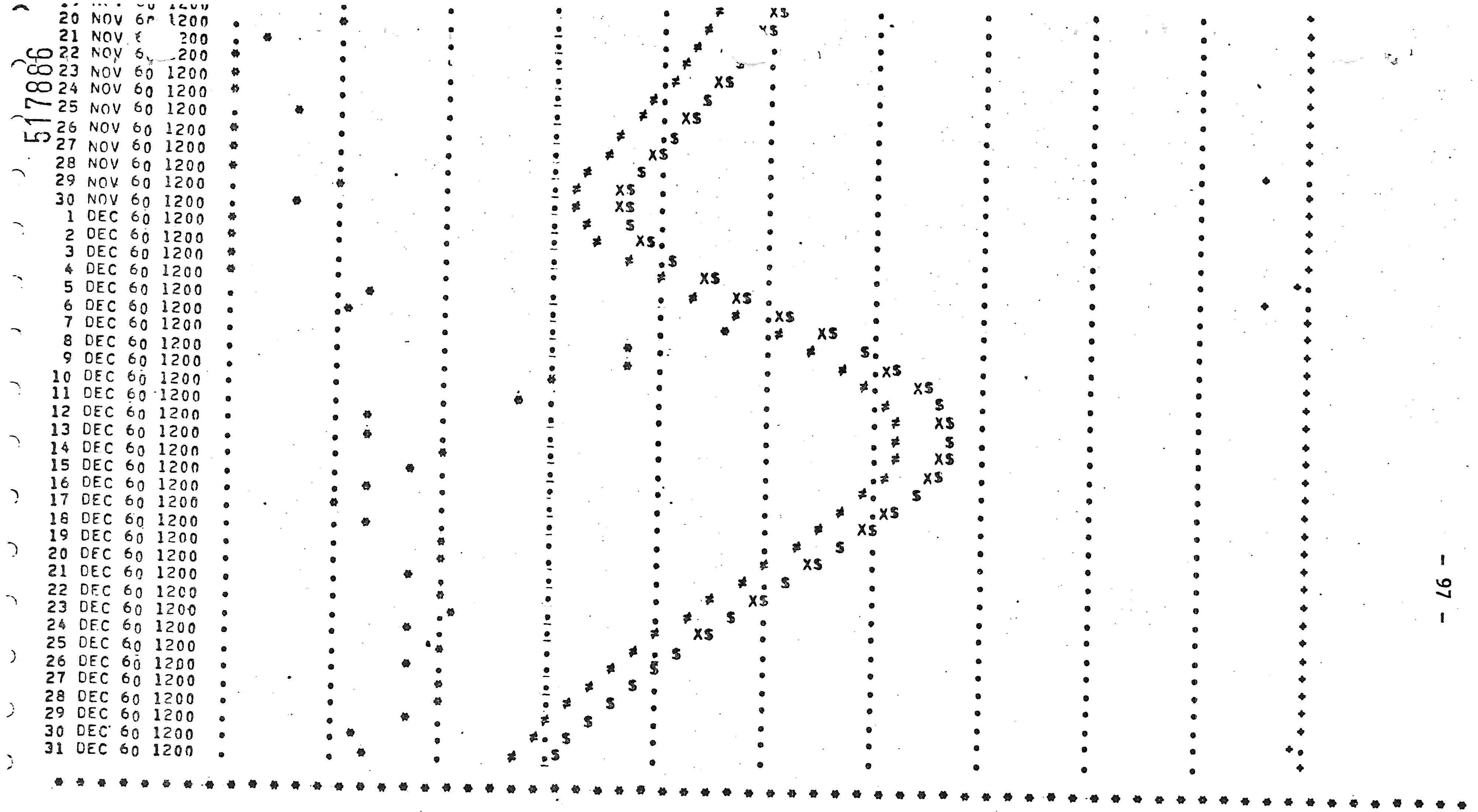

15 SEP 60 1200
16 SEP 60
17 SEP 60
18 SEP 60 1200
19 SEP 60 1200
20 SEP 60 1200
21 SEP 60 1200
22 SEP 60 1200
23 SEP 60 1200
24 SEP 60 1200
25 SEP 60 1200
26 SEP 60 1200
27 SEP 60 1200
28 SEP 60 1200
29 SEP 60 1200
30 SEP 60 1200
1 OCT 60 1200
2 OCT 60 1200
3 OCT 60 1200
4 OCT 60 1200
5 OCT 60 1200
6 OCT 60 1200
7 OCT 60 1200
8 OCT 60 1200
9 OCT 60 1200
10 OCT 60 1200
11 OCT 60 1200
12 OCT 60 1200
13 OCT 60 1200
14 OCT 60 1200
15 OCT 60 1200
16 OCT 60 1200
17 OCT 60 1200
18 OCT 60 1200
19 OCT 60 1200
20 OCT 60 1200
21 OCT 60 1200
22 OCT 60 1200
23 OCT 60 1200
24 OCT 60 1200
25 OCT 60 1200
26 OCT 60 1200
27 OCT 60 1200
28 OCT 60 1200
29 OCT 60 1200
30 OCT 60 1200
31 OCT 60 1200
1 NOV 60 1200
2 NOV 60 1200
3 NOV 60 1200
4 NOV 60 1200
5 NOV 60 1200
6 NOV 60 1200
7 NOV 60 1200
8 NOV 60 1200
9 NOV 60 1200
10 NOV 60 1200
11 NOV 60 1200
12 NOV 60 1200
13 NOV 60 1200
14 NOV 60 1200
15 NOV 60 1200
16 NOV 60 1200
17 NOV 60 1200
18 NOV 60 1200

Fig. 30f



20 NOV 60 1200
21 NOV 60 1200
22 NOV 60 1200
23 NOV 60 1200
24 NOV 60 1200
25 NOV 60 1200
26 NOV 60 1200
27 NOV 60 1200
28 NOV 60 1200
29 NOV 60 1200
30 NOV 60 1200
1 DEC 60 1200
2 DEC 60 1200
3 DEC 60 1200
4 DEC 60 1200
5 DEC 60 1200
6 DEC 60 1200
7 DEC 60 1200
8 DEC 60 1200
9 DEC 60 1200
10 DEC 60 1200
11 DEC 60 1200
12 DEC 60 1200
13 DEC 60 1200
14 DEC 60 1200
15 DEC 60 1200
16 DEC 60 1200
17 DEC 60 1200
18 DEC 60 1200
19 DEC 60 1200
20 DEC 60 1200
21 DEC 60 1200
22 DEC 60 1200
23 DEC 60 1200
24 DEC 60 1200
25 DEC 60 1200
26 DEC 60 1200
27 DEC 60 1200
28 DEC 60 1200
29 DEC 60 1200
30 DEC 60 1200
31 DEC 60 1200

Fig. 30g

PLOT CHARACTER | STATION NAME | STATION NUMBER | CONTROL

$-ST LOUIS POSTMING | 40165.1 | Q

≠-ST LOUIS WITH MINING OPERATIONS | 4016.5 | Q

X-ST LOUIS WITH NO MINING | 401657.6 | Q

FLOW CFS 0. 100. 200. 300. 400. 500. 600. 700. 800. 900. 1000.

PHC 39213 100+ 100 0

END 10.00 9.00 8.00 7.00 6.00 5.00 4.00 -3921 3 100. 3.00 2.00 1.00 0.00

END OF FILE ON INPUT DECK

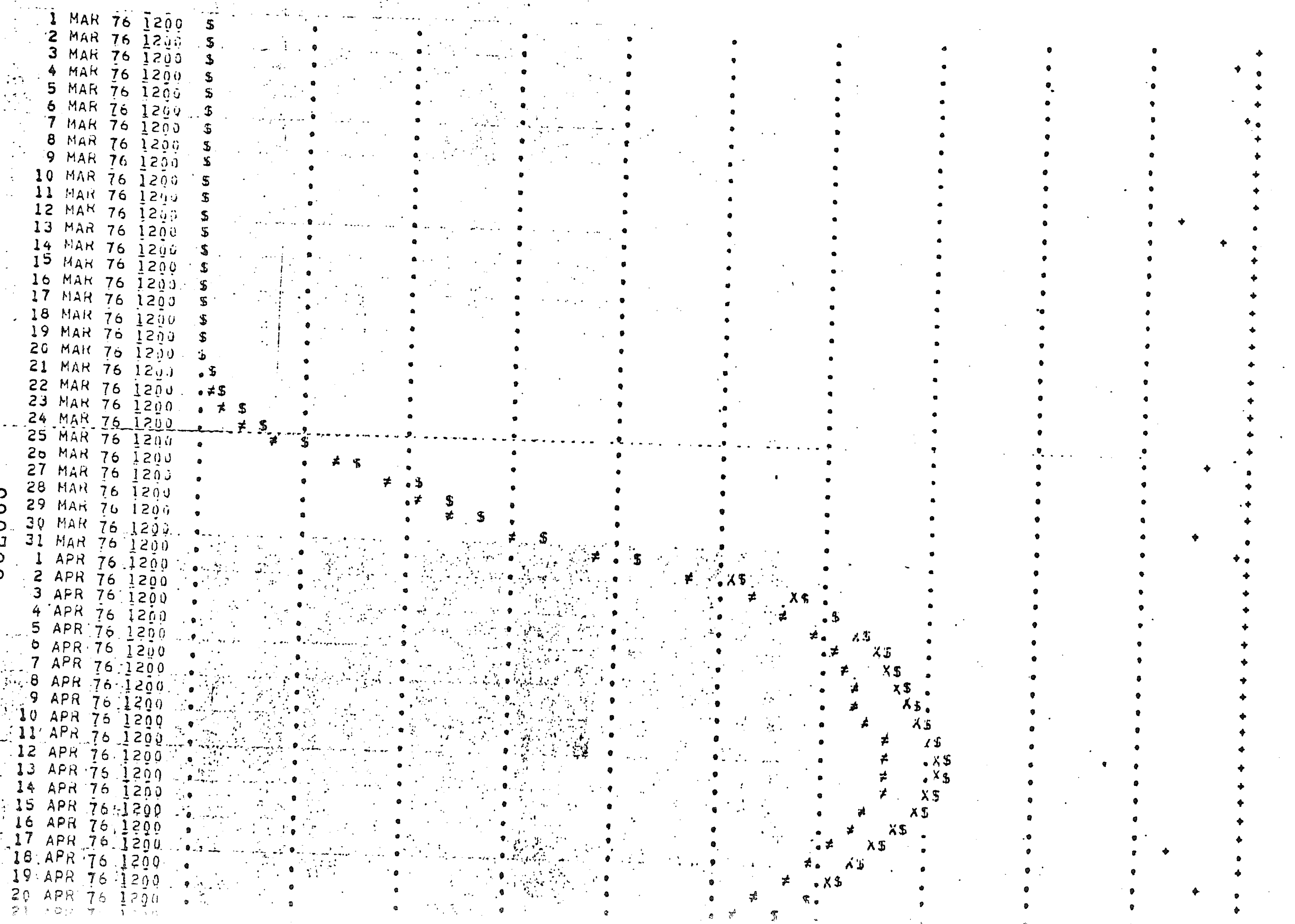


Fig. 31a

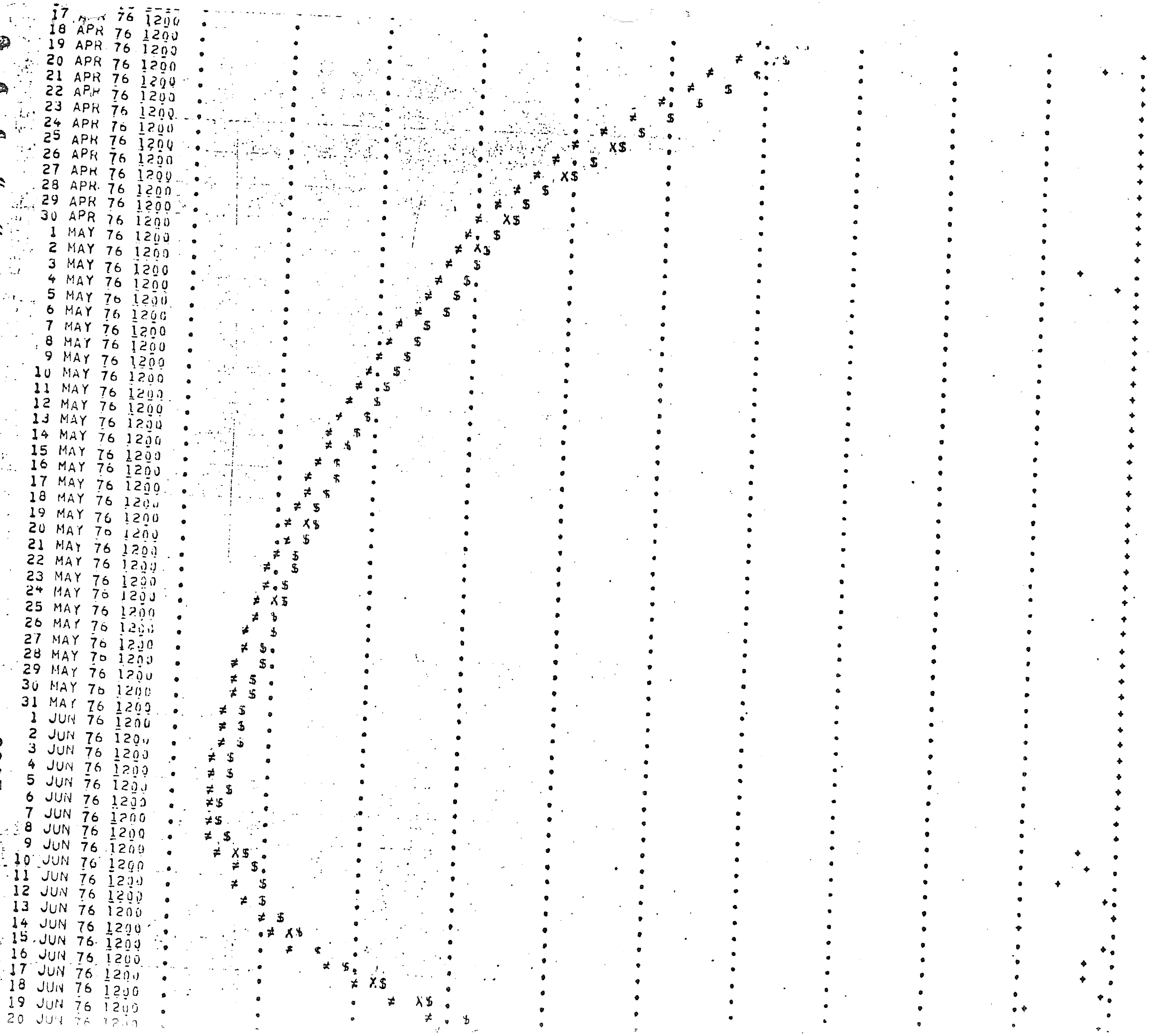

17 APR 76 1200
18 APR 76 1200
19 APR 76 1200
20 APR 76 1200
21 APR 76 1200
22 APR 76 1200
23 APR 76 1200
24 APR 76 1200
25 APR 76 1200
26 APR 76 1200
27 APR 76 1200
28 APR 76 1200
29 APR 76 1200
30 APR 76 1200
1 MAY 76 1200
2 MAY 76 1200
3 MAY 76 1200
4 MAY 76 1200
5 MAY 76 1200
6 MAY 76 1200
7 MAY 76 1200
8 MAY 76 1200
9 MAY 76 1200
10 MAY 76 1200
11 MAY 76 1200
12 MAY 76 1200
13 MAY 76 1200
14 MAY 76 1200
15 MAY 76 1200
16 MAY 76 1200
17 MAY 76 1200
18 MAY 76 1200
19 MAY 76 1200
20 MAY 76 1200
21 MAY 76 1200
22 MAY 76 1200
23 MAY 76 1200
24 MAY 76 1200
25 MAY 76 1200
26 MAY 76 1200
27 MAY 76 1200
28 MAY 76 1200
29 MAY 76 1200
30 MAY 76 1200
31 MAY 76 1200
1 JUN 76 1200
2 JUN 76 1200
3 JUN 76 1200
4 JUN 76 1200
5 JUN 76 1200
6 JUN 76 1200
7 JUN 76 1200
8 JUN 76 1200
9 JUN 76 1200
10 JUN 76 1200
11 JUN 76 1200
12 JUN 76 1200
13 JUN 76 1200
14 JUN 76 1200
15 JUN 76 1200
16 JUN 76 1200
17 JUN 76 1200
18 JUN 76 1200
19 JUN 76 1200
20 JUN 76 1200

Fig. 31b

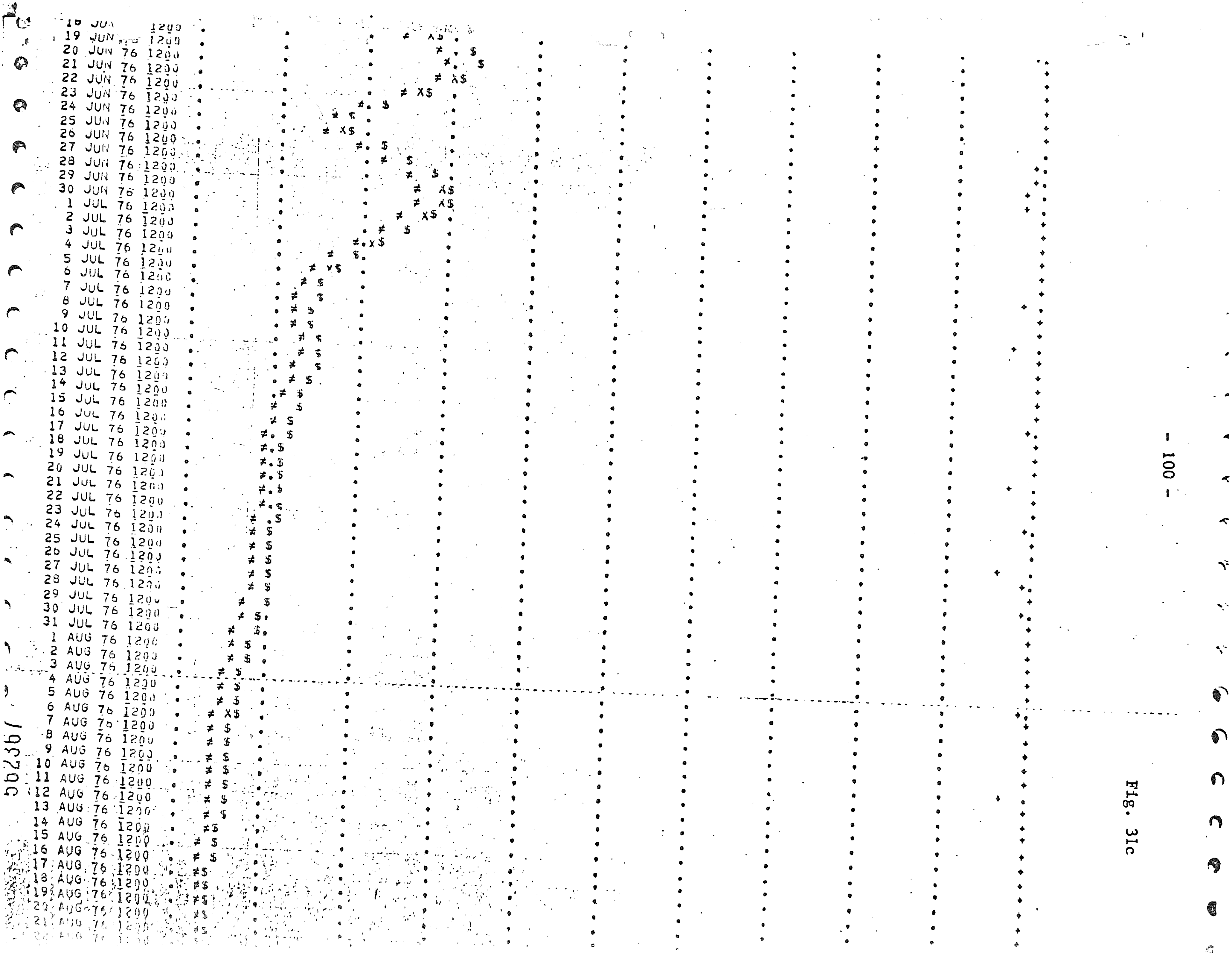

19 JUN 1200
20 JUN 76 1200
21 JUN 76 1200
22 JUN 76 1200
23 JUN 76 1200
24 JUN 76 1200
25 JUN 76 1200
26 JUN 76 1200
27 JUN 76 1200
28 JUN 76 1200
29 JUN 76 1200
30 JUN 76 1200
1 JUL 76 1200
2 JUL 76 1200
3 JUL 76 1200
4 JUL 76 1200
5 JUL 76 1200
6 JUL 76 1200
7 JUL 76 1200
8 JUL 76 1200
9 JUL 76 1200
10 JUL 76 1200
11 JUL 76 1200
12 JUL 76 1200
13 JUL 76 1200
14 JUL 76 1200
15 JUL 76 1200
16 JUL 76 1200
17 JUL 76 1200
18 JUL 76 1200
19 JUL 76 1200
20 JUL 76 1200
21 JUL 76 1200
22 JUL 76 1200
23 JUL 76 1200
24 JUL 76 1200
25 JUL 76 1200
26 JUL 76 1200
27 JUL 76 1200
28 JUL 76 1200
29 JUL 76 1200
30 JUL 76 1200
31 JUL 76 1200
1 AUG 76 1200
2 AUG 76 1200
3 AUG 76 1200
4 AUG 76 1200
5 AUG 76 1200
6 AUG 76 1200
7 AUG 76 1200
8 AUG 76 1200
9 AUG 76 1200
10 AUG 76 1200
11 AUG 76 1200
12 AUG 76 1200
13 AUG 76 1200
14 AUG 76 1200
15 AUG 76 1200
16 AUG 76 1200
17 AUG 76 1200
18 AUG 76 1200
19 AUG 76 1200
20 AUG 76 1200

Fig. 31c

```
17 AUG 76 1200  .  ≠$
18 AUG 76 1200  .  ≠$
19 AUG 76 1200  .  ≠$
20 AUG 76 1200  .  ≠$
21 AUG 76 1200  .  ≠$
22 AUG 76 1200  .  $
23 AUG 76 1200  .  ≠$
24 AUG 76 1200  .  ≠$
25 AUG 76 1200  .  ≠$
26 AUG 76 1200  .  ≠$
27 AUG 76 1200  .  ≠$
28 AUG 76 1200  .  ≠$
29 AUG 76 1200  .  ≠$
30 AUG 76 1200  .  $X
31 AUG 76 1200  .  $
 1 SEP 76 1200  .  $
 2 SEP 76 1200  .  $
 3 SEP 76 1200  .  $
 4 SEP 76 1200  .  $
 5 SEP 76 1200  .≠$
 6 SEP 76 1200  .≠$
 7 SEP 76 1200  .≠$
 8 SEP 76 1200  .≠$
 9 SEP 76 1200  .≠$
10 SEP 76 1200  .≠$
11 SEP 76 1200  .≠$
12 SEP 76 1200  .≠$
13 SEP 76 1200  .≠$
14 SEP 76 1200  .≠$
15 SEP 76 1200  .≠$
16 SEP 76 1200  .≠$
17 SEP 76 1200  .$X
18 SEP 76 1200  .$
19 SEP 76 1200  .$
20 SEP 76 1200  .≠$
21 SEP 76 1200  .≠$
22 SEP 76 1200  .  $X
23 SEP 76 1200  .  ≠$
24 SEP 76 1200  .  $
25 SEP 76 1200  .≠$
26 SEP 76 1200  .≠$
27 SEP 76 1200  .≠$
28 SEP 76 1200  .≠$
29 SEP 76 1200  .≠$
30 SEP 76 1200  .≠$
 1 OCT 76 1200  .≠$
 2 OCT 76 1200  .≠$
 3 OCT 76 1200  .$
 4 OCT 76 1200  .≠$
 5 OCT 76 1200  .≠ $
 6 OCT 76 1200  .  ≠$
 7 OCT 76 1200  .  ≠$
 8 OCT 76 1200  .  ≠$
 9 OCT 76 1200  .  ≠$
10 OCT 76 1200  .  ≠$
11 OCT 76 1200  .  ≠$
12 OCT 76 1200  .≠$
13 OCT 76 1200  .≠$
14 OCT 76 1200  .≠$
15 OCT 76 1200  .≠$
16 OCT 76 1200  .≠$
17 OCT 76 1200  .≠$
18 OCT 76 1200  .≠$
```

Fig. 31d

562368

562368

9 OCT 76 1200 . ≠$
10 OCT 76 1200 . ≠$
11 OCT 76 1200 . ≠$
12 OCT 76 1200 .≠$
13 OCT 76 1200 .≠$
14 OCT 76 1200 .≠$
15 OCT 76 1200 .≠$
16 OCT 76 1200 .≠$
17 OCT 76 1200 .≠$
18 OCT 76 1200 .≠$
19 OCT 76 1200 .≠$
20 OCT 76 1200 .≠$
21 OCT 76 1200 .≠$
22 OCT 76 1200 .≠$
23 OCT 76 1200 .≠$
24 OCT 76 1200 .≠$
25 OCT 76 1200 .≠$
26 OCT 76 1200 .≠$
27 OCT 76 1200 .≠$
28 OCT 76 1200 .≠$
29 OCT 76 1200 .≠$
30 OCT 76 1200 .$X
31 OCT 76 1200 .$
1 NOV 76 1200 .$
2 NOV 76 1200 .$
3 NOV 76 1200 .$
4 NOV 76 1200 .$
5 NOV 76 1200 .$
6 NOV 76 1200 .$
7 NOV 76 1200 .$
8 NOV 76 1200 .$
9 NOV 76 1200 .$
10 NOV 76 1200 .$
11 NOV 76 1200 .$
12 NOV 76 1200 .$
13 NOV 76 1200 .$
14 NOV 76 1200 .$
15 NOV 76 1200 .$
16 NOV 76 1200 .$
17 NOV 76 1200 .$
18 NOV 76 1200 .$
19 NOV 76 1200 .$
20 NOV 76 1200 .$
21 NOV 76 1200 .$
22 NOV 76 1200 .$
23 NOV 76 1200 .$
24 NOV 76 1200 .$
25 NOV 76 1200 .$
26 NOV 76 1200 .$
27 NOV 76 1200 .$
28 NOV 76 1200 .$
29 NOV 76 1200 .$
30 NOV 76 1200 .$
1 DEC 76 1200 $X
2 DEC 76 1200 $X
3 DEC 76 1200 ≠$
4 DEC 76 1200 ≠$
5 DEC 76 1200 .$
6 DEC 76 1200 .$
7 DEC 76 1200 .$
8 DEC 76 1200 .$
9 DEC 76 1200 .$
10 DEC 76 1200 .$

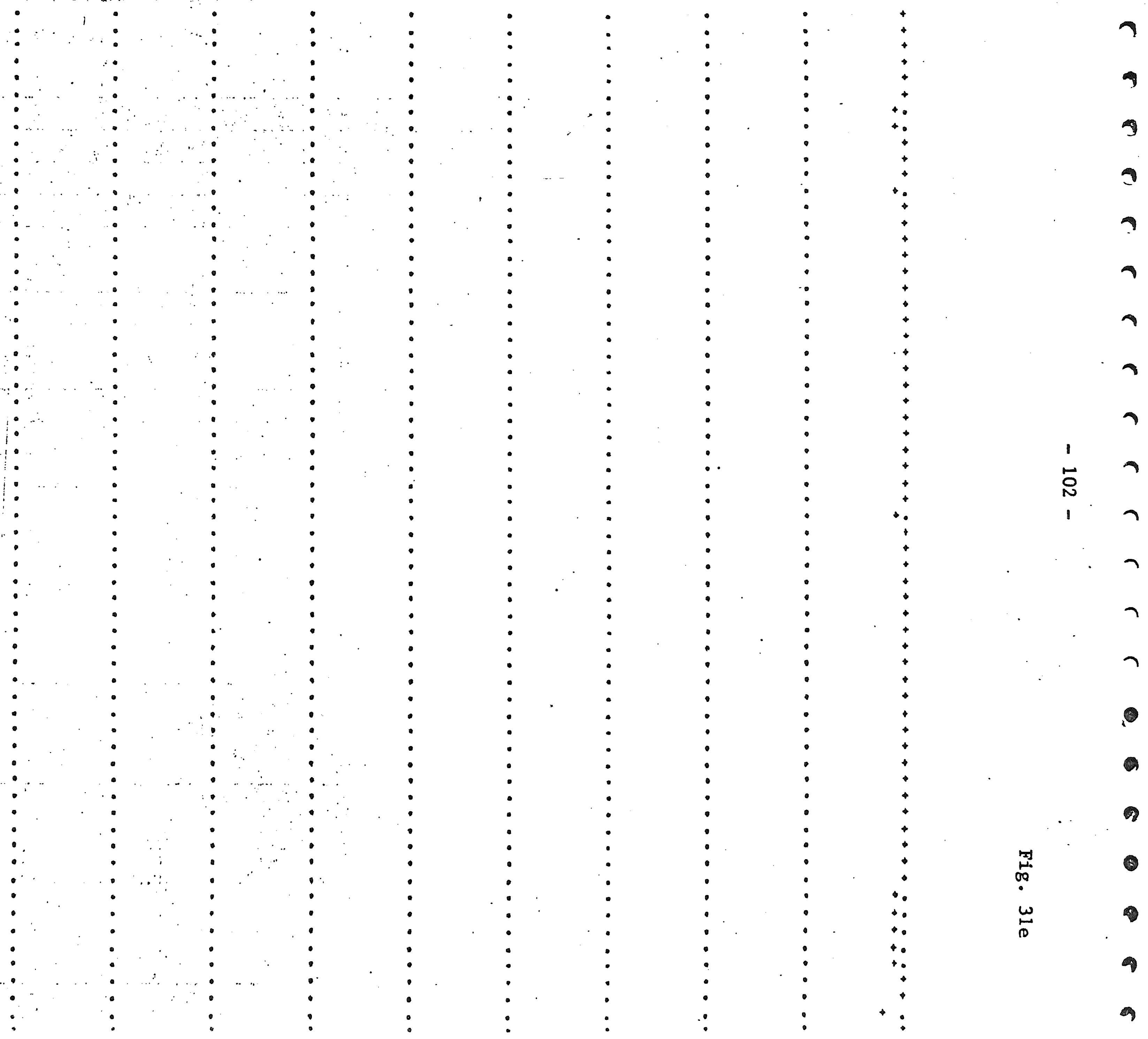


Fig. 31e

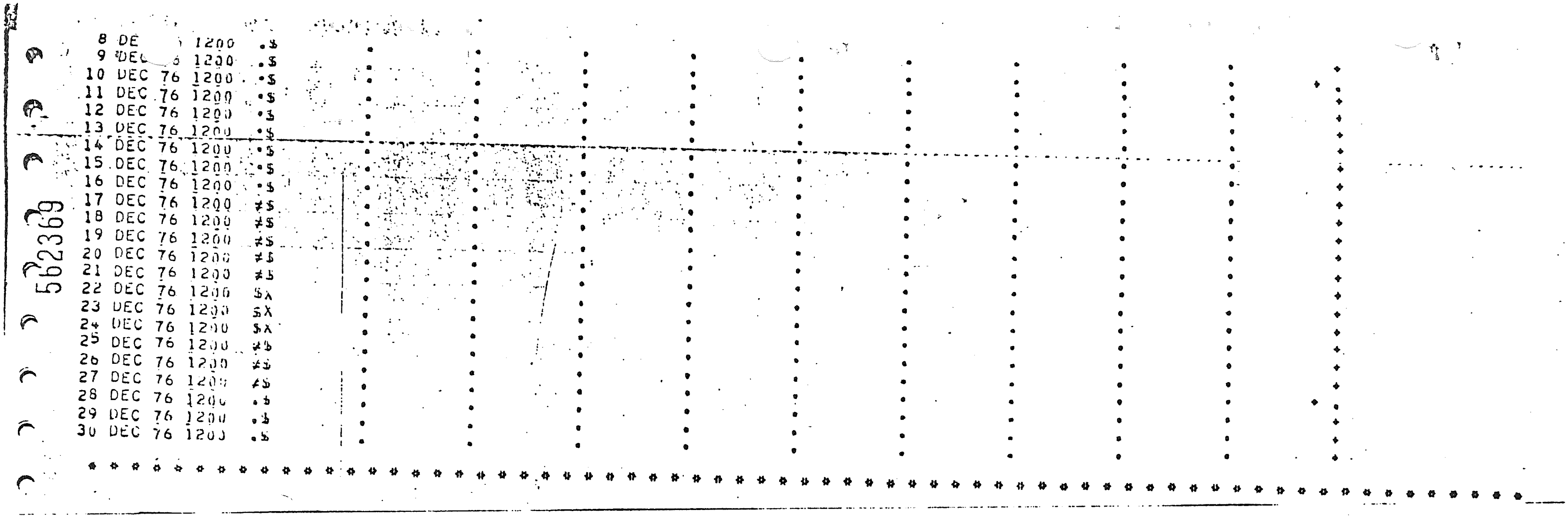
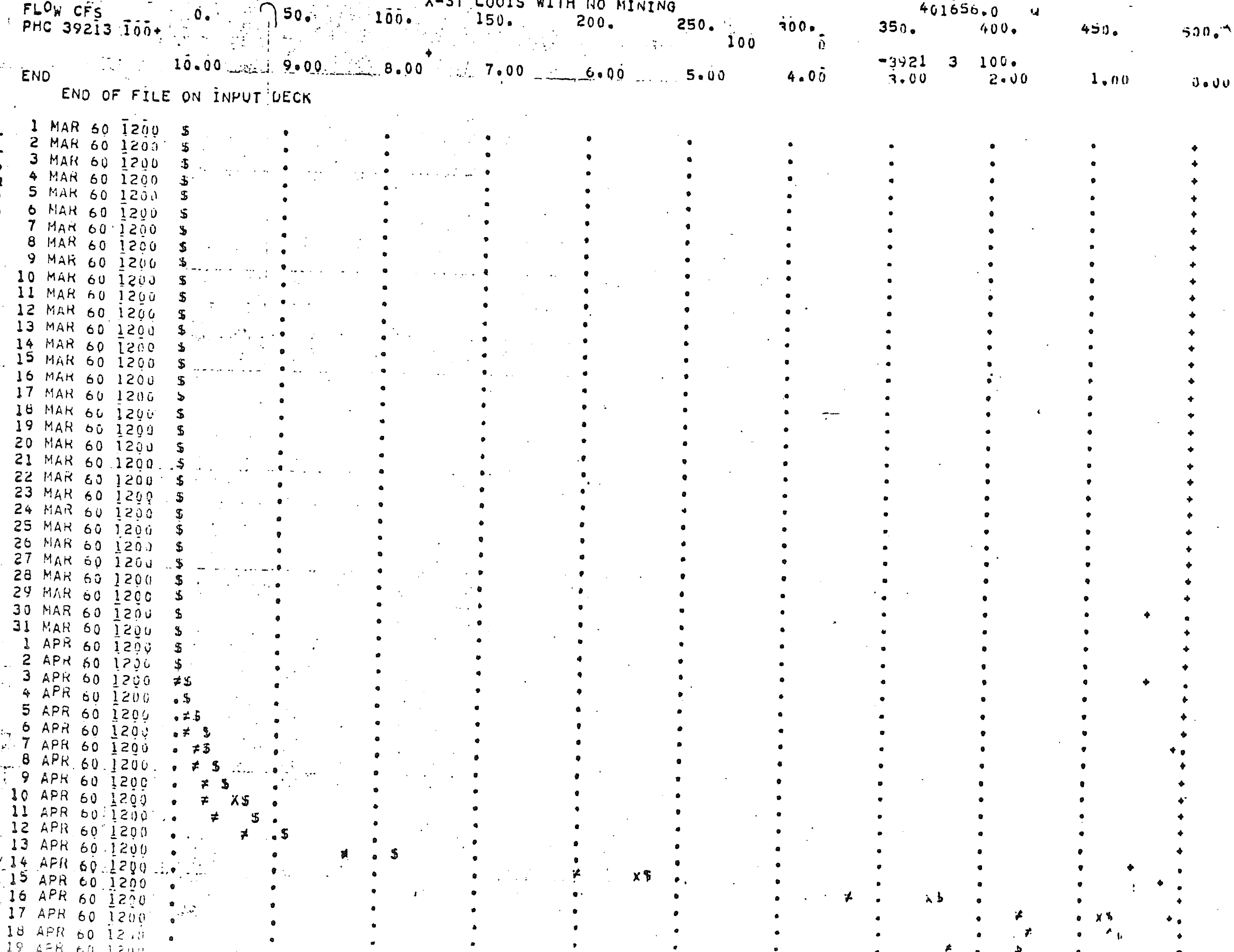

10 DEC 76 1200
11 DEC 76 1200
12 DEC 76 1200
13 DEC 76 1200
14 DEC 76 1200
15 DEC 76 1200
16 DEC 76 1200
17 DEC 76 1200
18 DEC 76 1200
19 DEC 76 1200
20 DEC 76 1200
21 DEC 76 1200
22 DEC 76 1200
23 DEC 76 1200
24 DEC 76 1200
25 DEC 76 1200
26 DEC 76 1200
27 DEC 76 1200
28 DEC 76 1200
29 DEC 76 1200
30 DEC 76 1200

Fig. 31f

PLOT CHARACTER — STATION NAME — STATION NUMBER — CONTROL

$-ST LOUIS POSTMINING — 40165.1 — W
≠-ST LOUIS WITH MINING OPERATIONS — 4016.5 — W
X-ST LOUIS WITH NO MINING — 401656.0 — W



