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INSTITUTO INTERAMERICANO
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INSTITUTO NACIONAL DE RECURSOS
HIDRAULICOS (INDRHI)

UNIVERSIDAD DEL
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(CSU)

ESTUDIOS SOBRE LA OPERACION Y SEGURIDAD DEL SISTEMA DE EMBALSES DE VALDESIA

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SECOND TECHNICAL REPORT [1]

VOLUME I

HYDROLOGICAL STUDIES

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Technical Report on the Project

OPERATIONAL AND SAFETY STUDIES OF THE VALDESIA RESERVOIR

for

Contract IICA/INDRHI/CSU
(Loan 1655-DO from World Bank)

VOLUME I

HYDROLOGIC STUDIES

by

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VOLUME I.
HYDROLOGIC STUDIES

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VOLUME I. HYDROLOGIC STUDIES

1.1 INTRODUCTION

The Valdesia reservoir system, located on the Nizao River in the Dominican Republic, was designed to provide irrigation water to the Nizao project areas and hydroelectric energy to the national electrical network system. The reservoir system consists of a main reservoir, dam and spillway, a power plant and outflow regulating works, together with an afterbay, diversion and spillway system a short distance downstream.

The study on the operational management of the Valdesia system reported in a series of volumes including this one, invloved several interrelated areas. This volume reports in detail the basic hydrologic studies including rainfall-runoff modeling, flood forecasting and stochastic data generation which are essential components of the entire study. The products reported in this volume are used for developing emergency and normal operation plans for the Valdesia system.

1.2 METHODS OF INVESTIGATION

Hydrologic studies are a prerequisite to any water resources management project. The required studies necessary for this project can be catagorized under four topics:

1. Design storms
2. Rainfall-runoff modeling
3. Streamflow forecasting
4. Stochastic data generation

Hypothetical design storms are required to compute hypothetical floods which are necessary for developing emergency operating procedures. Two types of hypothetical storms are considered: (a) Standard Project Storms (SPS); and (b) Probable Maximum Precipitation.

The rational behind the use SPS is discussed in many documents of the U.S. Army Corps of Engineers. Both types of hypothetical storms require depth-area-duration curves. These are developed from about 25 observed historic storms. Since two regimes of storms, namely hurricane and non-hurricane, are present in the Dominican Republic, two types of SPS are developed. The time distribution of SPS is also derived from the observed storms. The PMP is based on the Hurricane model of the U.S. National Weather Service (U.S. Weather Bureau, 1961) modified by the counterparts in the Dominican Republic.

An event type rainfall-runoff model suitable for conditions in the Nizao basic is necessary to compute hypothetical floods from hypothetical storms. The HEC-1 model of the U.S. Army Corps of Engineers is used for this purpose. It is calibrated by using data of historic storms and floods and a few flood data derived from Valdesia reservoir levels during storm events. The calibrated model is used to compute hypothetical floods for three different antecedent basin conditions. The model is also used to reconstruct the possible hydrographs from the precipitation that occurred during the Hurricane DAVID which struck the island on August 30, 1986.

For real-time forecasting, a modified version of the U.S. National Weather Service River Forecast Model is employed. The modification is necessary to (a) develop a version which will fit in the computing facilities at INDRHI/CDE; and (b) incoporate kinematic wave flood routing procedure in the model. The model is calibrated using several years of daily streamflow data and hourly precipitation data.

Synthetically generated data are necessary to develop and test the normal operating rules. Multivariate stochastic models of streamflow of three gauging stations (Ermitano, Palo de Caja, Rancho Arriba) are developed from extended existing historic data. The generated data at Ermitano is employed to generate another synthetic series of number of hours of energy generation at Valdesia dam. Both the series are used for developing and testing of normal operating rules.

1.3 SUMMARY OF CONCLUSIONS

Following is a summary of conclusions based on the hydrologic studies reported in this section:

1. Significant amount of errors and inconsistencies are found in various precipitation and streamflow data collected. A careful review of data collection processing and reporting of all hydrologic data is warrented.

2. The standard project storm (for 48-hour duration) based on non-hurricane storms is 260 mm whereas the same based on hurrican precipitation is 493 mm.

3. The watershed average PMP simulated by the hurricane model of U.S. Weather Brueau is 1338 mm.

4. The nonhurricane SPS simulated a peak inflow to Valdesia reservoir of 3469 m^3/sec for dry antecedent conditions whereas the same for wet antecedent conditions is 7544 m^3/s.

5. The hurricane SPS simulated a peak inflow to Valdesia reservoir of 10185 m^3/s for dry antecedent conditions whereas the same for wet antecedent conditions is 16548 m^3/s.

6. The flood peak simulated by using the calibrated HEC-1 and observed precipitation during hurricane DAVID is 5332 m^3/s for dry antecedent conditions and it is 10358 m^3/s for wet antecedent

conditions. The calibrated SAC-KW model resulted in peak of 7074 cms for the same event.

7. The PMP supplied by counterparts produces a PMF of 20,000 cms for dry antecedent conditions. For wet antecedent conditions it increases to 23,000 cms.

8. The calibration of the developed flood forecasting model for Nizao basin was performed on a year-to-year basis using the data from 1972 to 1975. It is concluded from this exercise that the best model calibration is in year 1972. Subsequent use of the 1972-model parameters to forecast the streamflow reqime during Hurricane DAVID (August, 1979) gave a highest hourly peak flow at Paso del Ermitano of 7074 m^3/sec. For stochastic modeling and data generation, a trivariate, contemporaneous firt-order autoregressive porcess with seasonal parameters has been found to adequately describe the streamflows of Rancho Arriva, Palo de Caja and Paso del Ermitano. On both monthly and wekly levles, the streamflows are concluded to be log-Pearson Type III distributed as indicated by the normalizing transformation used which is the combination of logarithmic and Wilson-Hufferty transformations. A similar model structure has also been found for modeling and generation of turbine operating hours time series at the Valdesia reservoir with bivariate dependence on Paso del Ermitano streamflows. Knowledge of the time series structure of the above said processes could be valuable to future analysis and applications such as data transposition, regional flood estimation and sampling frequency design.

1.4 ORGANIZATION OF THE VOLUME

The work involved in hydrologic studies are reported in five subsections. The general characteristics of the watershed physiography, vegetation, etc. and the details of availability and quality of data are included in Section 1.5. The development of hypothetical storms Standard Project Storm and the Probable Maximum Precipitation is discussed in Section 1.6. The details of rainfall-runoff modeling including the calibration of the selected HEC-1 model and its application to comupte hypothetical floods are included in Section 1.7. In Section 1.8, the development, calibration, testing and application of the SAC-KW model for real-time flood forecasting is discussed. Finally, Section 1.9 deals with the development and application of the stochastic models of streamflow and number of hours of energy generation.

1.5 NIZAO WATERSHED

1.5.1 Physiography

The Nizao Watershed is located in the south central part of the Dominican Republic (Figure 1.5.1). The drainage area up to the Valdesia reservoir which is located approximately 50 km away from the confluence of Nizao river and the Atlantic Ocean is about 900 sq. km. The watershed has a distinct elongated shape with a predominant orientation in the NW-SE direction (see Figure 1.5.2). Most of the headwater areas have high relief with main channel slopes reaching as much as 8 to 10 percent. The drop in elevation from the highest point to the Valdesia dam site is about 2500 meters. No significant flood plains exist in the entire Nizao watershed.

1.5.2 Vegetation

The watershed is covered primarily with forest and pasture. Less than 8 percent of the watershed is covered with agricultural lands.

1.5.3 Hydrometeorological Data

Precipitation data: A list of the precipitation data received from INDRHI and the Meteorology Agency is included in Table 1.5.1. Table 1.5.2 shows the available hourly precipitation data that was obtained in computer tape. For purposes of data analysis the nine computer files corresponding to these stations were used to create yearly files containing the hourly data. The precipitation data availability for station in and around Nizao watershed is shown in the form of a bar chart in Figure 1.5.3.

Climatological Data: Table 1.5.3 shows the stations in and around Nizao, for which climatological data is available. The evaporation data was used in the calibration of the real-time streamflow forecast model.

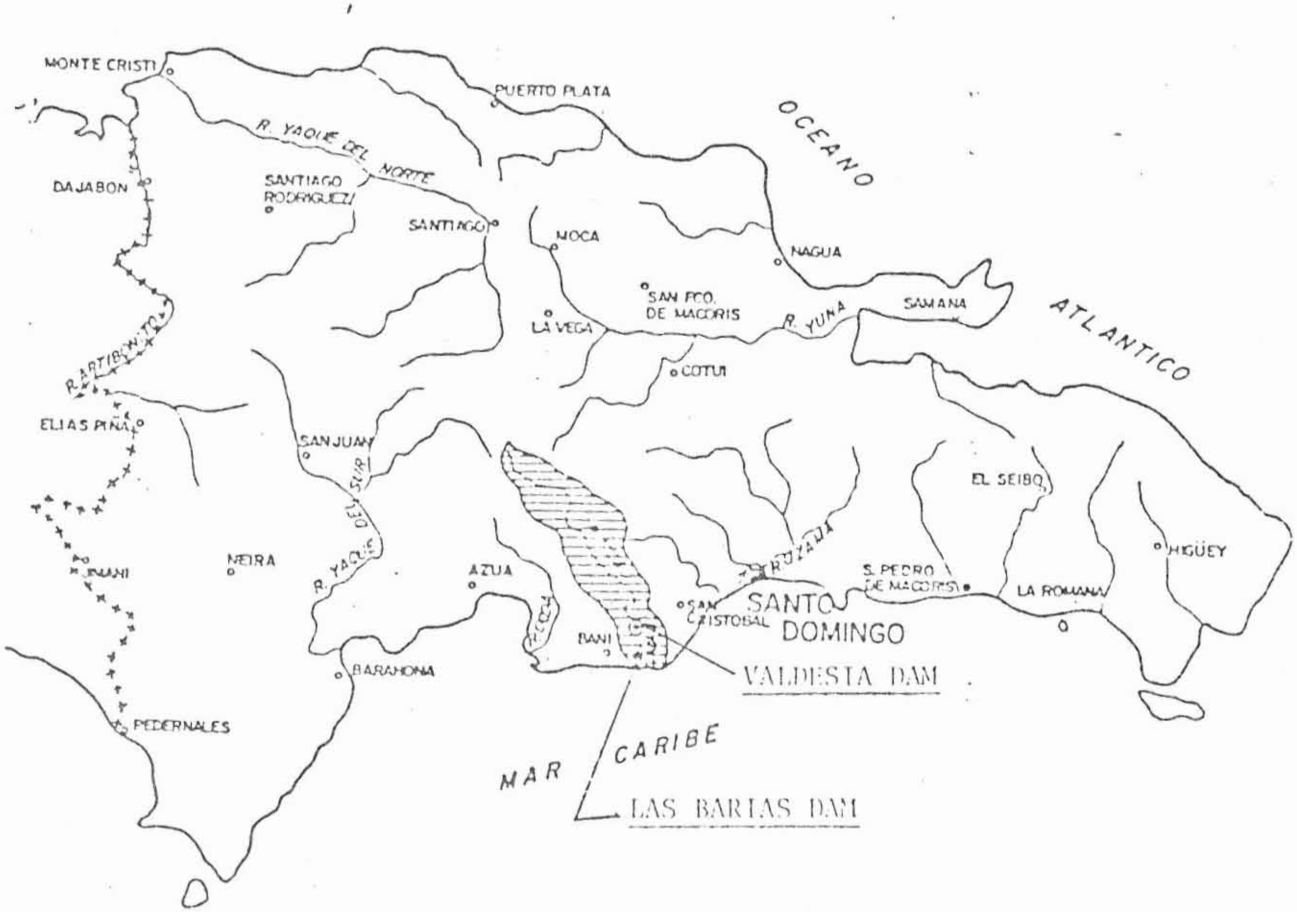


Figure 1.5.1. Location of the Nizao watershed in the Dominican Republic.

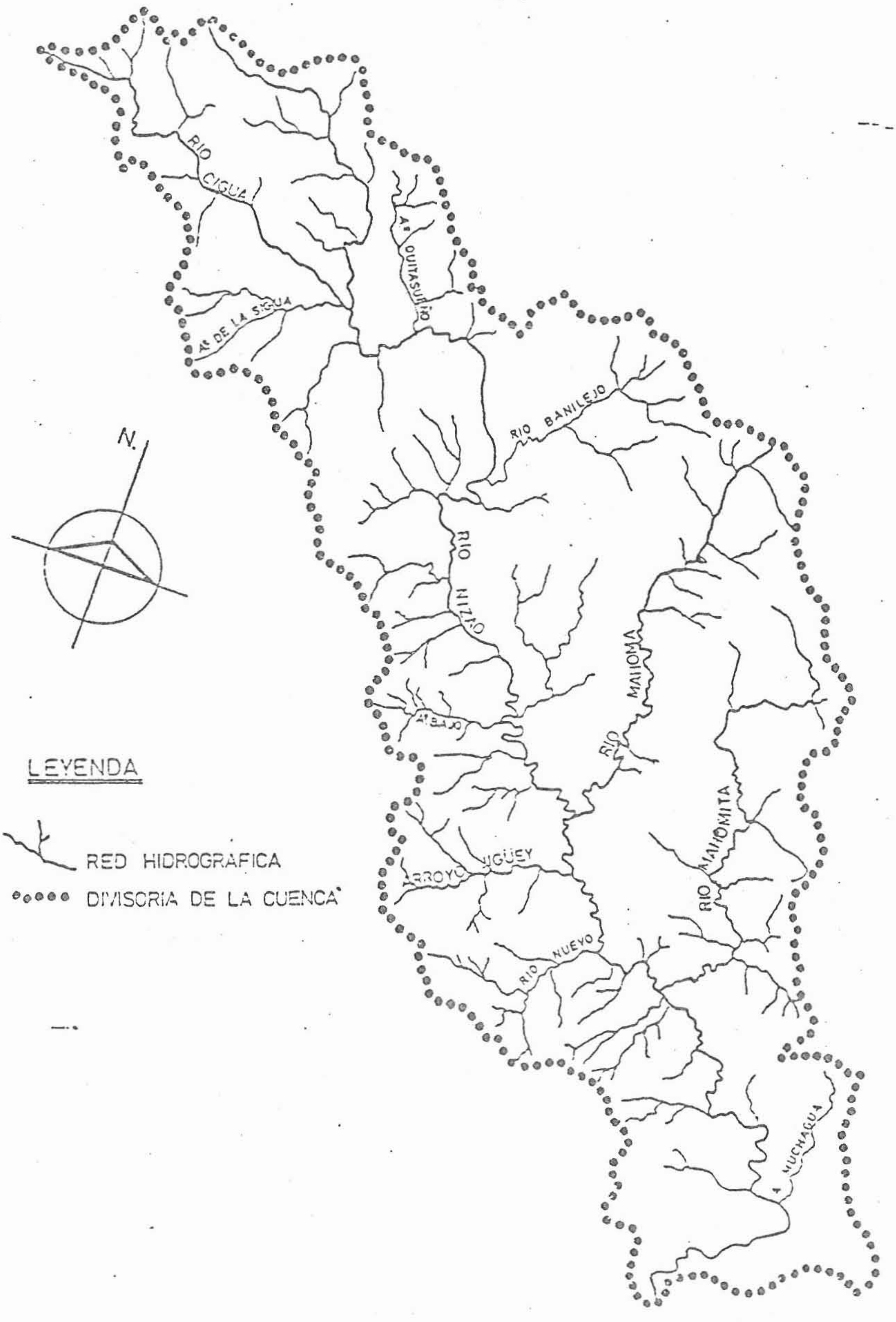


Figure 1.5.2. Nizao river basin.