562314

Fig. 32a

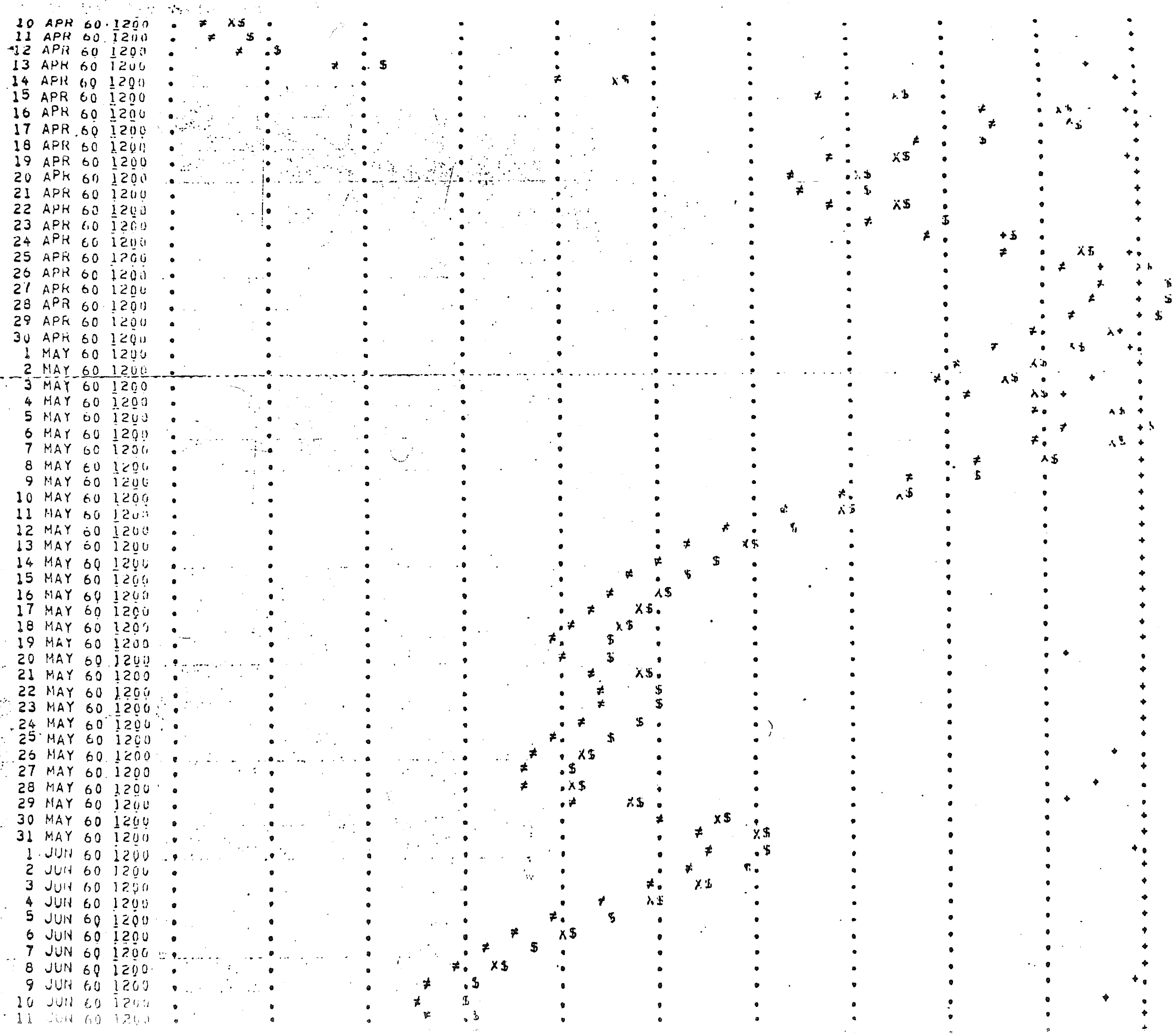

10 APR 60 1200
11 APR 60 1200
12 APR 60 1200
13 APR 60 1200
14 APR 60 1200
15 APR 60 1200
16 APR 60 1200
17 APR 60 1200
18 APR 60 1200
19 APR 60 1200
20 APR 60 1200
21 APR 60 1200
22 APR 60 1200
23 APR 60 1200
24 APR 60 1200
25 APR 60 1200
26 APR 60 1200
27 APR 60 1200
28 APR 60 1200
29 APR 60 1200
30 APR 60 1200
1 MAY 60 1200
2 MAY 60 1200
3 MAY 60 1200
4 MAY 60 1200
5 MAY 60 1200
6 MAY 60 1200
7 MAY 60 1200
8 MAY 60 1200
9 MAY 60 1200
10 MAY 60 1200
11 MAY 60 1200
12 MAY 60 1200
13 MAY 60 1200
14 MAY 60 1200
15 MAY 60 1200
16 MAY 60 1200
17 MAY 60 1200
18 MAY 60 1200
19 MAY 60 1200
20 MAY 60 1200
21 MAY 60 1200
22 MAY 60 1200
23 MAY 60 1200
24 MAY 60 1200
25 MAY 60 1200
26 MAY 60 1200
27 MAY 60 1200
28 MAY 60 1200
29 MAY 60 1200
30 MAY 60 1200
31 MAY 60 1200
1 JUN 60 1200
2 JUN 60 1200
3 JUN 60 1200
4 JUN 60 1200
5 JUN 60 1200
6 JUN 60 1200
7 JUN 60 1200
8 JUN 60 1200
9 JUN 60 1200
10 JUN 60 1200
11 JUN 60 1200

Fig. 32b

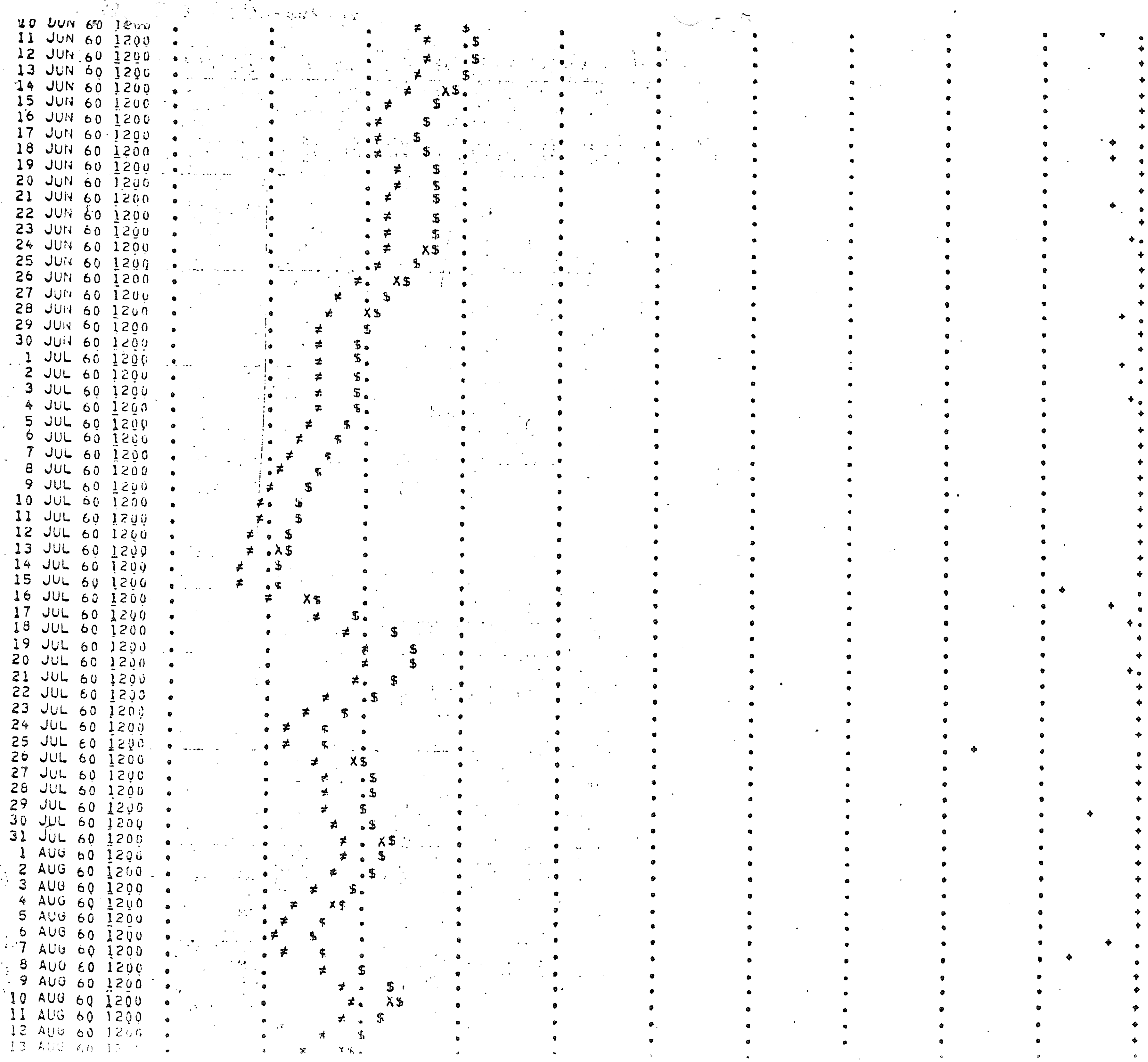

10 JUN 60 1200
11 JUN 60 1200
12 JUN 60 1200
13 JUN 60 1200
14 JUN 60 1200
15 JUN 60 1200
16 JUN 60 1200
17 JUN 60 1200
18 JUN 60 1200
19 JUN 60 1200
20 JUN 60 1200
21 JUN 60 1200
22 JUN 60 1200
23 JUN 60 1200
24 JUN 60 1200
25 JUN 60 1200
26 JUN 60 1200
27 JUN 60 1200
28 JUN 60 1200
29 JUN 60 1200
30 JUN 60 1200
1 JUL 60 1200
2 JUL 60 1200
3 JUL 60 1200
4 JUL 60 1200
5 JUL 60 1200
6 JUL 60 1200
7 JUL 60 1200
8 JUL 60 1200
9 JUL 60 1200
10 JUL 60 1200
11 JUL 60 1200
12 JUL 60 1200
13 JUL 60 1200
14 JUL 60 1200
15 JUL 60 1200
16 JUL 60 1200
17 JUL 60 1200
18 JUL 60 1200
19 JUL 60 1200
20 JUL 60 1200
21 JUL 60 1200
22 JUL 60 1200
23 JUL 60 1200
24 JUL 60 1200
25 JUL 60 1200
26 JUL 60 1200
27 JUL 60 1200
28 JUL 60 1200
29 JUL 60 1200
30 JUL 60 1200
31 JUL 60 1200
1 AUG 60 1200
2 AUG 60 1200
3 AUG 60 1200
4 AUG 60 1200
5 AUG 60 1200
6 AUG 60 1200
7 AUG 60 1200
8 AUG 60 1200
9 AUG 60 1200
10 AUG 60 1200
11 AUG 60 1200
12 AUG 60 1200
13 AUG

Fig. 32d

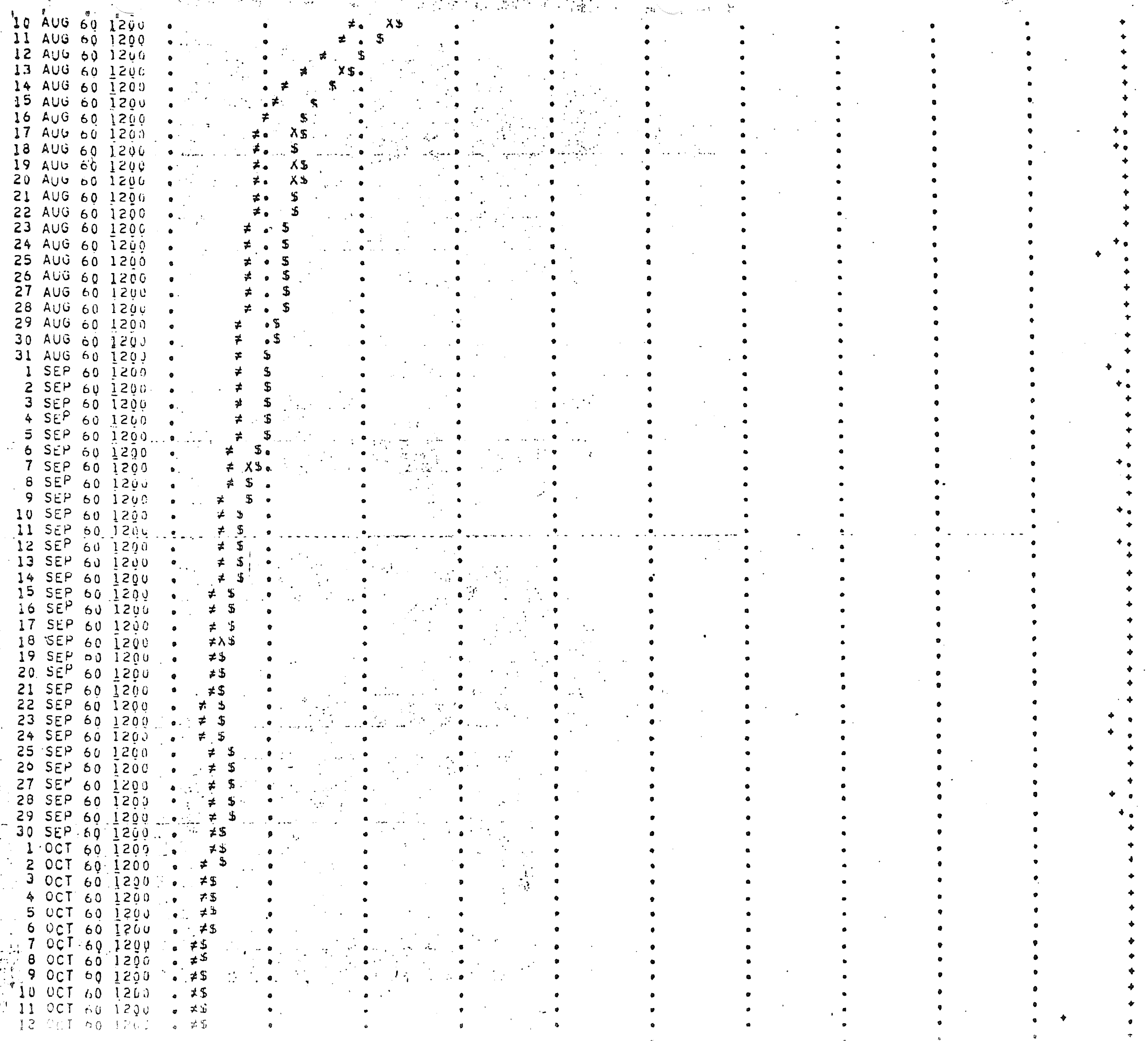

10 AUG 60 1200
11 AUG 60 1200
12 AUG 60 1200
13 AUG 60 1200
14 AUG 60 1200
15 AUG 60 1200
16 AUG 60 1200
17 AUG 60 1200
18 AUG 60 1200
19 AUG 60 1200
20 AUG 60 1200
21 AUG 60 1200
22 AUG 60 1200
23 AUG 60 1200
24 AUG 60 1200
25 AUG 60 1200
26 AUG 60 1200
27 AUG 60 1200
28 AUG 60 1200
29 AUG 60 1200
30 AUG 60 1200
31 AUG 60 1200
1 SEP 60 1200
2 SEP 60 1200
3 SEP 60 1200
4 SEP 60 1200
5 SEP 60 1200
6 SEP 60 1200
7 SEP 60 1200
8 SEP 60 1200
9 SEP 60 1200
10 SEP 60 1200
11 SEP 60 1200
12 SEP 60 1200
13 SEP 60 1200
14 SEP 60 1200
15 SEP 60 1200
16 SEP 60 1200
17 SEP 60 1200
18 SEP 60 1200
19 SEP 60 1200
20 SEP 60 1200
21 SEP 60 1200
22 SEP 60 1200
23 SEP 60 1200
24 SEP 60 1200
25 SEP 60 1200
26 SEP 60 1200
27 SEP 60 1200
28 SEP 60 1200
29 SEP 60 1200
30 SEP 60 1200
1 OCT 60 1200
2 OCT 60 1200
3 OCT 60 1200
4 OCT 60 1200
5 OCT 60 1200
6 OCT 60 1200
7 OCT 60 1200
8 OCT 60 1200
9 OCT 60 1200
10 OCT 60 1200
11 OCT 60 1200
12 OCT 60 1200

Fig. 32d

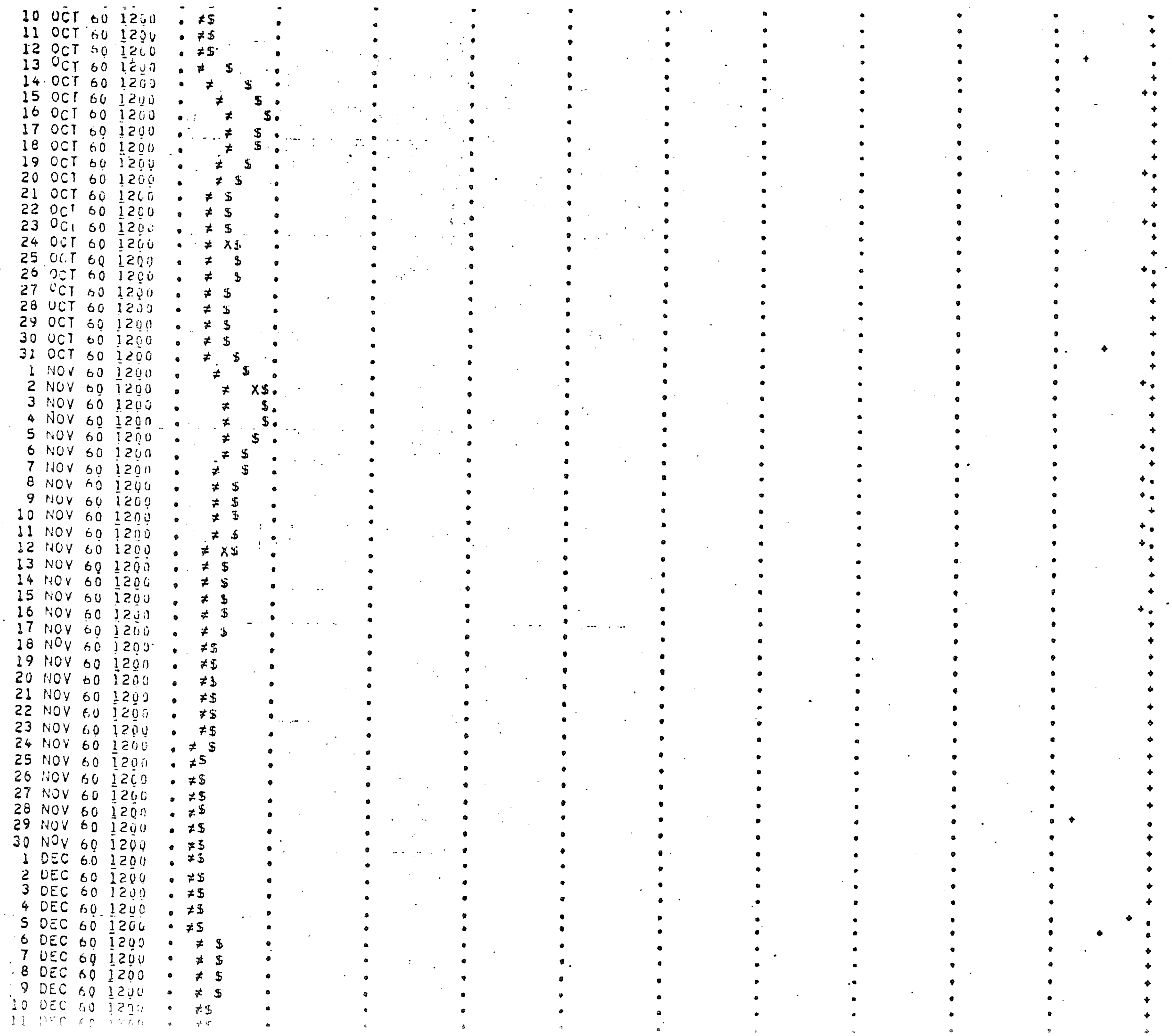

10 OCT 60 1200
11 OCT 60 1200
12 OCT 60 1200
13 OCT 60 1200
14 OCT 60 1200
15 OCT 60 1200
16 OCT 60 1200
17 OCT 60 1200
18 OCT 60 1200
19 OCT 60 1200
20 OCT 60 1200
21 OCT 60 1200
22 OCT 60 1200
23 OCT 60 1200
24 OCT 60 1200
25 OCT 60 1200
26 OCT 60 1200
27 OCT 60 1200
28 OCT 60 1200
29 OCT 60 1200
30 OCT 60 1200
31 OCT 60 1200
1 NOV 60 1200
2 NOV 60 1200
3 NOV 60 1200
4 NOV 60 1200
5 NOV 60 1200
6 NOV 60 1200
7 NOV 60 1200
8 NOV 60 1200
9 NOV 60 1200
10 NOV 60 1200
11 NOV 60 1200
12 NOV 60 1200
13 NOV 60 1200
14 NOV 60 1200
15 NOV 60 1200
16 NOV 60 1200
17 NOV 60 1200
18 NOV 60 1200
19 NOV 60 1200
20 NOV 60 1200
21 NOV 60 1200
22 NOV 60 1200
23 NOV 60 1200
24 NOV 60 1200
25 NOV 60 1200
26 NOV 60 1200
27 NOV 60 1200
28 NOV 60 1200
29 NOV 60 1200
30 NOV 60 1200
1 DEC 60 1200
2 DEC 60 1200
3 DEC 60 1200
4 DEC 60 1200
5 DEC 60 1200
6 DEC 60 1200
7 DEC 60 1200
8 DEC 60 1200
9 DEC 60 1200
10 DEC 60 1200

Fig. 32e

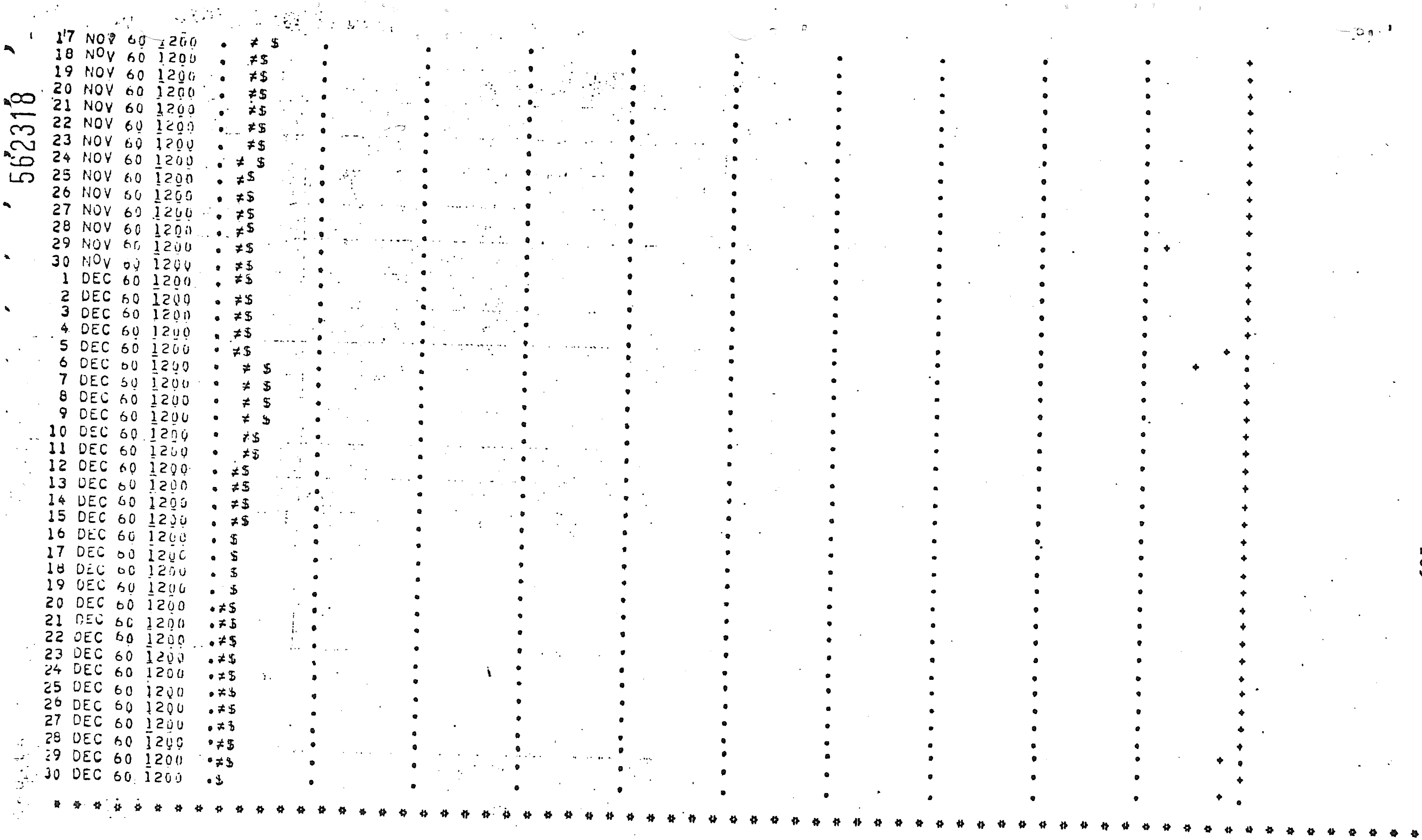

17 NOV 60 1200
18 NOV 60 1200
19 NOV 60 1200
20 NOV 60 1200
21 NOV 60 1200
22 NOV 60 1200
23 NOV 60 1200
24 NOV 60 1200
25 NOV 60 1200
26 NOV 60 1200
27 NOV 60 1200
28 NOV 60 1200
29 NOV 60 1200
30 NOV 60 1200
1 DEC 60 1200
2 DEC 60 1200
3 DEC 60 1200
4 DEC 60 1200
5 DEC 60 1200
6 DEC 60 1200
7 DEC 60 1200
8 DEC 60 1200
9 DEC 60 1200
10 DEC 60 1200
11 DEC 60 1200
12 DEC 60 1200
13 DEC 60 1200
14 DEC 60 1200
15 DEC 60 1200
16 DEC 60 1200
17 DEC 60 1200
18 DEC 60 1200
19 DEC 60 1200
20 DEC 60 1200
21 DEC 60 1200
22 DEC 60 1200
23 DEC 60 1200
24 DEC 60 1200
25 DEC 60 1200
26 DEC 60 1200
27 DEC 60 1200
28 DEC 60 1200
29 DEC 60 1200
30 DEC 60 1200

Fig. 32f

TABLE X - COMPARISON OF OBSERVED FLOWS AND COMPUTED FLOWS WITH NO MINING, MINING AND POST MINING CONDITIONS FOR 120 DAY DURATION OR AVERAGE.

River	Year	Duration Days	Obs. Flow cfs	Computed Pres. Cond. cfs	Computed with Mining cfs	Computed Post Mining cfs
Stony	1960	120		30.5	30.3	34.1
South Kawishiwi		120		192	189	193
Dunka		120		6.5	1	7.2
Birch Lake Local		120		221	207	220
Kawishiwi, Winton		120	434	312	270	322
St. Louis, Aurora		120	64	24.2	15.4	27.5
Stony	1976	120	9.3	8.8	8.5	8.8
South Kawishiwi		120		82.6	63.8	82.8
Dunka		120	0.3	2.1	0.7	2.4
Birch Lake Local		120		77.6	68.6	104.1
Kawishiwi, Winton		120	75.1	138.8	104.6	140.7
St. Louis, Aurora		120	19.3	13.7	9.2	13.4

Kawishiwi basin (4.4% of total area) and appropriations totaling 74 cfs). (The total area for the St. Louis River above Aurora (actual mining would be in the Partridge River) was based on 7,139 acres (3.8% of area above Aurora) and an appropriation of 18 cfs), and

(3) post mining conditions.

Also shown in Table X are observed flows for the Kawishiwi River near Winton and the St. Louis River near Aurora. As the capacity of the turbines at Winton is about 850 cfs, flows at or below this value are subject to considerable regulation. This might take the form of using the turbines during peak electrical demand periods of the day or intermittent use when flows are below 850 cfs for long periods. The overall operation involves regulation and storage of flow in Birch Lake as well as the Farm, Garden, and White Iron Lake complex.

During August 1976 the daily flow of the Kawishiwi River at Winton starting on August 16 was as follows: 70, 70, 70, 45, 0, 0, 0, 0, 0, 0, 0, 32, 0 0, 32, 0, 32, 0, 0, 0, 32....cfs. As all of these flows are less than 10 percent of the turbine capacity, it is assumed that the turbines were not in operation and that the flows are releases for fish and wildlife or seepage and leakage. The SSARR indicated flows ranging from 400 cfs down to 200 cfs during this period, without mining appropriations.

Due to regulation of the flow at Winton, it is desirable to compare average low flows rather than daily or instantaneous values. In Table X an average over a 120 day period was used. Of primary interest is a comparison of computed flows (present cond.), with mining and post mining conditions with input of the 1960 and 1976 hydrologic conditions. Observed flows are shown where available. In some instances the effect of mining was not as large as might be inferred from the appropriations of Table VIII. This may be due to attenuation of the effect or a restriction preventing appropriations that would reduce the flow to less than 1 cfs in any watershed.

The data of Table X are of interest to show the effect of mining on the low flow of streams in the area. Figures 29 and 30 provide a better overall evaluation and also point out that storage of the spring runoff is feasible and desirable. In this connection it is of interest to note that the flow at Winton exceeds the installed capacity of 850 cfs about 33 percent of the time. If additional storage were provided, there would usually be flood flows that could be used.

During mining operations the appropriation rates were not always at maximum values. The total volume appropriated during 1976 for the period March 1 through December 31 is given in Table XI.

TABLE XI - TOTAL APPROPRIATION AMOUNTS FOR 1976 DURING MINING OPERATIONS.

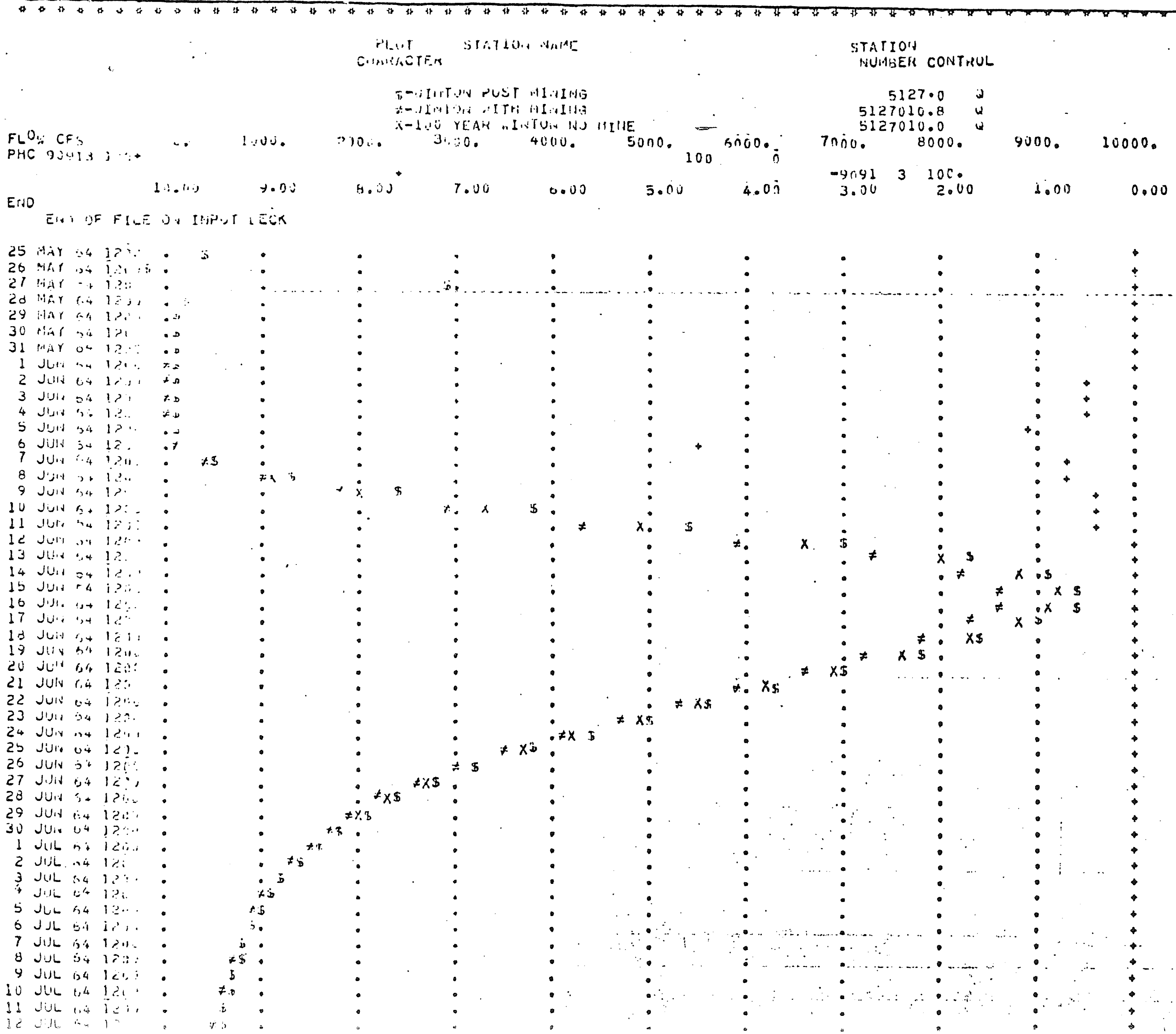
Subwatershed	Vol. Appropriated with SSARR (SFD) March 1-Dec. 31, 1976
St. Louis	3215
South Kawishiwi	5508
Dunka	2437
Birch Lake Local	4284

Changes in peak flows for the watershed outlets for the 100-year rain event were also for a 100-year rainstorm. The hydrographs for Winton and St. Louis are given in Figs. 33 and 34. Table XII lists the changes in calculated peak flows for the different conditions.

TABLE XII - CALCULATED PEAK FLOWS (CFS) FOR 100 YEAR RAIN EVENT

Watershed	Before Mining	Mining	Post Mining
Kawishiwi at Winton	9180	8590	9430
St. Louis	2140	1950	2220

Fig. 33



562403

5622559

PLOT CHARACTER	STATION NAME	STATION NUMBER	CONTROL
$	ST LOUIS POST MINING	4016.5	0
≠	100 YEAR ST LOUIS WITH MINING	4016510.7	0
X	ST LOUIS WITH NO MINING	4016510.0	0

FLOW CFS 0. 250. 500. 750. 1000. 1250. 1500. 1750. 2000. 2250. 2500.

PHC 39213 10 + 100 0 -3921 3 100.

10.00 9.00 8.00 7.00 6.00 5.00 4.00 3.00 2.00 1.00 0.00

END

END OF FILE ON INPUT DECK

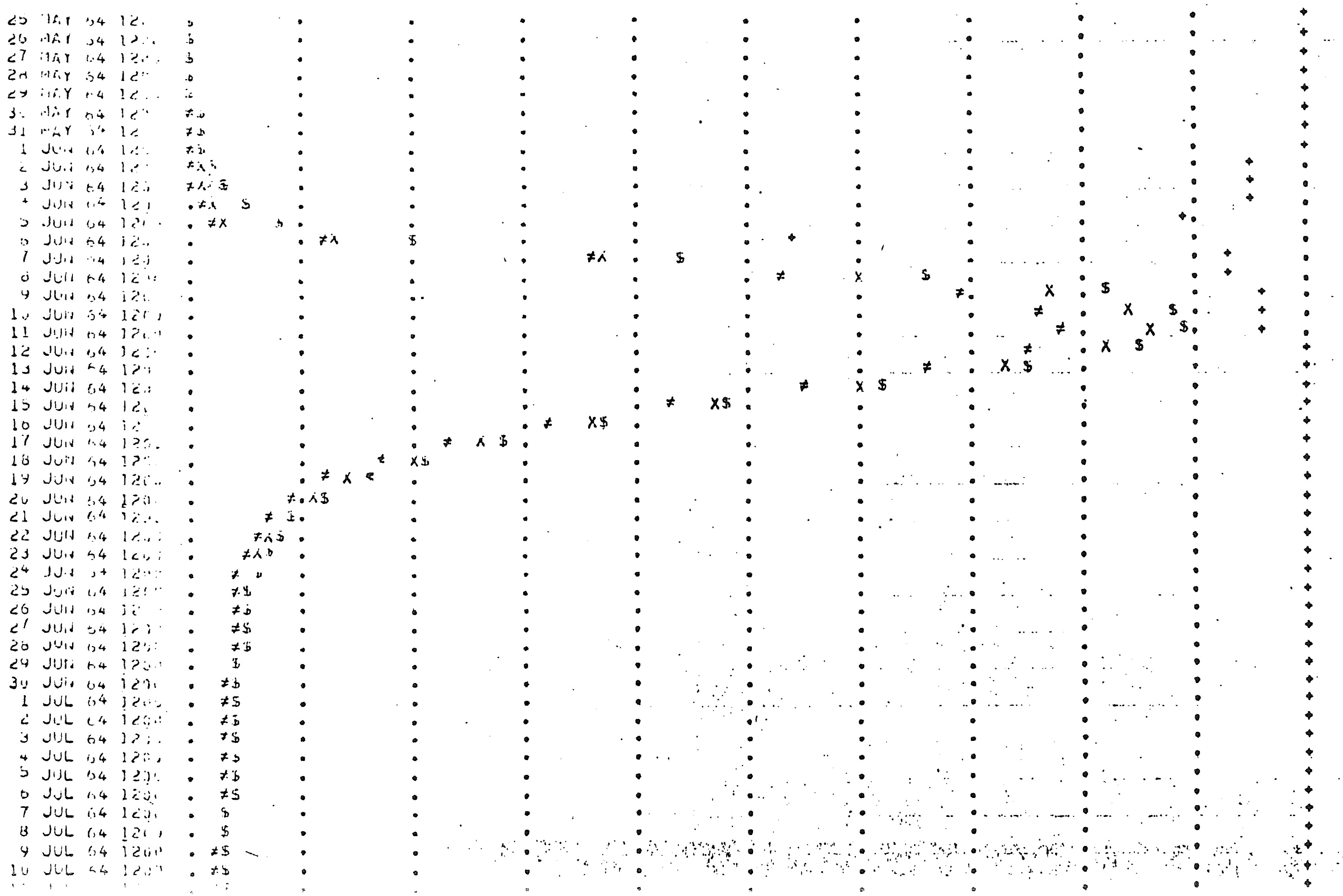


Fig. 34

The effect of mining operations on a 100-year rainstorm flood is on the order of 3 to 6 percent at Winton and 4 to 9 percent at Aurora.