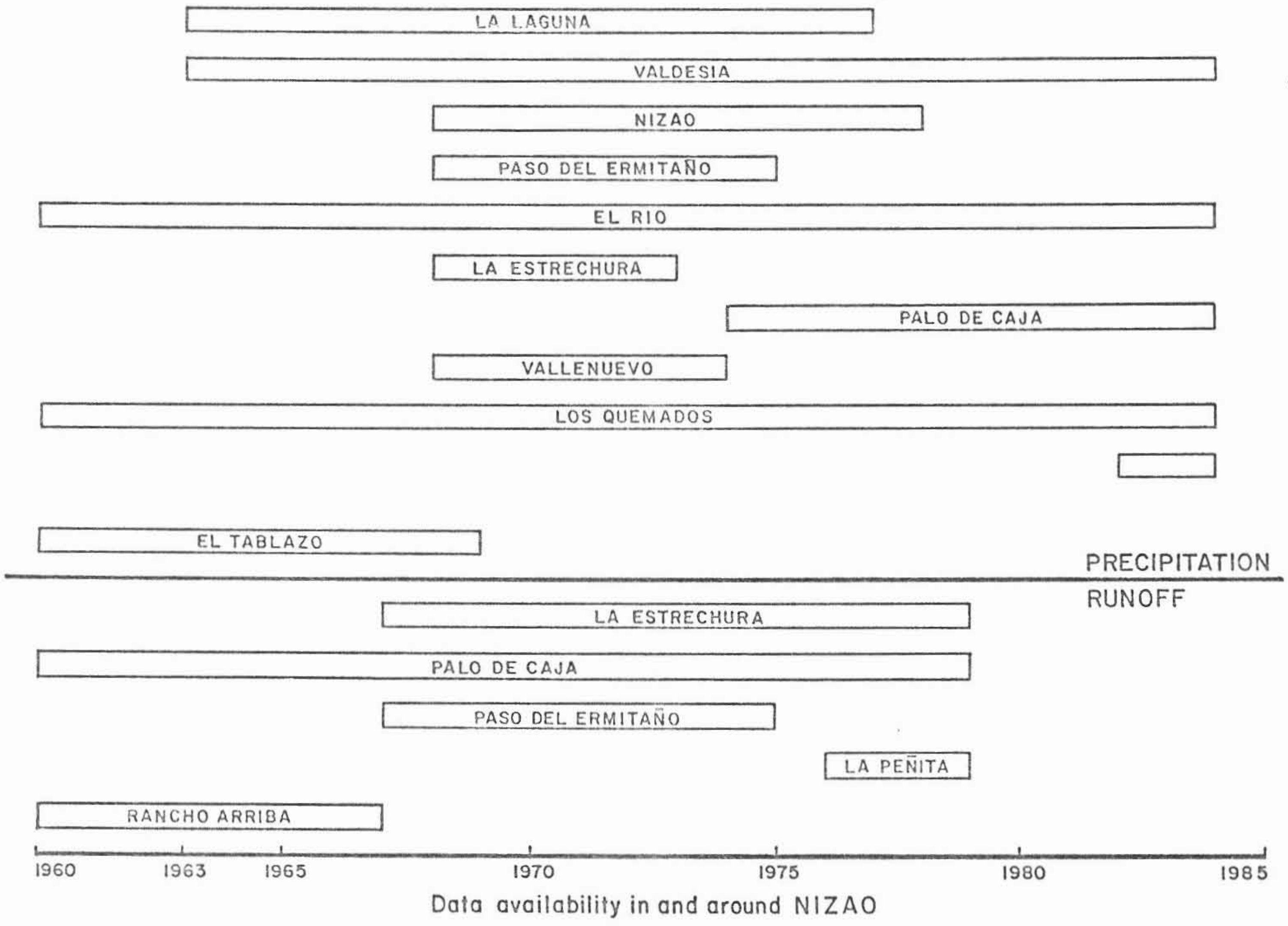


Figure 1.5.3. Precipitation and runoff data availability for stations in and around Nizao watershed.

TABLE 1.5.1 PRECIPITATION DATA

Station Name	Basin	Type	Start	End	Lat.	Lon.	Tap
La Laguna	Nizao	Day	12/62	12/77	18°32'30"	70°24'45"	Yes
Nizao	Nizao	Day	1/68	3/78	18°36'53"	70°27'07"	Yes
Paso Del Ermitano	Nizao	Day	4/68	11/75	18°26'00"	70°16'00"	Yes
Los Cacaos	Nizao	Day	8/67	7/70	18°31'40"	70°18'00"	Yes
Azua Hatillo	Ocoa	Day	8/69	3/84	18°23'40"	70°32'20"	Yes
Valdesia	Nizao	Day	2/63	7/84	18°24'30"	70°16'50"	Yes
La Estrechura	Nizao	Day	1/68	12/73	18°43'40"	70°29'00"	Yes
Presa Mana	Haina	Day	11/82	7/84	18°36'28"	70°12'55"	Yes
Presa Isa	Haina	Day	11/82	7/84	18°36'28"	70°12'32"	Yes
Quija Quieta	Nizao	Day	10/76	4/79	18°13'49"	70°27'31"	Yes
Engombre	Haina	12 hr	1/77	7/83	18°27'00"	70°00'07"	No
Palo De Caja	Nizao	Day	5/74	10/84	18°31'50"	70°24'00"	Yes
Valle Nuevo	Y. Del Sur	Day	1/68	6/74	18°49'27"	70°40'58"	Yes
Constanza	Y. Del Sur	Day	1/68	12/79	18°54'40"	70°43'00"	Yes
Guayabal	Y. Del Sur	Day	3/79	9/84			Yes
Los Quemados	Yuna	Day	1/60	10/84	18°53'30"	70°27'30"	Yes
Juma-Bonao	Yuna	Day	12/70	9/84	18°54'00"	70°23'10"	Yes
El Rio (Constanza)	Y. Del Sur	Day	6/60	9/84	18°58'30"	70°37'40"	Yes
Esta Bania	Grande Del Med.	Day	9/69	10/84	18°27'20"	70°38'45"	Yes
El Tablazo	Nigua	Day	8/60	1/69	18°29'10"	70°10'50"	Yes
Rancho Arriba	Nizao	Mon	1/39	12/80	18°42'	70°27'	No
Padre Las Casas	Y. Del Sur	Mon	1/38	12/83			No
Bani	Bani	Mon	1/36	12/83	18°16'	70°20'	No
Villa Autagracia	Haina	Mon	1/38	12/83			No
Azua	Via	Mon	1/31	12/83			No
Valdesia	Nizao	Hour	2/63	5/83	18°24'30"	70°16'50"	No
La Laguna	Nizao	Hour	12/62	11/77	18°32'30"	70°24'45"	No
Nizao	Nizao	Hour	1/63	4/78	18°36'53"	70°27'07"	No
Medina	Haina	12 hr	10/79	7/84	18°32'06"	70°08'40"	No
Quija Quieta	Nizao	12 hr	4/79	4/79	18°13'49"	70°27'31"	No
Medina	Haina	Day	3/76	12/84	18°32'06"	70°08'40"	Yes
Rancho Arriba	Nizao	Day	3/39	12/84	18°42'	70°27'	No
Padre Las Casas	Y. Del Sur	Day	10/38	12/84			No
Bani	Bani	Day	1/36	12/84	18°16'	70°20'	No
Villa Altagracia	Haina	Day	8/38	12/84			No
Azua	Via	Day	1/31	12/84			No

TABLE 1.5.2 HOURLY PRECIPITATION

STATION NAME	BASIN	START	END
Valdesia	Nizao	2/63	5/83
La Laguna	Nizao	12/62	5/78
Nizao	Nizao	1/63	4/78
Engombe	Haina	5/72	6/84
Palo De Caja	Nizao	2/79	9/83
Valle Nuevo	Y. Del Sur	9/77	3/83
El Eio (Const.)	Y. Del Sur	1/77	12/84
Los Quemados	Yuna	1/65	7/84
Juma-Bonao	Yuna	7/71	5/82

TABLE 1.5.3 CLIMATOLOGICAL DATA

CLIMATOLOGICAL REPORTS: Precipitation, evaporation, temperature, humidity, wind speed, cloudiness , radiation, pressure) (printouts)

CODE	STATION	BASIN	START	END	LAT.	LON.
34001	Engombe	Haina	10/68	7/84	18°27'00"	70°00'07"
34002	Medina	Haina	10/79	7/84	18°32'06"	70°08'40"
38002	Valdesia	Nizao	10/67	7/84	18°24'30"	70°16'50"
38001	Nizao	Nizao	10/67	4/78	18°36'53"	70°27'07"
38009	Quija Quieta	Nizao	10/76	4/79	18°13'49"	70°27'31"

EVAPORATION (Tape)

CODE	STATION	BASIN	START	END	LAT.	LONG.	TYPE
34001	Engombe	Haina	/77	/84	18°27'00"	70°00'07"	Daily

TABLE 1.5.4 RUNOFF DATA

Station Name	Basin	Type	Start	End	Lat.	Long.	Tape
La Estrechura	Nizao	Day	10/67	8/79	18°43'47"	70°29'00"	Yes
Palo De Caja	Nizao	Day	10/56	8/79	18°33'17"	70°22'52"	Yes
Paso Del Ermitano	Nizao	Day	11/67	10/75	18°26'02"	70°15'43"	Yes
Rio Abajo	Nizao	Day	5/58	10/67	18°35'08"	70°25'05"	Yes
La Penita	Nizao	Day	10/76	7/79	18°27'19"	70°16'32"	Yes
Caobal	Haina	Day	9/57	7/84	18°35'08"	70°08'57"	Yes
Los Corozos	Haina	Day	6/82	7/84	18°31'23"	70°07'10"	Yes
Arroyo Limon	Ocoa	Day	3/70	11/83	18°29'37"	70°30'43"	Yes
El Recodo	Bani	Day	2/79	9/83	18°22'27"	70°20'24"	Yes
Los Quemados	Yuna	Day	4/62	8/79	18°53'31"	70°27'25"	Yes
Blanco	Yuna/Bl.	Day	11/77	6/84	18°52'56"	70°31'17"	Yes
Maimon	Yuna/Mai.	Day	1/68	6/84	18°53'47"	70°17'71"	Yes
El Tablazo	Nigua	Day	1/59	3/84	18°28'39"	70°10'15"	Yes
Rancho Arriba	Nizao	Day	5/59	10/67	18°42'58"	70°27'59"	Yes
El Cacao	Nizao	Day	1/62	11/83	18°31'41"	70°17'59"	Yes
Los Ranchitos	Ocoa	Day	1/61	12/67	18°26'58"	70°29'55"	Yes
Carrizal	Jura	Day	10/64	10/81	18°32'27"	70°49'14"	Yes
Palomino	Y. Del. S.	Day	1/78	12/83	18°48'06"	70°58'26"	Yes
Mendez	Ocoa	Day	1/56	4/61	18°28'29"	70°30'48"	Yes
La Higuana	Nizao	Day	1/56	12/61	18°22'46"	70°16'22"	Yes

1.5.4 Streamflow Data

Daily Runoff Data: Table 1.5.4 shows the daily runoff data available for gauging stations in Nizao and other surrounding watersheds. The daily streamflow data at stations La Estrechura, Palo De Caja, Paso Del Ermitano, and Rancho Arriba was used for stochastic streamflow generation and in the calibration of the real-time streamflow forecast model. The data availability at these stations is summarized in the form of a bar chart in Figure 1.5.3.

Storm Hydrograph (Stage) Data: Table 1.5.5 presents the data availibility on selected storm hydrographs for stream gauging stations La Estrechura, Palo de Caja, Paso del Ermitano and La Penita. It is noted that the original raw data corresponds to stages observed during storm events and calibrated rating curves needed to be employed to convert them to actual discharges.

Rating Curves: INDRHI provided stage-discharge relations for stations La Estrechura, Palo De Caja, La Penita, and Paso del Ermitano to be used in transforming the hourly stage data to discharges. The plots of these curves are shown in Figures 1.5.4 to 1.5.13. In view of some inconsistencies present in these curves, the raw stage-discharge data were used to develop a new set of rating curves for this study. The development of these new rating curves is explained in detail in Appendix 1.5.A.

Reservoir Levels: In order to supplement the gauged storm hydrograph data, reservoir levels at Valdesia dam for certain major events were obtained from CDE. Hourly reservoir levels were obtained for following periods:

1. August 1-13, 1980

TABLE 1.5.5 HYDROGRAPH DATA OF SELECTED STORMS

Starting				Ending				Estrec	Palo de	La Peni	Ermitan	STORM
YR	MON	DAY	HR	YR	MON	DAY	HR					ID
69	Jul	18	1	69	Jul	22	24	Incom	N/A	N/A	Incomp	A
70	Jul	7	1	70	Jul	12	24	Incom	N/A	N/A	Comp	B
70	Nov	6	1	70	Nov	12	24	N/A	N/A	N/A	Comp	C
70	Dec	7	1	70	Dec	16	24	N/A	N/A	N/A	Comp	D
72	Mar	10	1	72	Mar	13	24	Comp	Comp	N/A	Comp	E
72	May	20	1	72	May	25	24	Incom	Comp	N/A	Comp	F
74	Aug	1	1	74	Aug	13	13	Incom	Comp	N/A	Comp	G
74	Sep	11	1	74	Sep	19	24	Incom	Comp	N/A	Comp	H
74	Oct	21	1	74	Oct	26	24	Incom	Comp	N/A	Incom	I
75	Sep	16	1	75	Sep	21	11	Incom	N/A	N/A	Comp	J
75	Oct	22	1	75	Oct	27	14	Incom	N/A	N/A	Comp	K
75	Nov	1	1	75	Nov	12	12	Incom	N/A	N/A	Comp	L
77	May	20	1	77	May	25	24	Incom	Comp	Comp	N/A	M
77	Nov	21	1	77	Nov	27	24	Incom	Comp	Comp	N/A	N
77	Dec	27	1	78	Jan	6	24	N/A	Comp	Comp	N/A	O
78	May	23	1	78	May	31	24	Incom	Comp	Comp	N/A	P
78	Aug	2	1	78	Aug	8	24	Incom	Comp	Comp	N/A	Q
79	Jun	29	1	79	Jul	5	24	N/A	N/A	Comp	N/A	R

Notes:
Incom = Some hourly data is missing
Comp = Complete - we have this data at CSU
N/A = Not available - no record available