Runs performed with a 100-year snow accumulation, using temperatures and spring rains for 1964, resulted in a peak flow of 18,200 cfs at Winton and 4,110 cfs at Aurora. Thus, the 100-year snowmelt floods appear to be on the order of twice as large as the 100-year rainstorm floods.

Figure 35 is a graph of the Frequency of Maximum Water Equivalent of Snow, March 1-15, in the Ely-Hoyt Lakes Area. The data are from U.S. Weather Bureau TP No. 50 (1964). The temperature and rainfall for 1964 were used with the appropriate snow-water content accumulation.

Tables XIII and XIV list peak flows for selected snowfall and rainfall conditions. The complete runs for these data are included in Addendum No. 1.

TABLE XIII - PEAK FLOWS-KAWISHIWI RIVER AT WINTON.

	Rainfall cfs	Snowfall cfs
Q_2 (two year)	1200	4580
Q_{25} (25 year)	5990	12500
Q_{100} (100 year)	9180	18200

TABLE XIV - PEAK FLOWS - ST. LOUIS RIVE AT AURORA.

	Rainfall cfs	Snowfall cfs
Q_2	276	628
Q_{25}	1290	2380
Q_{100}	2140	4110

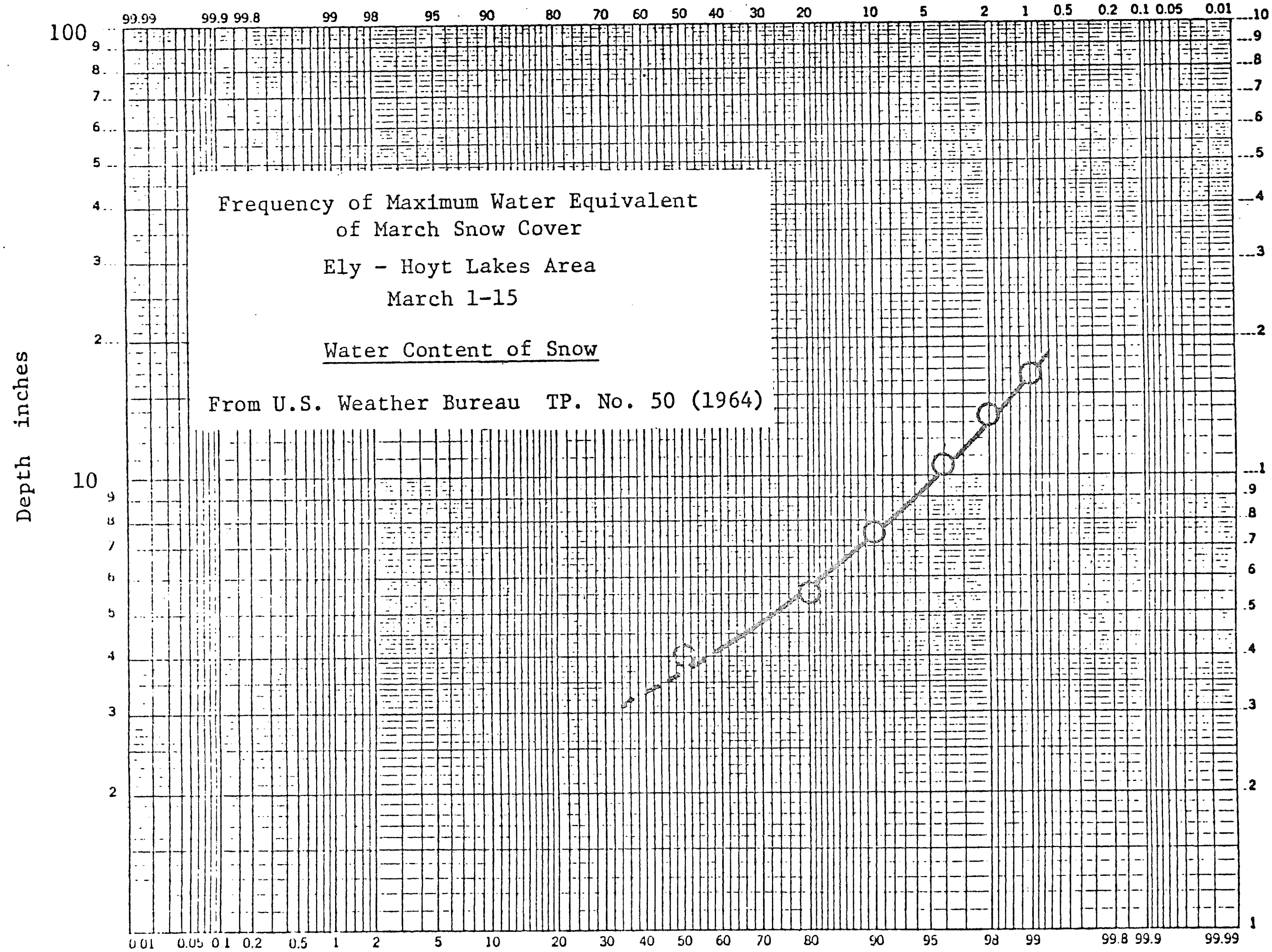

Frequency of Maximum Water Equivalent
of March Snow Cover
Ely - Hoyt Lakes Area
March 1-15
Water Content of Snow
From U.S. Weather Bureau TP. No. 50 (1964)
Depth inches
99.99 99.9 99.8 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 0.5 0.2 0.1 0.05 0.01
0.01 0.05 0.1 0.2 0.5 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.8 99.9 99.99
100
10
1

Fig. 35

Two copies of this Addendum are available; one has been provided for the Copper-Nickel project and a second is on file in Experimental Engineering at the University of Minnesota. Addendum No. 1 also includes calibration runs (1) for the Kawishiwi River at Winton for 1959, 60, 61, and 76, and (2) for the St. Louis River at Aurora for 1960, 61, 62, 63, 64, 75, and 76.

Referring to Tables XIII and XIV, it may be noted that there is a substantial difference between the 100-year snowmelt and rainstorm floods. Figures 36, 37, and 38 are graphs of annual floods of the Kawishiwi and St. Louis Rivers. An empirical curve was first drawn through the data and then a theoretical curve based on the Log Pearson Type III probability method was drawn on the graph. Finally, the 100-year, 25-year, and 2-year floods for snowmelt and for rainstorm floods were added.

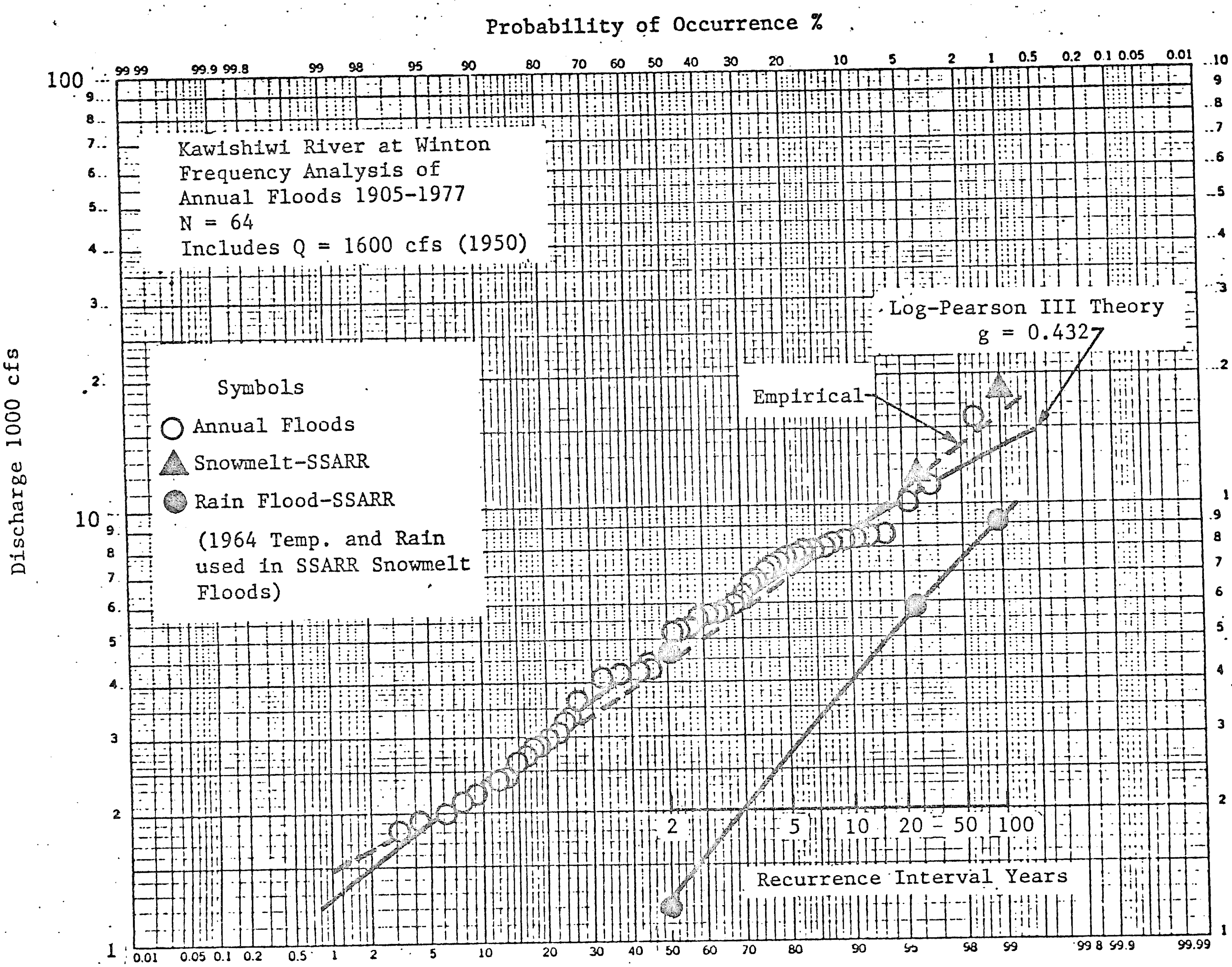
The most severe flood (16,000 cfs) of the Kawishiwi River at Winton occurred in 1950 and resulted in the failure of the dam at Birch Lake. The 1950 flood was included in this analysis, although a question might be raised as to the discharge which would have occurred if the dam had not failed.

Also, the floods of the St. Louis River at Aurora for 1961-64 and 1975 were corrected for mining effects in the Partridge River watershed. (Two were increased, two were decreased, and one had only a minor change (See Appendix C)).

Referring to Fig. 36, the 100-year flood of the Kawishiwi River at Winton as determined by the SSARR appears slightly above the annual flood data but in much better agreement than the 100-year rain flood by the SSARR. The 25-year (4% probability) and the 2-year (50% probability) snowmelt SSARR points are in excellent agreement with the annual floods. Whereas the 25-year and 2-year rain floods are low.

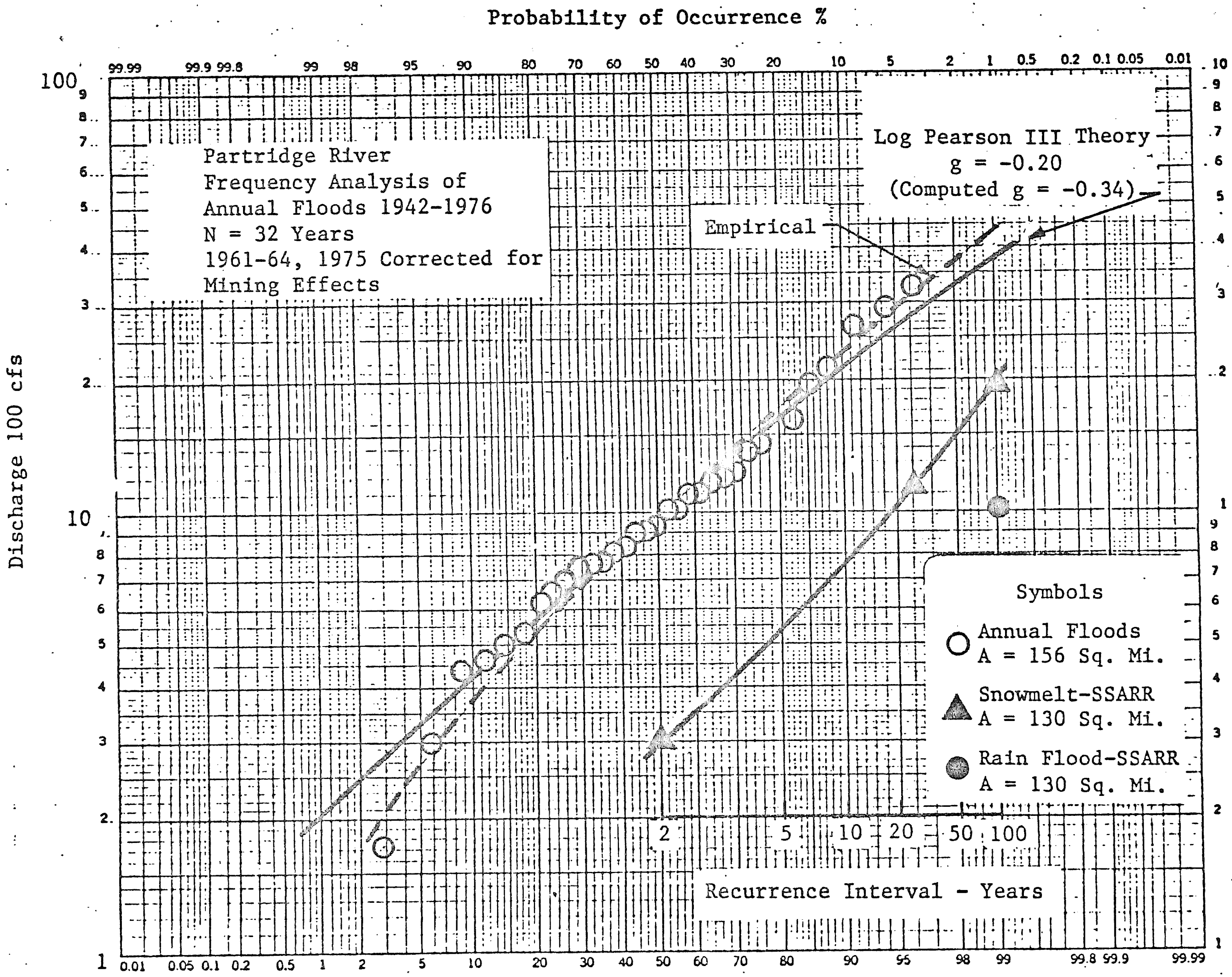
It might be concluded that the SSARR parameters have a better fit for snowmelt floods or possibly that most of our major floods are partially of snowmelt origin and we would expect this distribution.

For the Partridge River the annual floods are shown on Fig. 37 for the gauging station near Aurora (A = 156 sq. miles). Due to the mining effects on Second Creek, the SSARR was fitted for the Partridge area above Second Creek (A = 130 sq. miles). When the 100-, 25-, and 2-year snowmelt floods



Probability of Occurrence %
Discharge 1000 cfs
Kawishiwi River at Winton
Frequency Analysis of
Annual Floods 1905-1977
N = 64
Includes Q = 1600 cfs (1950)
Symbols
Annual Floods
Snowmelt-SSARR
Rain Flood-SSARR
(1964 Temp. and Rain
used in SSARR Snowmelt
Floods)
Log-Pearson III Theory
g = 0.432
Empirical
Recurrence Interval Years
2
5
10
20
50
100

Fig. 36



Probability of Occurrence %
Discharge 100 cfs
Partridge River
Frequency Analysis of
Annual Floods 1942-1976
N = 32 Years
1961-64, 1975 Corrected for
Mining Effects
Log Pearson III Theory
g = -0.20
(Computed g = -0.34)
Empirical
Symbols
Annual Floods
A = 156 Sq. Mi.
Snowmelt-SSARR
A = 130 Sq. Mi.
Rain Flood-SSARR
A = 130 Sq. Mi.
2
5
10
20
50
100
Recurrence Interval - Years

Fig. 37

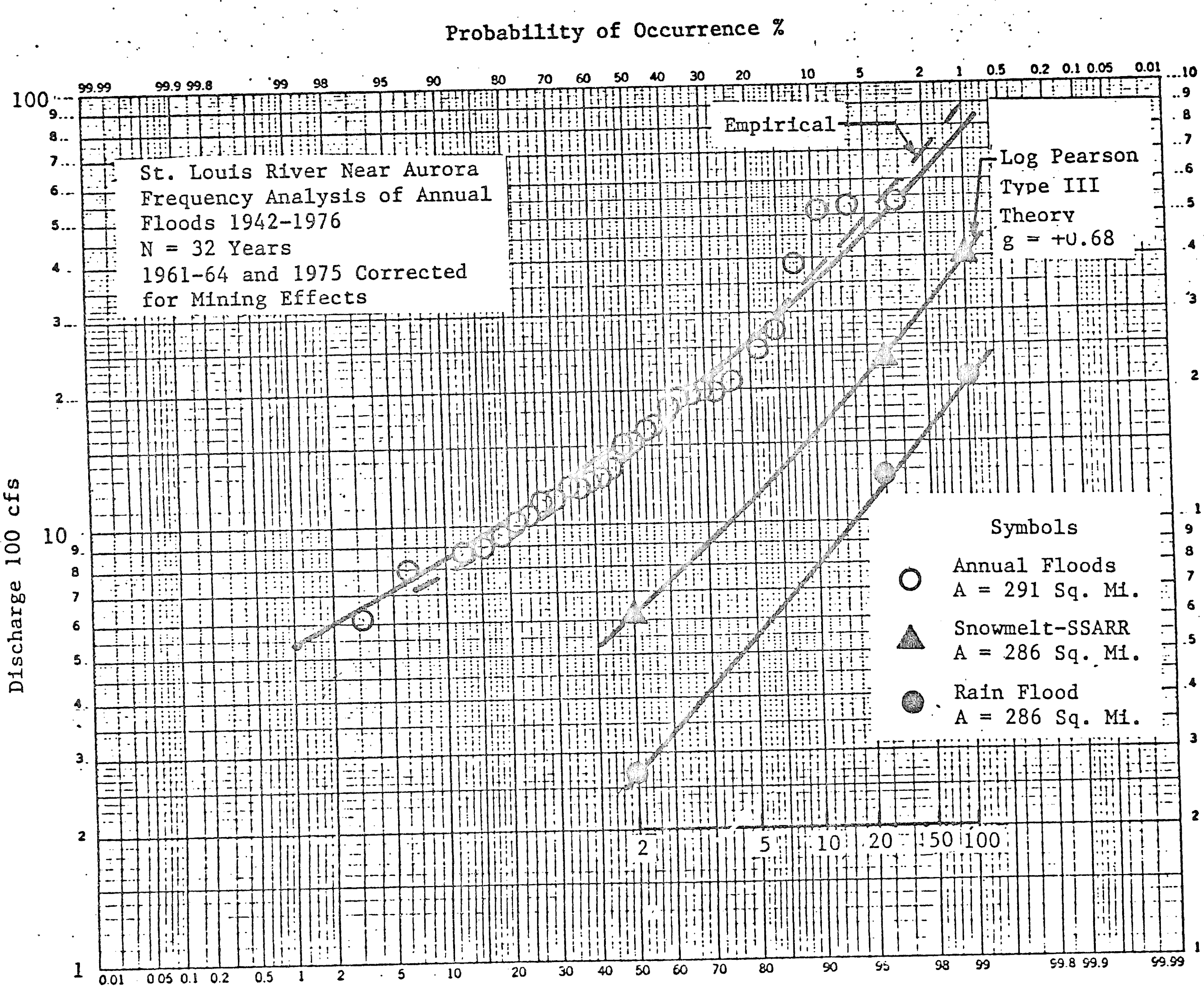

Probability of Occurrence %
Discharge 100 cfs
St. Louis River Near Aurora
Frequency Analysis of Annual
Floods 1942-1976
N = 32 Years
1961-64 and 1975 Corrected
for Mining Effects
Empirical
Log Pearson
Type III
Theory
g = +0.68
Symbols
Annual Floods
A = 291 Sq. Mi.
Snowmelt-SSARR
A = 286 Sq. Mi.
Rain Flood
A = 286 Sq. Mi.
2 5 10 20 50 100

Fig. 38

by the SSARR for the smaller (130 sq. mile) area are plotted on Fig. 37, they are on the order of 50 percent of the annual flood data. The rain floods are on the order of 50 percent of the snowmelt floods.

For the St. Louis River near Aurora, which includes the Partridge River watershed, the results are very similar to those for the Partridge River.

Summarizing, it appears that for high flows or floods the fitting of the SSARR to the Kawishiwi Basin above Winton is in the range of very good to excellent. The fitting of the SSARR to the St. Louis River above Aurora (for high flows) leaves much to be desired. It should be noted that the annual flood data on Fig. 37 are for an area of 156 sq. miles and the SSARR runs are for an area of 130 sq. miles. However, the main problem probably results from a lack of large floods in the fitting period (1959-64 and 1975-76). The choice of years to be used on the fitting process resulted from a restriction to these years for most gauging stations in the Kawishiwi Basin due to the brief number of years when gauging stations were operated. A shift to other years for the Partridge would have increased the work associated with data preparation.

Hindsight is usually quite good. In this case it appears that 1944 and 1948 (the two largest floods of record in the Partridge River watershed) should have been included in the fitting process. It is recommended that in future studies, these years be included in the fitting process. However, the objective would be to simulate the common or 2-year floods as well as the 100-year floods, similar to the fit achieved with the Kawishiwi River Basin.

While the fitting of a simulation model for high flows is of interest, it should be noted that low flows are of primary concern in the present study and an effort was made to achieve good simulation for low flows. Due to regulation of the Kawishiwi system for power development and of the Partridge River for mining activities, a final evaluation may require further study. The model may be providing a better evaluation of low runoff than the gauging stations.

Table X provides a basis for comparing low flows with or without mining.

FUTURE USAGE OF SSARR

The SSARR may be used to evaluate any number of different mining conditions and the associated regional hydrologic impacts. Caution should be exercised if the results are used for subwatershed analysis. Since the SSARR is conceptual, the calculated results are for an average subwatershed condition. Changes in the watershed may drastically affect the average response of the actual watershed and may not show up in the computed model results. Many small scale factors such as timing in the subwatershed were ignored so the large regional effect would not be to difficult to obtain.

To change loss in watershed area, the defining percent of the loss area station must be changed; or a new loss station created. The derived hydrograph for low flow events should then be subtracted using the adjacent station provision. For high flow events a TR-20 hydrograph can be generated, then input and subtracted in the same manner.

Appropriations must be taken after a new watershed outflow has been calculated, after mining area loss. Again the adjacent station provision is used to input the appropriation and remove it from the outflow.

The analysis for low and high flow events is different since the runoff characteristics are different. The SSARR does have the capability to provide the analytical tool for both conditions and to determine regional hydrologic impacts.

Future studies should consider additional fitting of the model, including high flow in the Partridge River watershed.

REVISED APPROPRIATION RATES

After the completion of the runs involving mining effects it was requested that additional runs be performed with smaller appropriation rates. Most of the data were as defined in Table VIII, with the exception that appropriations in the South Kawishiwi and in the Partridge River were decreased from 18 cfs to 9 cfs. Several runs were performed under these conditions and the results presented in Appendix H. In general, both the low and high flows increased by about 9 cfs except for the St. Louis River near Aurora where the low flows were so small that appropriations were probably restricted to less than 9 cfs.

Consideration should be given to storage of flood flows for use during droughts such as the one that occurred in 1976.

REFERENCES

1. Savard, C. S., Nelson, N. P., and Bowers, C. E., "Hydrologic Investigations of Selected Watersheds in the Copper-Nickel Region of Northeastern Minnesota", St. Anthony Falls Hydraulic Laboratory Memorandum No. 155, Feb. 1978.

2. Brooks, K. N., Davis, E. M., and Kuehl, D. W., "Program Description and User Manual for SSARR, Streamflow Synthesis and Reservoir Regulation", U.S. Army Engineer Division, North Pacific, June 1975.

3. Bowers, C. E. and Gutschick, C. K., "Kawishiwi River and Watershed Study, Part II Snowmelt and Rainstorm Floods with Normal and Modified Flow from the North Kawishiwi River", St. Anthony Falls Hydraulic Laboratory Ext. Memorandum No. 142, February 15, 1977.

4. Guetzlow, Lowell C., "Techniques for Estimating Magnitude and Frequency of Floods in Minnesota", USGS Water Res. Inves., 77-31, May 1977.

5. Medge, Howard, "Hydrology Guide for Minnesota", U.S. Dept. of Agriculture, Soil Conservation Service, St. Paul, Minn., 1976.

APPENDICES

A. Frequency Analysis for Low Flow.

B. TR-20 Analysis of Mining Effects.

C. Partridge River Correction Due to the Erie Mining Operations in the Lower Partridge River Watershed.

D. Rainfall Data for the SSARR Runs - Phase 2

E. Rainfall Data for 3 Watersheds - Phase 1

F. Frequency Analysis of Floods.

G. Selected Graphs from First Phase Report, External Memorandum No. 155.

H. Concluding Runs with 9 cfs Appropriation in Selected Watersheds.

Appendix A.
Low Flow Frequency Analysis

I. Introduction

In the analysis of low flow the duration as well as magnitude of low flow is important. The duration and severity of a drought is dependent on the rainfall or lack of rainfall over periods ranging up to several years in length.

One possible approach to this problem is to make a stochastic analyses of precipitation, temperature and runoff. Limitations on time and funds prevented this approach in the current study.

A second method is to utilize past rainfall and other hydrologic data as input to the mathematical simulation model (SSARR) and to determine the drought severity for that set of data by analyzing low flow data for 1, 7, 14, 30, 120, and 365 day periods. This was the method selected in the present study.

Two years data were selected for low-flow analysis, 1960 and 1976; 1960 was close to an average year. One of the severe drought years in Northeastern Minnesota was 1976.

II. Kawishiwi River Near Winton

A frequency analysis of data for the Kawishiwi River near Winton is available in USGS Open File Report - Water Resources 77-48, entitled "Low Flow Characteristics of Minnesota Streams", by K. L. Linskov. These data are summarized on the attached Fig. A-1 and the attached Table A-I (the Table was reproduced from the USGS Report). Table A-I includes data for 1960 and 1976 at selected stations.

Plotting the data from Table A-II on Fig. A-1, it may be noted that for a duration of 30 days the 1960 data plot at a probability occurrence of about 48% (or recurrence interval of about 2.1 years). This location

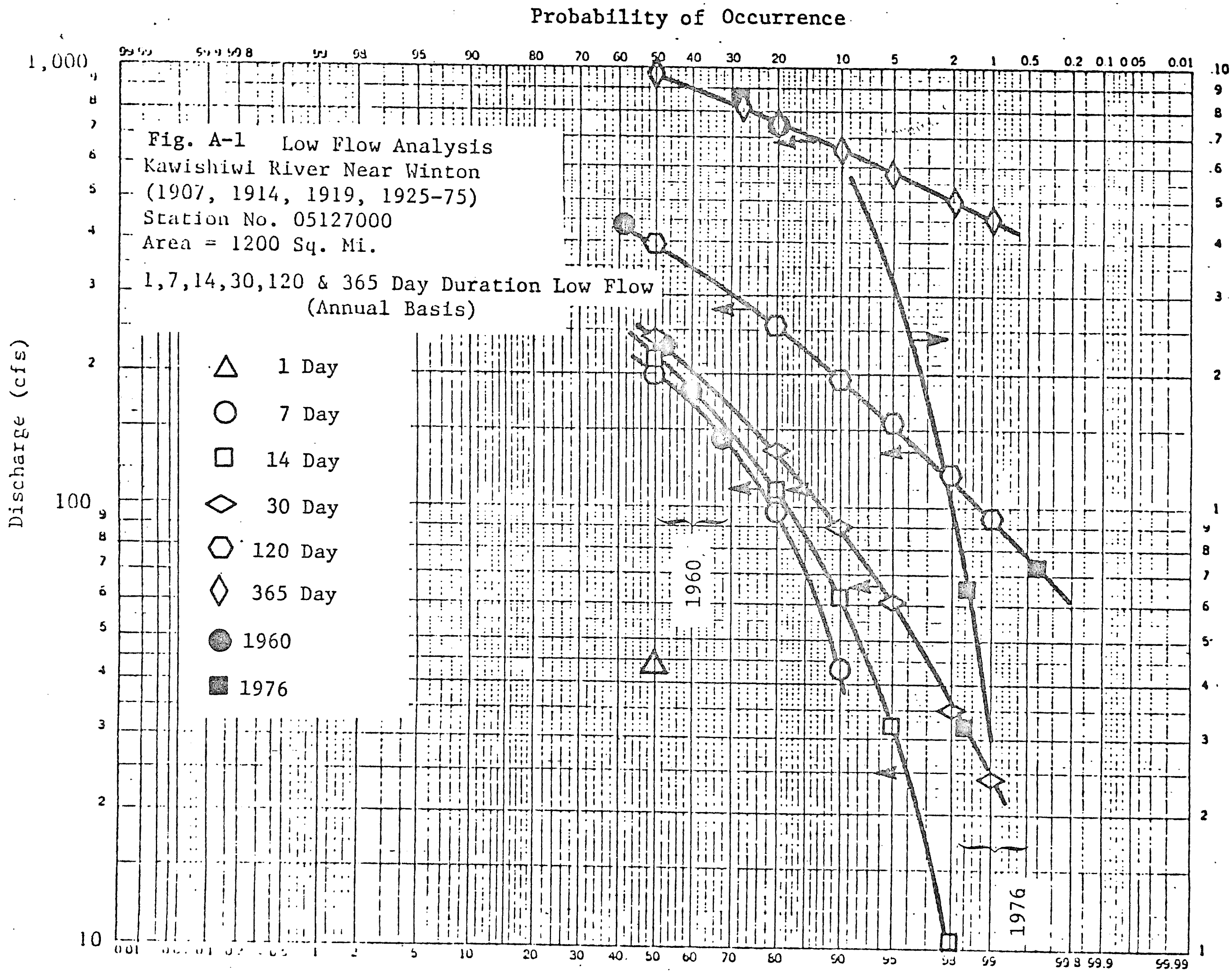

Probability of Occurrence
Fig. A-1 Low Flow Analysis
Kawishiwi River Near Winton
(1907, 1914, 1919, 1925-75)
Station No. 05127000
Area = 1200 Sq. Mi.
1,7,14,30,120 & 365 Day Duration Low Flow
(Annual Basis)
1 Day
7 Day
14 Day
30 Day
120 Day
365 Day
1960
1976
Discharge (cfs)
1,000
100
10
1960
1976

TABLE A-I. MAGNITUDE AND FREQUENCY OF ANNUAL LOW FLOWS AT CONTINUOUS-RECORD GAGING STATIONS.

Station No.	Station Name and Location	Record Used in Analysis	Drainage Area (mi²)	Period (consecutive days)	Annual low flow, in cubic feet per second, for indicated recurrence in years: 2	5	10	20	50	100
	LAKE OF THE WOODS BASIN--Continued									
05124500	Isabella River near Isabella	1954-61	341	1	51.3	43.5	39.5	--	--	--
	LOCATION.--Lat 47°48'00",			7	54.4	44.3	39.6	--	--	--
	long 91°31'15", in NW¼NE¼			14	56.2	45.7	40.7	--	--	--
	sec.6, T.61 N., R.9 W.,			30	60.2	49.0	43.3	--	--	--
	Lake County, 14.5 miles			60	66.2	54.2	47.7	--	--	--
	northwest of Isabella,			90	72.1	60.0	53.7	--	--	--
	Minn.			120	85.7	73.2	66.8	--	--	--
				183	112	86.6	75.1	--	--	--
				365	283	232	207	--	--	--
05125000	South Kawishiwi River near Ely	1953-61	--	1	107	69.6	49.1	--	--	--
	LOCATION.--Lat 47°50'24",			7	111	72.8	51.8	--	--	--
	long 91°41'43", in NE¼SW¼			14	114	75.9	55.4	--	--	--
	sec.23, T.62 N., R.11 W.,			30	120	81.3	59.5	--	--	--
	Lake County, 9 miles			60	137	97.5	73.3	--	--	--
	southeast of Ely, Minn.			90	150	113	89.6	--	--	--
				120	166	123	96.0	--	--	--
				183	193	134	103	--	--	--
				365	429	339	296	--	--	--
05125500	Stony River near Isabella	1954-64	180	1	13.9	9.29	7.32	--	--	--
	LOCATION.--Lat 47°41'10",			7	14.7	9.77	7.65	--	--	--
	long 91°38'20", in NW¼NW¼			14	15.1	10.1	7.86	--	--	--
	sec.17, T.60 N., R.10 W.,			30	16.4	11.1	8.76	--	--	--
	Lake County, 12.8 miles			60	18.8	13.4	10.9	--	--	--
	northwest of Isabella,			90	22.3	16.4	13.4	--	--	--
	Minn.			120	28.0	21.5	18.4	--	--	--
				183	43.7	30.3	24.1	--	--	--
				365	121	94.6	83.2	--	--	--
05126000	Dunka River near Babbitt	1953-62	53.0	1	1.82	1.14	.85	--	--	--
	LOCATION.--Lat 47°41'55",			7	2.14	1.39	1.04	--	--	--
	long 91°52'05", in NW¼NE¼			14	2.41	1.56	1.17	--	--	--
	sec.9, T.60 N., R.12 W.,			30	2.50	1.62	1.22	--	--	--
	St. Louis County, 3.8			60	2.81	1.91	1.51	--	--	--
	miles southeast of Babbitt,			90	3.56	2.43	1.90	--	--	--
	Minn.			120	4.79	3.49	2.87	--	--	--
				183	9.76	6.51	5.08	--	--	--
				365	33.8	28.4	26.3	--	--	--
05126500	Bear Island River near Ely	1954-62	68.5	1	2.23	.82	.46	--	--	--
	LOCATION.--Lat 47°49'56",			7	2.84	1.23	.76	--	--	--
	long 91°50'12", in SE¼SW¼			14	3.46	1.62	1.04	--	--	--
	sec.23, T.62 N., R.12 W.,			30	4.93	2.35	1.46	--	--	--
	St. Louis County, 5.0			60	7.21	3.96	2.67	--	--	--
	miles south of Ely, Minn.			90	9.62	5.92	4.16	--	--	--
				120	11.9	7.77	5.64	--	--	--
				183	15.4	9.94	7.32	--	--	--
				365	39.3	28.0	23.1	--	--	--
				(Flow affected by storage in lakes)						
05127000	Kawishiwi River near Winton	1907	a1200	1	44.4	0	0	0	0	0
	LOCATION.--Lat 47°56'05",	1914		7	200	97.5	43.4	0	0	0
	long 91°45'50", in NE¼NW¼	1917		14	214	107	61.2	31.9	10.3	3.05
	sec.20, T.63 N., R.11 W.,	1925-75		30	240	136	90.3	60.3	35.6	24.0
	Lake County, 1.8 miles			60	279	175	130	98.6	69.7	54.2
	east of Winton, Minn.			90	332	221	173	139	106	87.9
				120	391	255	197	155	117	95.1
				183	471	294	227	183	143	120
				365	994	752	649	573	498	453
				(Flow regulated by power plant and numerous lakes)						
05127500	Basswood River near Winton	1932-37	a1740	1	388	270	209	163	118	93.1
	LOCATION.--Lat 48°04'55",	1940-75		7	396	275	214	169	125	99.4
	long 91°39'10", in sec.30,			14	407	282	221	175	131	106
	T.65 N., R.10 W., Lake			30	430	293	229	183	139	113
	County, 14 miles north-			60	483	322	249	196	146	118
	east of Winton, Minn.			90	535	349	269	213	160	130
				120	582	371	285	225	170	140
				183	667	414	320	257	200	169
				365	1330	1000	866	765	665	605
				(Flow affected by storage in many lakes)						

a Approximately.

TABLE A-I. MAGNITUDE AND FREQUENCY OF ANNUAL LOW FLOWS AT CONTINUOUS-RECORD GAGING STATIONS. (Cont.)