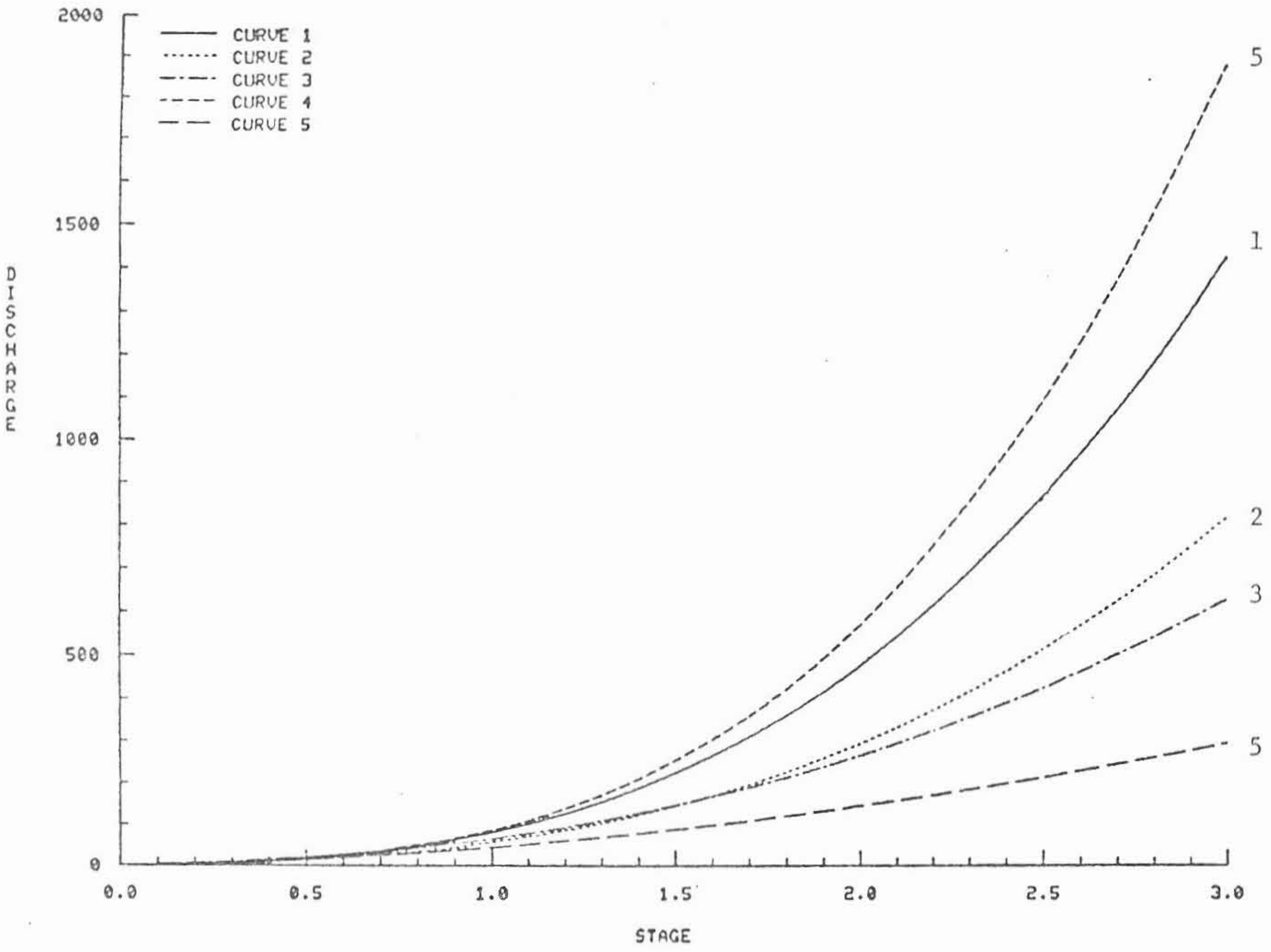


Figure 1.5.4 RATING CURVES FOR LA ESTRECHURA

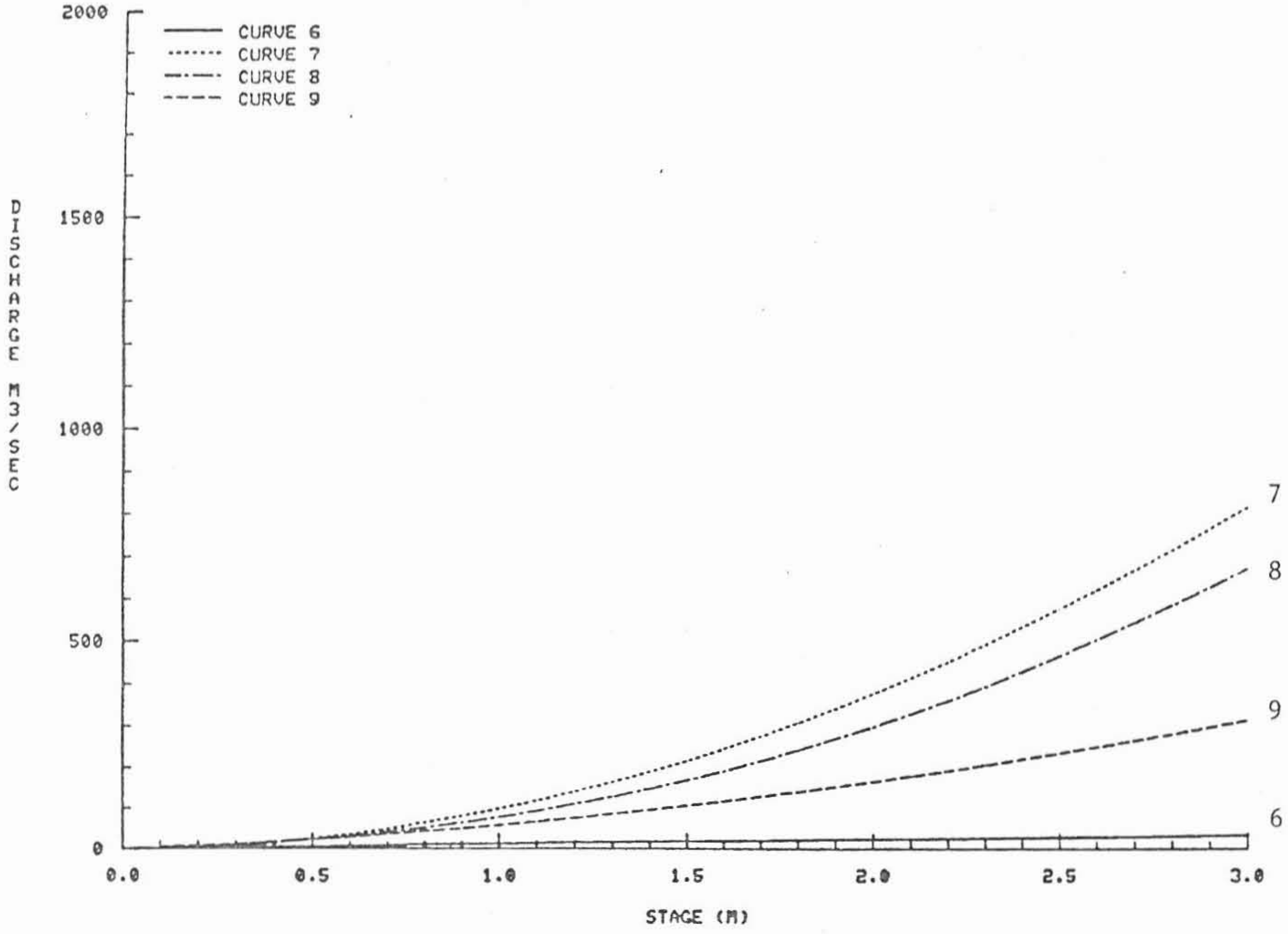


Figure 1.5.5 RATING CURVES FOR LA ESTRECHURA

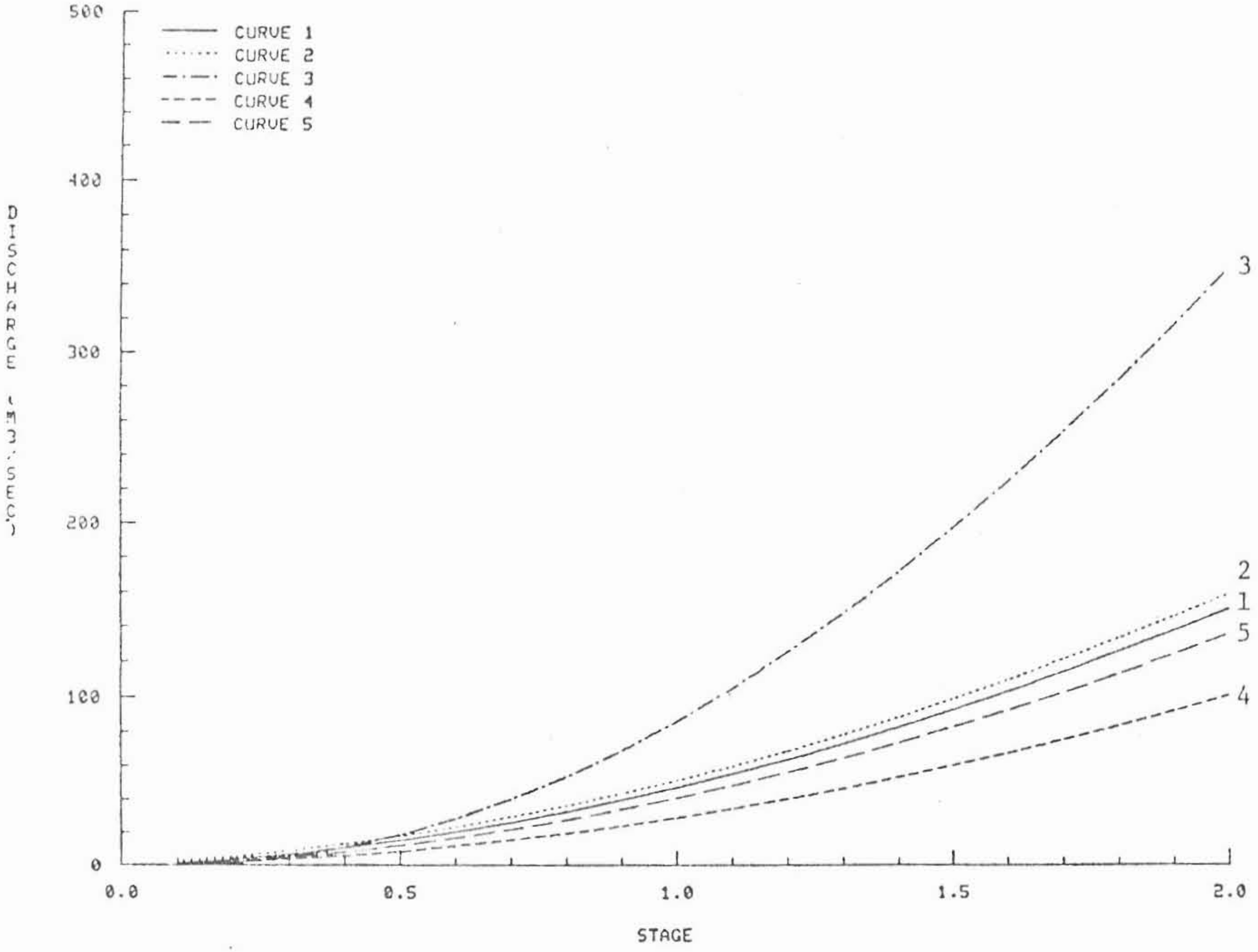


Figure 1.5.6 RATING CURVES FOR PALO DE CAJA

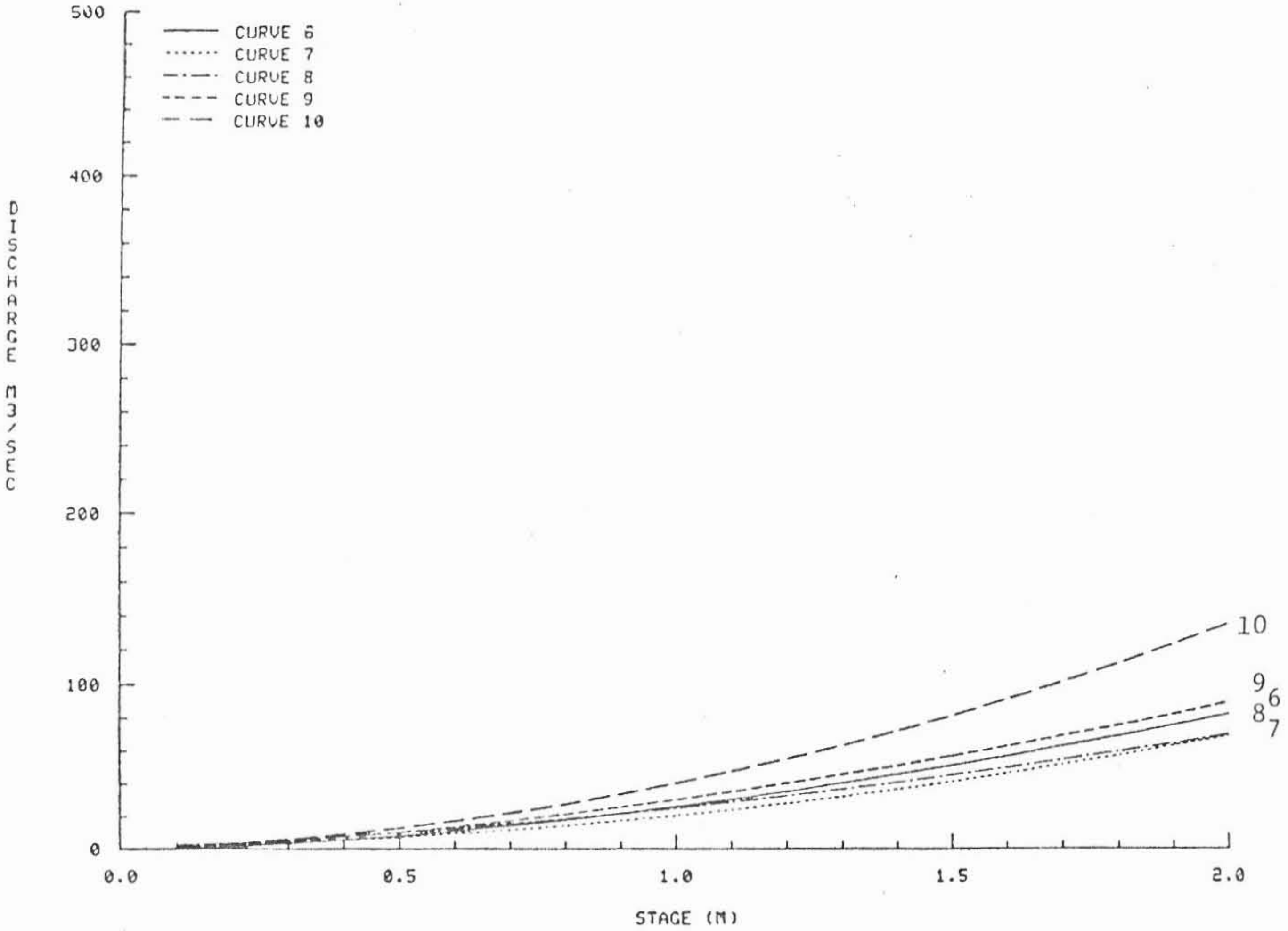


Figure 1.5.7 RATING CURVES FOR PALO DE CAJA

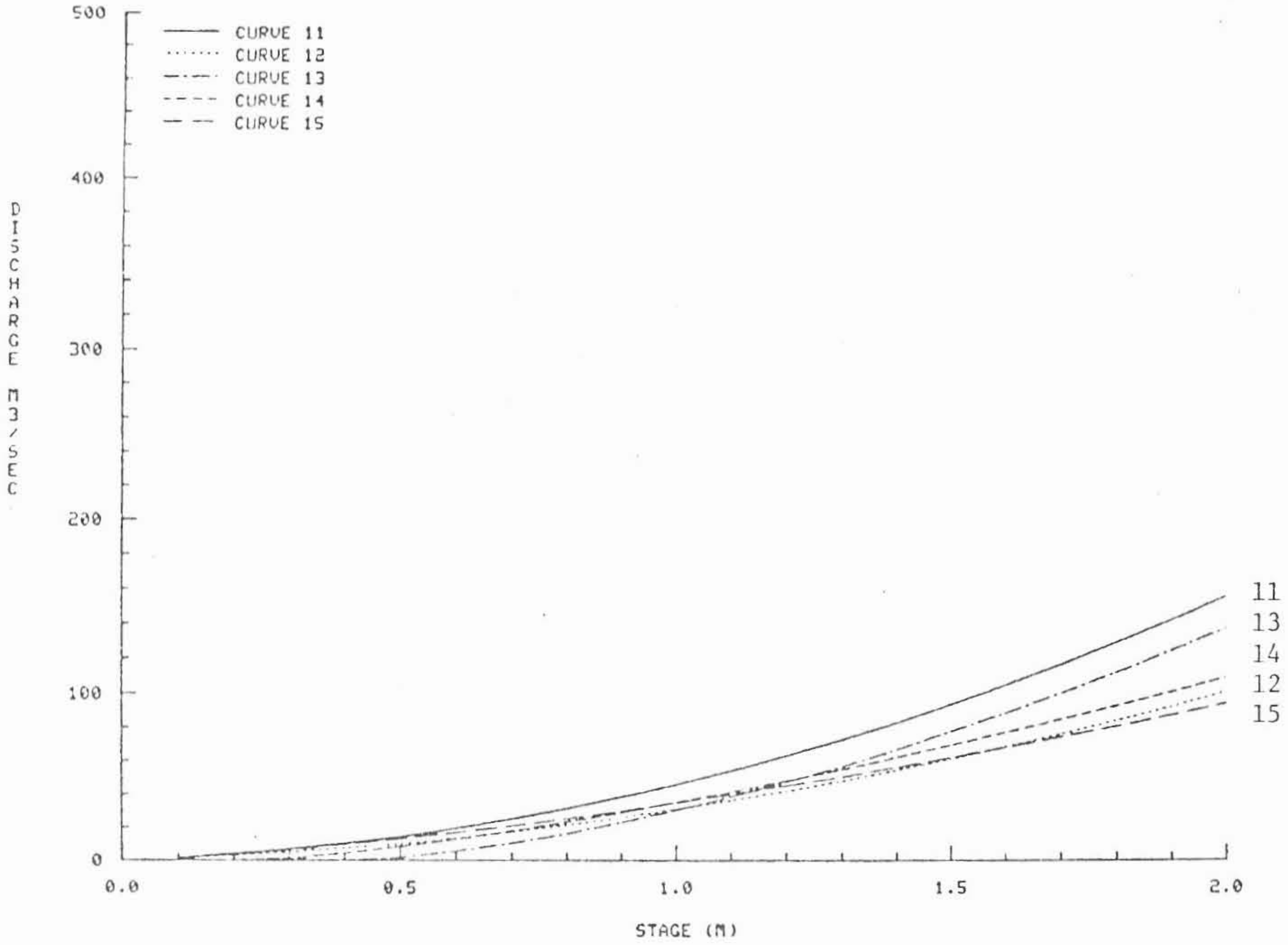


Figure 1.5.8 RATING CURVES FOR PALO DE CAJA

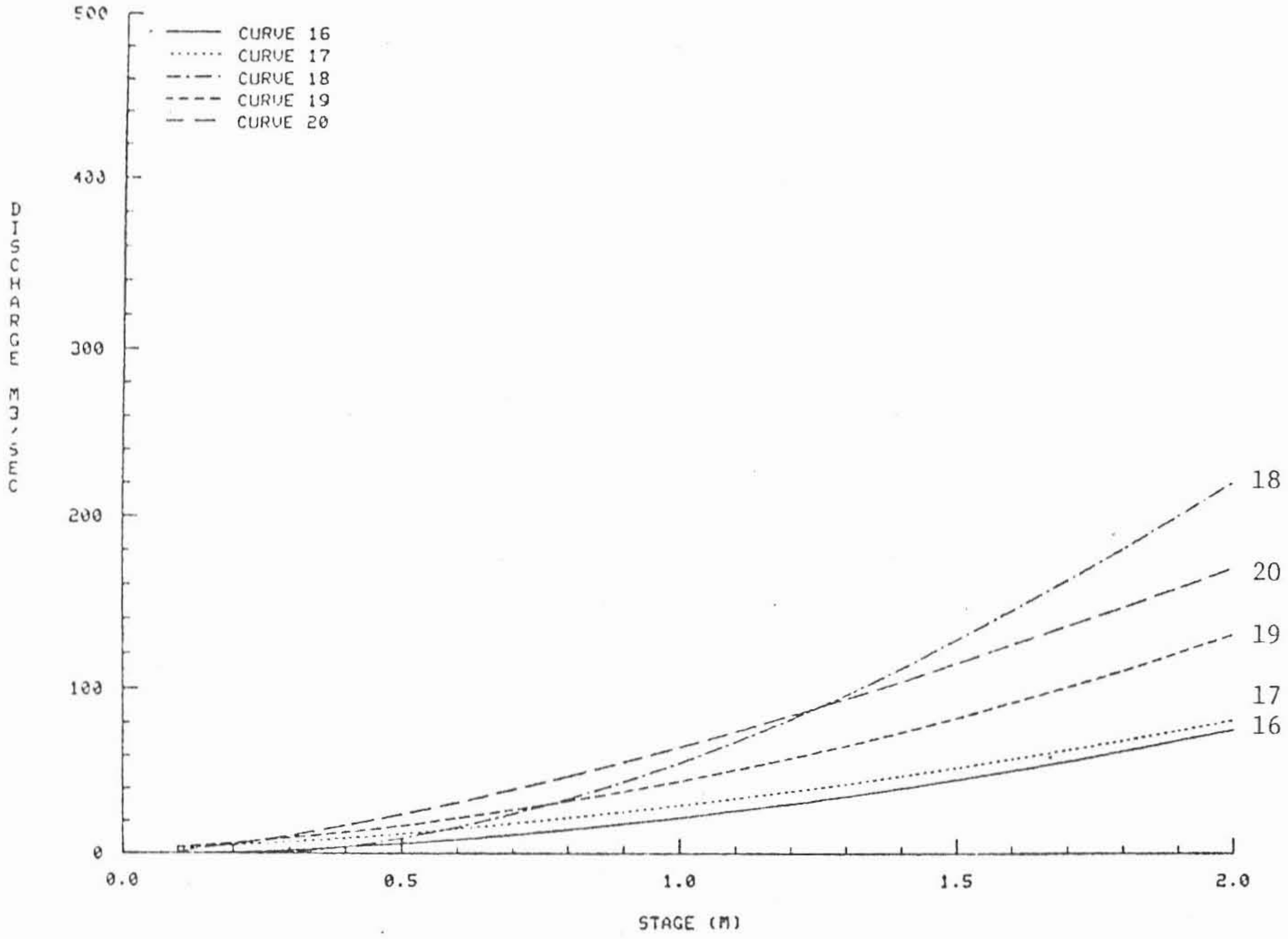


Figure 1.5.9 RATING CURVES FOR PALO DE CAJA

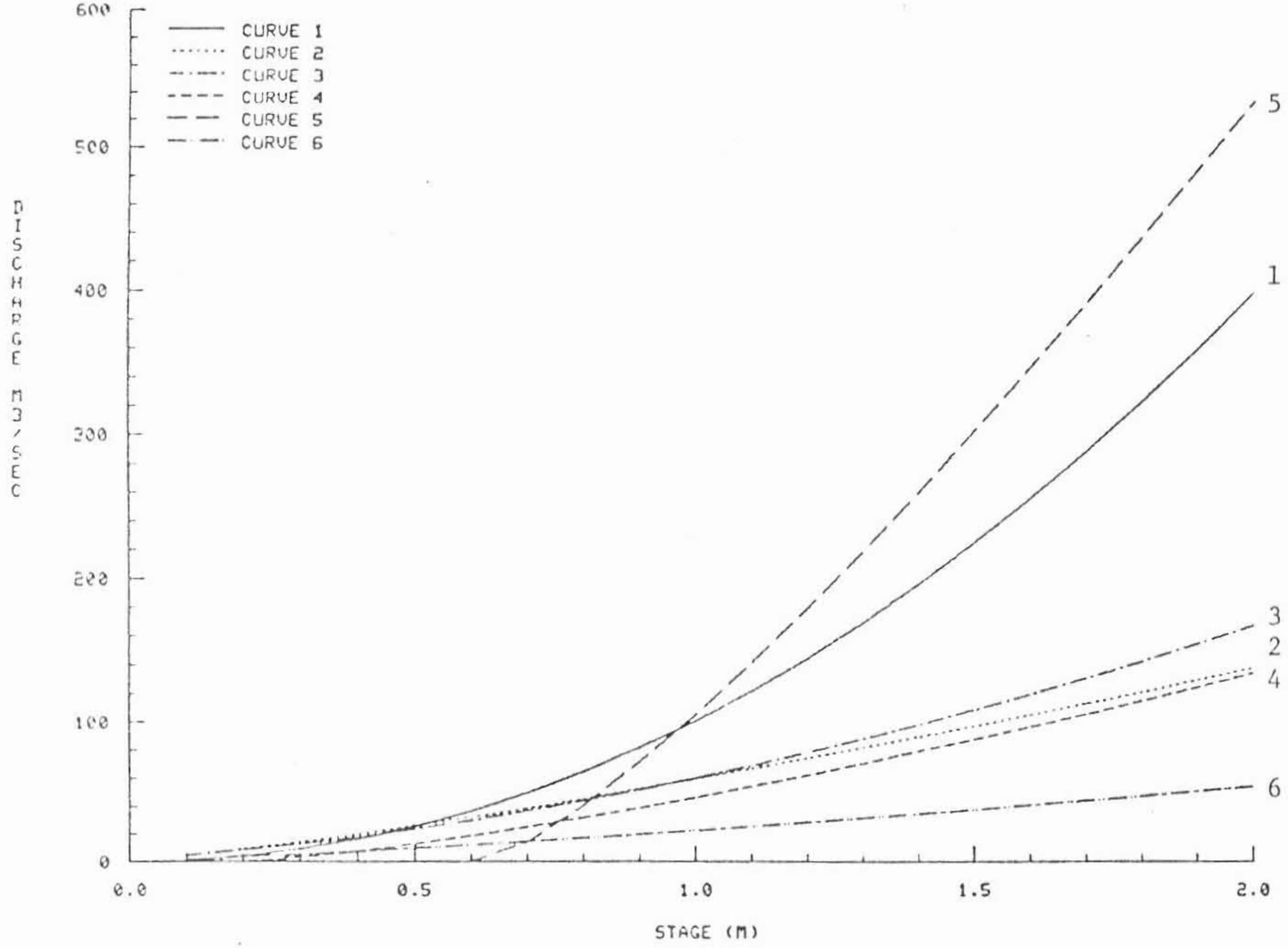


Figure 1.5.10 RATING CURVES FOR PASO DEL ERMITANO

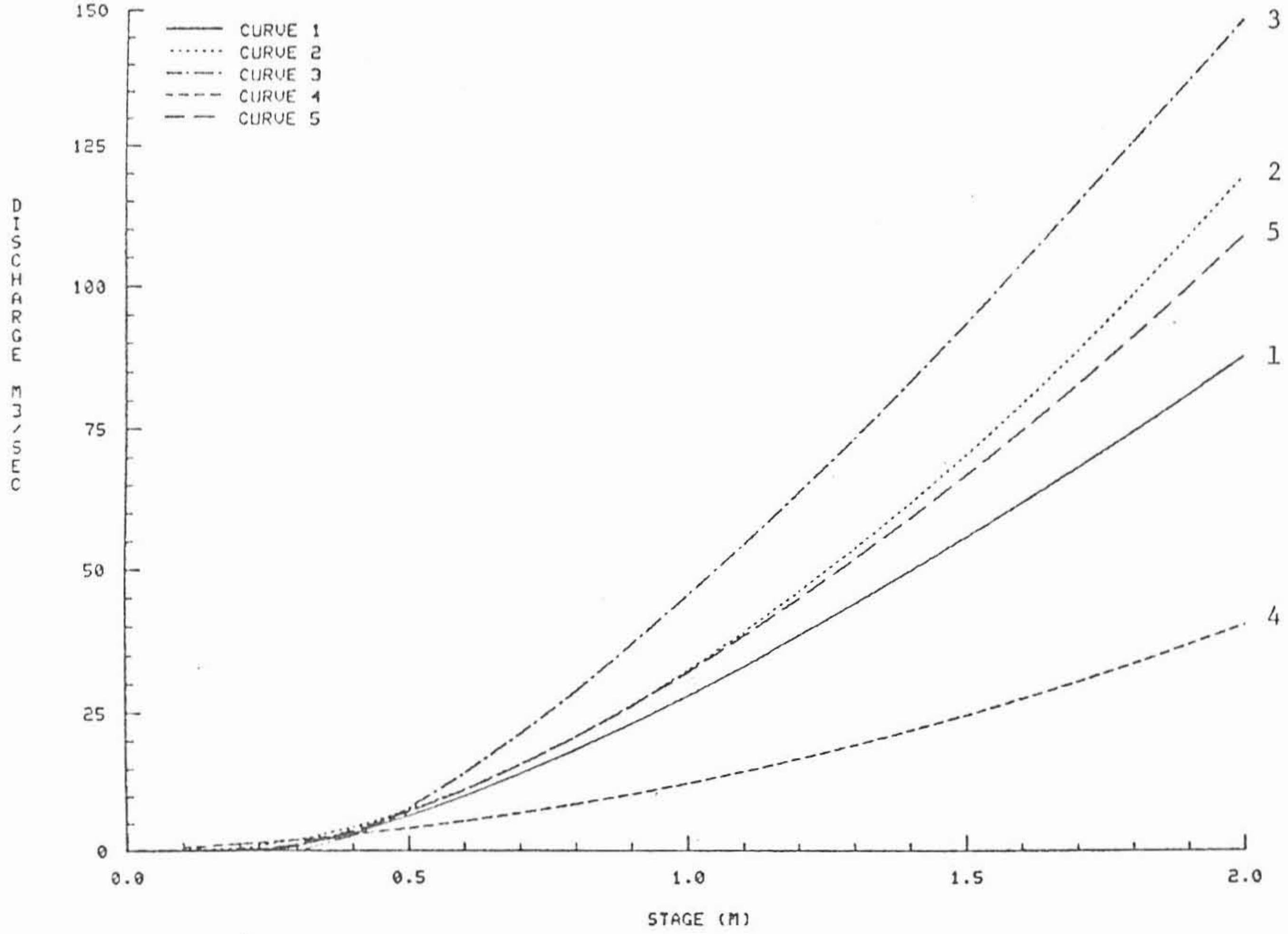


Figure 1.5.11 RATING CURVES FOR LA PENITA

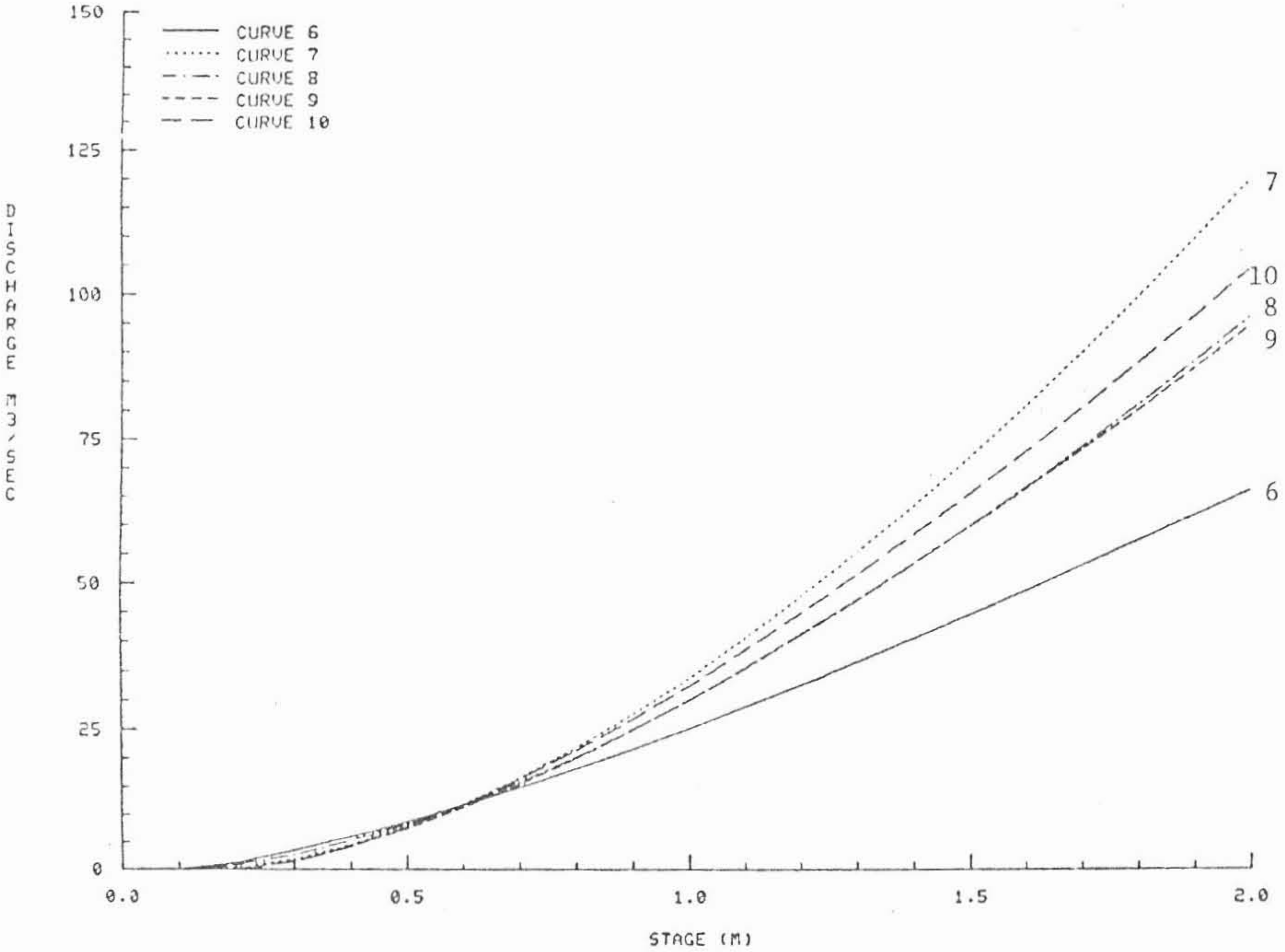


Figure 1.5.12 RATING CURVES FOR LA PENITA

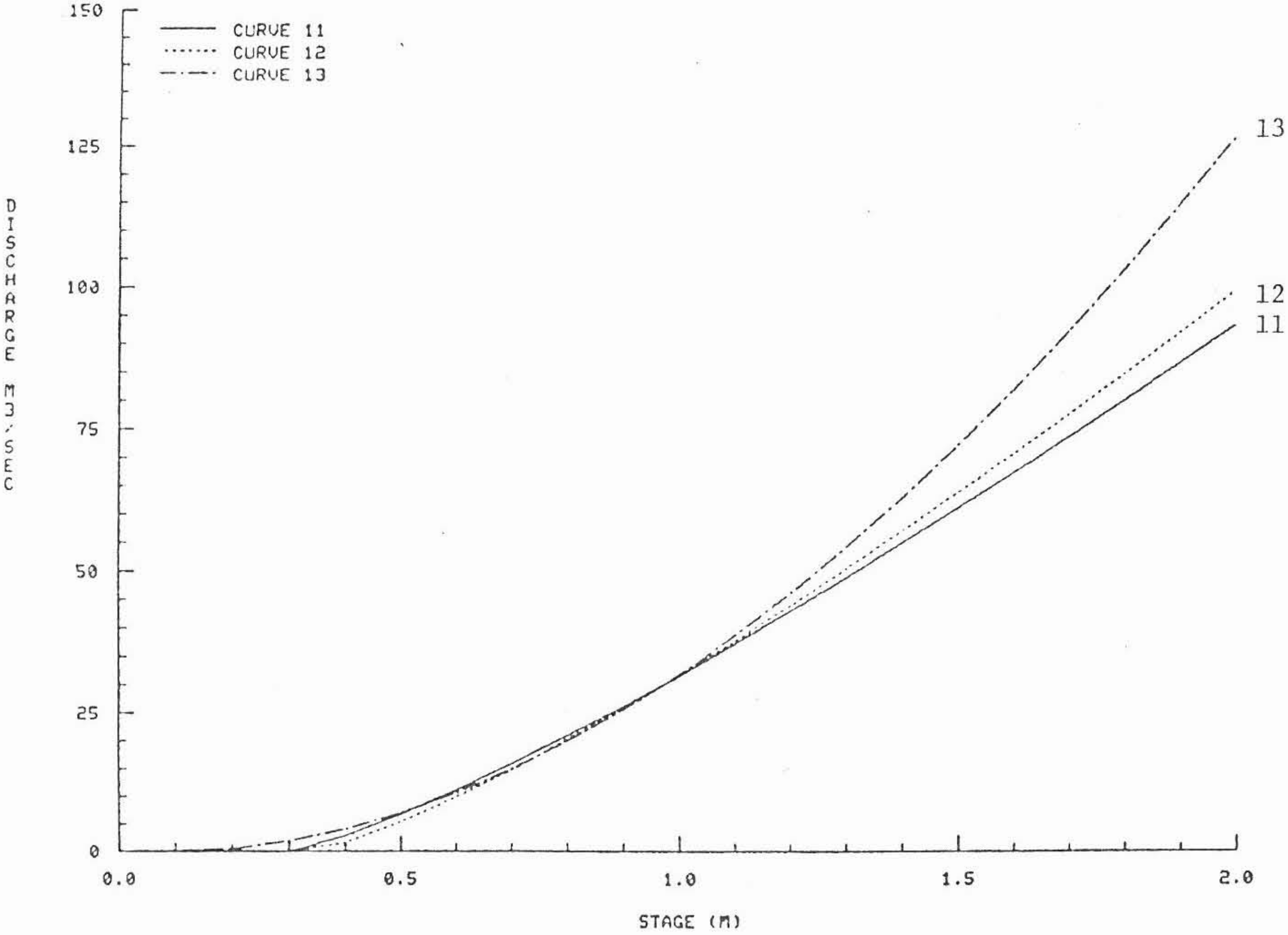


Figure 1.5.13 RATING CURVES FOR LA PEÑITA

2. May 6-20, 1981
3. April 10-20, 1983
4. September 13-14, 1985
5. October 23-26, 1985

For the two events in 1985, the data on operation of the spillway gates and turbines of Valdesia dam were also obtained. The two inflow hydrographs reconstructed using these data were found to be very valuable in rainfall-runoff model calibration.

1.5.5 Quality of Data

During the course of the study several obvious inconsistencies in rainfall and streamflow data were detected. The quality of data was of utmost concern since majority of modeling work to be carried out depended heavily on the accuracy of data. In general, it was felt that the entire data recording and processing procedures of INDRHI needs a careful review. Some specific problems are described below.

The first problem was encountered when the stage hourly data were transformed into discharges using the stage discharge relations provided by INDRHI. The curve numbers shown in Figures 1.5.4 to 1.5.13 refer to different equations corresponding to different time interval in which each is applicable. The equation parameters and dates are shown in Tables 1.5.6 to 1.5.11.

Very large differences are observed in some cases between consecutive curves; such is the case of curves 3 and 4 at La Penita, 5 and 6 at Paso del Ermitano, 4 and 5 at Estrechura and 3 and 4 at Palo De Caja. Curves 3 and 4 at La Penita are applicable at two consecutive periods with break point at May 22, 1977. This date coincides with storm M in the hydrograph classification and could mean that the flood wave modified the cross section at the station. But curve 4 gives discharges more than three times smaller than those obtained with curve 3, and that is very unlikely to be true. Usually a big flood causes scour which should increase discharges for a given level. The same case is present in curves 4 and 5 at La Estrechura, with break point at August 8, 1974, which coincides with storm G.

After these problems were detected, the information on the stage-discharge data used to obtain these curves were received. They were analyzed in conjunction with cross section data to come out with the new stage-discharge relations. While developing the new stage-discharge curves, some inconsistencies were found with the data. All of them are explained in Appendix 1.5.A dealing with the development of the new stage-discharge relations, but a special case will be pointed out here. In the data received for station El Ermitano, there are two stages measured on December 11, 1970. The values in the stage-discharge data give readings of 1.75 m and 1.93 m. However, storm D has data for the same day and the maximum observed stage is only 1.55 m. The same case is observed on the data from December 14, 1970. Two stages 1.81 and 1.89 m are observed on that date, but the hydrograph data show a maximum of 1.43 m. On March 13, 1972 a stage of 0.47 m is observed while the hydrograph of storm E shows a minimum of 0.64 m for that day.

Even after the new stage-discharge hydrographs were developed, some unrealistic situations still exist. For example, consider the three hydrographs corresponding to storm F (see plot in Section 1.7). The basin area upstream El Ermitano is 800 km^2 and the basin area upstream Palo De Caja is 535 km^2. The volume under the hydrograph at El Ermitano is 123.2 MCM while at Palo De Caja is 28.5 MCM. This means that the subbasins downstream Palo De Caja, that is an area of 265 km^2, must contribute to the total flow with 94.7 MCM, or 357 mm of equivalent excess rainfall depth, but the observed total storm depths have a maximum of only 231 mm at station Valdesia.

From the 18 storms for which hourly streamflow data are available, only four storms were selected for model calibration. In many other cases the runoff appears before the rainfall stations start recording any data. For example, compare the plots corresponding to storm C. The only recording station available inside the basin is Nizao and the only observed streamflow station is El Ermitano. If we superimpose both plots we see that the precipitation recorded in Nizao has no effect in the hydrograph at Ermitano, unless there's a timing error in one of the records. If the precipitation record is lagged 15 hours or more to the back the correct response in the hydrograph is observed. In this case the solution of lagging one series could be used, but when several rainfall and runoff stations are present the problem is more complex. A similar case is observed in storm D.