Station No.	Station Name and Location	Record Used in Analysis	Drainage Area (mi^2)	Period (consecutive days)	Annual low flow, in cubic feet per second, for indicated recurrence in years: 2	5	10	20	50	100
	RED RIVER OF THE NORTH BASIN--Continued									
05104000	South Fork Roseau River near Malung LOCATION.--Lat 48°47'00", long 95°44'16", in NE¼SW¼ sec.7, T.161 N., R.39 W., Roseau County, 1.1 miles northwest of Malung, Minn.	1913-14 1930-38 1941-46	312	1	0	0	0	0	--	--
				7	0	0	0	0	--	--
				14	0	0	0	0	--	--
				30	0	0	0	0	--	--
				60	0	0	0	0	--	--
				90	.04	0	0	0	--	--
				120	.12	0	0	0	--	--
				183	.26	0	0	0	--	--
				365	16.9	5.70	3.05	1.77	--	--
05104500	Roseau River below South Fork, near Malung LOCATION.--Lat 48°47'30", long 95°44'40", in SW¼ sec.6, T.161 N., R.39 W., Roseau County, 1.5 miles northwest of Malung, Minn.	1948-75	573	1	1.43	.60	.34	.16	0	0
				7	1.82	.70	.39	.18	0	0
				14	2.10	.89	.50	.25	0	0
				30	2.74	1.29	.78	.38	0	0
				60	4.65	2.00	1.13	.58	.18	.05
				90	5.72	2.80	1.78	1.17	.70	.48
				120	7.69	4.11	2.87	2.10	1.45	1.12
				183	17.3	6.60	4.07	2.71	1.72	1.26
				365	128	70.9	51.2	38.8	28.1	22.5
				(Undetermined amount of high flow bypasses the station through overflow channel 0.8 mile upstream and returns to river 0.5 mile downstream)						
05106000	Sprague Creek near Sprague LOCATION.--Lat 48°59'33", long 95°39'43", in NE¼ sec.34, T.164 N., R.39 W., Roseau County, 3.5 miles south of Sprague, Manitoba	1941-75	169	1	.78	.26	.06	0	0	0
				7	.91	.31	.08	0	0	0
				14	1.02	.34	.11	0	0	0
				30	1.26	.51	.27	.14	.06	.03
				60	1.46	.80	.56	.40	.26	.20
				90	1.76	1.02	.75	.58	.43	.35
				120	2.61	1.40	1.02	.79	.60	.49
				183	9.20	3.50	2.09	1.33	.81	.56
				365	59.3	28.8	17.7	11.1	6.15	3.98
05107000	Pine Creek near Pine Creek LOCATION.--Lat 48°59'35", long 95°55'04", in SW¼SW¼ sec.26, T.164 N., R.41 W., Roseau County, 2 miles northeast of Pine Creek, Minn.	1930-53	74.6	1	4.00	2.18	1.09	0	0	--
				7	4.45	2.54	1.35	0	0	--
				14	4.77	2.78	1.61	.40	0	--
				30	5.32	3.19	2.20	1.53	.95	--
				60	5.91	4.05	3.14	2.47	1.82	--
				90	6.58	4.55	3.55	2.80	2.07	--
				120	7.19	5.21	4.33	3.68	3.04	--
				183	10.6	6.96	5.58	4.64	3.77	--
				365	24.9	16.6	13.2	10.8	8.60	--
05107500	Roseau River at Ross LOCATION.--Lat 48°54'37", long 95°55'18", in SE¼ sec.27, T.163 N., R.41 W., Roseau County, 0.2 mile north of Ross, Minn.	1930-75	a1220	1	5.78	2.50	1.24	.52	.003	0
				7	7.00	2.88	1.52	.76	.31	.15
				14	7.59	3.47	2.04	1.23	.64	.40
				30	8.33	4.26	2.80	1.91	1.19	.85
				60	10.4	5.62	3.84	2.71	1.77	1.30
				90	12.3	7.04	5.08	3.81	2.70	2.13
				120	16.6	9.45	7.00	5.45	4.10	3.38
				183	33.7	15.3	10.2	7.25	4.92	3.82
				365	225	112	74.3	51.8	33.7	24.9
05112000	Roseau River below State ditch No. 51, near Caribou LOCATION.--Lat 48°58'54", long 96°27'46", in SE¼SW¼ sec.34, T.164 N., R.45 W., Kittson County, 0.6 mile west of Caribou, Minn.	1921-30 1933 1937 1941-43 1973-75	1570	1	16.0	5.57	2.08	.73	--	--
				7	16.6	5.85	2.64	1.18	--	--
				14	16.7	6.61	3.30	1.65	--	--
				30	16.9	7.93	5.01	3.29	--	--
				60	18.3	10.1	7.38	5.73	--	--
				90	20.0	11.6	9.02	7.44	--	--
				120	25.8	14.5	11.0	8.86	--	--
				183	51.1	23.7	16.0	11.6	--	--
				365	226	128	94.1	72.4	--	--
	LAKE OF THE WOODS BASIN									
05124480	Kawishiwi River near Ely LOCATION.--Lat 47°55'22", long 91°32'06", in SE¼ sec.24, T.63 N., R.10 W., Lake County, 14 miles east of Ely, Minn.	1968-75	253	1	45.5	34.8	29.4	--	--	--
				7	47.6	36.7	31.3	--	--	--
				14	50.8	38.4	32.6	--	--	--
				30	54.2	40.9	34.8	--	--	--
				60	61.5	45.2	37.5	--	--	--
				90	71.1	53.0	44.2	--	--	--
				120	89.5	64.0	51.2	--	--	--
				183	139	96.2	77.2	--	--	--
				365	252	201	177	--	--	--

a Approximately.

TABLE A-I. MAGNITUDE AND FREQUENCY OF ANNUAL LOW FLOWS AT CONTINUOUS-RECORD GAGING STATIONS. (Cont.)

Station No.	Station Name and Location	Record Used in Analysis	Drainage Area (mi^2)	Period (consecutive days)	Annual low flow, in cubic feet per second, for indicated recurrence in years: 2	5	10	20	50	100
	STREAMS TRIBUTARY TO LAKE SUPERIOR									
04010500	Pigeon River at Middle Falls	1925-75	600	1	71.6	51.1	43.2	37.7	32.5	29.5
	near Grand Portage			7	73.8	52.6	44.5	38.8	33.4	30.4
	LOCATION.--Lat 48°00'44",			14	78.0	55.3	46.5	40.5	34.8	31.6
	long 89°36'58", in NE¼			30	84.7	60.4	51.1	44.8	38.8	35.4
	sec.24, T.64 N., R.6 E.,			60	95.3	69.5	60.0	53.7	47.9	44.6
	Cook County, 4.7 miles			90	107	78.0	67.7	59.3	52.0	48.0
	northeast of Grand			120	124	87.2	74.3	65.8	58.1	53.8
	Portage, Minn.			183	174	111	89.0	74.9	65.0	60.0
				365	494	376	322	282	240	216
04012500	Poplar River at Lutsen	1914-17	112	1	14.4	9.69	7.63	6.16	4.75	3.95
	LOCATION.--Lat 47°38'23",	1931-32		7	16.1	11.2	9.04	7.48	5.96	5.08
	long 90°42'31", in SW¼NE¼	1935-47		14	17.8	12.7	10.4	8.67	6.97	5.98
	sec.33, T.60 N., R.3 W.,	1954-61		30	20.7	14.9	12.2	10.2	8.14	6.94
	Cook County, at Lutsen,			60	25.8	18.6	15.1	12.5	9.89	8.35
	Minn.			90	29.3	21.3	17.6	14.8	12.0	10.4
				120	34.5	25.4	21.3	18.2	15.1	13.2
				183	45.9	33.7	28.7	25.1	21.6	19.5
				365	106	84.4	72.9	63.7	53.8	47.7
04014500	Baptism River near Beaver	1931-47	140	1	9.15	4.32	2.57	1.55	.82	.50
	Bay	1951-75		7	10.1	5.00	3.17	2.08	1.22	.83
	LOCATION.--Lat 47°20'15",			14	11.4	5.82	3.77	2.52	1.52	1.06
	long 91°12'00", in SE¼NE¼			30	14.1	7.35	4.87	3.35	2.10	1.51
	sec.15, T.56 N., R.7 W.,			60	17.5	10.0	7.14	5.24	3.60	2.75
	Lake County, 7 miles			90	20.7	12.8	9.67	7.53	5.57	4.50
	northeast of Beaver Bay,			120	28.5	19.1	15.1	12.4	9.74	8.24
	Minn.			183	56.3	33.7	25.6	20.4	15.7	13.2
				365	164	128	112	99.5	87.3	79.8
04015500	Second Creek near Aurora	1956-75	26.3	1	4.86	2.68	1.96	1.52	1.14	--
	LOCATION.--Lat 47°31'25",			7	5.16	2.84	2.09	1.62	1.22	--
	long 92°11'35", in SW¼			14	5.47	2.99	2.18	1.68	1.26	--
	sec.12, T.58 N., R.15 W.,			30	5.92	3.24	2.37	1.83	1.37	--
	St. Louis County, 2.1			60	6.81	3.72	2.70	2.07	1.53	--
	miles east of Aurora,			90	7.61	4.38	3.30	2.61	2.01	--
	Minn.			120	8.49	5.18	4.06	3.35	2.71	--
				183	12.1	7.57	6.03	5.05	4.17	--
				365	21.0	16.2	14.4	13.1	11.9	--
				(Natural flow affected by continually changing iron-mining activities)						
04016000	Partridge River near Aurora	1944-75	156	1	10.8	6.18	4.47	3.36	2.39	1.88
	LOCATION.--Lat 47°31'02",			7	11.4	6.53	4.74	3.57	2.55	2.02
	long 92°11'24", in SE¼SW¼			14	11.9	6.78	4.90	3.70	2.65	2.10
	sec.12, T.58 N., R.15 W.,			30	12.7	7.23	5.31	4.08	3.01	2.45
	St. Louis County, 2.5			60	14.4	8.34	6.24	4.88	3.70	3.06
	miles east of Aurora,			90	16.5	10.1	7.86	6.38	5.06	4.33
	Minn.			120	21.6	13.8	10.8	8.82	7.00	5.99
				183	36.8	20.3	14.8	11.4	8.51	6.98
				365	112	76.5	61.2	50.2	39.5	33.4
				(Flow regulated at times by storage in off-channel Partridge Reservoir, formerly known as Whitewater Lake)						
04016500	St. Louis River near Aurora	1944-75	291	1	24.5	14.5	10.7	8.19	5.96	4.77
	LOCATION.--Lat 47°29'30",			7	25.8	15.4	11.4	8.80	6.45	5.19
	long 92°14'20", in SW¼			14	27.6	16.6	12.3	9.51	6.98	5.62
	sec.22, T.58 N., R.15 W.,			30	28.9	18.0	13.8	11.0	8.38	6.97
	St. Louis County, 1.5			60	32.5	21.1	16.7	13.7	11.0	9.44
	miles south of Aurora,			90	38.5	25.8	20.8	17.4	14.1	12.3
	Minn.			120	49.7	33.4	26.7	22.0	17.5	15.0
				183	82.5	47.0	34.6	26.8	20.0	16.3
				365	227	172	148	130	113	102
				(Flow regulated at times by storage in off-channel Partridge Reservoir, formerly known as Whitewater Lake)						
04017000	Embarrass River at Embarrass	1944-64	93.8	1	3.32	2.16	1.67	1.34	1.02	--
	LOCATION.--Lat 47°39'24",			7	3.61	2.30	1.75	1.44	1.06	--
	long 92°11'51", in NW¼			14	3.88	2.46	1.86	1.51	1.13	--
	sec.25, T.60 N., R.15 W.,			30	4.18	2.69	2.08	1.65	1.26	--
	St. Louis County, at			60	4.87	3.18	2.46	1.95	1.47	--
	Embarrass, Minn.			90	5.65	3.82	3.06	2.53	2.03	--
				120	7.91	5.44	4.45	3.76	3.10	--
				183	15.8	9.02	6.71	5.24	3.96	--
				365	61.7	44.9	37.8	32.6	27.5	--

Table A-II

Low Flow Discharges for Selected Years, for Durations of 1 Day to 365 Days

River	Days 1	7	14	30	120	365
	1960					
Isabella River near Isabella	54.0	58.9	62.0	64.8	99.4	272
Stony River near Isabella*	10.0	10.7	11.6	12.7	23.4	103
Dunka, River near Babbitt	1.9	2.2	2.4	2.4	4.1	29.5
Kawishiwi River near Winton	32	143	179	234	434	755
St. Louis River near Aurora	39	45	45.6	46.4	63.9	170
	1976 (Cal. Yr.)					
Isabella River near Isabella	24.0	25.1	25.1	26.3	31.5	--
Stony River near Babbitt**	6.7	7.0	6.7	7.4	9.3	180?
Dunka River near Babbitt	0	0	0	0	0.33	29.8
Kawishiwi River near Winton	0	0	6.86	33.9	75.1	826
St. Louis River near Aurora	16.0	18.2	17.1	17.0	19.3	146

*A = 180 sq. mi.
**A = 210 sq. mi.

Dunka River and Kawishiwi River near Winton were subject to considerable regulation for short durations.

was determined by noting that the 30 day average low flow of the Kawishiwi River near Winton (Table II) was 234 cfs and that this value on Fig. A-1 occurs at 48% probability of occurrence.

The curves on Fig. A-1 are for 7, 14, 30, 120, and 365 days (average low flow). There is no curve for one day because power regulation at Winton seriously affects the analysis of one day low flows. The 7-day low flow is likewise seriously affected. It is difficult to assess the effect for 14, 30, and 120 days. As the storage in Birch, White Iron, and Farm Lakes is relatively small compared with the annual flow, the 365 day low flow may not be seriously affected.

The 7-day low flow is frequently used in urban studies because cities may have storage for a period of this duration. For a mining operation of the type being considered it would appear desirable to store volumes equivalent to normal use for periods of 14 to 120 days, and possibly much longer.

Therefore, these durations were considered in assigning a frequency to low flow data. While a single large storm (such as the 100-year storm) may be used to determine a 100-year flood, a similar low precipitation period cannot be used for a 100-year low flow because the low flow is dependent on the precipitation amount and distribution for periods ranging up to a year or more.

Kawishiwi River Near Winton

Figure A-1 shows data from a USGS report by Linskov. Average low flows of 1, 7, 14, 30, 120, and 365 days duration are plotted as a function of probability of occurrence. The actual low flow data for 1960 and 1976 are shown in Table A-II. These data were used to determine the corresponding probability of occurrence of each duration for 1960 and 1976.

For example, taking the 7-day average low flow of the Kawishiwi River near Winton for 1960, 143 cfs, it may be noted on Fig. A-1 that this flow occurs at a probability of 31% (or recurrence interval of 3.22 years). Table A-III shows data for other durations in 1960 of 14, 30, 120, and 365 days (P_{oc} = 39%, 48% 59%, and 20%, respectively). The corresponding recurrence intervals are 2.56, 2.09, 1.69, and 5 years, respectively.

Table A-III

Low Flow Frequency Data for 1960 and 1976
Probability of Occurrence % - 1960 Low Flow Data

River / Duration Days	1	7	14	30	120	365
Isabella River near Isabella	56	66	68	70	80	43
Stony River near Isabella (180)	24	25	27	28	28	60
Dunka River near Babbitt	51	51	46	46	35	24
Bear Island River near Ely						
Kawishiwi River near Winton	—	31	39	48	59	20
				48.7% (Tr=2.05 yrs)		
St. Louis River near Aurora	84	87	86	83	74	20
				80.5 (Tr=1.24 yr.)		

Probability of Occurrence % - 1976 Low Flow Data

River / Duration Days	1	7	14	30	120	365
Isabella River near Isabella	0.1	0.2	0.2	0.30	0.01	
Stony River near Isabella (210)	8	8	6	6	0.04	60
Dunka River* near Babbitt	0	0	0	0		
Bear Island River near Ely						
Kawishiwi River near Winton	0	0	1.6	1.7	0.4	27
				1.23 (Tr=81 yr.)		
St. Louis River near Aurora	26	27	22	22	3.1	8.5
				15.70 (Tr-6.4)		

*mining operations

Averaging the values for 14, 30, and 120 days we come up with a nominal probability of the 1960 low flow at Winton of 48.7% or 2.05 years. Thus, this was a fairly common low flow occurring about every other year. However, the data for 1976 indicate a drought.

As noted on Table A-III, an average of probabilities for durations of 14, 30, and 120 days suggested the following:

Year	P_{oc} (%)	T_r (years)
1960	48.7	2.05
1976	1.23	81

These should be rounded off to about:

1960	50%	2.0 years
1976	1.3%	80.0 years

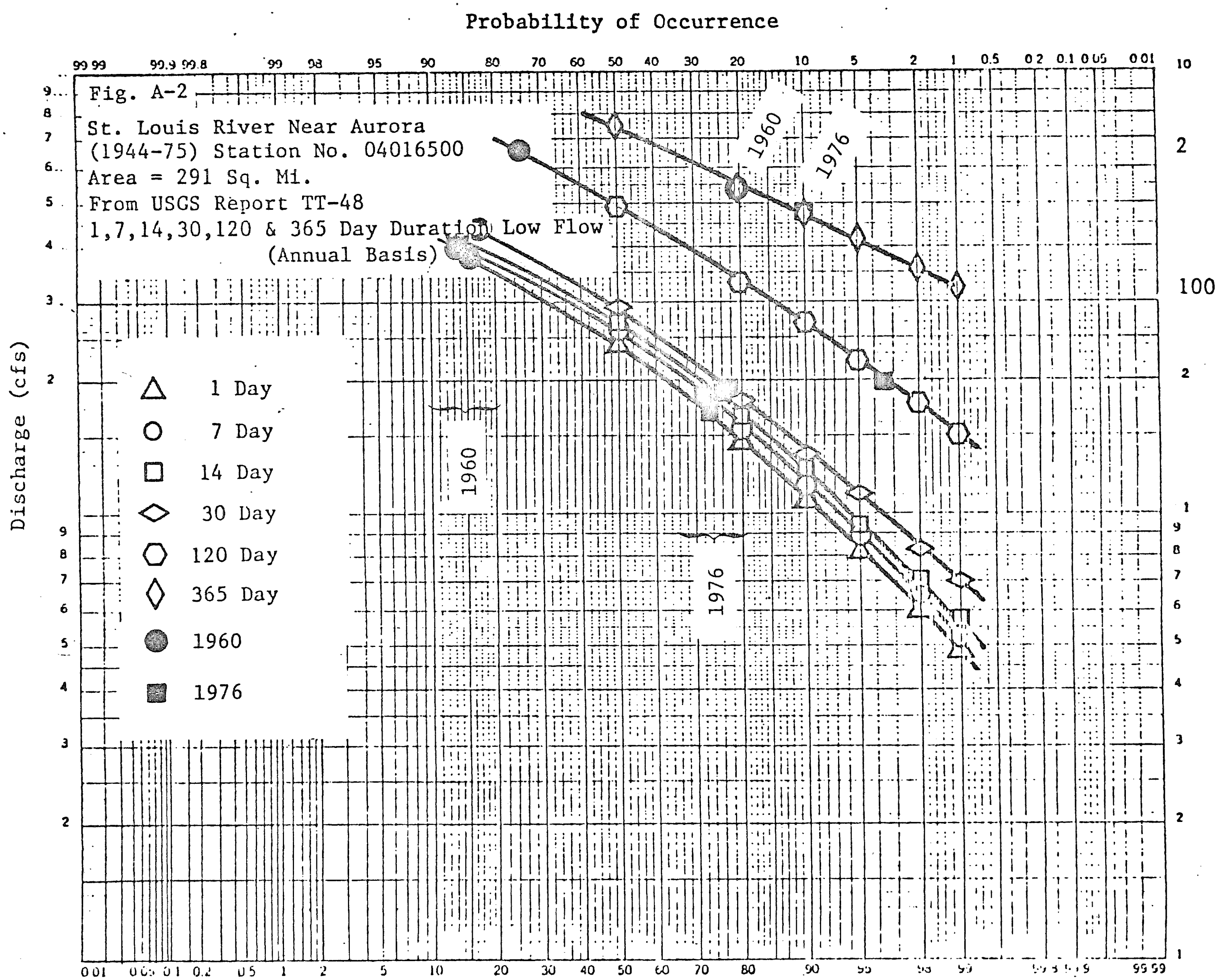
Of special interest is the fact that 1976 was a drought year of a severity equal to a recurrence interval of about once in 80 years, for flow durations of 14 to 120 days.

As the spring flows were quite high, the flow for the complete year was not as deficient as the shorter periods.

St. Louis River Above Aurora

Figure A-2 shows the frequency curves for the St. Louis River at Aurora in accordance with the report by Linskov noted above. Plotting the data from Table A-1 on this graph indicates the following:

Year	Duration Days	Probability %	Recurrence Interval Years	
1960	1	8.4	1.19	
	7	86	1.15	
	14	85	1.16	Ave. = 1.24 (P_{oc} = 80.5) (14, 30, 120 days)
	30	82	1.20	
	120	72	1.35	
	365	20	5.00	
1976	1	24	4.17	
	7	27	3.70	
	14	22	4.55	Ave. = 6.40 (P_{oc} = 15.7) (14, 30, 120 days)
	30	22	4.55	
	120	3.1	32.26	
	365	8.5	11.76	



Probability of Occurrence
Fig. A-2
St. Louis River Near Aurora
(1944-75) Station No. 04016500
Area = 291 Sq. Mi.
From USGS Report TT-48
1,7,14,30,120 & 365 Day Duration Low Flow
(Annual Basis)
1 Day
7 Day
14 Day
30 Day
120 Day
365 Day
1960
1976
Discharge (cfs)
100
1960
1976

On the Upper St. Louis River (above Aurora) these data would suggest a probability of occurrence for the 1960 data of about 80.5% (or Tr = 1.24 years). The 1976 data have a probability of about 15.7% (Tr = 6.4 years).

The above data indicate that the 1976 drought was much more severe (recurrence interval = 80 years) in the Kawishiwi River Basin than it was in the Upper St. Louis River Basin (recurrence interval = 6.4 years). This may be due to three possible causes:

(1) the records of the St. Louis River at Aurora are much shorter than the Kawishiwi River at Winton,

(2) one substantial storm striking the St. Louis watershed and missing the Kawishiwi River could strongly affect the St. Louis River flows, and

(3) pumping operations in the Partridge River watershed, associated with mining operations, could have seriously affected the low flow records.

For the present, it appears desirable to place more emphasis on the Kawishiwi River data than the Upper St. Louis River data for 1976.

Appendix B - TR-20 Runs

The TR-20 computer program was used to generate hydrographs for the proposed mining areas in various subwatersheds of the Kawishiwi and St. Louis Basins. Two conditions were considered, the present conditions and the post mining condition for these proposed areas.

Table B-I lists the subwatersheds and the corresponding input parameters

Table B-I Input Parameters For TR-20

Subwatershed	Mining Area (Sq. Mi)	Time of Concentration (Hrs.)	10-Day Storm Curve No Present	Post Mining
Filson Creek	4.88	9.8	62	81
Dunka River	22.58	31.5	40	81
Stony River	9.88	18	58	81
Birch Lake, Local Area	4.80	9.8	58	81
Partridge River	11.15	19.5	65	81

One disadvantage in using the TR-20 is that snowmelt events cannot be input to generate hydrographs. Thus, the 10 Day, 100 Year Rainstorm was input to the TR-20 to generate flows from the mining areas. Table B-II lists the peak flows. The actual peak flow generated by th TR-20 and used by the SSARR differ slightly due to the difference in time increment, 6 hrs. and 24 hrs, respectively.

Table B-II Peak Flows

Subwatershed	Peak Flows (CFS) Present		Restored	
	TR-20	SSARR	TR-20	SSARR
Filson Creek	313	285	420	389
Dunka River	222	220	584	582
Stony River	289	286	366	390
Birch Lake, Local Area	289	262	423	393
Partridge River	204	203	293	371

To apply the TR-20 to these mining areas the ground condition had to be simulated. This is done in part by the curve numbers that were chosen and the designing of structures to substitute for storage by swamps.

The curve numbers for the present condition of the mining areas, Figs. B-1 to B-5, were developed in the first phase of this study [1]. With the exception of the Dunka River's mining area these results were applied with the SSARR. The hydrograph for the mining area in the Dunka watershed (Fig. B-5) caused some problems when incorporated into the SSARR. Negative flows resulted at times when the TR-20 hydrograph was subtracted from the "hydrograph calculations by the SSARR for the total Dunka watershed". Because of this the curve number was lowered from the assumed 58 to 40. This change reduced the negative flows somewhat. To correct the problem completely the data was graphed and the TR-20 hydrograph was modified to eliminate the negative flows; see Fig. B-5.

The curve number for the post mining condition was selected in discussions with the St. Paul Office of the SCS, after examining different aspects of the proposed mining development and the various restorative measures which may occur.

The structures used in the TR-20 runs of Figs. B-1 to B-5 were modeled from a structure used when fitting the total Stony River Watershed; this information is from the first phase of this study. A 0.10 foot head was assumed over the spillway of these structures.

In the earlier report [1], a relationship between area A and time of concentration T_c was noted. This relationship was studied further; see Fig. B-6. By analysis it was found that $T_c = 63(\frac{A}{45})^{.85}$ assuming a high storage condition similar to the Stony watershed. This probably overestimates T_c for the mining area in the Partridge watershed, and underestimates for the mining area in the Filson Creek watershed.

In addition to the 10-day, 100-year rainstorm as input, the 10-day, 2 and 25-year rainstorms were input. These data are available in the computer printout addendum.

Fig. B-1

Mining Areas in Filson Creek, Present and Restored Condition Hydrographs

10 Day, 100 Yr. Storm

Area = 4.88 Sq. Mi.
T_c = 9.8 Hrs.

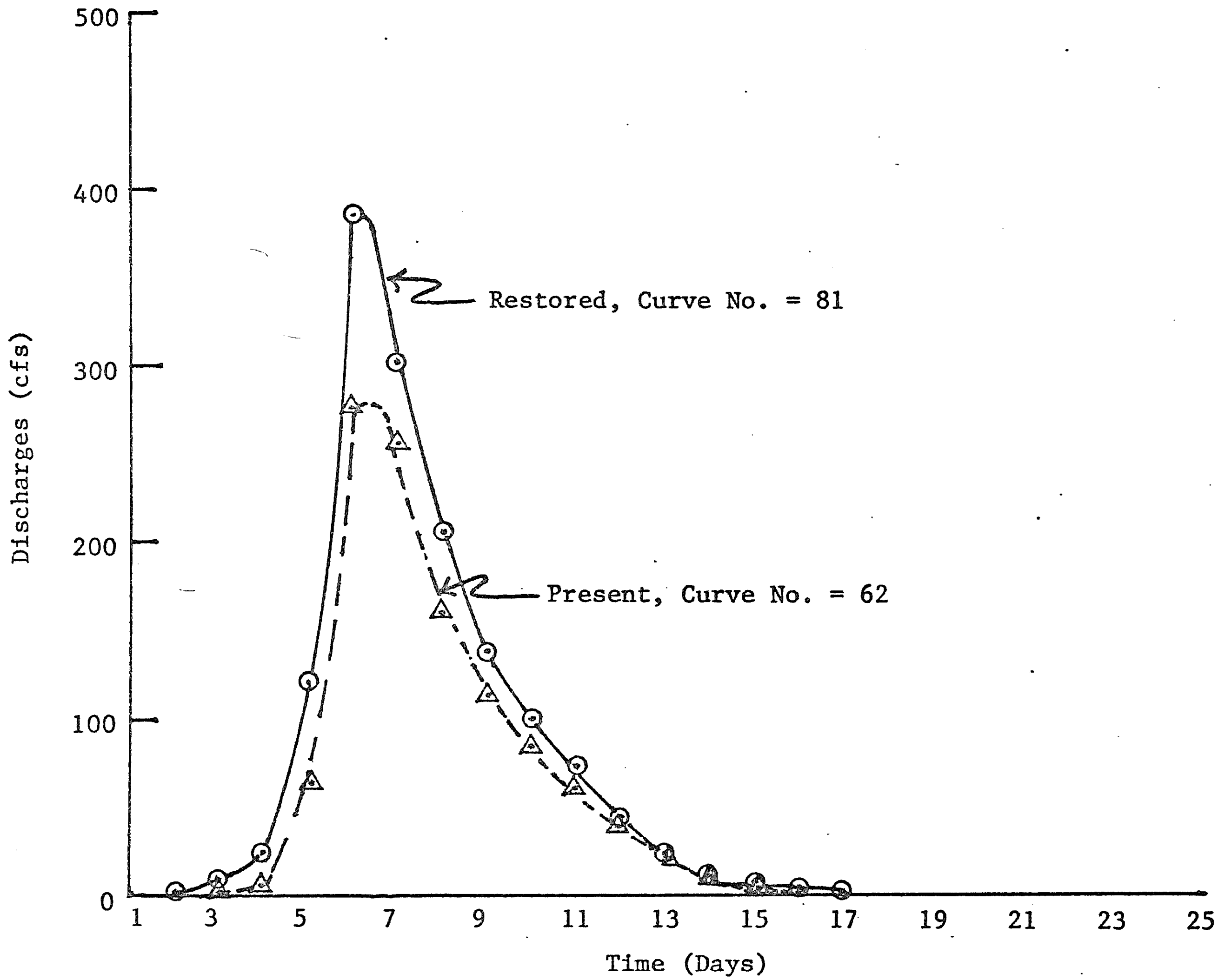


Fig. B-2

Stony River W.S., Present and Restored Condition Hydrographs

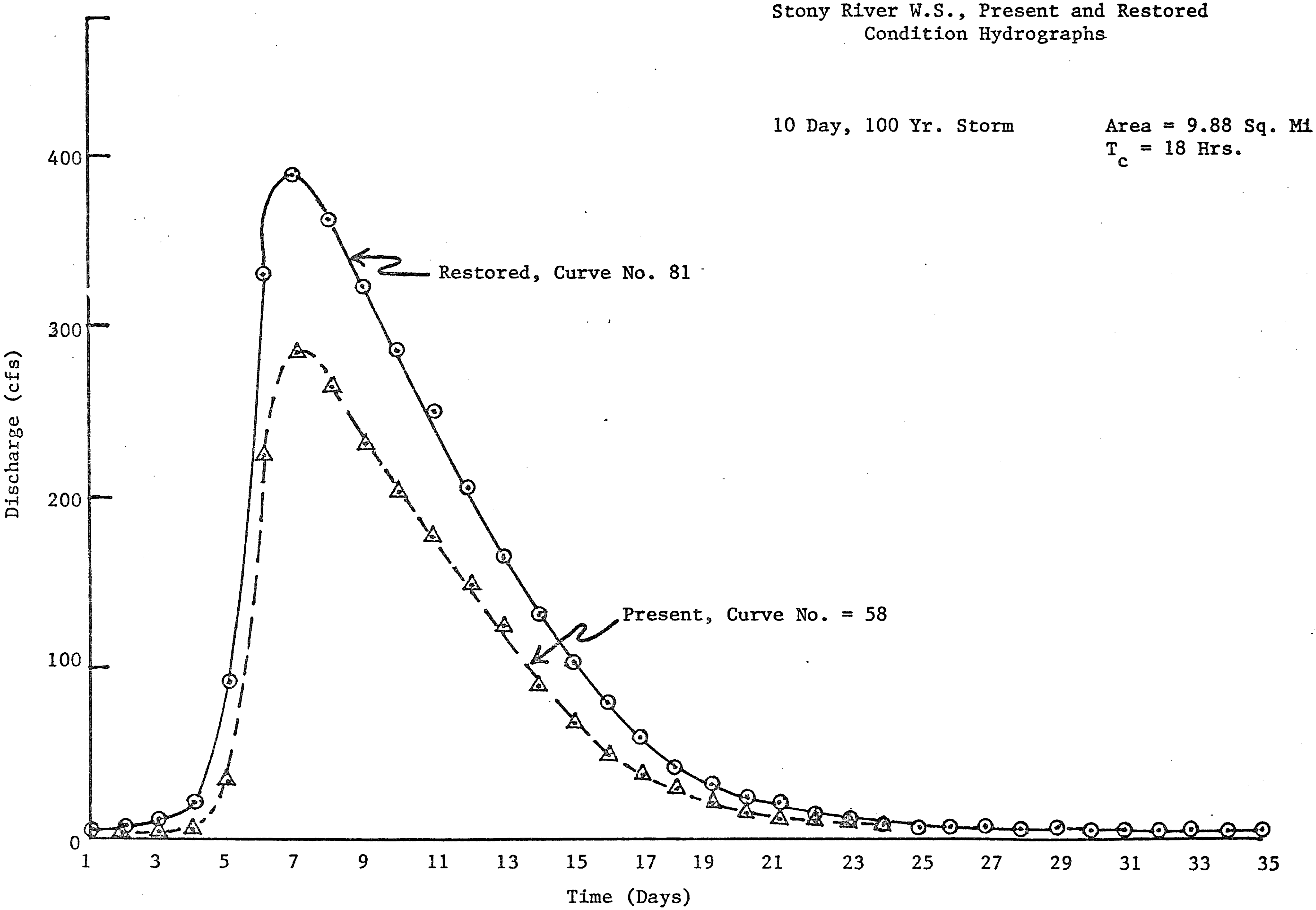


Fig. B-3

Birch Lake W.S., Present and Restored Condition Hydrographs

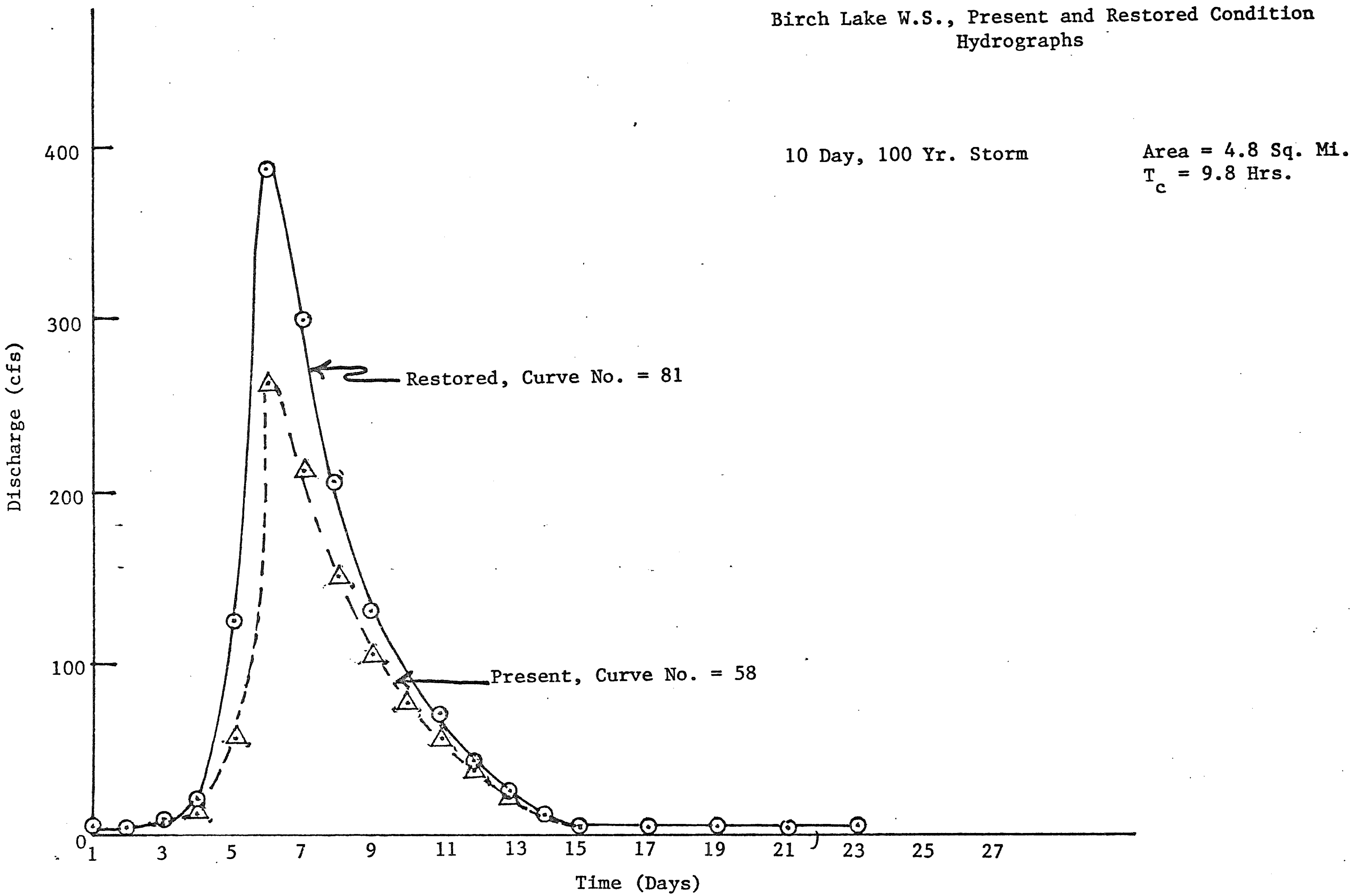


Fig. B-4

Partridge River W.S., Present and Restored Condition Hydrographs

10 Day, 100 Yr. Storm

Area = 11.15 Sq. Mi.
T_c = 19.5 Hrs.