The hydrographs at storm N shows a very peculiar case. The volume under the hydrograph at station Palo De Caja is larger than the one at La Penita, even though very significant precipitation was observed in the lower subbasins.

When the precipitation data used in the development of the DAD curves was compiled, several discrepancies between the hourly data and the daily data at the same station were detected. In many cases the hourly values added to values completely different from the daily ones.

The results of the HEC-1 calibration presented in Section 1.7 also point out some very severe problems in the timing of the hydrographs.

This was confirmed after checking the calibrated model with two hydrographs reconstructed from reservoir levels. In these two cases the timing seems to be correct, but in the cases of storms A, B, F, and M, we observe sharp differences in the timing of the hydrographs.

APPENDIX 1.5.A

Calibration of Stage-Discharge Curves

Reliable stage-discharge curves are essential tools to convert stage readings into flow discharges, since we only normally measure variations of flow stages. Unfortunately the data used to correlate stage with flow discharge were collected at low flows. Thus a great deal of effort was used to construct and extend stage-discharge curves for gaging stations at La Estrechura, Palo de Caja, La Penita and Ermitano. The procedures of developing these stage-discharge curves are described below:

Step 1: Number of curves to be used for each station:
After plotting all stage-discharge data on logarithm papers for each station, (see Figures 1.5.A.1 through 1.5.A.4) the number of curves to describe the stage-discharge relationship for each station were decided by visual inspection.

Step 2: Separation of the low and high stage data:

For each curve chosen in step 1, we separate the data in two parts. The first part corresponds to stages lower than or equal to the stage of an expected break point which corresponds to the upper end of the low flow cross section. The second part includes stages higher than that of the above break point. For sake of illustration of the curve separation criterion a sketch is shown in Figure 1.5.A.5.

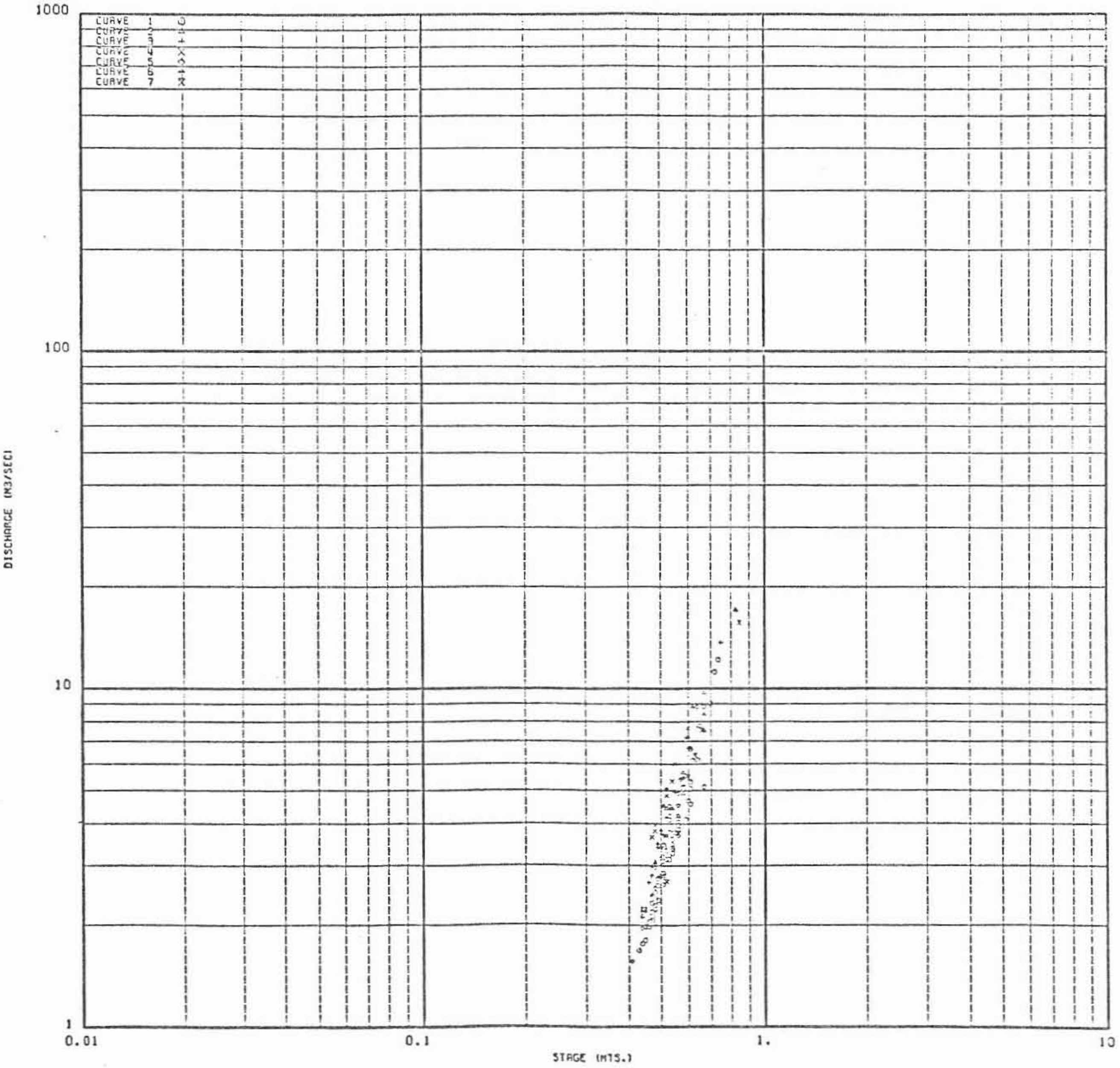


Figure 1.5.A.1. La Estrechura stage-discharge calibration points.

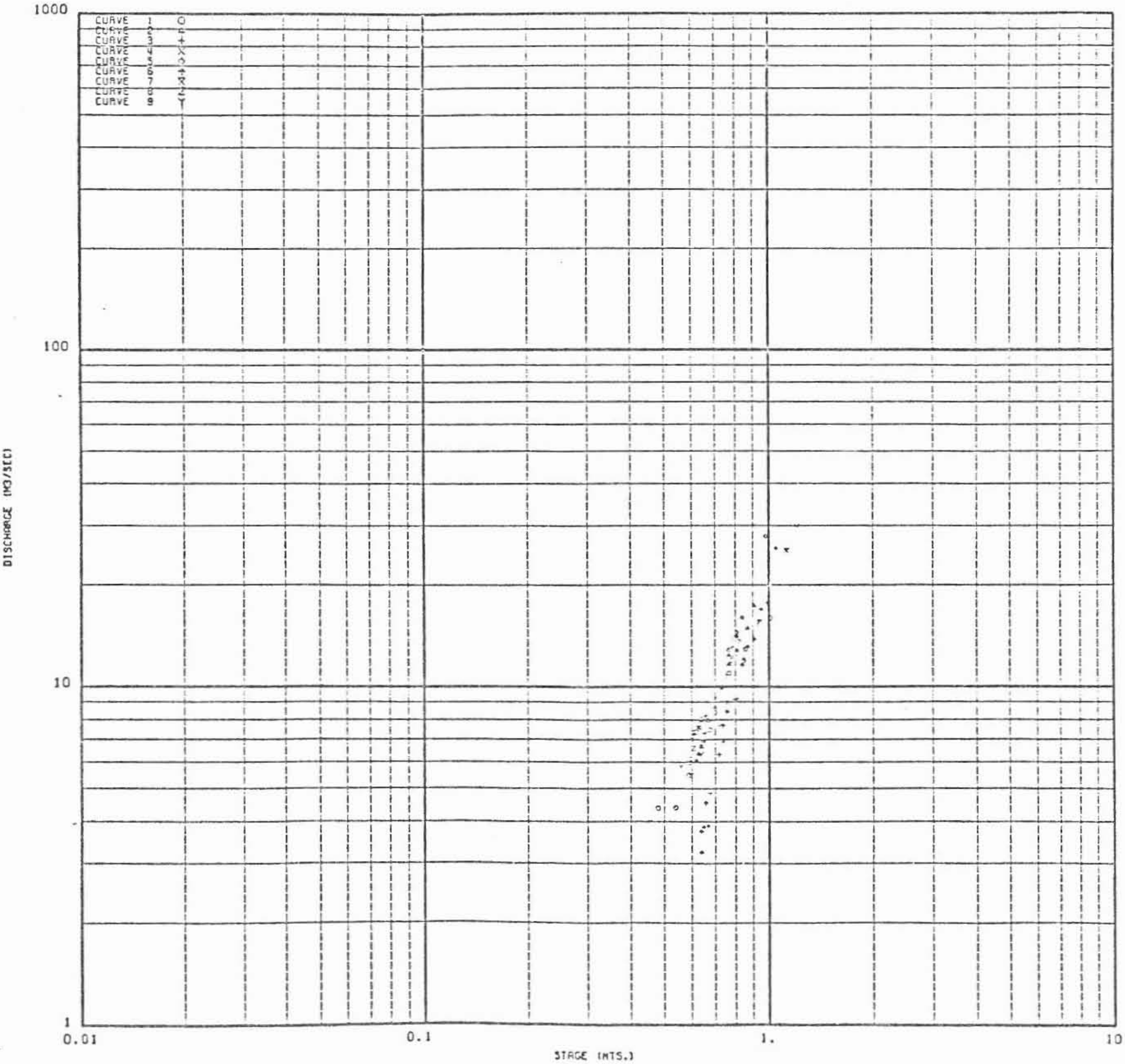


Figure 1.5.A.2. Palo de Caja stage-dishcarge calibration points.

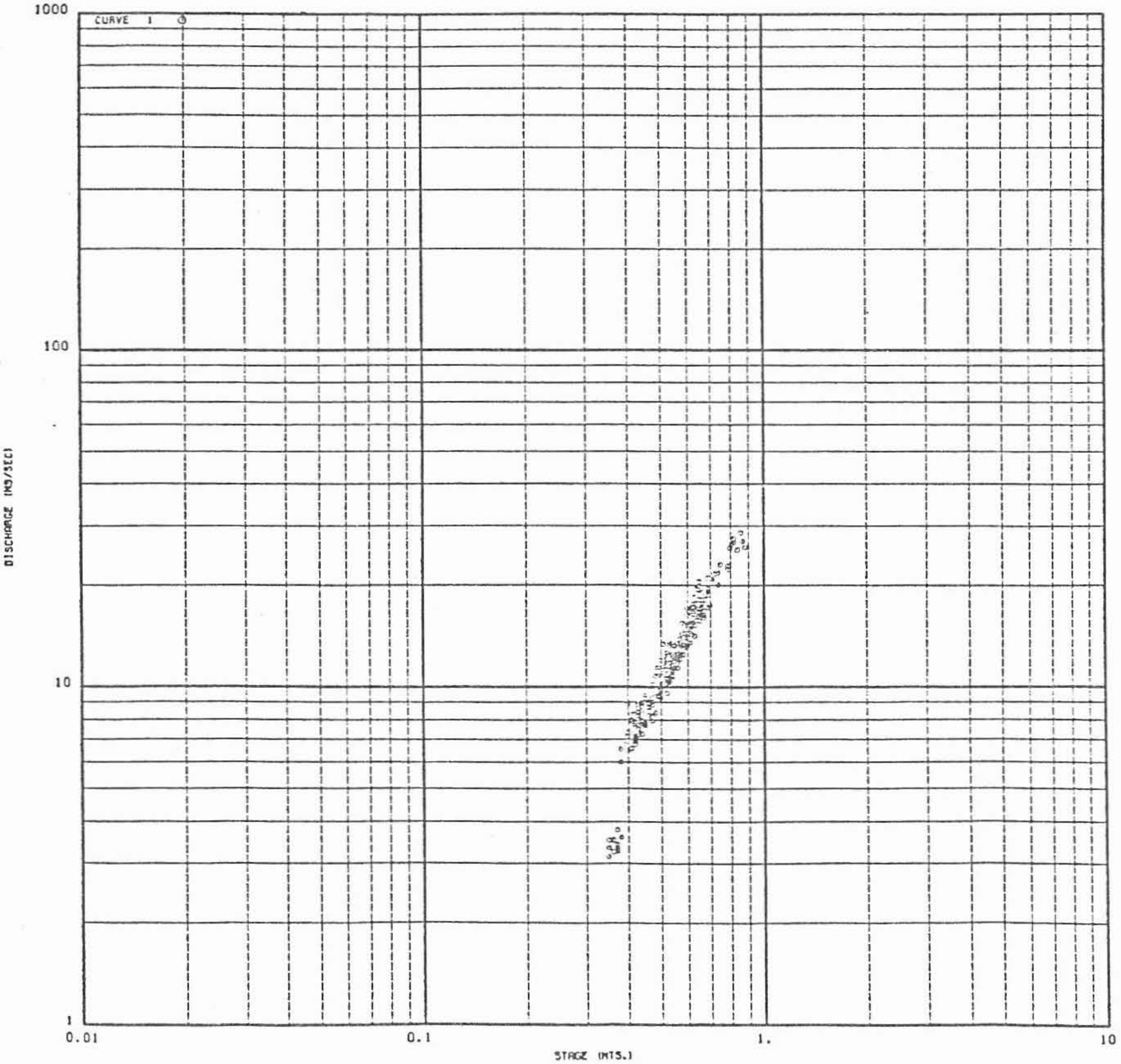


Figure 1.5.A.3. La Penita stage-discharge calibration points.

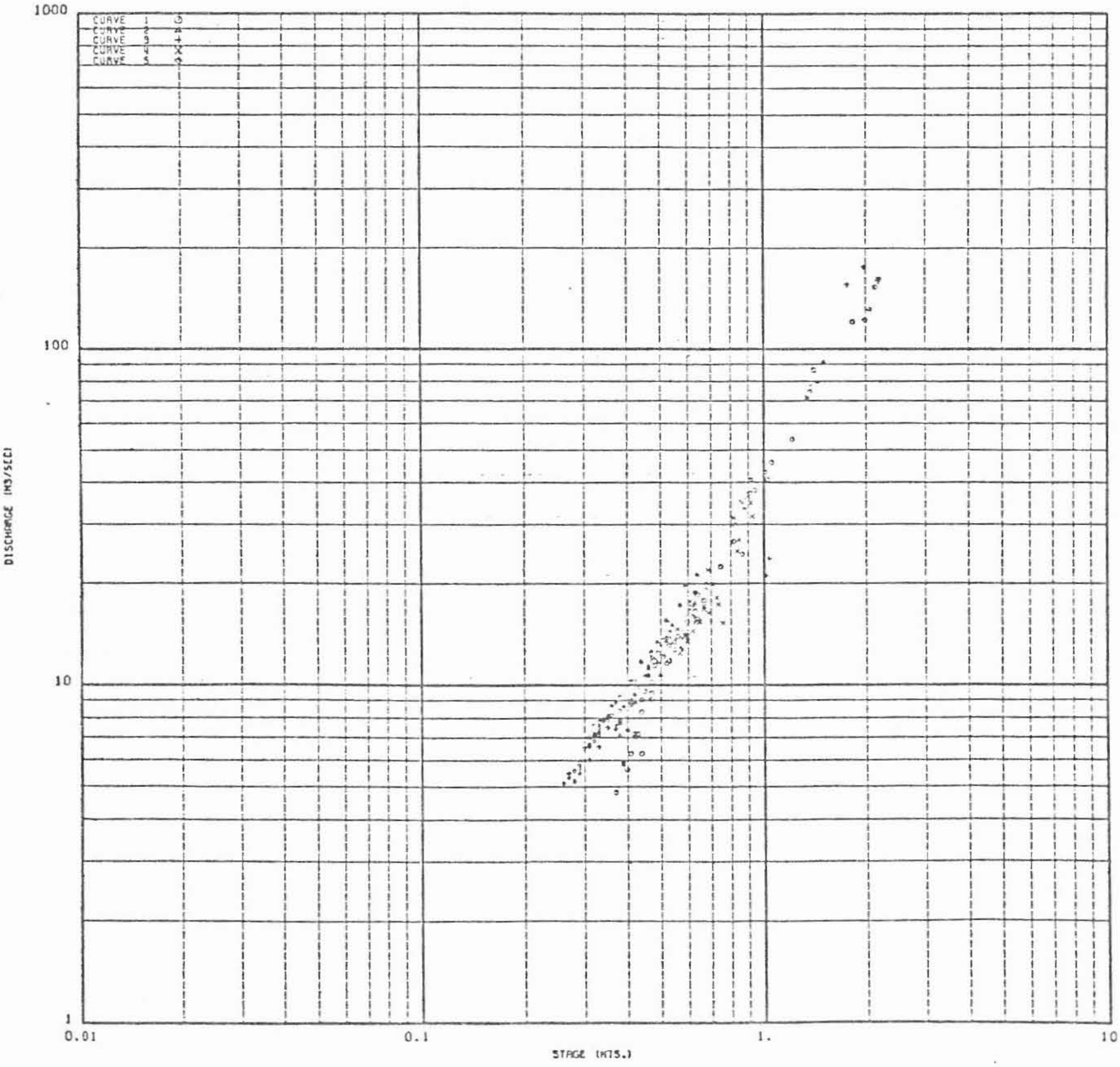


Figure 1.5.A.4. Paso del Ermitano stage-dishcarge calibration points.

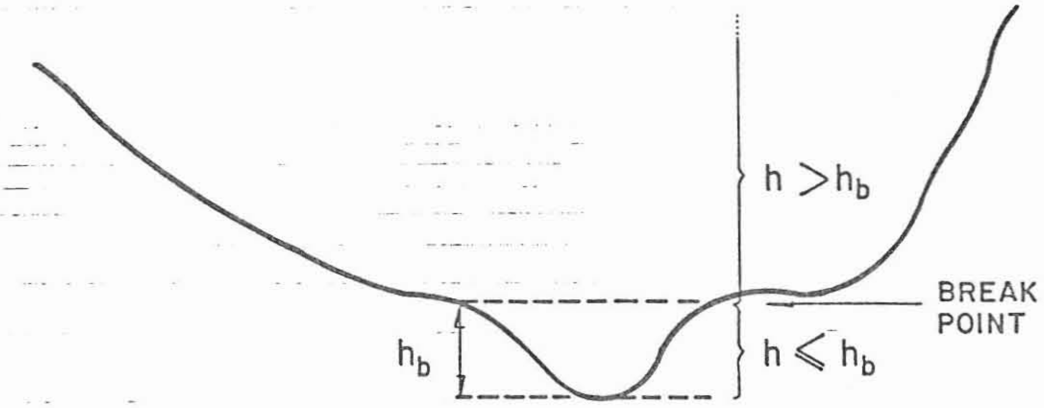


Figure 1.5.A.5 Possible gaging stations cross section shape.

Sometimes we cannot separate the data in two parts because all the stages are either lower or higher than h_b. Therefore, we fit only one curve for such the data.

Since we dispose only of cross sections of May 1985 are available, a rough estimate of the h_b was deduced from the shape of these cross sections.

Step 3: Development of the stage-discharge curves for low stages:

By using the stage and discharge data at low stages (as defined in step 2), and an optimization scheme of the polynomial function, we obtained the values of h_o, c and m corresponding to each low-discharge curve. Same procedure was used for all stages greater than h_b.

Step 4: Decision on the number of curves to be used for stages above h_b:

First, the discharges Q versus $(h+h_o)$~~Y~~ were plotted on a log-log paper, where h_o corresponded to the values obtained in step 3. If all points showed a tendency to scatter around a single straight line, at high stages only one curve will be used. Otherwise several straight lines will be used for each group of points.

Step 5: Development of stage-discharge curve for higher stages:

A single straight line, at high stages, in the logarithmic plot of Q versus $(h+h_o)$ usually indicates that the upper part of the cross section $(h>h_b)$ can be considered as stable. In this case all the cross section rating curves will have the same parameters of the polynomial function except the value of h_o. Each of the rating curves will have its respective h_o.

More than one straight line, at high stages, in the logarithmic plot of Q versus $(h+h_o)$ might be caused by a nonstable upper part of the cross section or a change of the site of the cross section.

Once the high stage-discharge curves are fitted, they may be used for purpose of extension. It should be stressed that the extension or extrapolation is valid only for the range of the observed hourly stages at a given station and storm.

Results

Some inconsistency has been detected in the stage-discharge data of La Estrechura, La Penita and Ermitano. The inconsistant or questionable data were either deleted or corrected.

All the stations, except La Penita, have shown an instability in the lower part of the cross section and a stability in the upper part of the cross section. Therefore, more than one rating curve was used in the low stages and a single expression was used for the upper part of the Q versus $(h+h_o)$ logarithmic plot. The value of h_o differs from one rating curve to another. The actual break points between the upper curve and each of the low stage discharge curves are determined by simultaneous solution of both polynomial equations corresponding to each of the lower and the upper portion of the rating curve.

La Penita logarithmic plot of Q versus $(h+h_o)$ shows a single straight line for the whole range of data, except the inconsistant points which have been deleted. This indicates that a single control is effective for the complete range of discharge. The stability of La Penita station might be due to its location just upstream the Valdesia reservoir.

A detailed description of the above results are given below for each station.

La Estrechura

Inconsistant data: The reliability of data measured on 11-03-69 with h=0.36 m and a corresponding discharge of 5.14 m^3/s is doubtful. The error seems to be more related to an inadequate stage height reading rather than an inadequate measurement of the flow discharge.

Correction: Since there is no objective evidence regarding the origin of the error and since we have enough data to fit the observations of curve 1 (which includes the above questionable data) we have decided to delete the above doubtful observation.

Fitting and extrapolation of the stage-discharge curves: After a close study of the data, we have decided to used seven rating curves. Three of the latter have different polynomial expressions in each of their low and high portion. Each of the four other rating curves have a single polynomial expression. We are only confident the extrapolation of the above seven curves only in the range of the observed hourly stages measured during the storm events.

Palo De Caja

Inconsistant data: None.

Fitting and extrapolation of the stage-discharge curves: Nine rating curves have been selected. Four of these curves have different polynomial expressions in for low and high flows. The remaining five curves have one unique polynomial expression for all flows. The extrapolation of the nine curves is valid only in the range of the hourly stages recorded during the storm events.

La Penita

Inconsistancy: Both the plot of Q versus h on arithmetic scale and the logarithmic plot of Q versus $(h+h_o)$ show that the 14 data points observed for the time periods 03-03-77 to 03-15-77 were questionable. The latter doubtful data points would be due to inaccurate readings of the rate of revolution of the propeller-type meter. If the discharges corresponding to the above data are multiplied by 2, these 14 adjusted data points would join the same straight line as determined by all the other data. Next a logarithmic plot of Q versus $(h+h_o)$ was performed. Again the 392 data points (except the same 14 data points) defined a single curve with about 30 data points having a stage height between 0.40 and 0.50 m (range of the stage height of the 14 doubtful data points). It was then decided to discard these 14 questionable stage-discharge observations.

Fitting and extrapolation of the stage-discharge curve: Only one curve is used for the whole range of data since a plot of Q versus $(h+h_o)$ of the above 392 data points follow a single straight line. The extrapolation of the latter curve is guaranteed only for the range of the hourly stages corresponding to the observed storms.