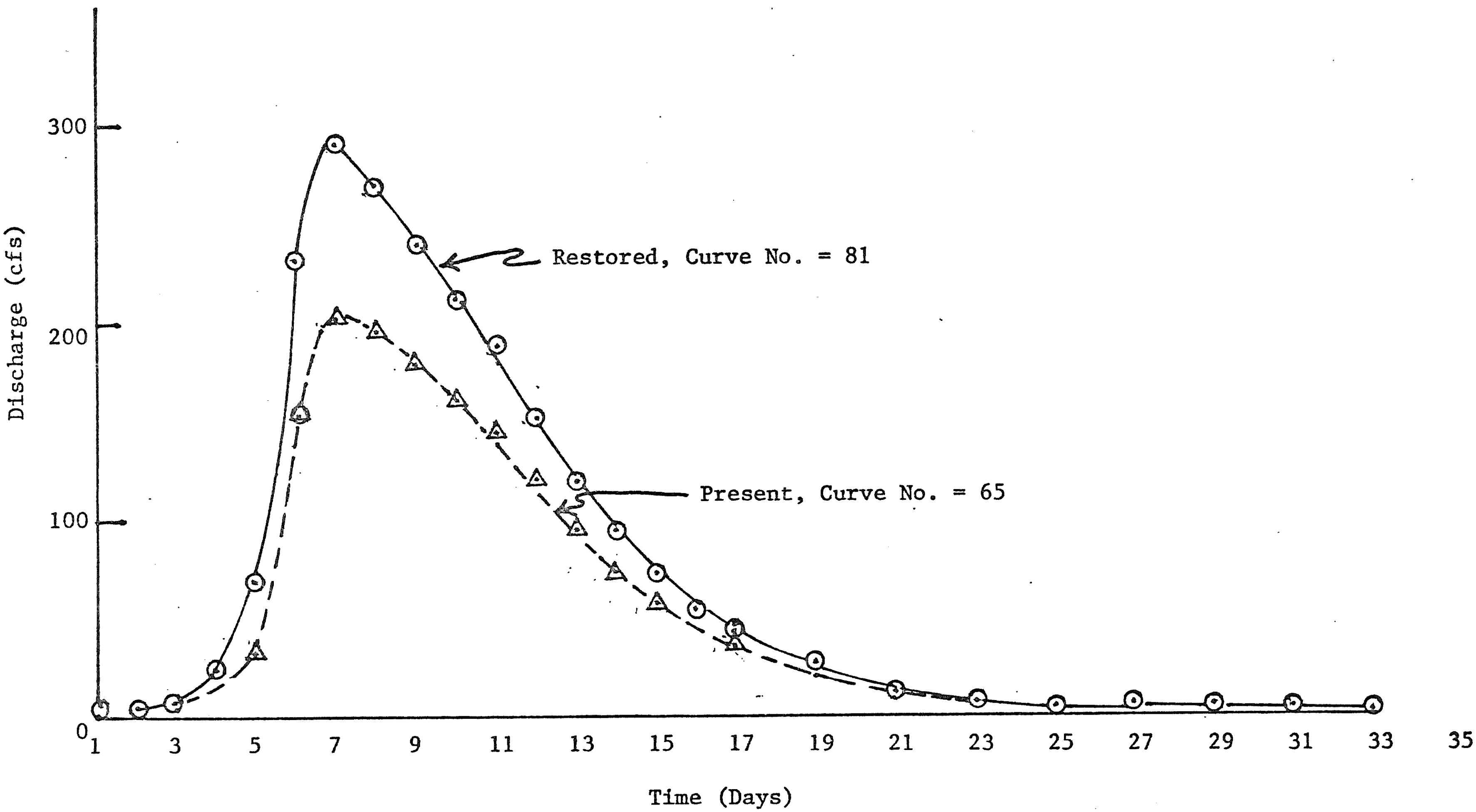
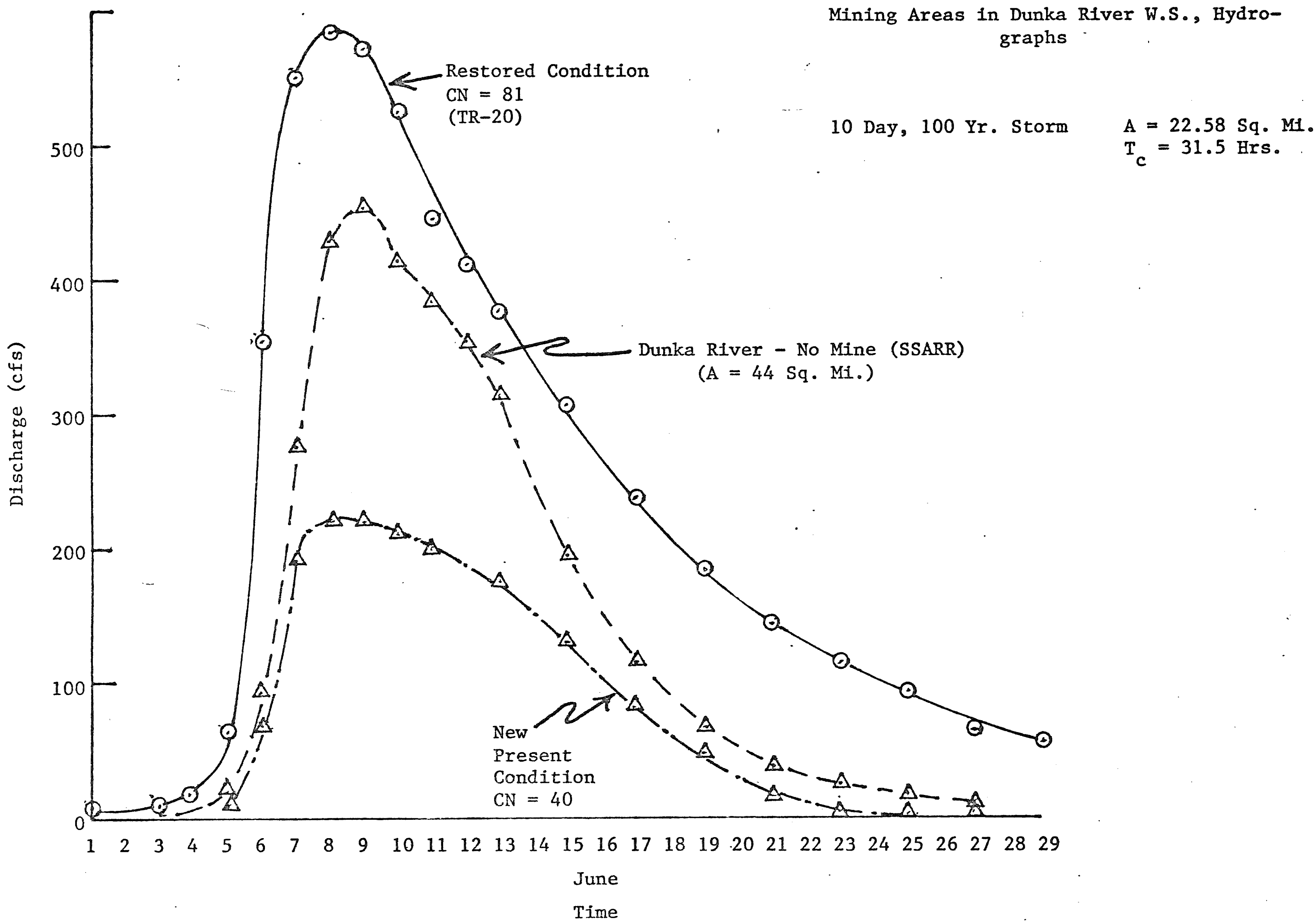
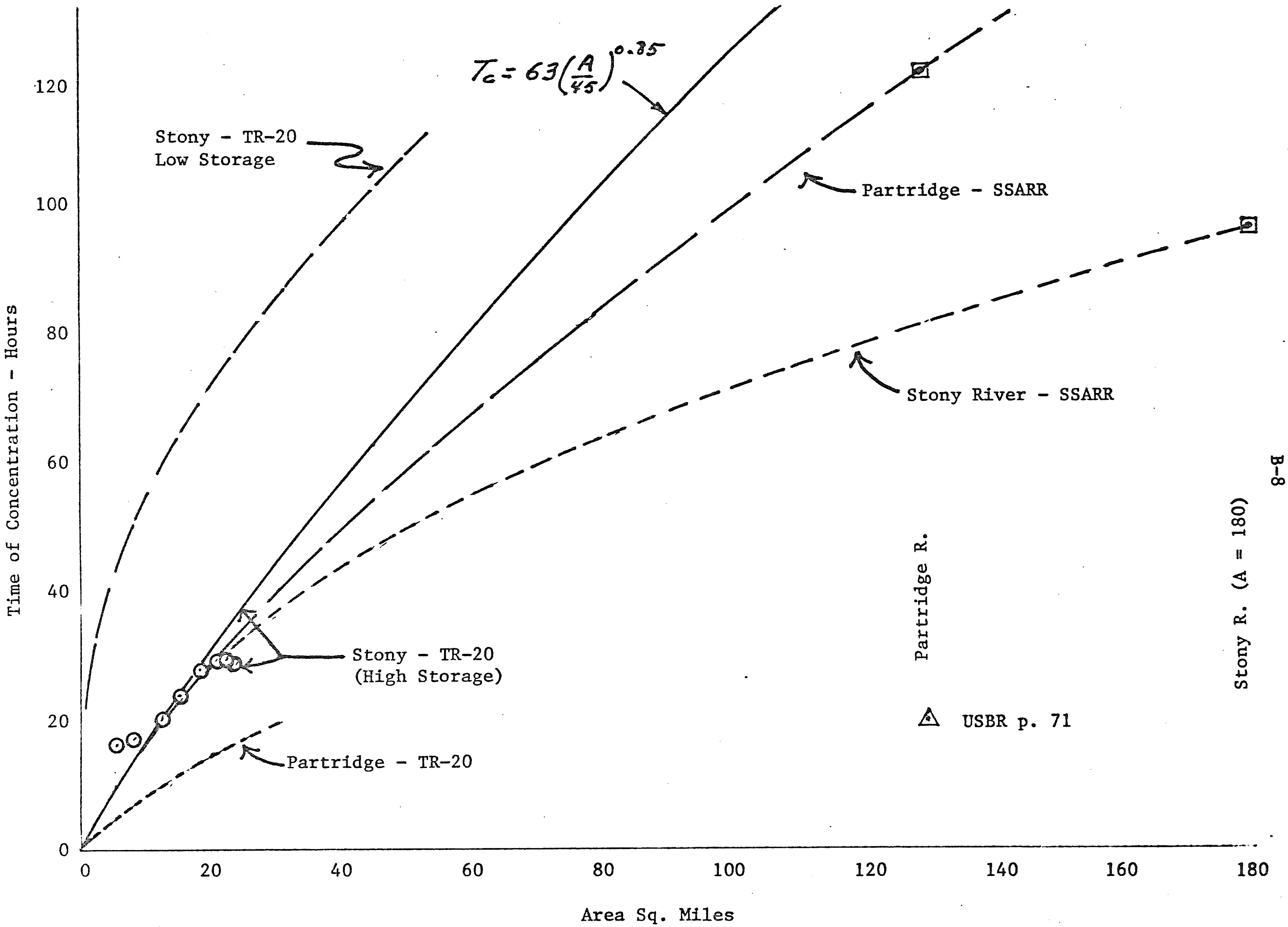


Fig. B-5

Mining Areas in Dunka River W.S., Hydrographs





$T_c = 63\left(\frac{A}{45}\right)^{0.35}$
Stony - TR-20
Low Storage
Partridge - SSARR
Stony River - SSARR
Stony - TR-20
(High Storage)
Partridge - TR-20
Partridge R.
Stony R. (A = 180)
USBR p. 71
Time of Concentration - Hours
Area Sq. Miles
0
20
40
60
80
100
120
140
160
180

Fig. B-6

Appendix C

Partridge River Correction Due to the Erie Mining Operations in the Lower Partridge River Watershed

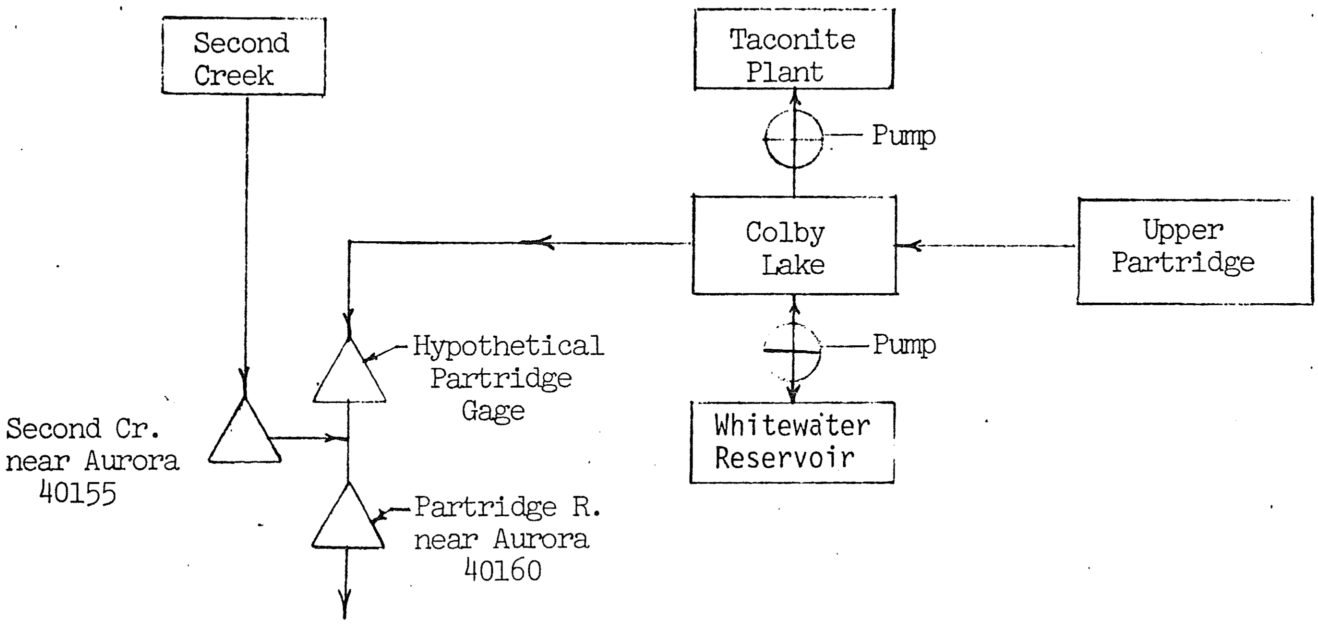


Fig. C-1.

Schematic Map of Lower Partridge River Watershed Near Aurora, MN

Introduction

The following is a physical description of the Erie Mining hydrologic impacts on the Partridge River gauge and the associated computer techniques used to analyze and obtain a corrected Partridge River gauge. The corrections were used during watershed modeling of the copper-nickel region. The computer techniques are specifically geared for use with the SSARR computer model.

Physical Description

The Erie Mining Company has three major operations that affect the hydrology of the Partridge River. First, there is open pit dewatering operations in the

Second Creek subwatershed. Then there is an appropriation at Colby Lake for taconite plant operations. And lastly, there is storage and diversion of the Partridge River into White face Lake for later release to Colby Lake.

For modeling purposes a watershed without man-made influences was desirable. The U.S.G.S gauging station data is not corrected for daily flows, only a monthly average correction is given. Thus, for modeling, a daily correction was needed.

For ease of modeling the Second Creek subwatershed was subtracted from the Partridge River watershed. Thus, the modelled watershed went from 156 square miles to 130 square miles. A hypothetical Partridge River gauge was created just upstream of where Second Creek entered the Partridge using this method.

The effects of the taconite plant pumping then were taken care of. The amount pumped from Colby Lake was added back to the gauge data to represent the amount of water which should have been flowing in the Partridge River.

The diversion of river water into Whiteface Lake is for later release during low flow periods to replace water pumped from Colby Lake to the taconite plant. The permit under which Erie Mining operates states a minimal level that Colby Lake may reach. During high flow periods water is stored in Whiteface. When low flow conditions exist, water is pumped back into Colby Lake to maintain the lake above the minimal level.

The corrections for the pumpage follow. When water is pumped into Whiteface, the same amount is added to the gauge for what should have been there. When water is pumped back into Colby, the same amount is subtracted for the amount that should not be in the river system.

Computer Techniques

The computer techniques were designed with the SSARR math model being used for the streamflow modeling. The equation covering the correction factors is as follows:

$$\text{Corrected Partridge} = \text{Uncorrected Partridge} - \text{Second Creek} + \text{Taconite Plant Pumpage} + \text{Whiteface Storage} - \text{Whiteface Release}$$

The above equation is for daily flow values. The uncorrected Partridge and Second Creek daily flow values are available as U.S.G.S. gauging stations, respectively 40160 and 40155. The other daily pumpage records were made available by the Minnesota DNR as obtained from Erie Mining records. The records contain the daily pumpage volume in gallons.

The program DIVERT written in the summer of 1977 will provide the corrected Partridge River flow data in punched card format ready for SSARR input. At the time of last processing the program was working with MNF fortran compiler version 5.2 and KRONOS operating system version 2.1.2. DIVERT uses all of the daily flow values stored in files in the system.

The uncorrected Partridge River data should be stored in the file "PART." The flow data should be stored in card images just like GD card format of the SSARR. The Second Creek data should be stored in the same manner but in the file "SECOND."

The daily pumpage in gallons is put in the file "ERIE." The data should be stored in card images with each card containing the gallons per day pumpage volume. With the gallons right justified the amount pumped into Whiteface is right justified on column 17. The amount pumped to the plant is right justified in column 30, and the amount pumped from Whiteface back into Colby right justified in column 45. The first six columns of a card contain the month, day and year digits as MMDDYY. Note on certain days pumpage may occur both directions from Whiteface to Colby. Also after each month's worth of data in the file ERIE, a card should be inserted with the word MONTH printed in columns 1-5. This is a flag for the program DIVERT.

Once the three files PART, SECOND and ERIE have been established in the system the program DIVERT can be run. Output from the program includes a listing of the file contents, and a daily inventory of the flow values. Also, punched cards in GD format for the corrected Partridge River are created.

For every different year the old PART, SECOND and ERIE files must be wiped out and new ones established.

The correction factor was also sent downstream to the St. Louis River (40165) gauge. This was done by comparing the corrected and uncorrected Partridge River flows and applying the same correction factor to the St. Louis gauge.

Example of pompage records

ERIE MINING COMPANY
Hoyt Lakes Plant

WATER COLLECTION & PUMPING REPORT

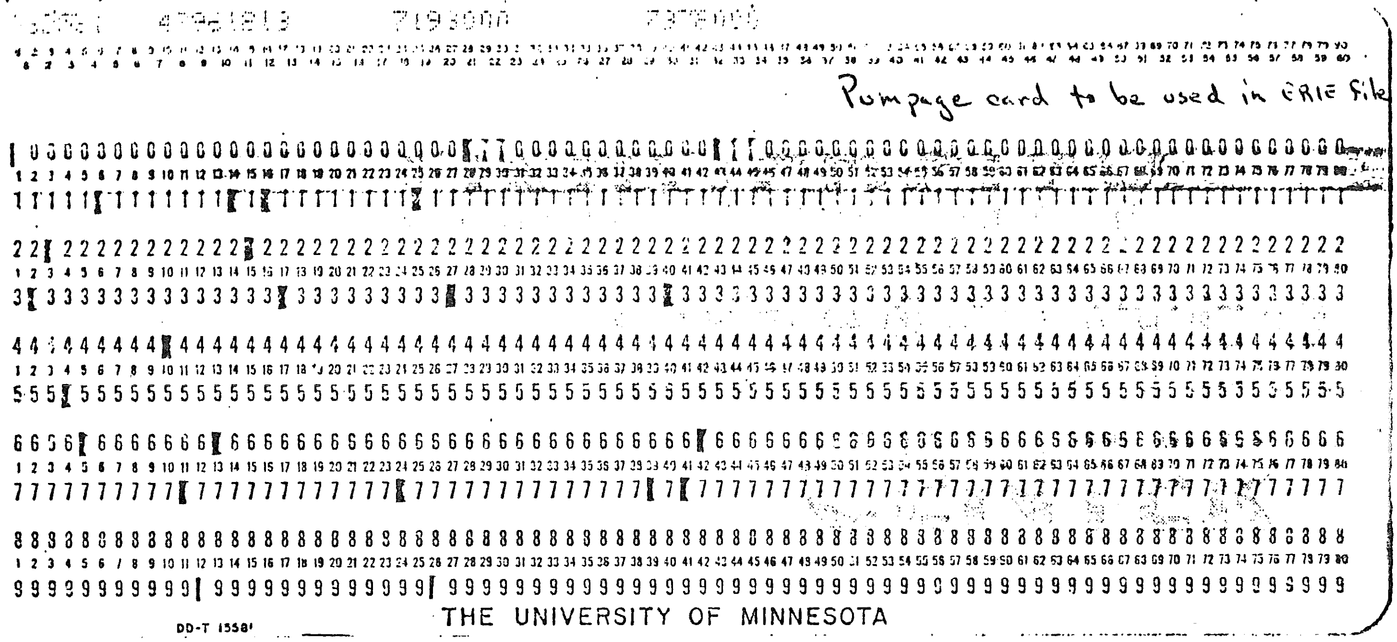
Month March 1961

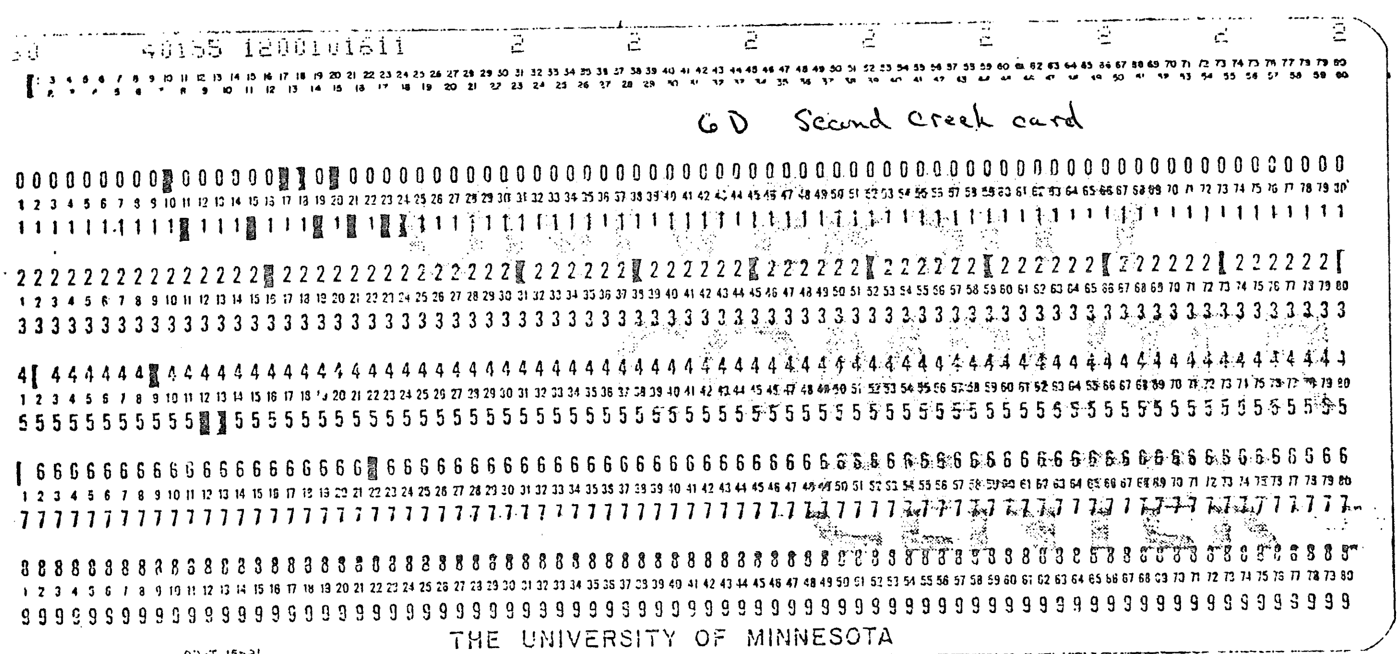
PUMPED INTO WHITEFACE ↓ (Amount Collected) — PUMPED TO TACONITE PLANT ↓ (Gals. Pump. to Plant) — PUMPED BACK INTO COLBY ↓ (Gals. Pump. to Colby)

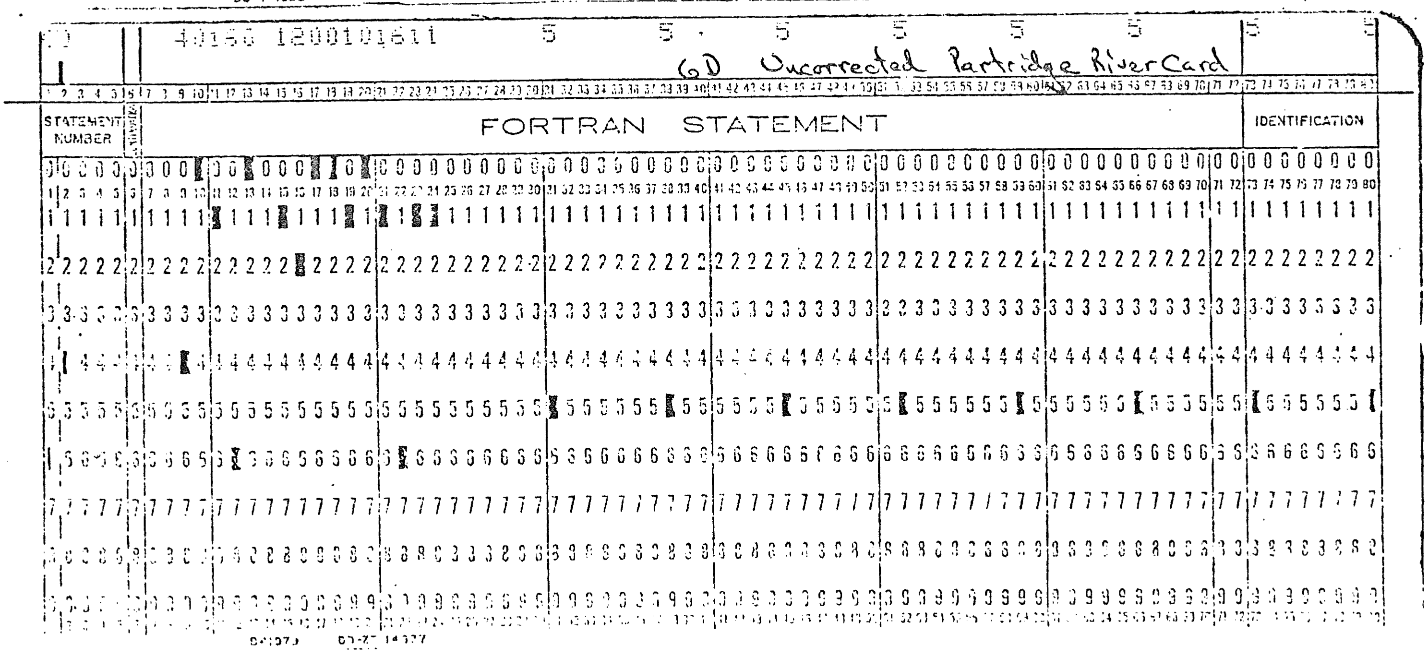
ATE	ELEVATION COLBY	ELEVATION RESERVOIR	HRS. COLL.	AMOUNT COLLECTED	GALS. PUMP. TO PLANT	GALS. PUMP. TO COLBY	DIFFERENCE
1	1,438.4	1,427.5	-	-	9,629,000	12,930,000	+3,301,000
2	1,438.5	1,427.4	-	-	8,375,000	13,087,000	+4,712,000
3	1,438.4	1,427.4	-	-	7,720,000	-0-	-7,720,000
4	1,438.4	1,427.3	-	-	7,764,000	15,229,000	+7,465,000
5	1,438.4	1,427.3	-	-	7,938,000	8,269,000	+331,000
6	1,438.4	1,427.2	-	-	7,590,000	7,808,000	+218,000
7	1,438.4	1,427.2	-	-	7,555,000	7,601,000	+46,000
8	1,438.4	1,427.2	-	-	7,590,000	7,740,000	+150,000
9	1,438.4	1,427.2	-	-	7,900,000	2,930,000	-4,970,000
10	1,438.4	1,427.1	-	-	7,400,000	7,280,000	-120,000
11	1,438.4	1,427.1	-	-	7,550,000	7,370,000	-180,000
12	1,438.4	1,427.0	-	-	7,390,000	7,440,000	+50,000
13	1,438.4	1,427.0	-	-	7,380,000	7,510,000	+130,000
14	1,438.4	1,427.0	-	-	7,652,000	8,044,000	+392,000
15	1,438.4	1,427.0	-	-	7,206,000	7,125,000	-81,000
16	1,438.4	1,426.9	-	-	7,360,000	7,614,000	+254,000
17	1,438.4	1,426.9	-	-	7,228,000	7,173,000	-55,000
18	1,438.4	1,426.8	-	-	7,334,000	7,138,000	-196,000
19	1,438.4	1,426.8	-	-	7,325,000	7,677,000	+352,000
20	1,438.4	1,426.8	-	-	7,560,000	8,015,000	+455,000
21	1,438.4	1,426.8	-	-	6,830,000	6,363,000	-467,000
22	1,438.4	1,426.8	-	-	9,574,000	7,608,000	-1,966,000
23	1,438.4	1,426.7	-	-	7,270,000	9,710,000	+1,440,000
24	1,438.5	1,427.1	3.1	33,059,947	7,539,000	5,812,000	-1,727,000
25	1,438.0	1,427.1	4.5	47,961,213	7,193,000	7,376,000	+183,000
26	1,438.1	1,427.1	-	- -	7,519,000	7,571,000	+52,000
27	1,438.4	1,427.3	-	-	7,198,000	6,913,000	-285,000
28	1,438.5	1,427.4	19.3	30,420,995	7,218,000	5,456,000	-1,762,000
29	1,438.5	1,427.6	24.0	37,829,216	7,602,000	812,000	-6,890,000
30	1,438.5	1,427.7	24.0	31,470,915	7,331,000	-0-	-7,331,000
31	1,438.5	1,428.0	24.0	32,627,401	10,637,000	-0-	-10,637,000
otal-Month			98.9	213,369,687	239,377,000	215,601,000	
ota. Year To Date			98.9	213,369,687	833,429,000	789,714,000	

PUMPING	Ave. GPM	Maximum GPM
Colby Lake to Plant		
Reservoir to Colby		

| DATE | PUMPED TO WHITEFACE | PUMPED TO PLANT | PUMPED TO COLBY |







Appendix D

Precipitation Analysis for SSARR, Phase 2

1. Procedure:

   Use TP-40 and TP-49 to get point rainfall.
   Reduce point rainfall for areas of 10-400 mi^2.
   Plot on semi-log paper.
   Extrapolate out to 1200 mi^2.

2. Tabulation and Graphs.

   See TABLE I, GRAPHS I-III, following.

3. Results

   For the 100-year storm over an area of 1200 mi^2 the rainfall amounts to the nearest tenth of an inch for the 24 hr.; 7-day and 10-day storms were 4.5", 8.5" and 9.6", respectively.

4. Comments

   i) The greatest source of error was in reading the charts from TP-40, TP-49. For the low frequency storms the charts could be read to about 0.1" prec. The higher frequency (esp. 2-yr.) storms were generally not able to be read as accurately.

   ii) Linear interpolation was used between isohyets.

   ii) A nominal value representative of the whole basin was read from the charts.

Table 1.

I. Point Prec. from T.P. 40 for the Kawishiwi Basin Area

Duration (days)	Recurrence interval (years) 2	10	25	100
1	*2.35"	3.60"	4.05"	5.0"
7	*3.8"	6.00	7.25"	8.95"
10	*4.25"	*6.75	8.1"	10.1"

*rough estimates due to the way the lines were drawn.

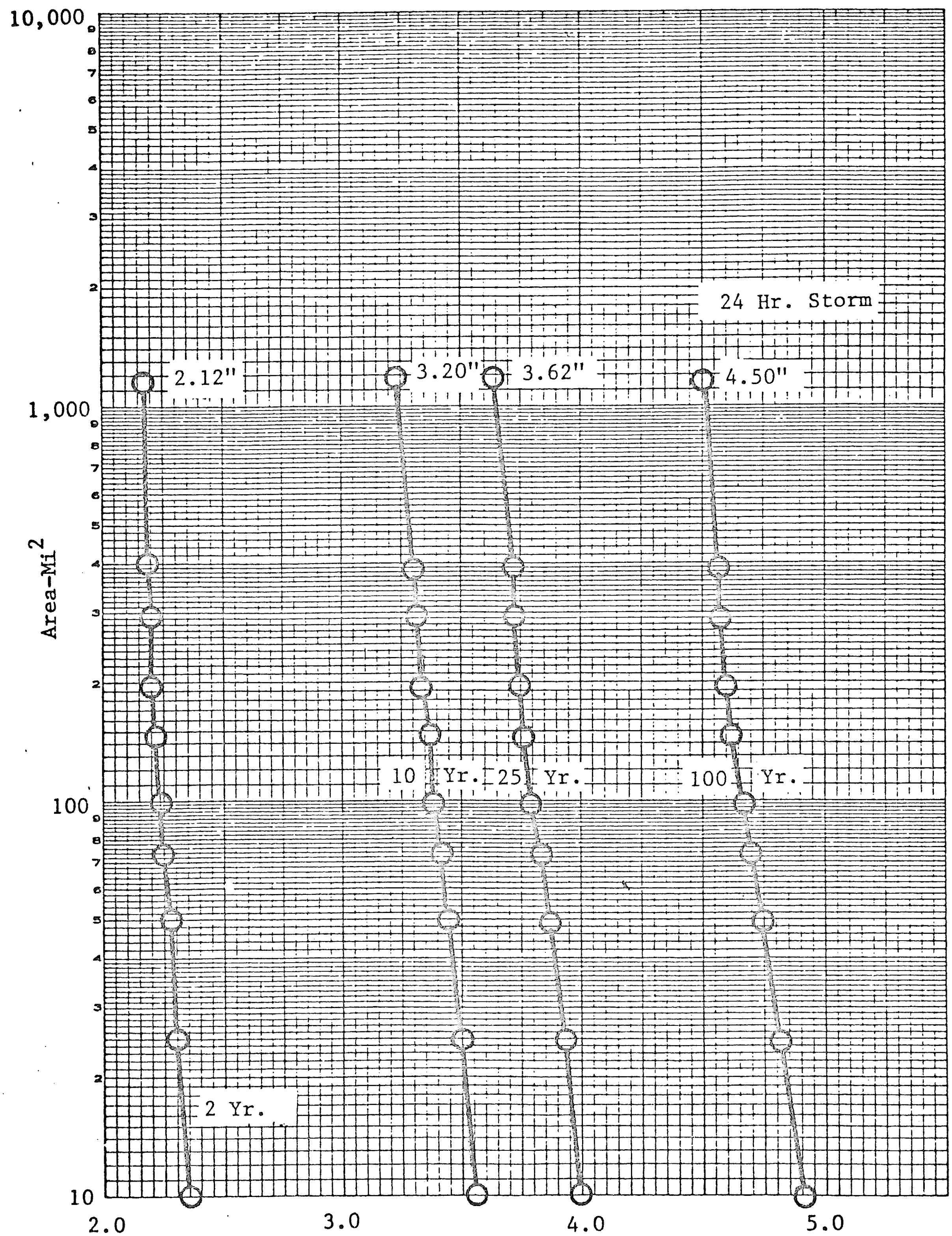
II. Correction factors for area

Prec. duration	Area (mi^2) 10	25	50	75	100	150	200	300	400
24 hr.	.980	.964	.948	.938	.932	.924	.917	.911	.909
7d	.991	.981	.972	.966	.963	.958	.955	.952	.951
10d	.993	.983	.975	.969	.966	.962	.959	.956	.955

III. Pred. for area & recurrence interval

a.

mi^2	10	25	50	75	100	150	200	300	400
24 hour storm									
2 yr.	2.30	2.26	2.23	2.20	2.19	2.17	2.15	2.14	2.14
10 yr.	3.53	3.47	3.41	3.38	3.35	3.33	3.30	3.28	3.27
25 yr.	3.97	3.90	3.84	3.80	3.77	3.74	3.71	3.69	3.68
100 yr.	4.90	4.82	4.74	4.69	4.66	4.62	4.59	4.56	4.55
7 day storm									
2 yr.	3.77	3.72	3.69	3.67	3.66	3.64	3.63	3.62	3.61
10 yr.	5.95	5.88	5.83	5.80	5.78	5.75	5.73	5.71	5.71
25 yr.	7.18	7.11	7.05	7.00	6.98	6.95	6.92	6.90	6.89
100 yrs.	8.87	8.77	8.70	8.65	8.62	8.57	8.55	8.52	8.51
10 day storm									
2 yrs.	4.22	4.18	4.14	4.12	4.11	4.09	4.08	4.06	4.06
10 yrs.	6.70	6.64	6.58	6.54	6.52	6.49	6.47	6.45	6.45
25 yrs.	8.04	7.96	7.90	7.85	7.82	7.79	7.77	7.74	7.73
100 yrs.	10.03	9.93	9.85	9.79	9.76	9.72	9.69	9.66	9.65



Prec. - In.

Fig. D-1

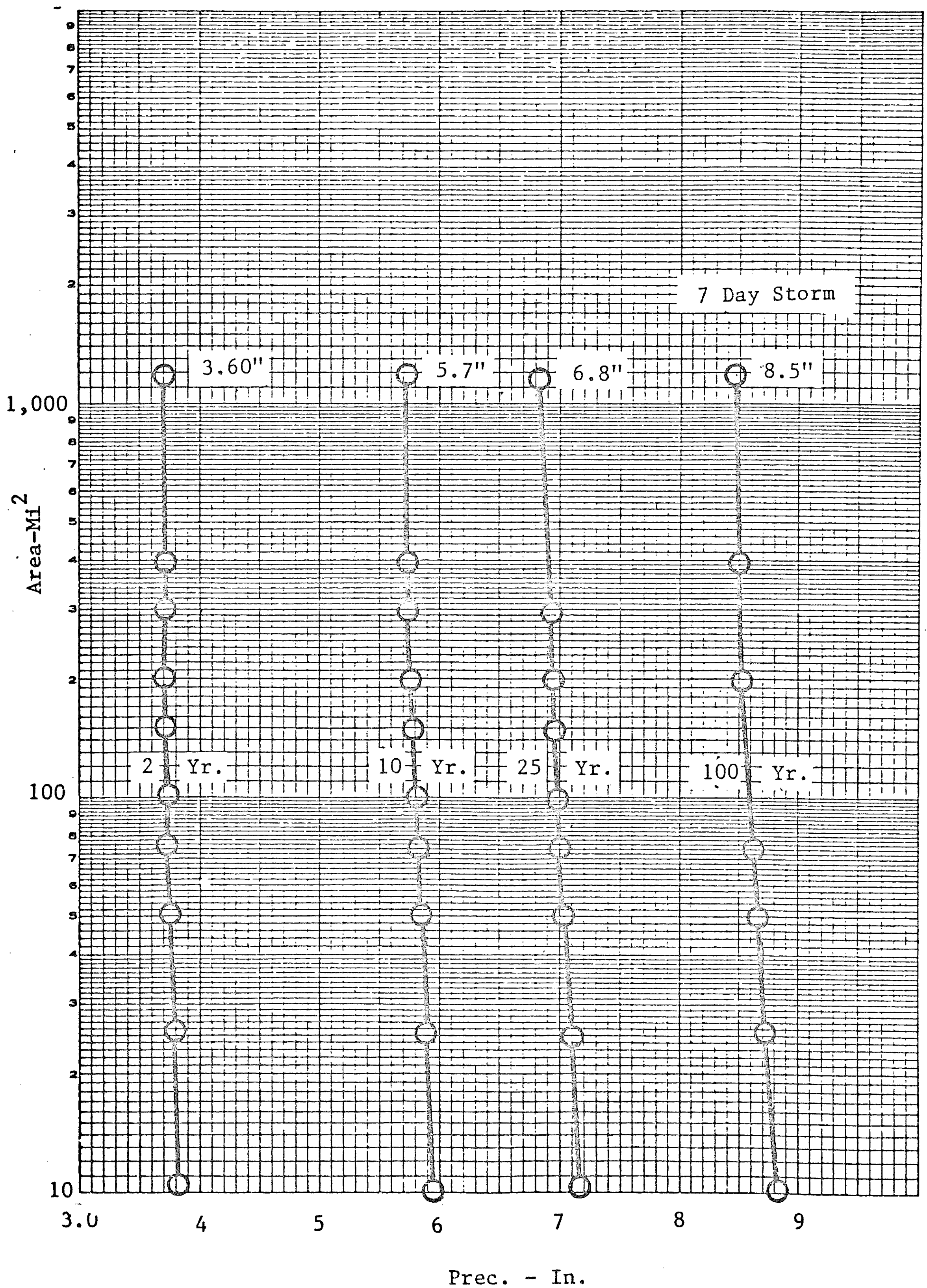

7 Day Storm
3.60"
5.7"
6.8"
8.5"
2 Yr.
10 Yr.
25 Yr.
100 Yr.
1,000
100
10
Area-Mi2
3.0
4
5
6
7
8
9
Prec. - In.

Fig. D-2

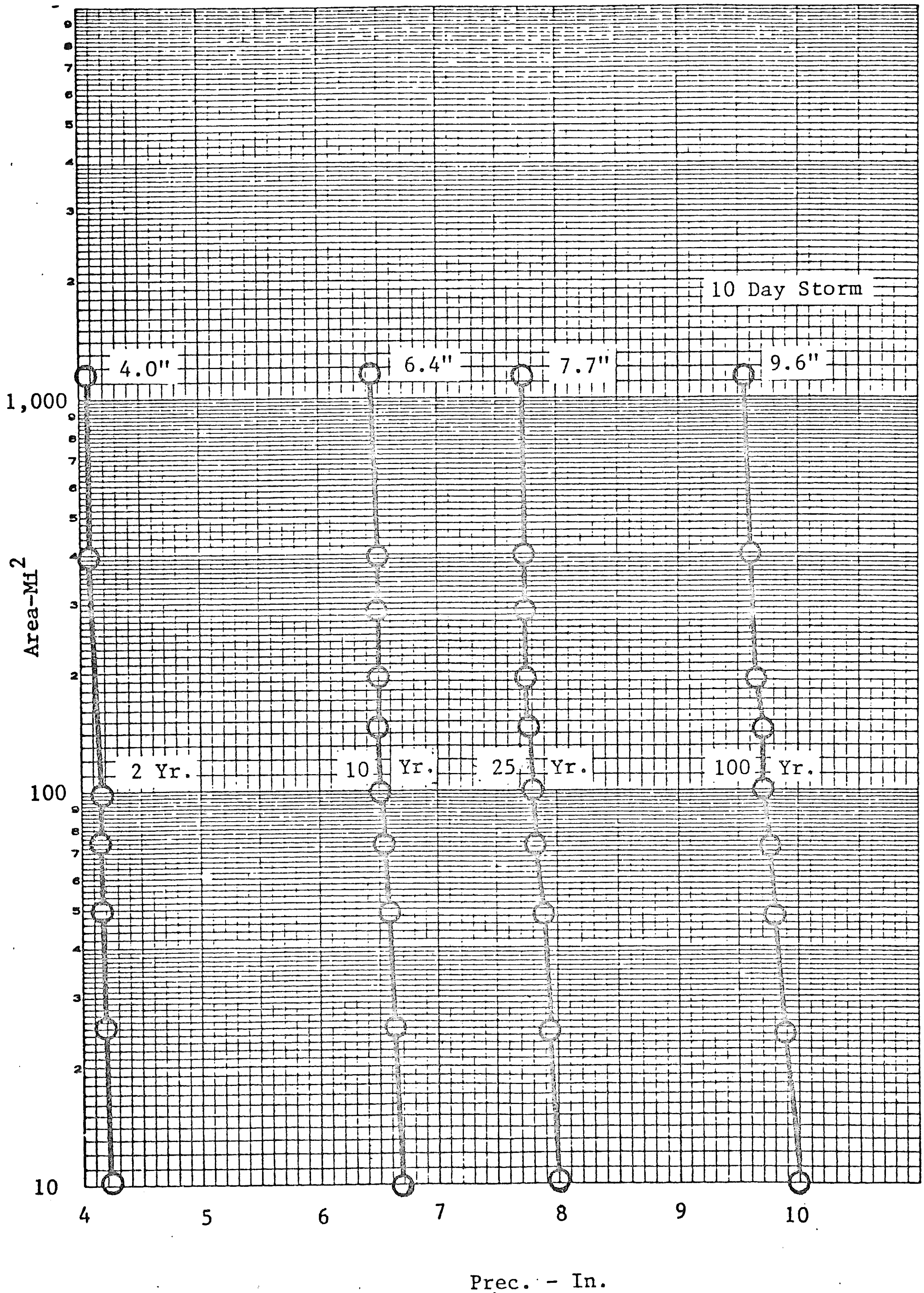

10 Day Storm
4.0"
6.4"
7.7"
9.6"
2 Yr.
10 Yr.
25 Yr.
100 Yr.
Area-Mi2
1,000
100
10
4
5
6
7
8
9
10
Prec. - In.

Fig. D-3

Appendix D

Snowfall Data

Source: U.S. Forest Service - Ely, Minnesota

Date	Depth in.	Estimated Water Content in.
1960	40.2	4.02
1956-67	67.3	6.73
1955-54	91.5	9.15
1953-54	79.9	7.99
1949-50	128-0	12.88
1943-44	53.6	5.36
1977-78 (Mar. 31, 1978)	21.74	5.0

Usually the Forest Service assumes a 10% water content based on accumulated snowfall. On March 31, 1978 the water content was 23%, giving water content of 5.0".

Appendix E

Precipitation Data for 3 Watersheds - Phase I

Precipitation Events for Northeastern Minnesota

Data obtained from weather bureau TP-40 and TP-49.

The point for determining precipitation amounts was midway across Lake County, directly west of the Cook County, Lake County and Lake Superior border intersection.

Procedure:
1) Determine point rainfall amounts for the different durations and frequencies required from the isopluvial maps.
2) Apply the depth area correction factor from Fig. 10 & 15
3) Determine the rainfall increments
4) Rearrange the storm about the middle of the time period, oscillate the rainfall amounts about the middle value.

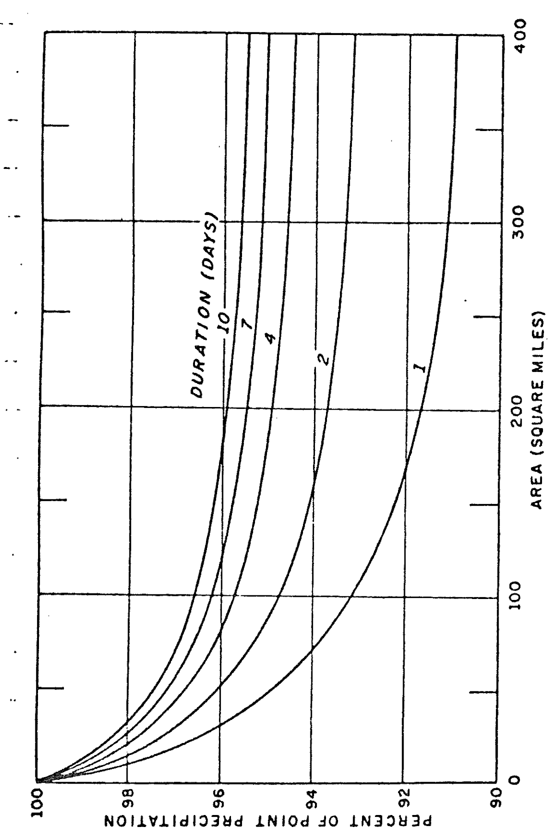


Figure 10.—Depth-area curves.

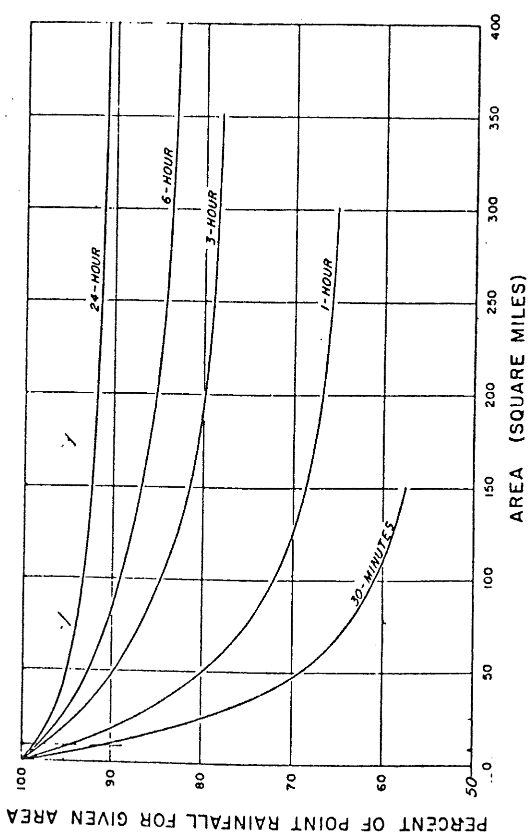


Figure 15.—Area-depth curves.

Calculations for 10-day storm - Stony River Watershed (180 sq mi)

Duration (Days)	Precipitation Amount	Correction Factor	Corrected Precipitation	Change in Precipitation	Rearranged Storm Days	Daily amt.
2 year						
1	2.40	.918	2.20	2.20	1-3	.10
2	2.85	.938	2.67	.47	4	.47
4	3.50	.953	3.33	.66	5	2.20
7	3.80	.956	3.63	.30	6-7	.33
10	4.30	.960	4.13	.50	8-10	.17
10 year						
1	3.65	.918	3.35	3.35	1-3	.33
2	4.10	.938	3.85	.50	4	.50
4	5.05	.950	4.80	.95	5	3.35
7	6.05	.956	5.78	.98	6-7	.48
10	6.85	.960	6.58	.80	8-10	.27
25 year						
1	4.10	.918	3.76	3.76	1-3	.39
2	4.90	.938	4.60	.84	4	.84
4	6.00	.950	5.70	1.10	5	3.76
7	7.20	.956	6.88	1.18	6-7	.55
10	8.13	.960	7.82	.94	8-10	.31
100 year						
1	5.05	.918	4.64	4.64	1-3	.51
2	6.10	.938	4.72	1.08	4	1.08
4	7.50	.950	7.13	1.41	5	4.64
7	9.05	.956	8.65	1.52	6-7	.71
10	10.15	.960	9.74	1.09	8-10	.36

Calculations for 10-day Storm - Partridge River Watershed (130 sq mi)

Duration (days)	Precipitation Amount	Correction Factor	Corrected Precipitation	Change in Precip.	Rearranged storm Days	Daily amt.
2 year						
1	2.40	.925	2.22	2.22	1-3	.10
2	2.85	.943	2.69	.47	4	.47
4	3.50	.953	3.34	.65	5	2.22
7	3.80	.958	3.64	.30	6-7	.33
10	4.30	.963	4.4	.50	8-10	.17
10 year						
1	3.65	.925	3.38	3.38	1-3	.33
2	4.10	.943	3.87	.49	4	.49
4	5.05	.953	4.81	.94	5	3.38
7	6.05	.938	5.80	.99	6-7	.47
10	6.85	.963	6.60	.80	8-10	.27
25 year						
1	4.10	.925	3.79	3.79	1-3	.39
2	4.90	.943	4.62	.83	4	.83
4	6.00	.953	5.72	1.10	5	3.79
7	7.20	.958	6.90	1.18	6-7	.55
10	8.15	.963	7.85	.95	8-10	.32
100 year						
1	5.05	.925	4.67	4.67	1-3	.51
2	6.10	.943	5.75	1.08	4	1.08
4	7.50	.953	7.15	1.40	5	4.67
7	9.05	.958	8.67	1.52	6-7	.70
10	10.15	.963	9.77	1.10	8-10	.37

Calculations for Daily Storm - Filson Creek Watershed (8 sq. mi.)

Duration (Days)	Precipitation Amount	Correction Factor	Corrected Precipitation	Change in Precip.	Rearranged Storm Hours	Hourly Amt.
2 year						
1	1.05	.95	1.00	1.00	1-7	.01
2	1.35	.96	1.30	.30	8-10	.10
3	1.45	.975	1.41	.11	11	.30
6	1.75	.98	1.72	.31	12	1.00
12	2.20	.98	2.16	.44	13	.11
24	2.40	.985	2.30	.14	14-19	.07
10 year						
1	1.60	.95	1.52	1.52	1-7	.05
2	1.90	.96	1.82	.30	8-10	.13
3	2.20	.975	2.15	.33	11	.30
6	2.60	.98	2.55	.40	12	1.52
12	3.10	.98	3.04	.49	13	.33
24	3.65	.985	3.60	.56	14-19	.08
					20-24	.05
25 year						
1	1.85	.95	1.76	1.76	1-7	.05
2	2.30	.96	2.21	.45	8-10	.17
3	2.50	.975	2.44	.23	11	.45
6	3.00	.98	2.94	.50	12	1.76
12	3.55	.98	3.48	.54	13	.23
24	4.10	.985	4.04	.56	14-19	.09
100 year						
1	2.30	.95	2.19	2.19	1-7	.06
2	2.85	.96	2.74	.55	8-10	.23
3	3.00	.975	2.93	.19	11	.55
6	3.70	.98	3.63	.70	12	2.19
12	4.40	.98	4.31	.68	13	.19
24	5.05	.985	4.97	.66	14-19	.11
					20-24	.06

The precipitation bar graphs have been taken from the SSARR listings in Addendum 3 of Memo 155. Using the appropriate listings the data can be found in the watershed basin results. The precipitation amounts are found in the PCPN column. The runoff depth for the time period is found in the RGP column. The runoff depth has been determined by the SMI runoff percentage and the depth of precipitation.

The precipitation pattern used was from Isabella and Babbitt during 1964. The Stony River and Filson Creek used 85% Theissen weighting for Isabella and 15% for Babbitt. The Partridge River watershed used 66%Isabella and 34% Babbitt. Since Filson Creek was computed hourly, the daily value was divided by eight and evenly distributed between 0900 and 1600 hours every day.

Day of Month	Babbitt Feb	Isa Feb	Babbitt Mar	Isa Mar	Babbitt Apr	Isa Apr	Babbitt May	Isa May
1							.30	.02
2							.05	.16
3								
4			.03	.15			.14	.20
5							.35	.33
6				.06	.42	.76	.94	.36
7	.01	.06			.09	.18		.66
8								
9								
10								
11							.07	
12								.36
13					.19	.70		
14						.11		
15								
16				.05				
17		.05						
18							.55	.53
19			.09	.01				
20			.27	.42				
21					.38	.33		
22	.11					.27		
23	.06			.02			1.74	.80
24	.12	.32	.04	.20			.22	.66
25	.02	.05						
26								
27		.03				.83		
28					.40	.47		
29					.10	.34		
30					.24	.29		
31								

SNOWCOVER DATA

Recurrence Interval (years)	Total Seasonal Snowmelt Runoff (inches)
2	3.0
10	7.0
25	10.5
100	17.0

From Corps of Engineers maps - same values used for Stony, Partridge and Filson Creek watersheds.

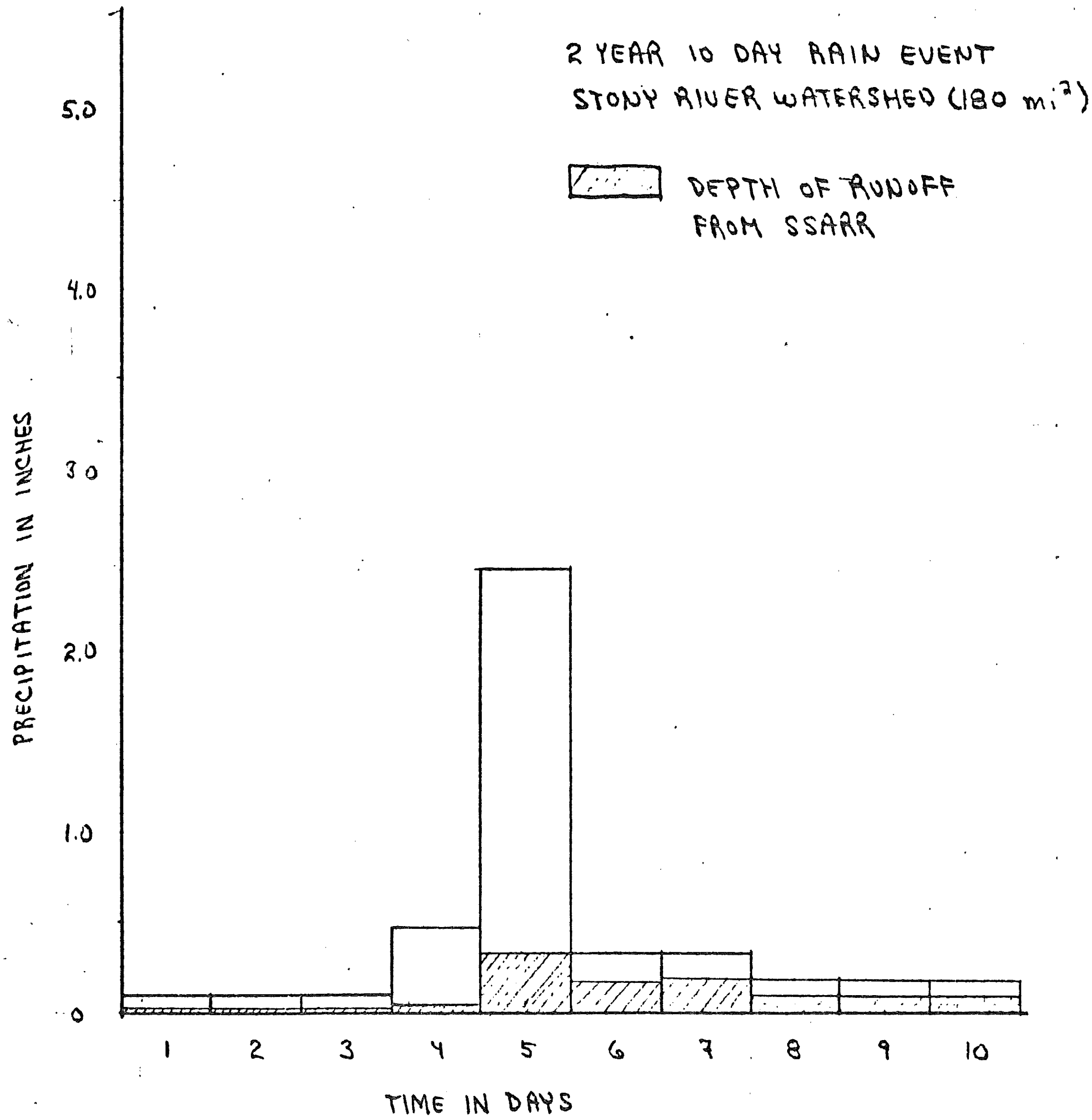

2 YEAR 10 DAY RAIN EVENT
STONY RIVER WATERSHED (180 mi²)
DEPTH OF RUNOFF FROM SSARR
PRECIPITATION IN INCHES
5.0
4.0
3.0
2.0
1.0
0
1
2
3
4
5
6
7
8
9
10
TIME IN DAYS

Fig. E-1

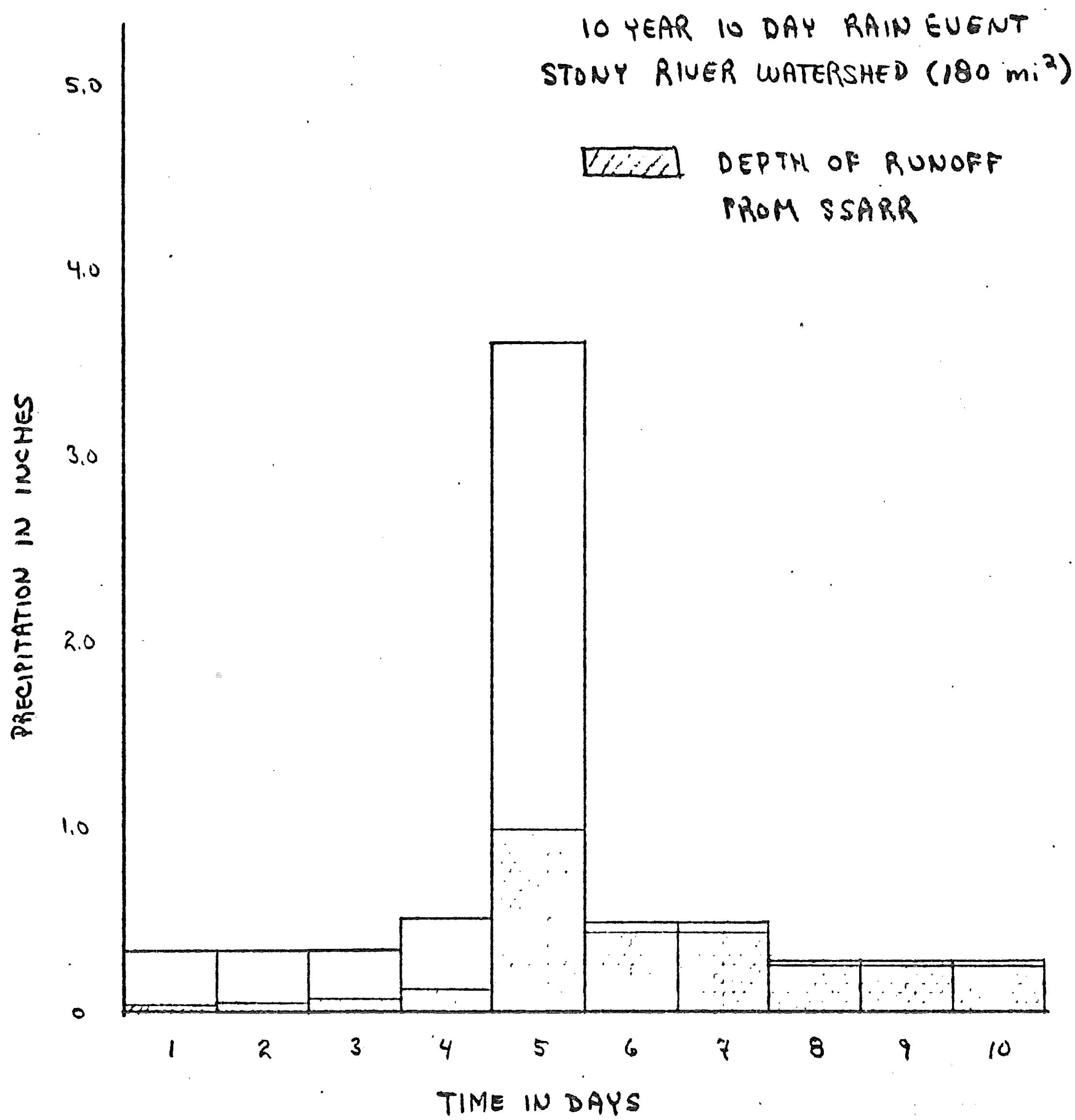

10 YEAR 10 DAY RAIN EVENT
STONY RIVER WATERSHED (180 mi²)
DEPTH OF RUNOFF FROM SSARR
PRECIPITATION IN INCHES
5.0
4.0
3.0
2.0
1.0
0
1
2
3
4
5
6
7
8
9
10
TIME IN DAYS

Fig. E-2

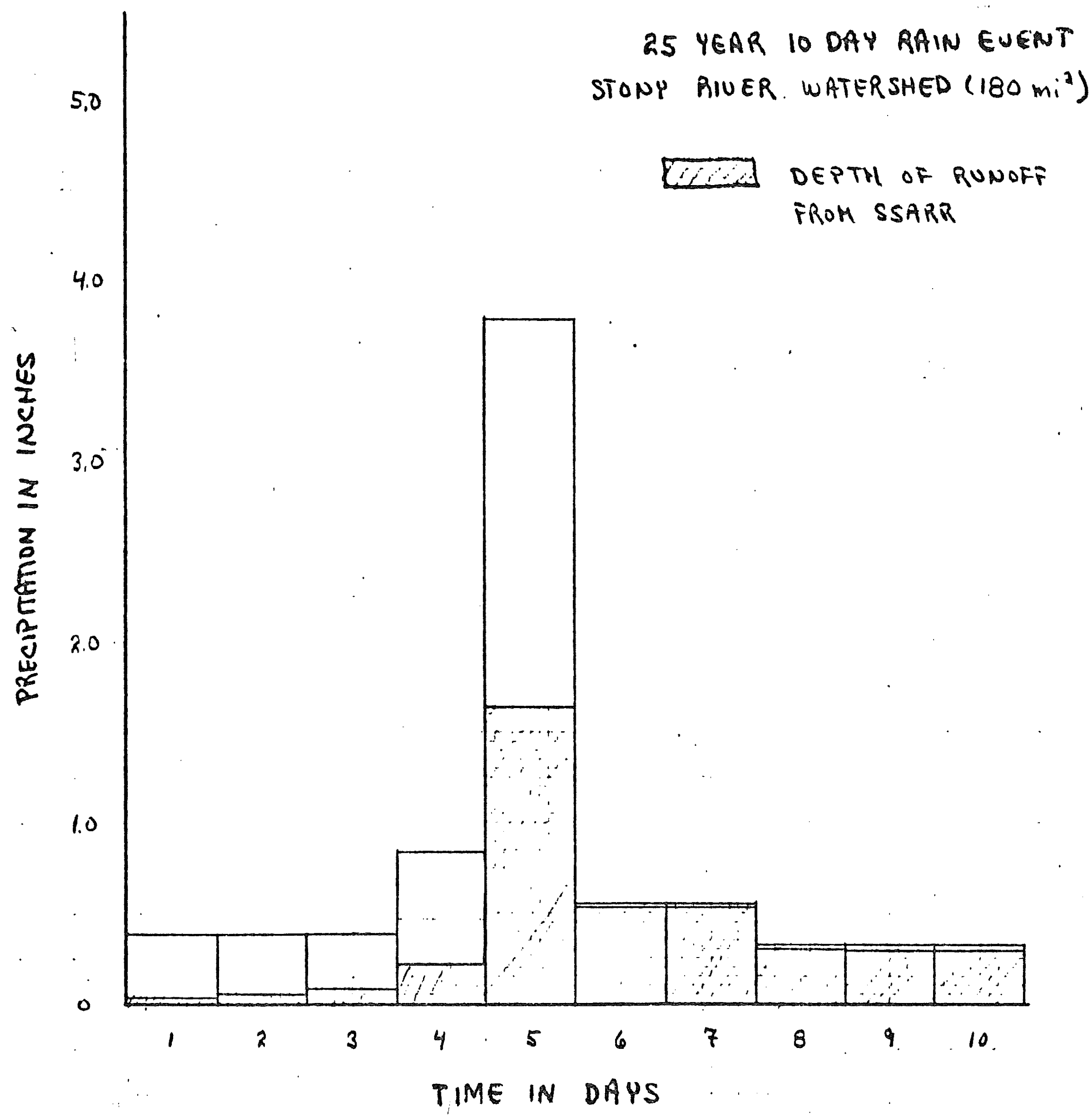

25 YEAR 10 DAY RAIN EVENT
STONY RIVER WATERSHED (180 mi²)
DEPTH OF RUNOFF FROM SSARR
PRECIPITATION IN INCHES
5.0
4.0
3.0
2.0
1.0
0
1
2
3
4
5
6
7
8
9
10
TIME IN DAYS

Fig. E-3

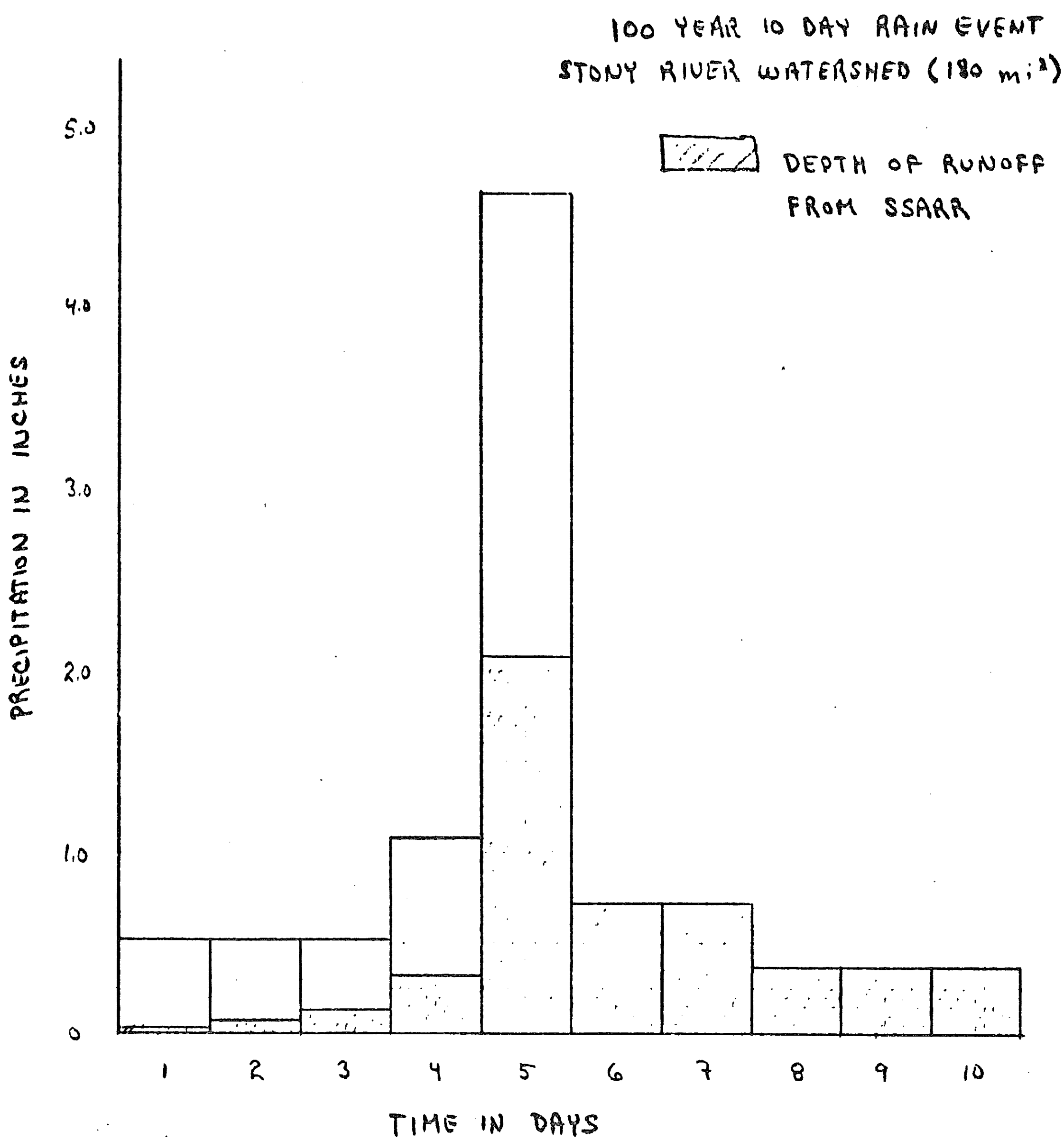

100 YEAR 10 DAY RAIN EVENT
STONY RIVER WATERSHED (180 mi²)
DEPTH OF RUNOFF FROM SSARR
PRECIPITATION IN INCHES
5.0
4.0
3.0
2.0
1.0
0
1
2
3
4
5
6
7
8
9
10
TIME IN DAYS

Fig. E-4

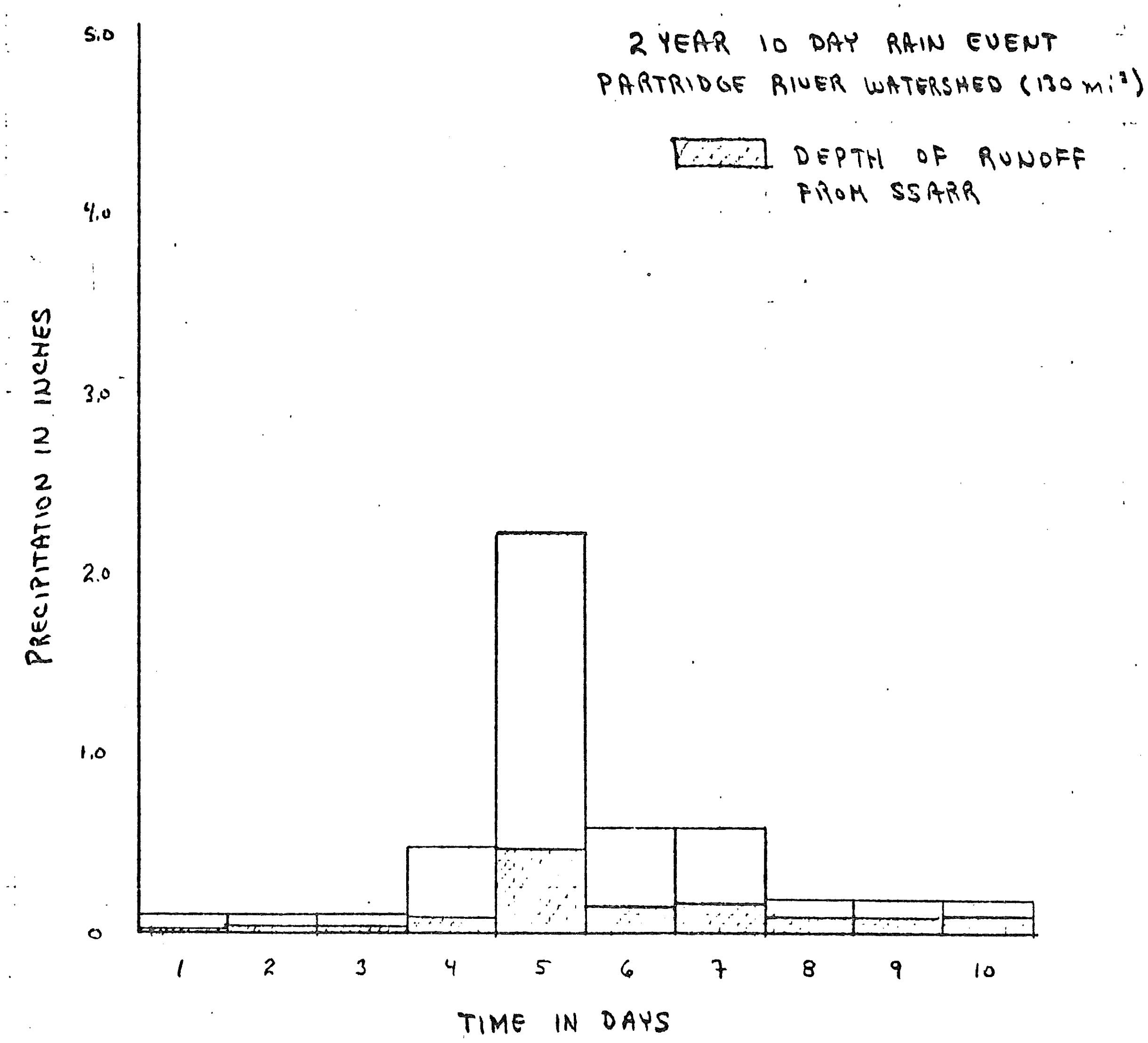

2 YEAR 10 DAY RAIN EVENT
PARTRIDGE RIVER WATERSHED (130 mi²)
DEPTH OF RUNOFF FROM SSARR
PRECIPITATION IN INCHES
5.0
4.0
3.0
2.0
1.0
0
1
2
3
4
5
6
7
8
9
10
TIME IN DAYS

Fig. E-5

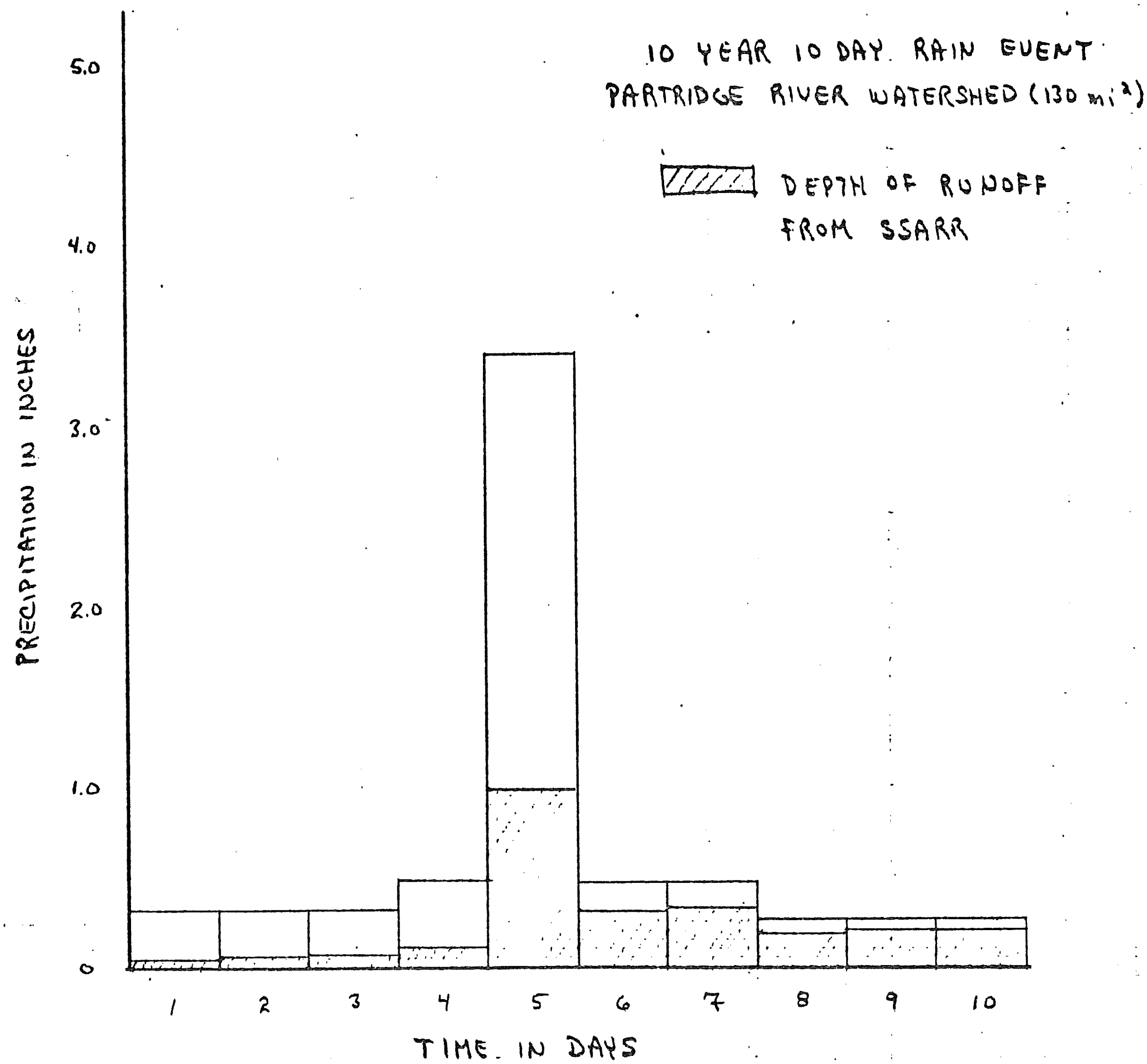

10 YEAR 10 DAY RAIN EVENT
PARTRIDGE RIVER WATERSHED (130 mi²)
DEPTH OF RUNOFF FROM SSARR
PRECIPITATION IN INCHES
5.0
4.0
3.0
2.0
1.0
0
1
2
3
4
5
6
7
8
9
10
TIME IN DAYS