. Ermitano

Inconsistancy: After a comparison of the stages of the stage-discharge measurements with those of the hourly storms observations we found that the stage-discharge data measured on the 12-11-70, the 12-14-70 and the 03-13-72 might be subject to inaccurate stage height reading. For the two rating curve measurements of the 12-11-70 the stages were set respectively to 1.75 and 1.89 m but, the maximum hourly stage observed during the same day was only 1.55 m. The same remark can be done for the 12-14-70 measurements where the maximum hourly observed stages is 1.43 m and the two stage-discharge data were set respectively to 11.81 m and 1.89 m. The 03-13-72 stage of the rating curve was 0.47 m, whereas the minimum hourly observed stage on the same day was 0.64 m. All the above five questionable stage discharge observations were deleted. A plot of Q versus $(h+h_o)$ has shown that the stage-discharge data measured from 05-22-72 to 05-24-72 were doubtful. The error might be due to incorrect rate of revolution of the propeller-type meter. It was decided to correct the above observation on account of the need for higher stage-discharge data in the period between 05-22-72 to 09-14-72.

Correction: The questionable stage-discharge data measured from 05-22-72 to 05-24-72 were corrected by dividing their corresponding discharges by 2.

Fitting and extrapolation of the stage-discharge curves: Five rating curves have been selected. One rating curve as a single polynomial expression for both low and high stages. Each of the other four curves has two polynomial expressions, one for the low portion and the other for the higher portion. The extrapolation of each of the rating curves is reliable only for the range of the hourly stages recorded during the storm events.

The polynomial parameters of all the rating curves, the date of validity, and some observations are shown in a tabular form for each station in Tables 1.5.A.1 through 1.5.A.4.

Table 1.5.A.1 Rating Curve Equations $Q = c(h + h_o)^m$ for La Estrechura

Station	Date	h_o in m	C	m	Stage in m	Observation
La Estrechura	10/20/67 to 7/15/70	0.31	38.75	3.51	$h \geq 0.10$	
	12/9/70 to 12/16/72	0.36	46.05	3.75	$h \leq 0.13$	
		0.36	38.75	3.51	$h > 0.13$	
	1/12/73 to 11/15/73	0.30	38.75	3.51	$h \geq 0.10$	
	12/11/73 to 7/9/74	0.25	38.75	3.51	$h \geq 0.15$	
	8/10/74 to 10/8/76	0.34	56.66	4.30	$h \leq 0.27$	
		0.34	38.75	3.51	$h > 0.27$	
	11/9/76 to 7/12/78	0.35	38.75	3.51	$h \geq 0.05$	
	8/23/78 to 3/7/79	0.45	40.20	4.11	$h \leq 0.49$	
		0.45	38.75	3.51	$h > 0.49$	

Table 1.5.A.2 Rating Curves for Palo De Caja

Station	Date	h_o in m	C	m	Stage in m	Observation
Palo De Caja	6/22/71 to 9/12/73	0.26	20.26	2.20	$h \geq 0.20$	
	4/4/74 to 6/11/74	0.31	22.06	2.62	$h \leq 0.50$	
		0.31	20.26	2.20	$h > 0.50$	
	7/5/74 to 7/29/74	0.44	19.29	3.49	$h \leq 0.60$	
		0.44	20.26	2.20	$h \geq 0.60$	
	8/6/74 to 8/30/74	0.22	20.26	2.20	$h \geq 0.48$	
	9/6/74 to 10/16/74	0.04	20.26	2.20	$h \geq 0.60$	
	10/28/74 to 10/22/75	0.27	38.39	5.35	$h \leq 0.55$	
		0.27	20.26	2.20	$h \geq 0.55$	
	2/26/76 to 9/17/76	0.30	19.80	2.11	$h \leq 0.47$	
		0.30	20.26	2.20	$h > 0.47$	
	11/9/76 to 5/12/77	0.09	20.26	2.20	$h \geq 0.50$	
	6/23/77 to 3/22/79	0.33	20.26	2.20	$h \geq 0.20$	

Table 1.5.A.3 Rating Curves for La Penita

Station	Date	h_o in m	C	m	Stage in m	Observatio
La Penita	11/30/76 to 8/9/79	-0.14	40.00	1.63	$h \geq 0.40$	The 14 poi observed between 3/3 3/15/77 ar deleted. curve will to get the observed hydrograph.
		-0.08	36.81	1.79	$h \geq 0.40$	The above 14 points a corrected b multiplying their dis- charges by

Table 1.5.A.4 Rating Curves for Ermitano

Station	Date	h_o in m	C	m	Stage in m	Observatior
Ermitano	8/27/68 to 12/14/70	0.25	42.42	1.999	$h \le 0.80$	Curve 1.
		0.25	43.11	1.70	$h > 0.80$	The data co responding h=1.75, 1.9 1.81, and 1 are deleted
	1/14/71 to 5/16/72	-0.01	43.11	1.70	$h \ge 0.40$	The data co responding h = is deleted.
	5/22/72 to 9/14/72	0.30	20.73	2.98	$h \le 1.47$	The dischar
		0.30	43.11	1.70	$h > 1.47$	correspondi to $h \ge 0.95$ are multipl by 2.
	10/3/72 to 8/12/74	-0.22	20.86	1.48	$h \le 0.25$	
		-0.22	43.11	1.70	$h > 0.25$	
	1/22/75 to 10/17/75	-0.07	43.11	1.70	$h > 0.50$	

1.6 DESIGN STORMS

1.6.1 Historic Storms

Analysis of critical historic storms is a prerequisite to the development of Depth-Area-Duration (DAD) curves which are required to develop hypothetical floods such as the standard project flood (SPF). The past records of hourly rainfall and daily runoff were examined to single out a critical storm for every year. A preliminary analysis of maximum 1-day, 2-day, and 3-day rainfall data at each station and the inspection of daily runoff plots allowed a rough determination of the dates of occurrence of the critical storms. More than one critical storm were included for certain years. The initial selection included the rainfall due to hurricane David (August 30, 1979), and the tropical storm Frederic (September 5, 1979). Then a careful inspection of the hourly rainfall records at many gages enabled the selection of exact dates and times of occurrence of the storms which are to be analyzed further. Table 1.6.1 below presents the historic storms selected for further analysis. The mass curves of rainfall for these storms, are shown in Appendix 1.6.A.

1.6.2 Isohyetal Mapping

To derive the depth-area-duration curves, the first step is to analyze each storm for its isohyetal pattern. The isohyetals are computed by a spatial interpolation technique known as multiquadratic interpolation. In multiquadratic interpolation, the influence of each sampling point is represented by quadric cones as a function of the coordinates of these points. The estimate for a given point with coordinates (x_o, y_o) is thus obtained by the sum of the contributions from all those quadric cones. This is mathematically expressed as

TABLE 1.6.1 HISTORIC STORMS SELECTED FOR ANALYSIS

	Beginning Date and Time				Ending Date and Time			
	Year	Month	Date	Hour	Year	Month	Date	Hour
1	1963	Oct.	1	20	1963	Oct.	5	5
2	1964	Aug.	6	8	1964	Aug.	7	3
3	1965	May	2	8	1965	May	5	8
4	1966	May	25	8	1966	May	27	8
5	1966	Sept.	28	20	1966	Sept.	30	8
6	1967	Sept.	10	8	1967	Sept.	13	8
7	1968	Aug.	8	8	1968	Aug.	10	8
8	1969	July	19	8	1969	July	20	8
9	1970	Aug.	22	8	1970	Aug.	23	8
10	1971	Feb.	19	8	1971	Feb.	21	8
11	1972	May	20	8	1972	May	23	8
12	1973	Oct.	14	8	1973	Oct.	21	8
13	1974	Aug.	30	8	1974	Aug.	31	8
14	1975	Sept.	16	8	1975	Sept.	18	8
15	1976	Oct.	10	8	1976	Oct.	12	8
16	1977	May	21	8	1977	May	24	8
17	1977	Dec.	28	8	1978	Jan.	1	8
18	1978	Aug.	3	8	1978	Aug.	6	8
19	1979	Aug.	30	8	1979	Sept.	2	8*
20	1979	Sept.	5	8	1979	Sept.	8	3**
21	1980	Aug.	4	8	1980	Aug.	7	8
22	1981	May	8	8	1981	May	11	8
23	1982	May	9	8	1982	May	13	8
24	1983	April	12	8	1983	April	13	8
25	1984	Aug.	1	8	1984	Aug.	3	8

*Hurricane David
**Tropical Storm Frederick

$$h_o = \sum_{i=1}^{n} c_i d_{oi} \qquad (1.6.1)$$

where h_o is an estimate of rainfall process at any point (x_o, y_o), c_i is the multiquadric coefficient of sampling point with coordinates (x_i, y_i), d_{oi} is the distance between point (x_o, y_o), and (x_i, y_i), and n is the number of sampling points. The distance d_{oi} is computed from the formula:

$$d_{oi} = \sqrt{(x_o - x_i)^2 + (y_o - y_i)^2} \qquad (1.6.2)$$

The estimate h_o at any point (x_o, y_o) can be represented by a weighted linear combination of the observed values h_j at each sampling point (x_j, y_j) as

$$h_o = \sum_{j=1}^{n} w_j h_j \qquad (1.6.3)$$

where w_j is the weight at sampling point j. To estimate the coefficients c_i and express Eq. (1.6.1) in terms of the weights as in Eq. (1.6.3), we do the following.

Let h_j of each sampling point (x_j, y_j) assume Eq. (2.1) as

$$h_j = \sum_{i=1}^{n} c_i d_{ji} \qquad \text{for } j = 1,2,\ldots,n$$

Then the coefficients c_i are determined by

$$c_i = \sum_{j=1}^{n} \delta_{ij} j_j \qquad \text{for } i = 1,2,\ldots,n \quad (1.6.4)$$

where δ_{ij} is an element of the inverse of the nxn interstation distance matrix with element d_{ji}, $j = 1,\ldots,n$ and $i=1,\ldots,n$. Substitution of Eq. (1.6.4) in Eq. (1.6.1) yields

$$h_o = \sum_{i=1}^{n} d_{oi} \sum_{j=1}^{n} \delta_{ij} h_j$$

or upon rearranging the numeration terms,

$$h_o = \sum_{j=1}^{n} \left[\sum_{i=1}^{n} \delta_{ij} d_{oi}\right] h_j$$

Thus, the interpolation equation (1.6.3) has weights

$$w_j = \sum_{i=1}^{n} \delta_{ij} d_{oi} \qquad \text{for } j = 1,\ldots,n \quad (1.6.5)$$

For this study, Eqs. (1.6.3) and (1.6.5) are used to compute the isohyetal pattern of each storm at any point (x_o, y_o) in the study area using the data h_j at each sampling point (x_j, y_j) available from $j=1,\ldots,n$ stations.

From the previous explanation it is noted that rainfall interpolates at any point in the basic area of interest are solely function of the distances between such point and the observation points (rainfall stations) available in the area. By virtue of this method, rainfall pattern anomalies due to orographic effects or bias in rainfall information due to topography are not accounted for in the interpolation. The Hydrology Group at INDRHI strongly suggested that perhaps such rainfall pattern anomalies should be considered in the derivation of the isohyetal patterns. In this connection, two approaches are tried which are briefly described below.

First is the adoption of the precipitation weighing method given by the U.S. Corps of Engineers in the HEC-1 Flood Hydrograph Package which was likewise suggested by the INDHRI Hydrology Group. This method is based on the weighting equation given by

$$h_o = h_{B_o} \frac{\sum_{j=1}^{n} h_j w_j}{\sum_{j=1}^{n} \bar{\bar{h}}_j w_j} \qquad (1.6.6)$$

where h_o is the rainfall interpolate at any point in the area, h_{B_o} is the interpolated (using optimal interpolation) normal annual precipitation at any point in the area, h_j is the total storm precipitation at sampling station j and $\bar{\bar{h}}_j$ is the jth station normal annual precipitation. The weight w_j of station j can likewise be obtained using the multiquadric interpolation technique such that

$$w_j = \sum_{i=1}^{n} \delta_{ij} d_{oi} \qquad \text{for } j=1,\ldots,n \qquad (1.6.7)$$

where d_{oi} is the distance between the point with coordinates (x_o, y_o) and jth station point with coordinates (x_j, y_j), and δ_{ij} is an element of the inverse of an n x n interstation distance matrix with elements d_{ij}, $j=1,\ldots,n$ rows and $i=1,\ldots,n$ columns.

As indicated by the U.S. Corps of Engineers, the above approach could correct rainfall estimation bias associated to elevation effects which is accounted for by the station normal annual precipitation term $\bar{\bar{h}}_j$. However, this claim may be rather dubious since the elevation is not explicitly parameterized in the weighting scheme and that any adjustments for bias affected by incorporating either or both terms h_B and $\bar{\bar{h}}_j$ can be associated to rainfall anomalies other than elevation effects.

In view of this, the second approach tried accounts for orographic effects which explicitly parameterized the basin elevation. This approach is based on representing the rainfall by a polynomial function written as

$$h_o = a_o + \sum_{k=1}^{m} a_k E_o^k + H_o \tag{1.6.8}$$

where h_o is the rainfall estimate at any point (x_o,y_o), the a's are polynomial coefficients, E_o is the elevation at point (x_o,y_o) and H_o is the elevation-free rainfall values. Similarly, the observed rainfall values at the available station points can be represented as in the above equation as

$$h_j = a_o + \sum_{j=1}^{n} a_k E_j + H_j \tag{1.6.9}$$

where w_j is the jth station weight obtained by the multiquadric interpolation technique. Finally, the rainfall interpolate in the actual domain can be obtained using Equation (1.6.8) given the elevation E_o.

Note that an elevation map is required in the above approach for interpolating over an area. The multiquadric interpolation technique is used also to derive the elevation map for the basin.

The two approaches above were tried in this study followed by developing a new set of depth-area-duration (DAD) curves. A comparison was made using the two approaches as well as the previously obtained DAD curves based on rainfall isohyetal patterns without considering orographic effects.

From results obtained, it is found that using the second approach in which the elevation of the basing is explicitly parameterized gave the most reasonable and constant rainfall isohyetal pattern. The elevation map required in this approach on multiquadric interpolation is based on more than 200 elevation data points. A first-order polynomial is found sufficient to represent the rainfall-elevation anomaly function such that m=1 in Equation (1.6.8). The listing of programs used is given in Appendix 1.6.B.

1.6.3 Development of Depth-Area-Duration (DAD) Curves

Given the rainfall isohyetal patterns described in the previous section and the Mass Curves shown in Appendix 1.6.A, the procedure to develop the Depth-Area-Duration curves can be summarized as follows.

First, define class intervals based on the observed range of precipitation depths. Based on the 25 storms selected (see Table 1.6.1) the range is taken as 0 to 625 mm. Twenty five classes of class widths 25 mm each (i.e., class 1 is defined as 600-625, class 2 as 575-600, etc.) were selected. From the derived isohyetal pattern map of a given storm, the total area and average depth for each class are computed using the following equations:

$$A_i = \Delta A \sum_{j=1}^{NG} I_j \qquad (1.6.10)$$

and

$$D_i = \frac{\sum_{j=1}^{NG} d_j I_j}{\sum_{j=1}^{NG} I_j} \qquad (1.6.11)$$

where:

A_i = area corresponding to class interval i

ΔA = unit area of one grid point

NG = total number of grids

D_i = average depth of class interval i

d_j = depth at grid point j

$I_j = \begin{cases} 1 \text{ if } L_i \leq d_j < U_i \\ 0 \text{ otherwise} \end{cases}$

L_i = lower class limit of class i

U_i = upper class limit of class i

After obtaining the area and average depth corresponding to each class interval cumulative areas and corresponding average depths were computed using the following equations:

$$AC_i = \sum_{j=1}^{i} A_j \tag{1.6.12}$$

$$DC_i = \frac{\sum_{j=1}^{i} A_j D_j}{AC_i} \tag{1.6.12}$$

where

AC_i = cumulative area of classes greater than or equal to class i

DC_i = weighted average depth corresponding to classes greater than or equal to class i

Note that the cumulative areas and average depths computed above correspond to what is referred to as "extended class" where each extended class always has an upper limit of 625 mm and a lower limit equal to the lower class limit of class i defined earlier.