Fig. E-6

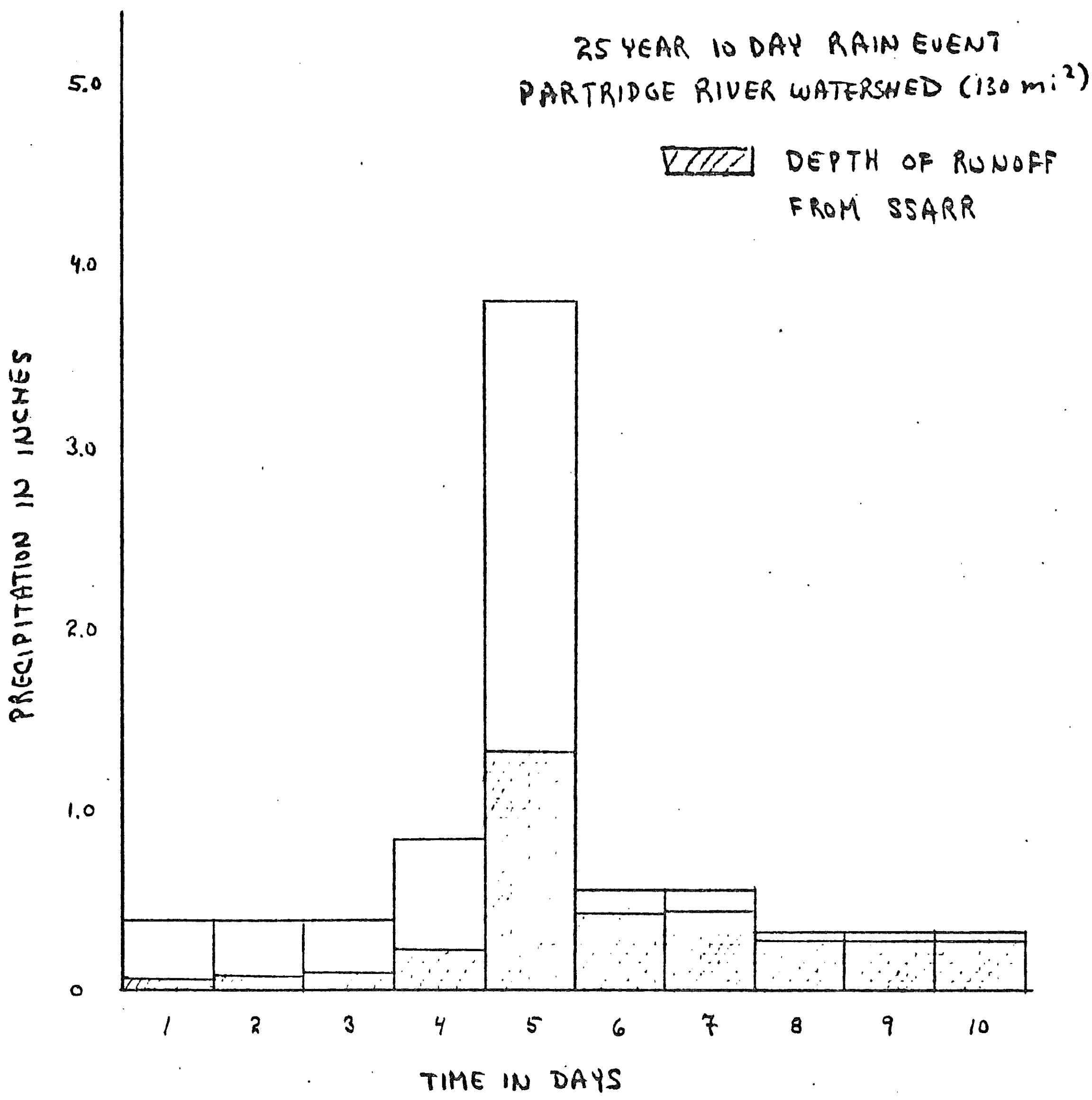

25 YEAR 10 DAY RAIN EVENT
PARTRIDGE RIVER WATERSHED (130 mi.²)
DEPTH OF RUNOFF FROM SSARR
PRECIPITATION IN INCHES
5.0
4.0
3.0
2.0
1.0
0
1
2
3
4
5
6
7
8
9
10
TIME IN DAYS

Fig. E-7

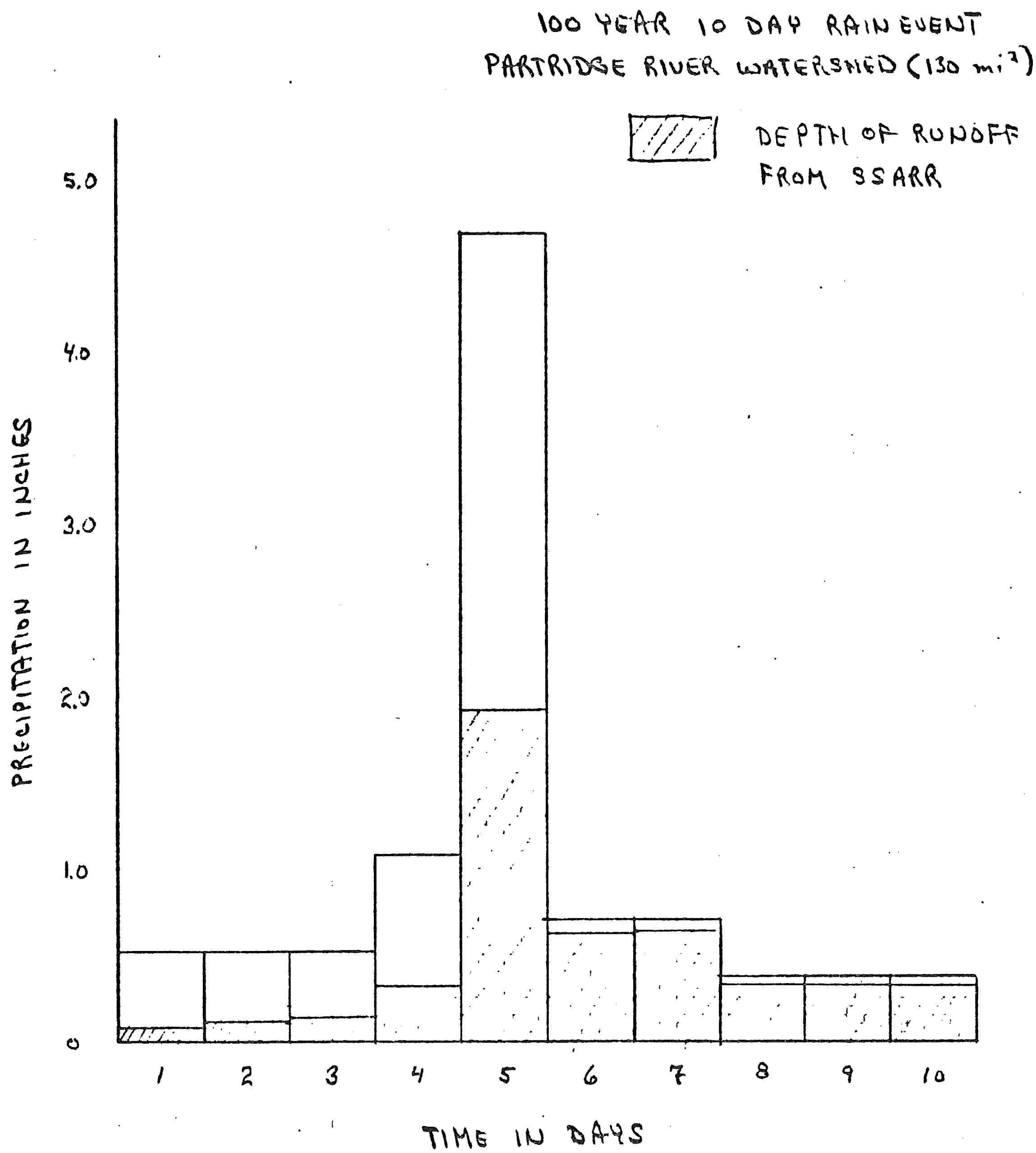

100 YEAR 10 DAY RAIN EVENT
PARTRIDGE RIVER WATERSHED (130 mi²)
DEPTH OF RUNOFF FROM SSARR
PRECIPITATION IN INCHES
5.0
4.0
3.0
2.0
1.0
0
1
2
3
4
5
6
7
8
9
10
TIME IN DAYS

Fig. E-8

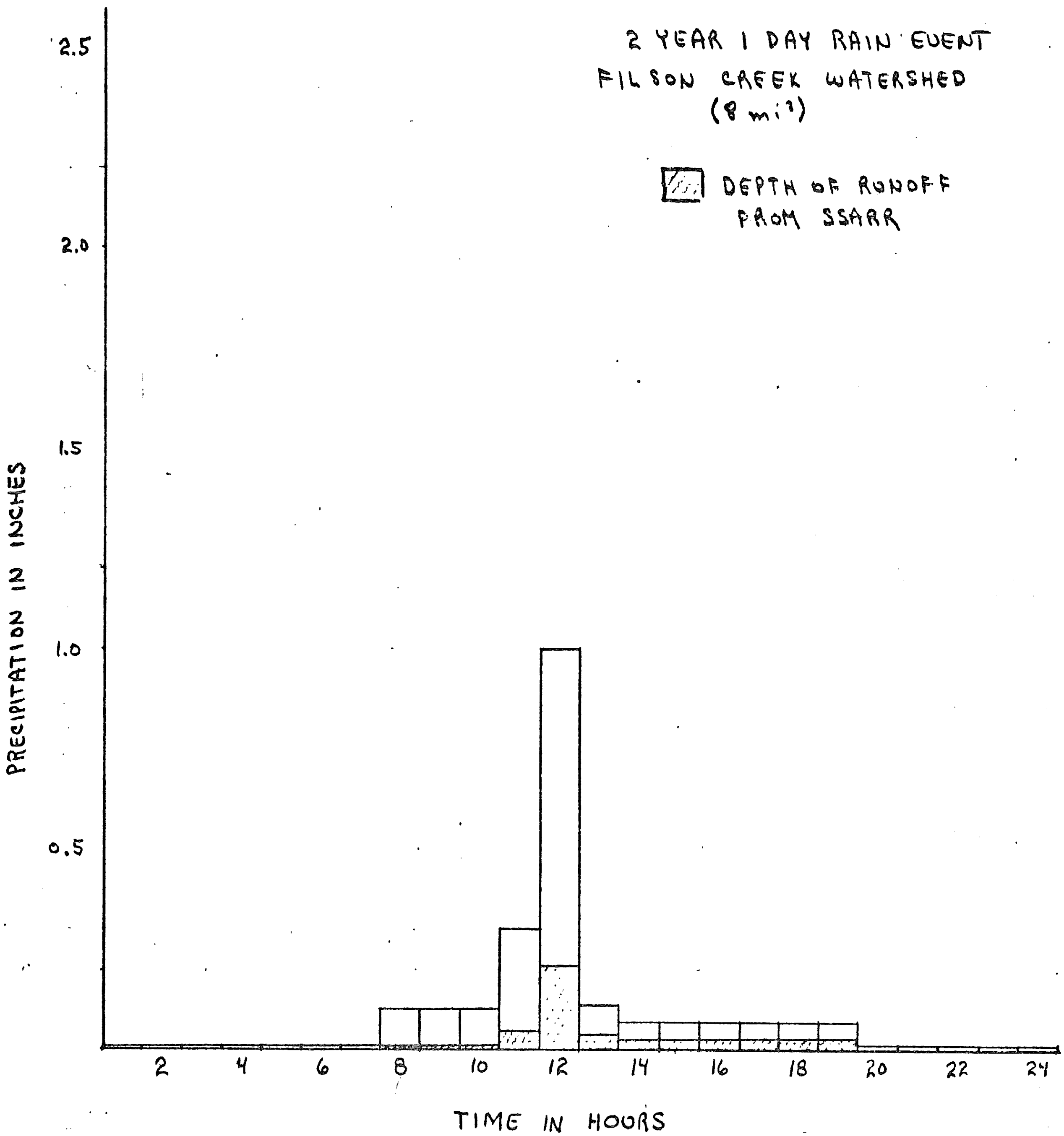
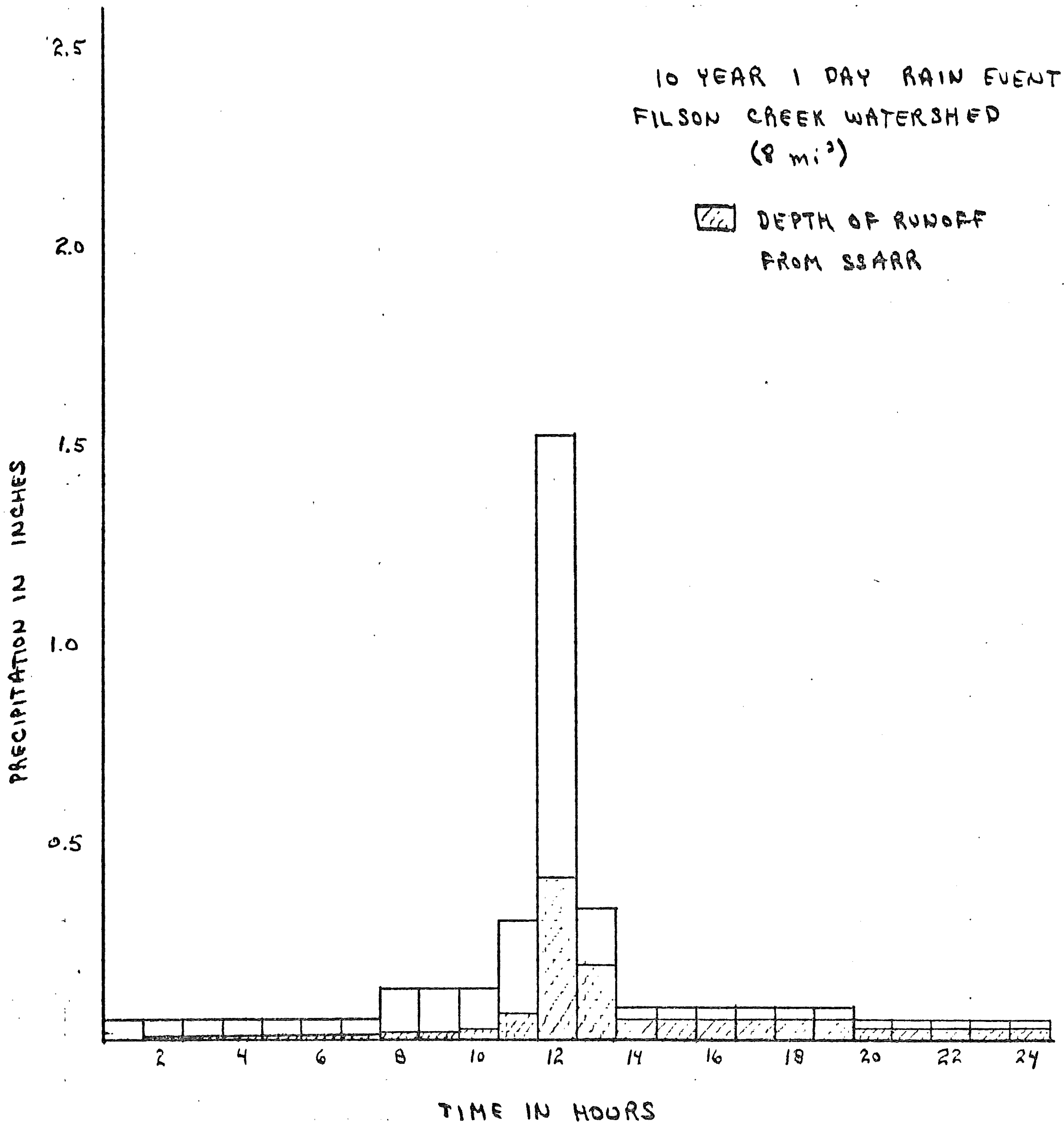
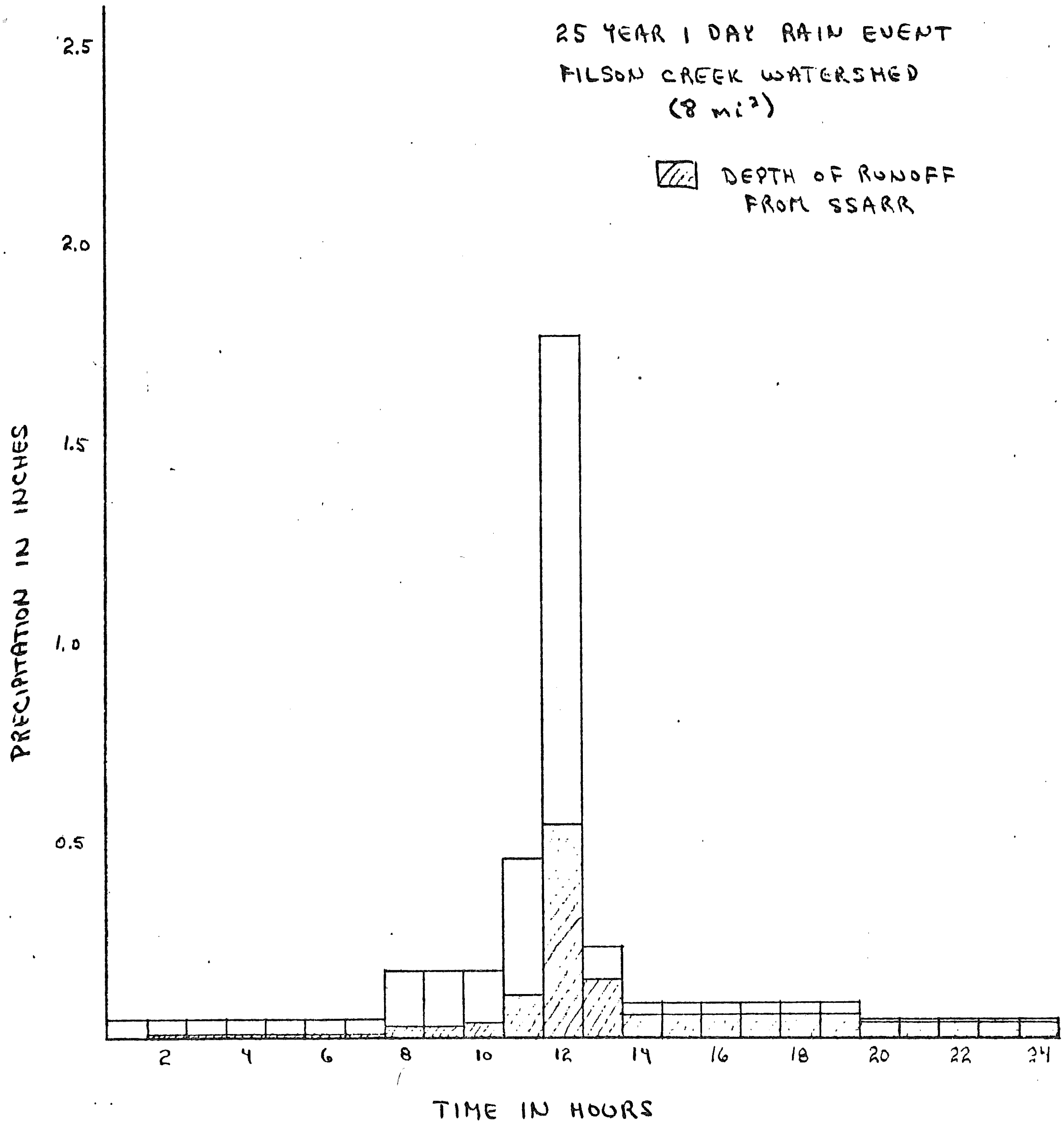

2 YEAR 1 DAY RAIN EVENT
FILSON CREEK WATERSHED
(8 mi²)
DEPTH OF RUNOFF FROM SSARR
PRECIPITATION IN INCHES
2.5
2.0
1.5
1.0
0.5
2
4
6
8
10
12
14
16
18
20
22
24
TIME IN HOURS

Fig. E-9



10 YEAR 1 DAY RAIN EVENT
FILSON CREEK WATERSHED
(8 mi²)
DEPTH OF RUNOFF FROM SSARR
PRECIPITATION IN INCHES
2.5
2.0
1.5
1.0
0.5
2
4
6
8
10
12
14
16
18
20
22
24
TIME IN HOURS

Fig. E-10



25 YEAR 1 DAY RAIN EVENT
FILSON CREEK WATERSHED
(8 mi²)
DEPTH OF RUNOFF FROM SSARR
PRECIPITATION IN INCHES
2.5
2.0
1.5
1.0
0.5
2
4
6
8
10
12
14
16
18
20
22
24
TIME IN HOURS

Fig. E-11

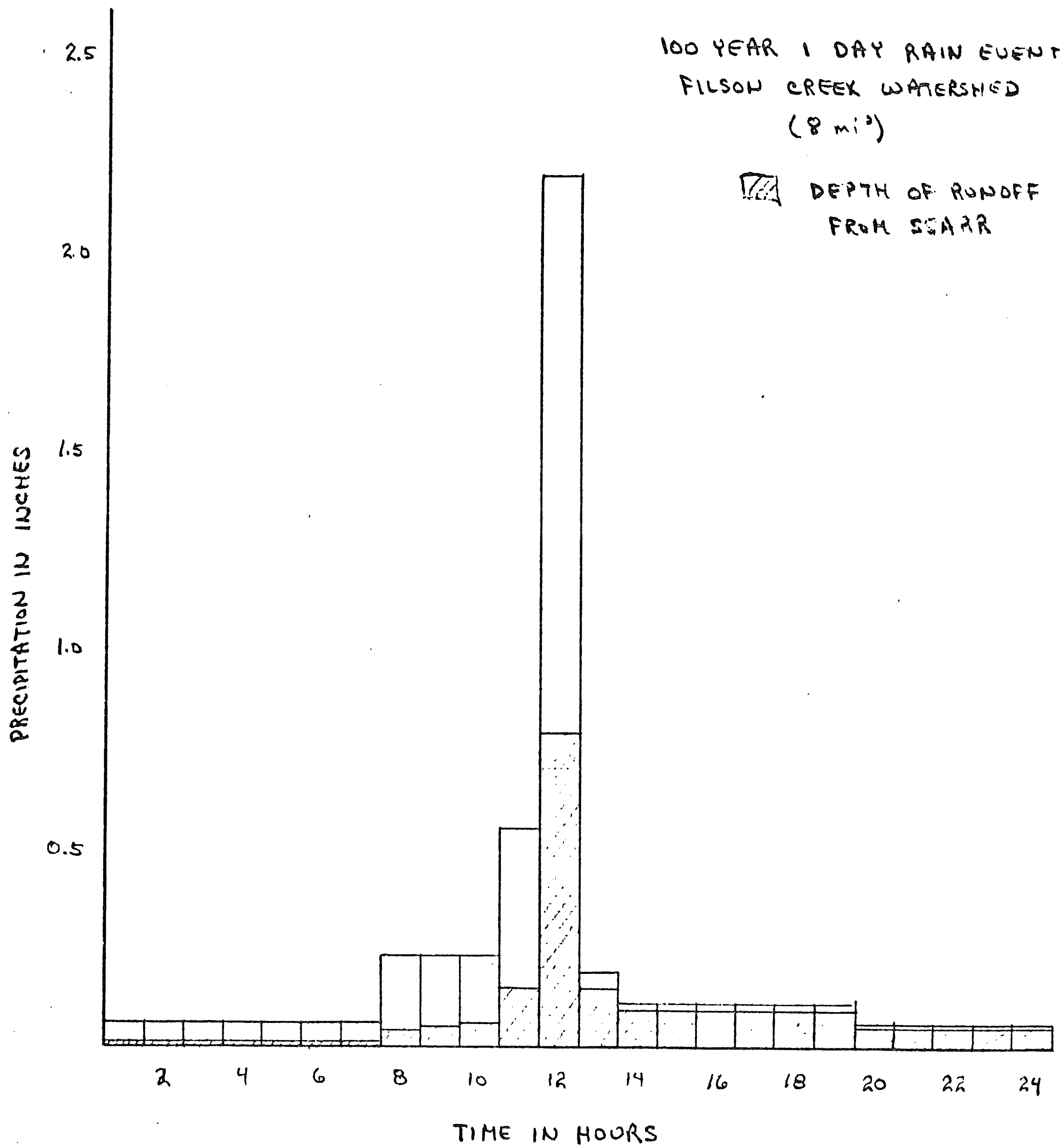
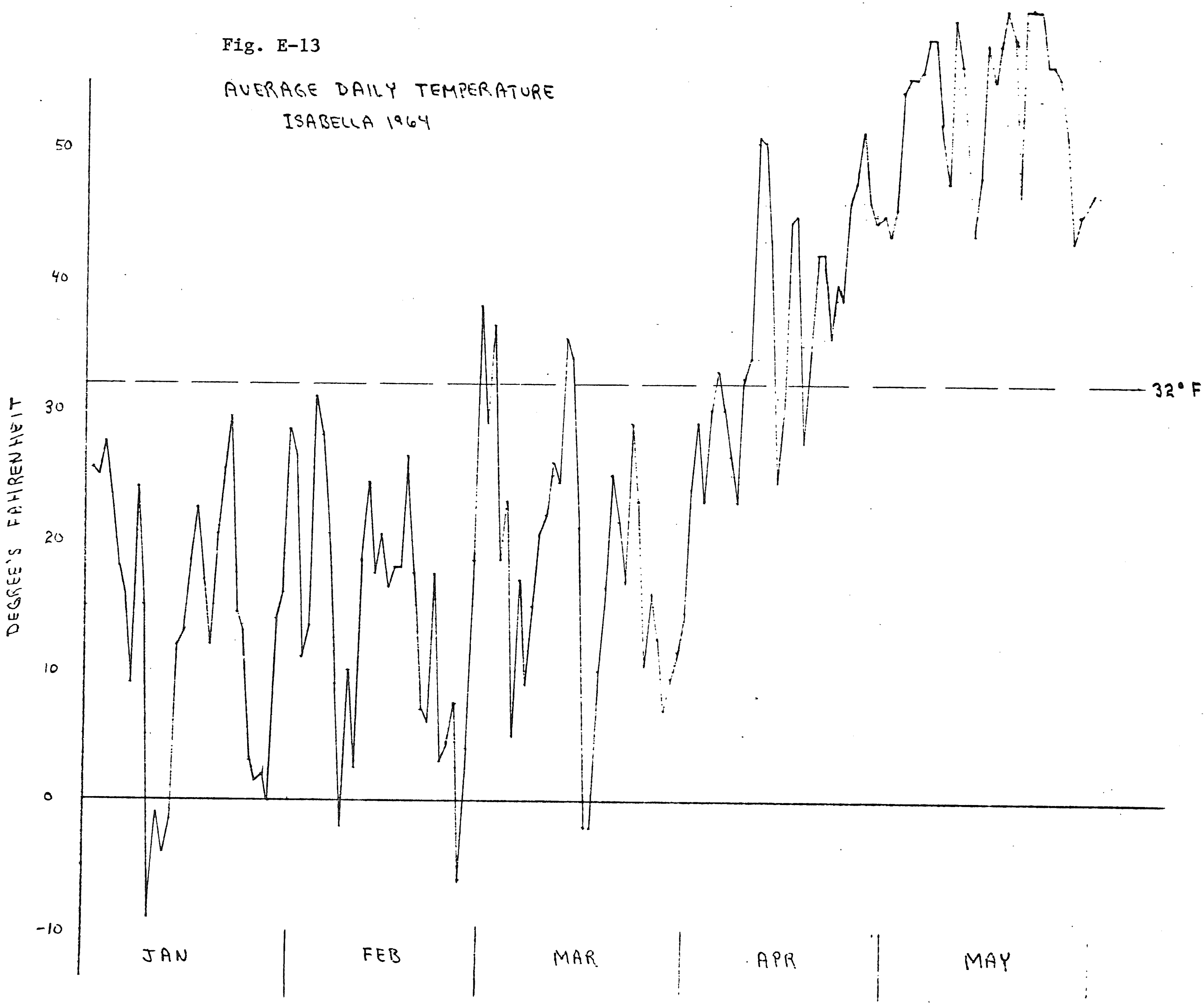

100 YEAR 1 DAY RAIN EVENT
FILSON CREEK WATERSHED
(8 mi²)
DEPTH OF RUNOFF FROM SSARR
PRECIPITATION IN INCHES
2.5
2.0
1.5
1.0
0.5
2
4
6
8
10
12
14
16
18
20
22
24
TIME IN HOURS

Fig. E-12

Fig. E-13


AVERAGE DAILY TEMPERATURE
ISABELLA 1964
DEGREE'S FAHRENHEIT
50
40
30
20
10
0
-10
32° F
JAN
FEB
MAR
APR
MAY

Appendix F

Frequency Analysis of Floods

KAWISHIWI NEAR WINTON 1905-07 1913-19 1924-77 WITH 1950

ORDER	FLOOD MAGNITUDE	EMPIRICAL RECURRENCE INTERVAL	EMPIRICAL EXCEEDANCE PROBABILITY (PERCENT)	LOG10 FLOOD MAGNITUDE
1	16000.00	65.00	1.54	4.204120
2	11200.00	32.50	3.08	4.049218
3	10200.00	21.67	4.62	4.008600
4	8740.00	16.25	6.15	3.941511
5	8620.00	13.00	7.69	3.935507
6	8520.00	10.83	9.23	3.930440
7	8500.00	9.29	10.77	3.929419
8	8260.00	8.13	12.31	3.916980
9	8030.00	7.22	13.85	3.904716
10	8010.00	6.50	15.38	3.903633
11	8010.00	5.91	16.92	3.903633
12	7730.00	5.42	18.46	3.888179
13	7680.00	5.00	20.00	3.885361
14	7600.00	4.64	21.54	3.880814
15	7360.00	4.33	23.08	3.866878
16	7210.00	4.06	24.62	3.857935
17	6840.00	3.82	26.15	3.835056
18	6780.00	3.61	27.69	3.831230
19	6370.00	3.42	29.23	3.804139
20	6030.00	3.25	30.77	3.780317
21	6030.00	3.10	32.31	3.780317
22	5860.00	2.95	33.85	3.767898
23	5800.00	2.83	35.38	3.763428
24	5780.00	2.71	36.92	3.761928
25	5740.00	2.60	38.46	3.758912
26	5690.00	2.50	40.00	3.755112
27	5480.00	2.41	41.54	3.738781
28	5350.00	2.32	43.08	3.728354
29	5330.00	2.24	44.62	3.726727
30	5300.00	2.17	46.15	3.724276
31	5250.00	2.10	47.69	3.720159
32	4620.00	2.03	49.23	3.664642
33	4530.00	1.97	50.77	3.656098
34	4340.00	1.91	52.31	3.637490
35	4330.00	1.86	53.85	3.636488
36	4320.00	1.81	55.38	3.635484
37	4300.00	1.76	56.92	3.633468
38	4280.00	1.71	58.46	3.631444
39	4260.00	1.67	60.00	3.629410
40	4240.00	1.63	61.54	3.627366
41	4240.00	1.59	63.08	3.627366
42	4160.00	1.55	64.62	3.619093
43	4131.00	1.51	66.15	3.616055
44	3970.00	1.48	67.69	3.598791
45	3860.00	1.44	69.23	3.586587
46	3760.00	1.41	70.77	3.575188
47	3740.00	1.38	72.31	3.572872
48	3380.00	1.35	73.85	3.528917
49	3330.00	1.33	75.38	3.522444
50	3100.00	1.30	76.92	3.491362

748383

KAWISHIWI NEAR WINTON 1905-07 1913-19 1924-77 WITH 1950

ORDER	FLOOD MAGNITUDE	EMPIRICAL RECURRENCE INTERVAL	EMPIRICAL EXCEEDANCE PROBABILITY (PERCENT)	LOG10 FLOOD MAGNITUDE
51	3010.00	1.27	78.46	3.478566
52	2900.00	1.25	80.00	3.462398
53	2890.00	1.23	81.54	3.460898
54	2720.00	1.20	83.08	3.434569
55	2640.00	1.18	84.62	3.421604
56	2440.00	1.16	86.15	3.387390
57	2430.00	1.14	87.69	3.385606
58	2410.00	1.12	89.23	3.382017
59	2290.00	1.10	90.77	3.359835
60	2190.00	1.08	92.31	3.340444
61	2040.00	1.07	93.85	3.309630
62	1950.00	1.05	95.38	3.290035
63	1830.00	1.03	96.92	3.262451
64	916.00	1.02	98.46	2.961895

MEAN OF FLOODS = 5294.48
STANDARD DEVIATION OF FLOODS = 2644.25

MEAN OF LOG10(FLOOD) = 3.67049
STANDARD DEVIATION OF LOG10(FLOOD) = .22422
COEFFICIENT OF SKEWNESS OF LOG10(FLOOD) = -.43183

748384

KAWISHIWI NEAR WINTON 1905-07 1913-19 1924-77 WITH 1950

EXCEEDANCE PROBABILITY (PERCENT)	RECURRENCE INTERVAL	FLOOD MAGNITUDE ZERO SKEWNESS CS= 0	FLOOD MAGNITUDE COMPUTED SKEWNESS CS= -.432	FLOOD MAGNITUDE ASSIGNED SKEWNESS CS= -.200
99.0	1.0101	1409.17	1199.77	1306.86
95.0	1.0526	2002.88	1689.73	1946.81
90.0	1.1111	2415.72	2370.12	2392.14
80.0	1.2500	3031.81	3076.82	3050.65
50.0	2.0000	4682.65	4858.51	4763.11
20.0	5.0000	7232.40	7282.30	7262.33
10.0	10.0000	9076.90	8819.25	8965.12
4.0	25.0000	11563.65	10661.05	11147.45
2.0	50.0000	13521.75	11957.40	12781.83
1.0	100.0000	15560.36	13186.99	14415.70
.5	200.0000	17704.10	14366.63	16066.49

PARTRIDGE RIVER NEAR AURORA CORRECTED Q 1961-64 1975 1944-1976

ORDER	FLOOD MAGNITUDE	EMPIRICAL RECURRENCE INTERVAL	EMPIRICAL EXCEEDANCE PROBABILITY (PERCENT)	LOG10 FLOOD MAGNITUDE
1	3230.00	34.00	2.94	3.509203
2	2930.00	17.00	5.88	3.466868
3	2660.00	11.33	8.82	3.424882
4	2150.00	8.50	11.76	3.332438
5	1980.00	6.80	14.71	3.296665
6	1610.00	5.67	17.65	3.206826
7	1560.00	4.86	20.59	3.193125
8	1420.00	4.25	23.53	3.152288
9	1390.00	3.78	26.47	3.143015
10	1230.00	3.40	29.41	3.089905
11	1217.00	3.09	32.35	3.085291
12	1190.00	2.83	35.29	3.075547
13	1104.00	2.62	38.24	3.042969
14	1103.00	2.43	41.18	3.042576
15	1010.00	2.27	44.12	3.004321
16	1010.00	2.13	47.06	3.004321
17	950.00	2.00	50.00	2.977724
18	930.00	1.89	52.94	2.968483
19	916.00	1.79	55.88	2.961895
20	848.00	1.70	58.82	2.928396
21	823.00	1.62	61.76	2.915400
22	784.00	1.55	64.71	2.894316
23	779.00	1.48	67.65	2.891537
24	764.00	1.42	70.59	2.883093
25	711.00	1.36	73.53	2.851870
26	675.00	1.31	76.47	2.829304
27	636.00	1.26	79.41	2.803457
28	535.00	1.21	82.35	2.728354
29	505.00	1.17	85.29	2.703291
30	463.00	1.13	88.24	2.665581
31	441.00	1.10	91.18	2.644439
32	300.00	1.06	94.12	2.477121
33	174.00	1.03	97.06	2.240549

MEAN OF FLOODS = 1152.36
STANDARD DEVIATION OF FLOODS = 727.11

MEAN OF LOG10(FLOOD) = 2.98288
STANDARD DEVIATION OF LOG10(FLOOD) = .27311
COEFFICIENT OF SKEWNESS OF LOG10(FLOOD) = -.34276

DATE	OBSERVED Q	CORRECTED Q
1961	694	1103
62	680	636
63	252	441
64	1420	1217
1975	1110	1104

PARTRIDGE RIVER NEAR AURORA CORRECTED Q 1961-64 1975 1944-197(

699155

EXCEEDANCE PROBABILITY (PERCENT)	RECURRENCE INTERVAL	FLOOD MAGNITUDE ZERO SKEWNESS CS= 0	FLOOD MAGNITUDE COMPUTED SKEWNESS CS= -.343	FLOOD MAGNITUDE ASSIGNED SKEWNESS CS= -.200
99.0	1.0101	222.65	190.45	203.12
95.0	1.0526	341.67	322.61	330.06
90.0	1.1111	429.29	421.15	424.19
80.0	1.2500	566.13	573.81	570.42
50.0	2.0000	961.35	996.33	981.51
20.0	5.0000	1632.46	1644.67	1640.69
10.0	10.0000	2152.84	2095.42	2120.59
4.0	25.0000	2891.35	2674.75	2765.09
2.0	50.0000	3498.28	3108.31	3266.52
1.0	100.0000	4150.89	3537.94	3781.99
.5	200.0000	4857.57	3967.71	4315.92

ST. LOUIS NEAR AURORA, MINN. 1942-47,1949-57,1959-76
(CORRECTED 1961-64, 1975)

ORDER	FLOOD MAGNITUDE	EMPIRICAL RECURRENCE INTERVAL	EMPIRICAL EXCEEDANCE PROBABILITY (PERCENT)	LOG10 FLOOD MAGNITUDE
1	5380.00	33.00	3.03	3.730782
2	5380.00	16.50	6.06	3.730782
3	5180.00	11.00	9.09	3.714330
4	3960.00	8.25	12.12	3.597695
5	2770.00	6.60	15.15	3.442480
6	2510.00	5.50	18.18	3.399674
7	2370.00	4.71	21.21	3.374748
8	2160.00	4.13	24.24	3.334454
9	2090.00	3.67	27.27	3.320146
10	2070.00	3.30	30.30	3.315970
11	2000.00	3.00	33.33	3.301030
12	1967.00	2.75	36.36	3.293804
13	1880.00	2.54	39.39	3.274158
14	1700.00	2.36	42.42	3.230449
15	1640.00	2.20	45.45	3.214844
16	1583.00	2.06	48.48	3.199481
17	1560.00	1.94	51.52	3.193125
18	1340.00	1.83	54.55	3.127105
19	1320.00	1.74	57.58	3.120574
20	1290.00	1.65	60.61	3.110590
21	1240.00	1.57	63.64	3.093422
22	1240.00	1.50	66.67	3.093422
23	1196.00	1.43	69.70	3.077731
24	1180.00	1.38	72.73	3.071882
25	1090.00	1.32	75.76	3.037426
26	1040.00	1.27	78.79	3.017033
27	981.00	1.22	81.82	2.991669
28	909.00	1.18	84.85	2.958564
29	892.00	1.14	87.88	2.950365
30	862.00	1.10	90.91	2.935507
31	810.00	1.06	93.94	2.908485
32	637.00	1.03	96.97	2.804139

MEAN OF FLOODS = 1944.59
STANDARD DEVIATION OF FLOODS = 1294.99

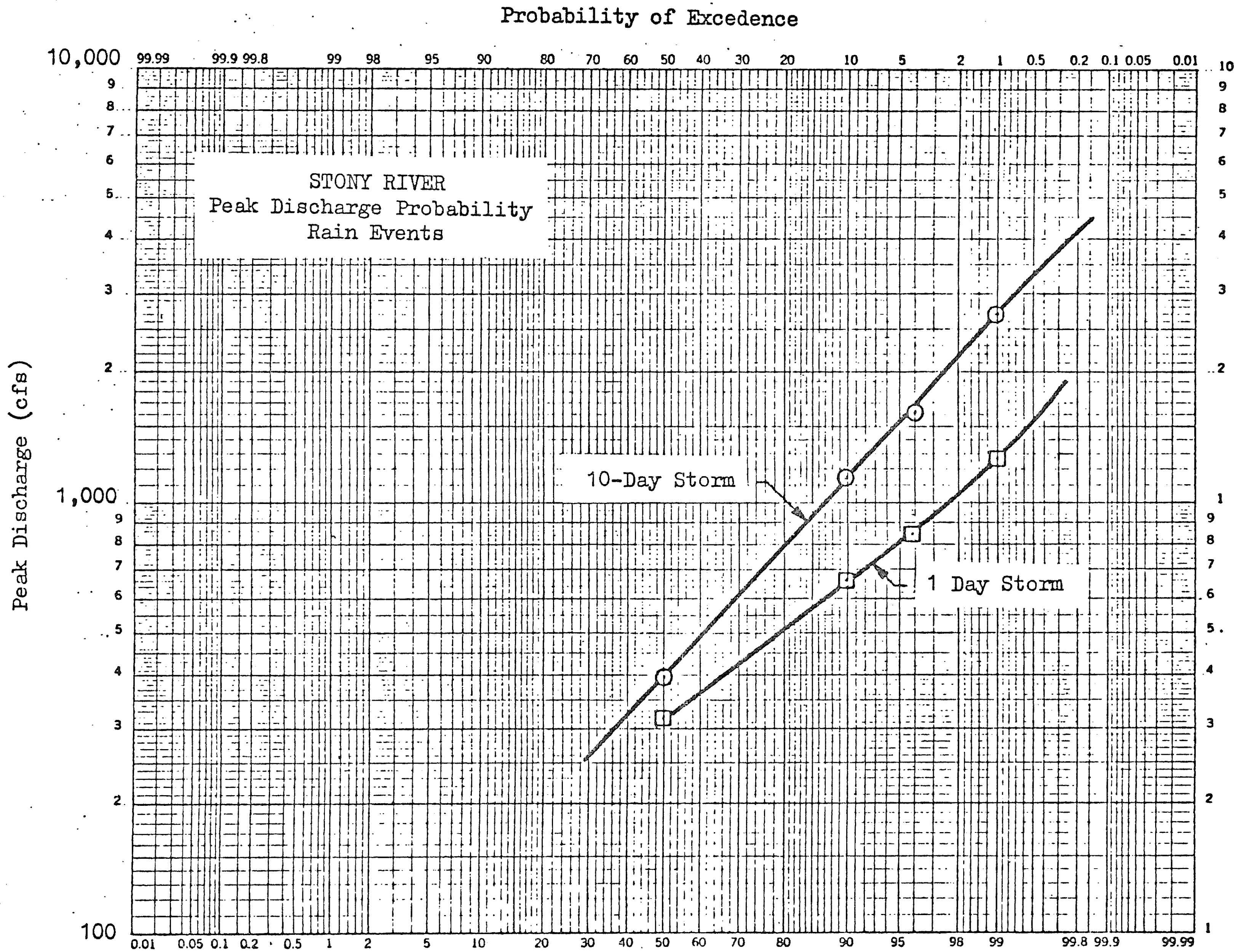
MEAN OF LOG10(FLOOD) = 3.21768
STANDARD DEVIATION OF LOG10(FLOOD) = .24005
COEFFICIENT OF SKEWNESS OF LOG10(FLOOD) = .68736

ST. LOUIS NEAR AURORA, MINN. 1942-47,1949-57,1959-76

EXCEEDANCE PROBABILITY (PERCENT)	RECURRENCE INTERVAL	FLOOD MAGNITUDE ZERO SKEWNESS CS= 0	FLOOD MAGNITUDE COMPUTED SKEWNESS CS= .687	FLOOD MAGNITUDE ASSIGNED SKEWNESS CS= -.200
99.0	1.0101	456.39	605.22	421.01
95.0	1.0526	664.98	749.96	645.07
90.0	1.1111	812.73	857.42	804.24
80.0	1.2500	1036.49	1027.93	1043.39
50.0	2.0000	1650.76	1550.08	1681.14
20.0	5.0000	2629.07	2556.36	2640.72
10.0	10.0000	3352.91	3447.56	3308.72
4.0	25.0000	4345.13	4886.55	4177.91
2.0	50.0000	5137.32	6223.23	4836.95
1.0	100.0000	5970.75	7824.87	5501.76
.5	200.0000	6855.51	9740.64	6178.90

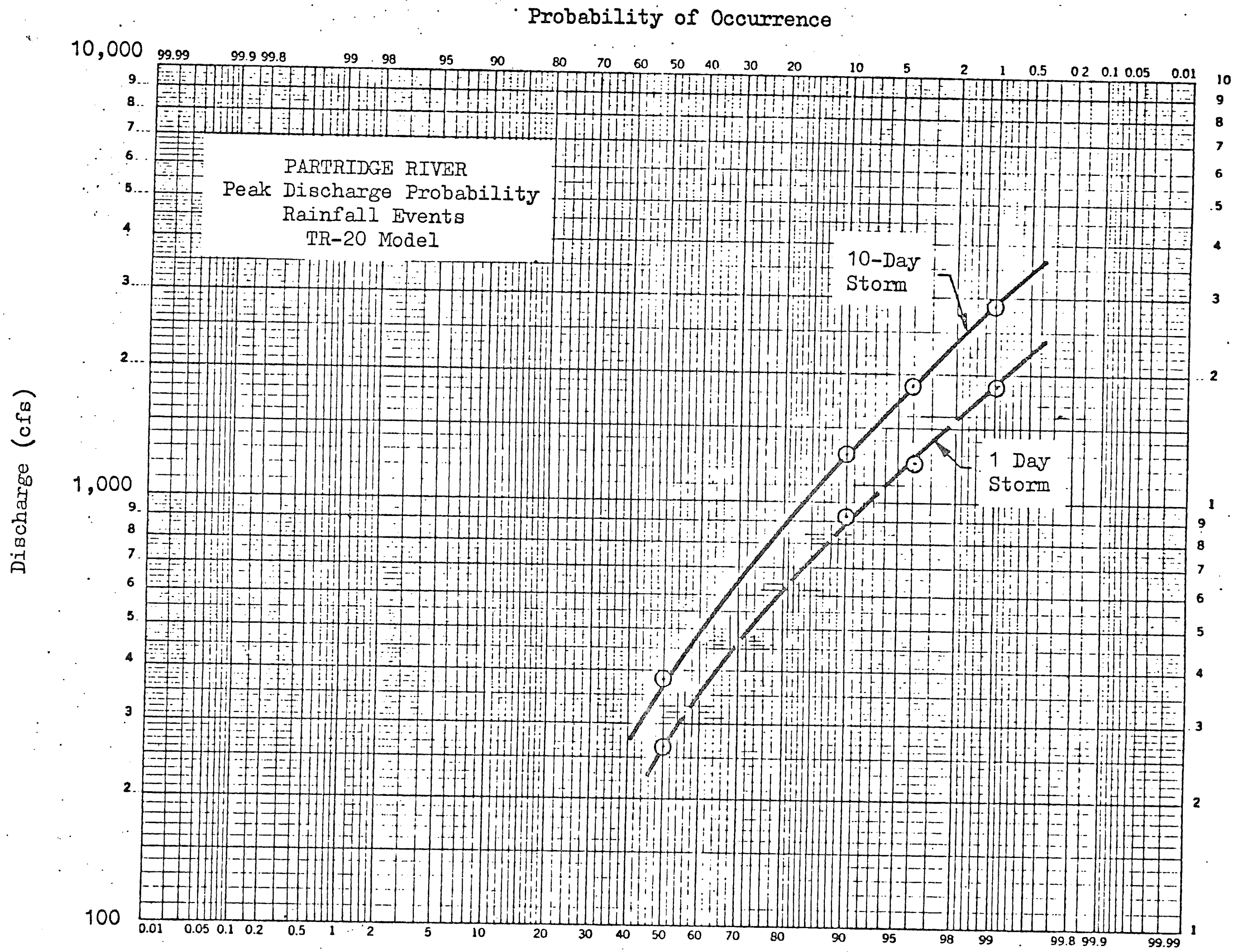
Appendix G

Selected Figures from Phase I Report



Probability of Excedence
Peak Discharge (cfs)
STONY RIVER
Peak Discharge Probability
Rain Events
10-Day Storm
1 Day Storm
10,000
1,000
100

Fig. G-1



Probability of Occurrence
PARTRIDGE RIVER
Peak Discharge Probability
Rainfall Events
TR-20 Model
10-Day
Storm
1 Day
Storm
Discharge (cfs)
10,000
1,000
100
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
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

Fig. G-2

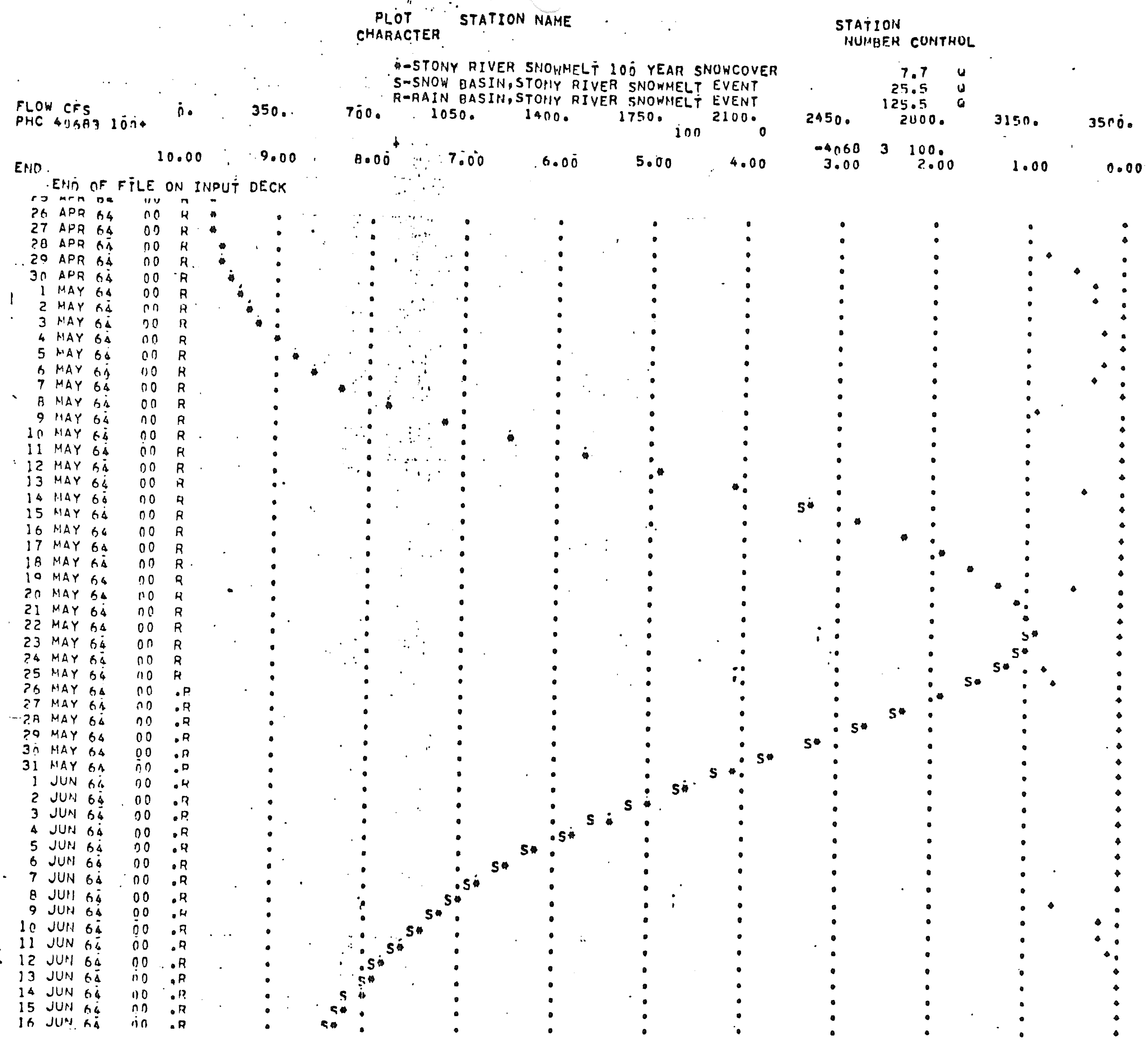


Fig. G-3 - Stony River 100-Year Snowmelt Flood (SSARR).

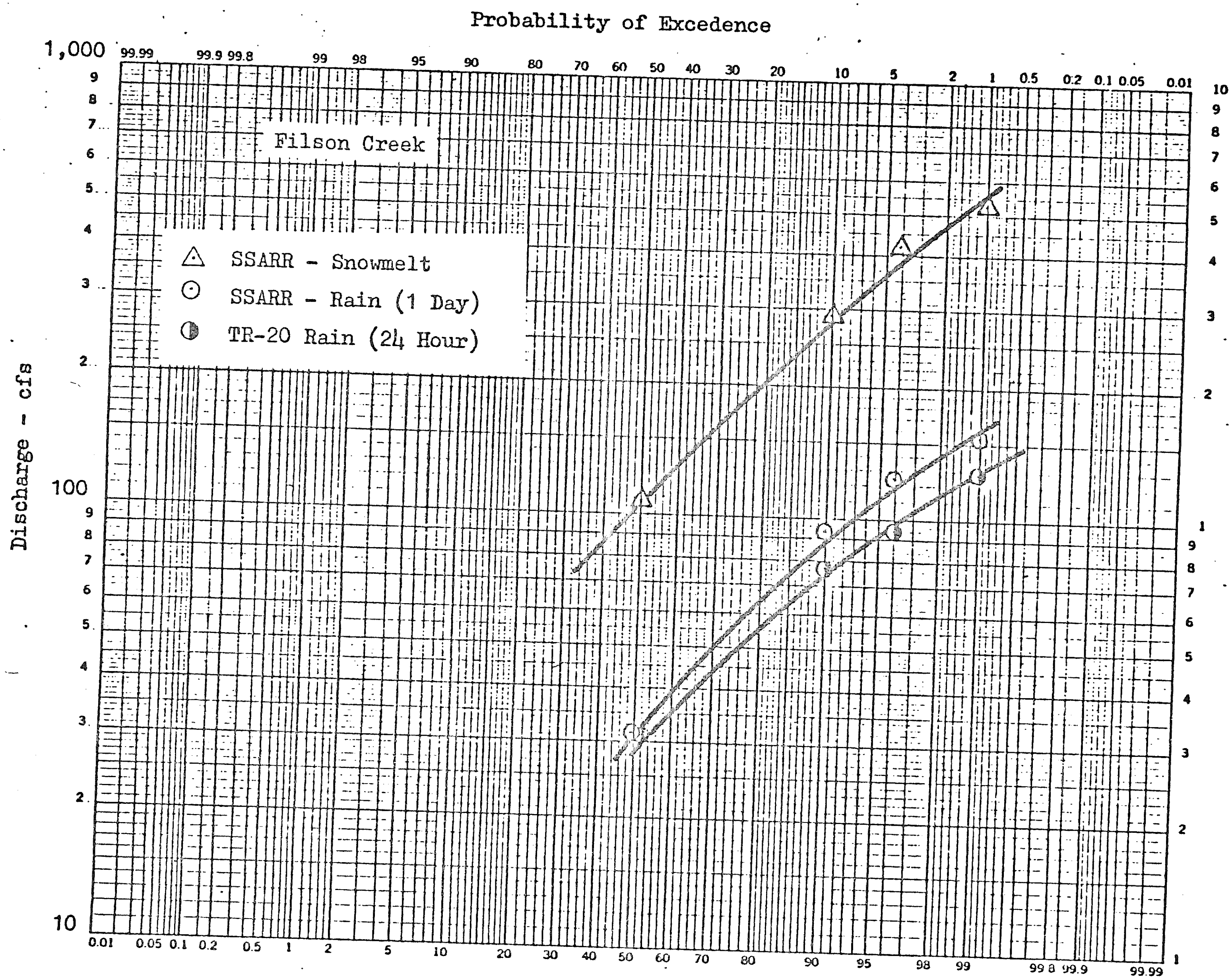


Fig. G-4 - Comparison of SSARR and TR-20 for Filson Creek.

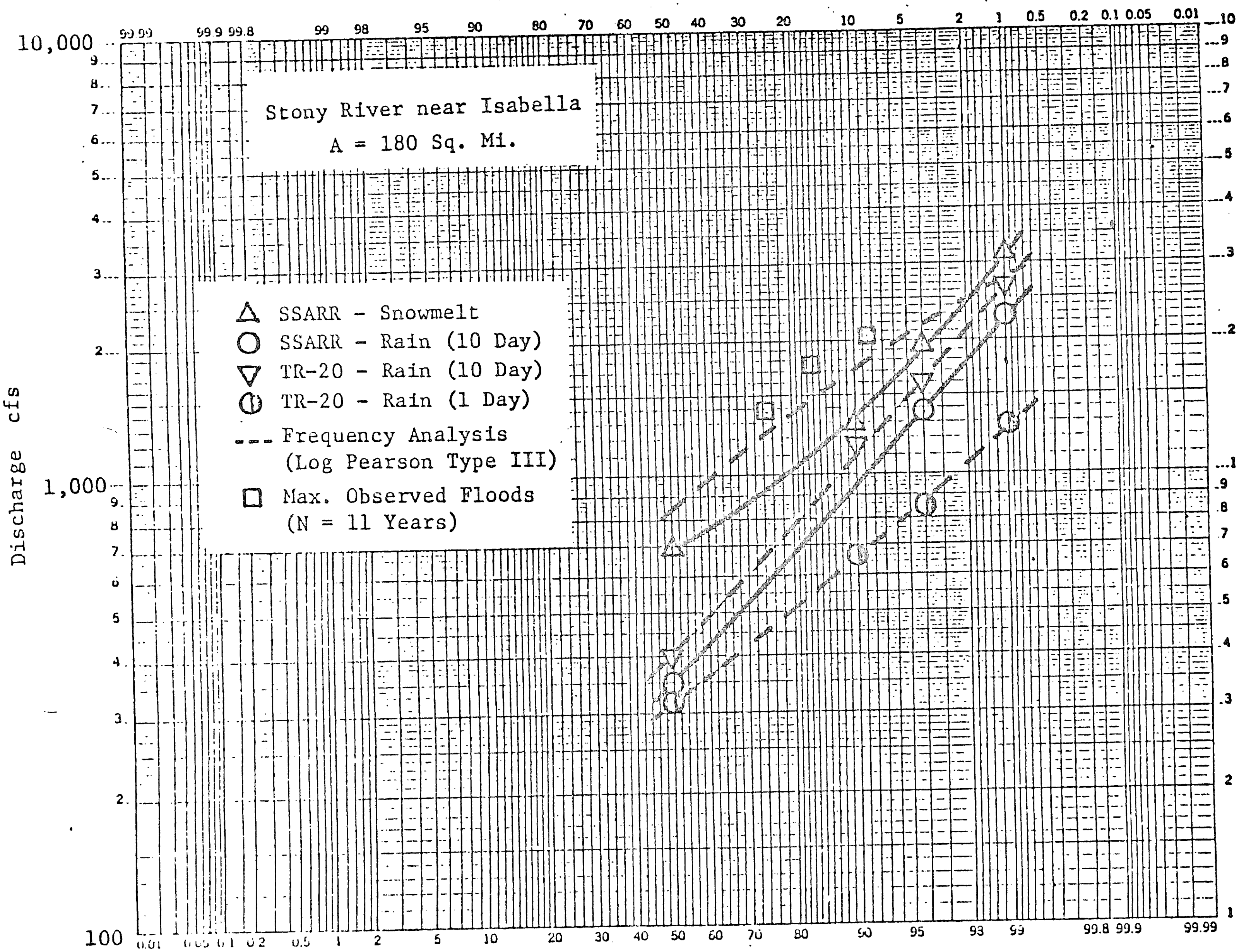


Fig. G-5 - Comparison of SSARR, TR-20, Frequency Analysis, and Maximum Observed Floods for the Stony River Floods.

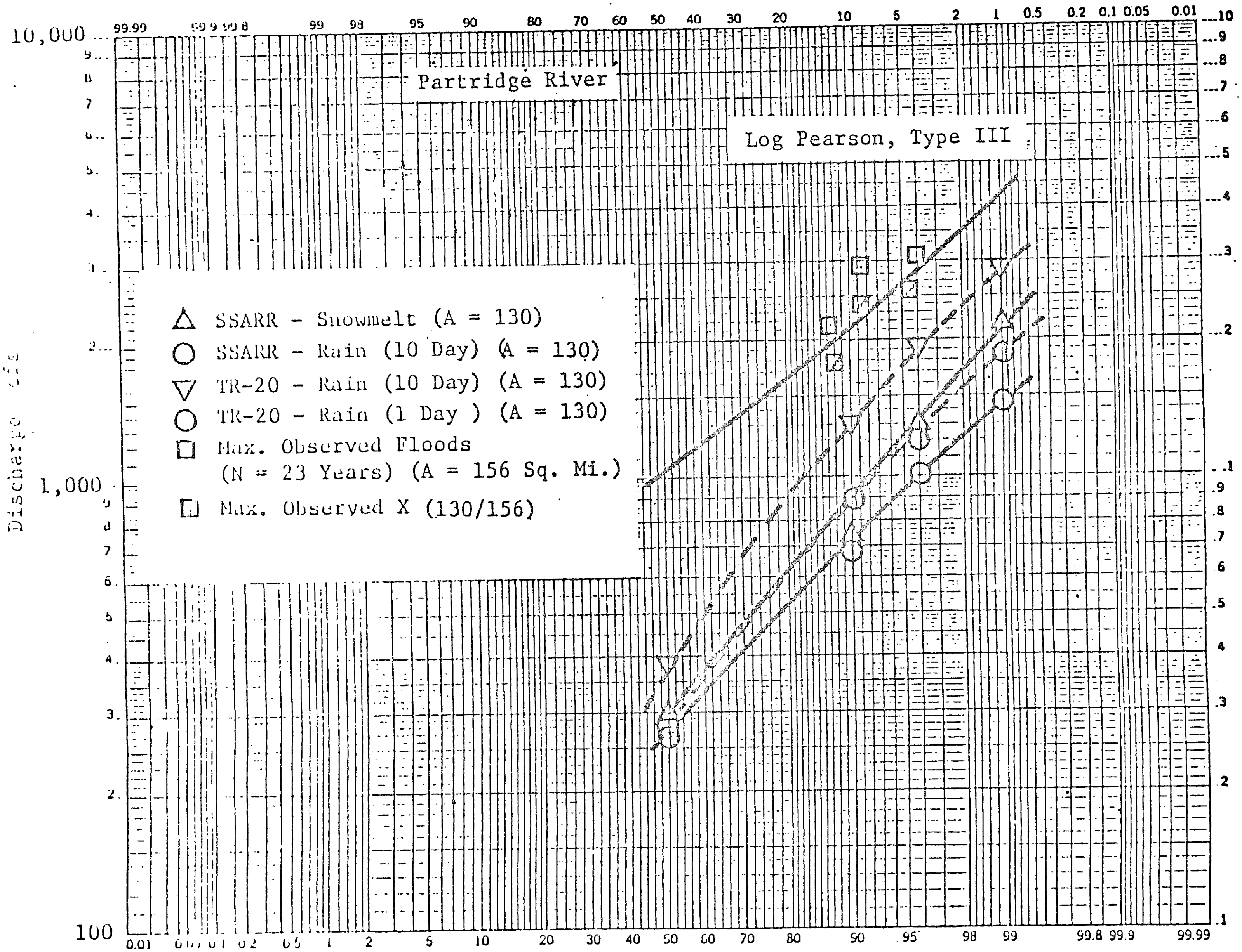


Fig. G-6 - Comparison of SSARR, TR-20, and Maximum Observed Floods for the Partridge River.

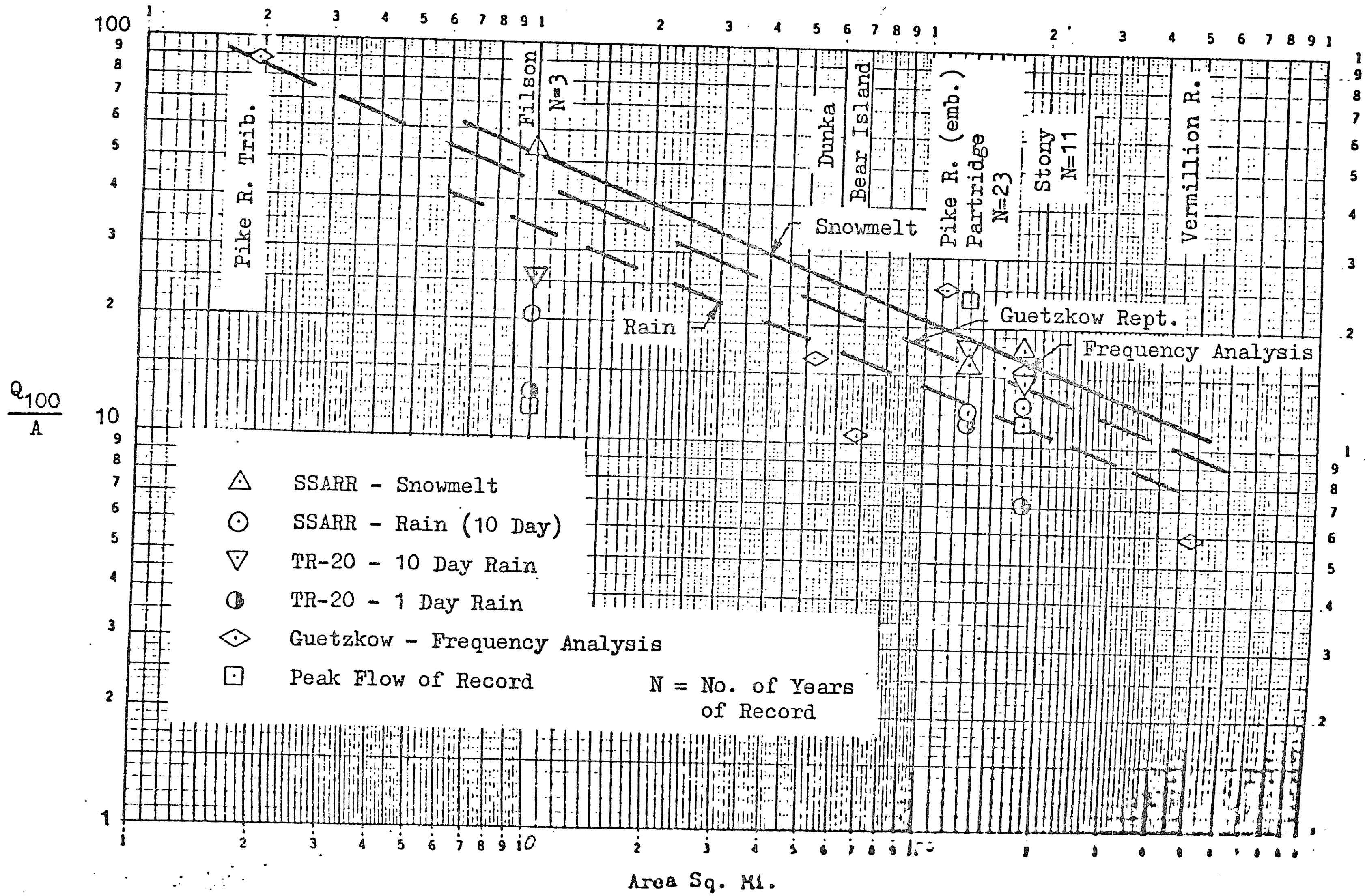


Fig. G-7 - Drainage Intensity [illegible]

Appendix H

Alternative Scenarios of Proposed Mining Development in the Kawishiwi and St. Louis Basins.

As suggested, alternative scenarios of mining development during low flow years 1960 and 1976 were attempted as time permitted. Table H-1 lists the changes proposed by the Copper-Nickel Group. Of these special runs, time limitations permitted only the latter two. Special runs 2 and 3 required the changing of the end values of the appropriation tables. Special run 1, due to the reduction of loss of watershed area and the switching of the other subwatersheds to a no mining condition, introduces a series of data changes that could not be rerun with the time and funds available.

Tables 2 and 3 summarize the results of the special runs. As noted above, the primary difference relative to the original runs were (1) reduction of appropriation for the South Kawishiwi from 18 cfs to 8 cfs, and (2) reduction of appropriation in the Partridge River watershed from 18 to 9 cfs.

Referring to Table 2 for the Kawishiwi River Basin, it may be noted that for high flow the discharge at Winton increases from 6660 to 6670 cfs and the low flows (September 30) increase from 147 to 156 cfs, or an increase of 9 cfs. The SSARR rounds off flows to the nearest whole number. The results are as expected.

Referring to Table 3, it may be noted that the peak flows of the St. Louis River (late April and early May) increase by 9 cfs due to a reduction of appropriation in the Partridge River of 9 cfs. However, in late September the flows are the same for the original and special runs. This is probably due to the fact that the appropriation for the Partridge River may be less than 9 cfs. Figure H-1 shows the appropriation graph for low discharges, where the appropriation could be larger than the streamflow. This provides an appropriation of zero if the streamflow drops below 1 cfs and a minimum streamflow of 1 cfs up to 9 or 18 cfs appropriation.

It is of interest to note that

(1) for the Kawishiwi River at Winton the appropriations of 32 cfs (total) would have been 21% of the low flow (September 30) in 1976 and

TABLE H-1

Alternative Scenarios of Mining Development Appropriations and Loss of Watershed Areas.

Special Run		Appropriation (cfs)	Loss of Watershed Area (acres)
1	Dunka River near Babbitt	9	7139
2	Partridge River near Aurora	9	7139
3	S. Kawishiwi River near Ely	9	3124
	Birch Lake Local*	14	3077
	Stony River near Babbit*	-	6324
	Dunka River near Babbit*	24	14453

*These appropriations and areas did not change from the original runs.

**Special Run No. 1 was not performed because of limitations in time and funds.

TABLE H-2

Kawishiwi Basin, Calculated Flow at Winton with Mining; Appropriations in South Kawishiwi River of 18 cfs (original runs) and 9 cfs (special runs).

Runs	Year	Peak Flow cfs	Sept. 30 cfs
Original (SK = 18)	1976	6660	147
Special (SK = 9)	1976	6670	156

TABLE H-3

St. Louis Basin, Calculated Flow Near Aurora with Mining; Appropriation of Partridge River of 18 cfs (original runs) and 9 cfs (special runs).

Runs	Year	Peak Flow cfs	Sept. 30 cfs
Original	1960	478	18
"	1976	662	11
Special	1960	487	18
"	1976	671	11

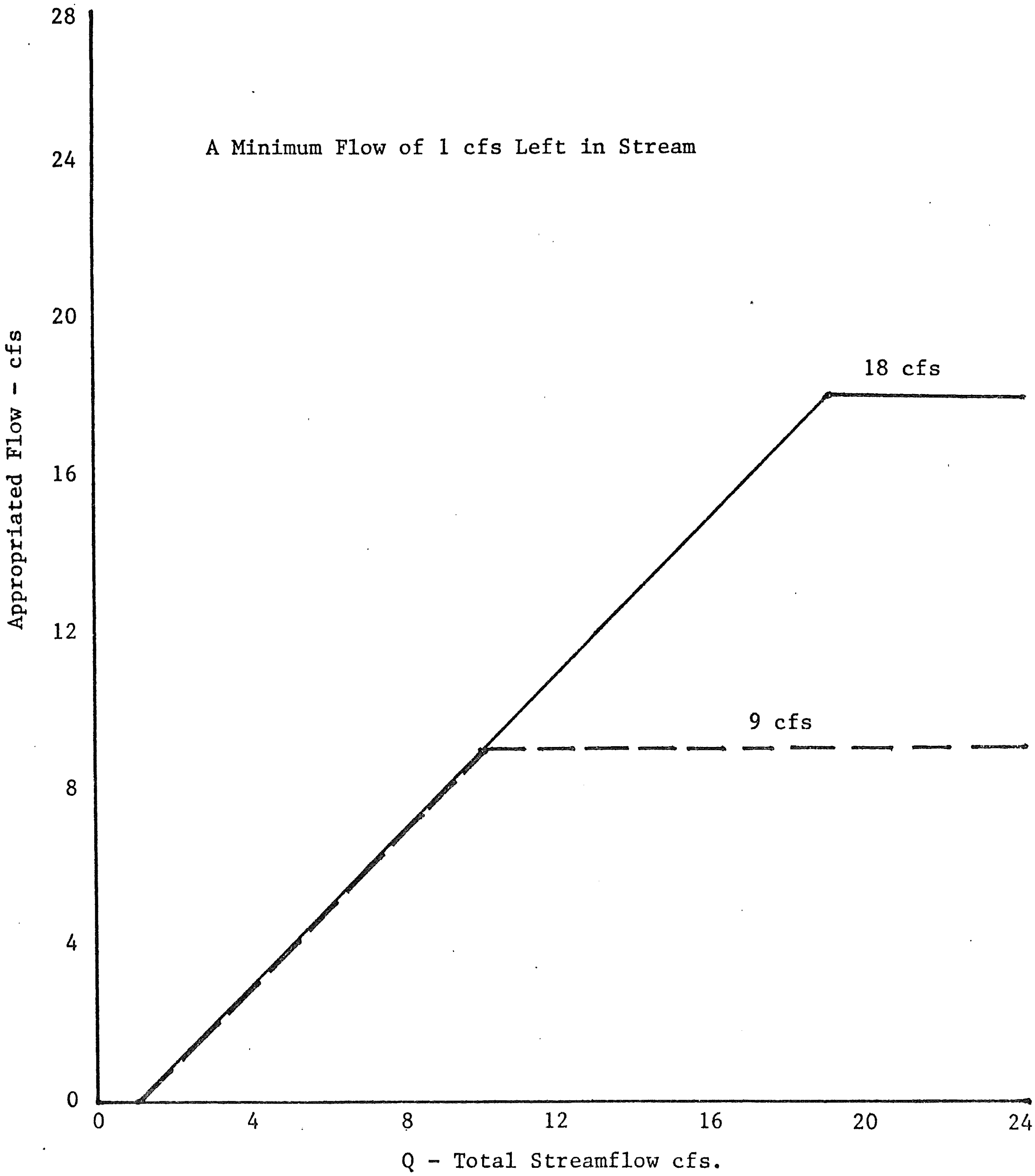


Fig. H-1 - Low Flow Appropriation.

(2) for the St. Louis River near Aurora the appropriation of 9 cfs (Partridge River) would have been 82% of the low flow on September 30, 1976.

Of more importance is the fact that storage of higher flows in the spring may have provided the necessary water during the drought in the latter part of 1976. Further analysis of these data and possible storage reservoir areas would be desirable.