The above defines the Depth-Area curve for the total duration of the given storm. Now, the Depth-Area curves for shorter durations are derived by using mass curves of rainfall. To do this, one has to compute the weights that will be used in obtaining an average mass curve for each class interval.

The weight given to each recording station vary according to the distribution of the area assigned to a certain class interval. Since we know which grid points belong to each class interval, we can compute the distance between a point and the recording stations and determine the closest one. Then we can count what fraction of the total area was assigned to each station and compute the weights accordingly, using the equation below.

$$W_i(k) = \frac{\sum_{j=1}^{NG} S_j(k)}{\sum_{j=1}^{NG} I_j} \qquad (1.6.14)$$

where

$W_i(k)$ = Weight assigned to station k in class interval i

$$S_j(k) = \begin{cases} 1 \text{ if } L_i \leq d_j < U_i \text{ and k is the nearest station to grid point j} \\ 0 \text{ otherwise} \end{cases}$$

The cumulative weights corresponding to each extended class is computed by using the equation.

$$WC_i = \frac{\sum_{j=1}^{i} W_j(k) A_j}{AC_i} \qquad (1.6.15)$$

Using the cumulative weights an average mass curve for each cumulative class is computed. From this average mass curve one obtains the maximum precipitation recorded at different durations and compute the fraction of the total storm depth for each duration. These fractions are multiplied by the depth at the corresponding class interval to obtain the depths for different storm durations. The procedure is repeated for all the extended classes. The individual DAD curves for the 25 selected storms as well as the enveloping curves obtained by picking the maximum observed depth for each area and duration are included in Appendix 1.6.C.

As explained in the previous section, two methods were tried to account for topographic effects in the rainfall interpolation program. The results from both trials were used to derive two new sets of DAD curves. The performance of the two methods were judged based on the

TABLE 1.6.2 CLASSIFICATION OF STORMS USED IN DAD CURVES COMPUTATION

STARTING DATE	CLASSIFICATION	
8/1/84	non-hurricane	
4/12/83	non-hurricane	
5/9/82	non-hurricane	
5/8/81	non-hurricane	
8/4/80	hurricane	Hurricane Allen
9/5/79	hurricane	Tropical Storm Frederick
8/30/79	hurricane	Hurricane David
8/3/78	non-hurricane	
12/28/77	non-hurricane	
5/21/77	non-hurricane	
10/10/76	non-hurricane	
9/16/75	hurricane	Hurricane Eloise
8/30/74	hurricane	Hurricane Carmen
10/14/73	hurricane	Tropical Storm Gilda
5/20/72	non-hurricane	
2/19/71	non-hurricane	
8/22/70	hurricane	Tropical Storm Dorothy
7/19/69	non-hurricane	
8/8/68	non-hurricane	
9/10/67	hurricane	Hurricane Beulah
9/28/66	hurricane	Hurricane Inez
5/25/66	non-hurricane	
5/2/65	non-hurricane	
8/6/64	non-hurricane	
10/1/63	hurricane	Hurricane Flora

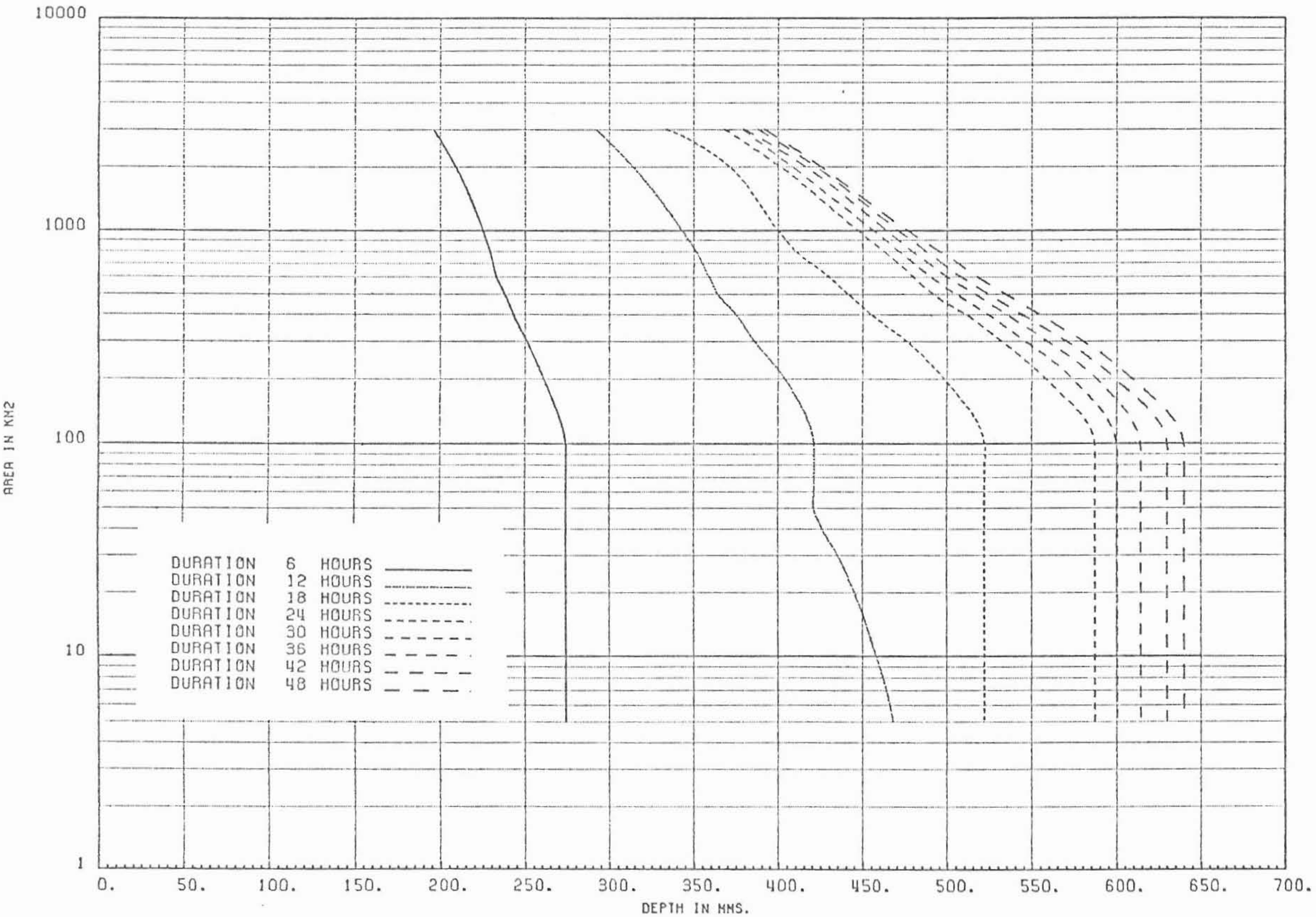


Figure 1.6.1. Hurricane depth-area-duration curves for Nizao basin.

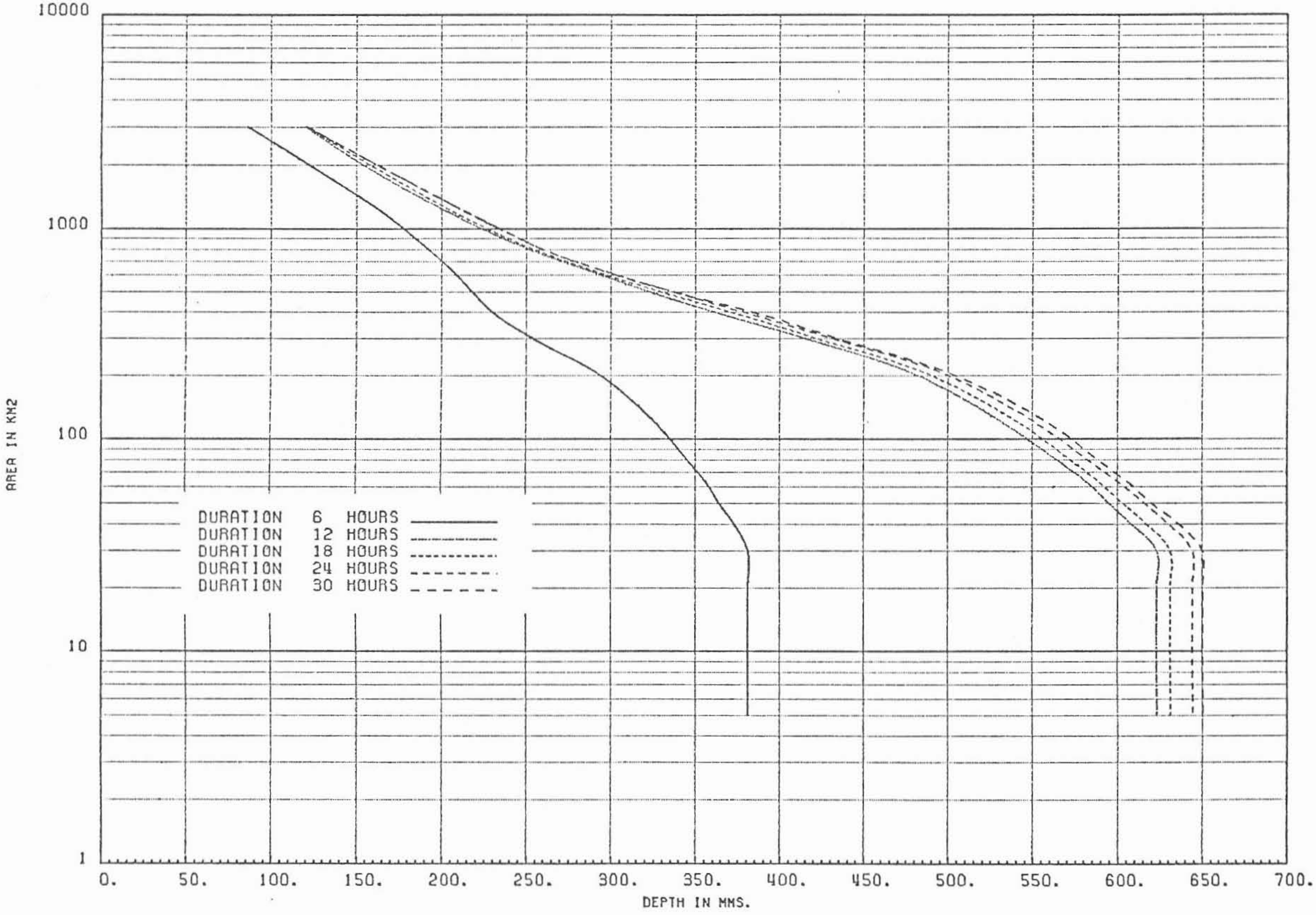


Figure 1.6.2. Non-hurricane depth-area duration curves for Nizao basin.

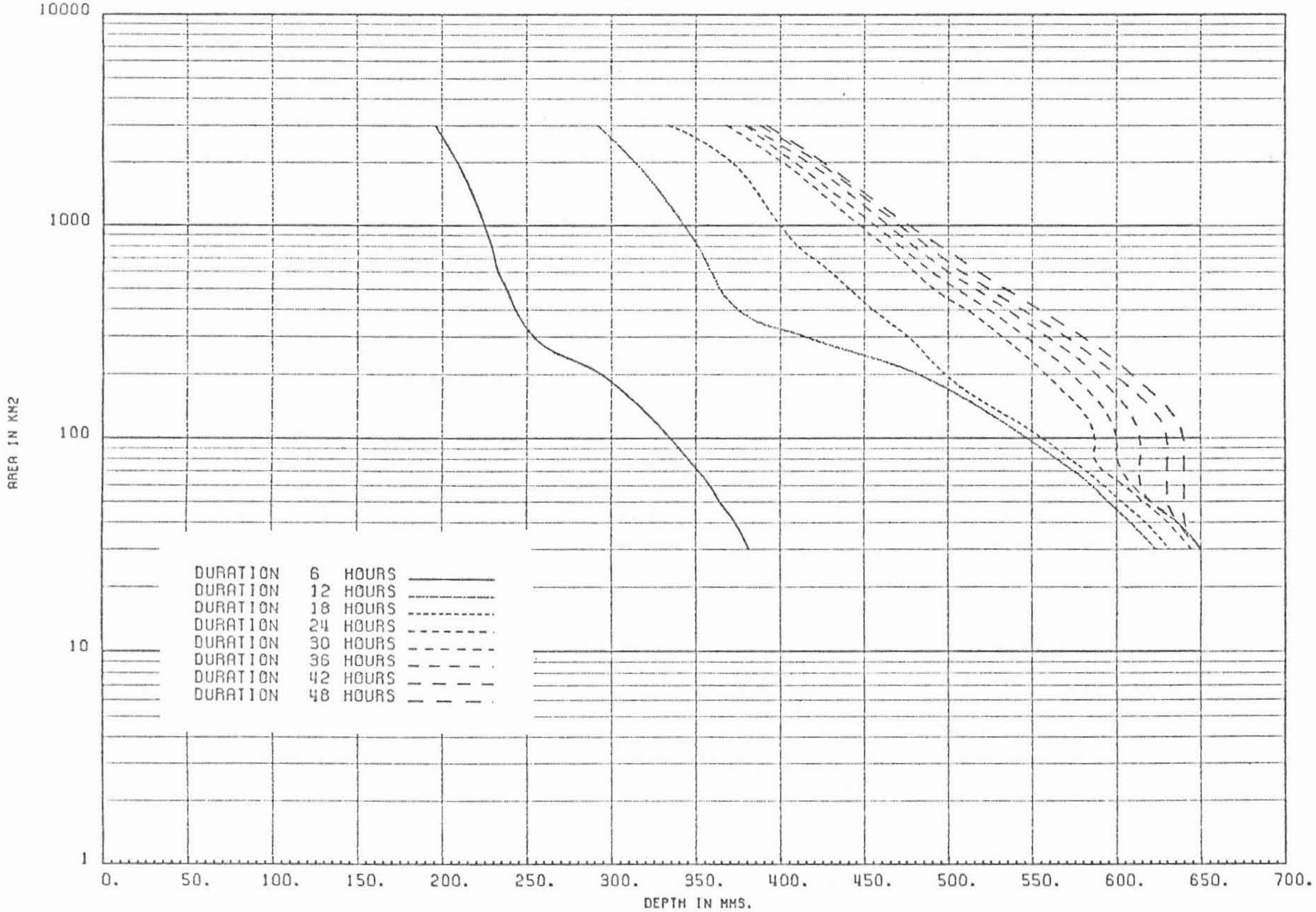


Figure 1.6.3. Enveloping depth-area-duration curves for Nizao basin.

comparison of the isohyetal patterns with those obtained without considering the topographic effects as well as by observing the DAD curves obtained with each method. Based on these it was decided that parameterizing the elevation in the interpolation function gave the most realistic results. The DAD curves obtained with the two methods are also included in Appendix 1.6.C.

Before obtaining the enveloping DAD curve from the individual curves computed with the selected method, the 25 storms used were divided into two groups: (a) hurricane and (b) non-hurricane. Table 1.6.2 shows this classification. Then the "hurricane" DAD curves and the "non-hurricane" DAD curves were derived from the corresponding groups. Based on these, a third set of curves that represent the worst conditions observed in the basin was derived. The "hurricane", "non-hurricane", and "enveloping" DAD curves are shown in Figures 1.6.1 to 1.6.3.

1.6.4 Standard Project Storm (SPS)

From the three sets of DAD curves shown in Figures 1.6.1 through 1.6.3, the standard project storms corresponding to duration of 24 hours and 48 hours for an area of 820 sq. km. (Nizao basin upstream of Valdesia dam) were derived. The total precipitation magnitudes of these standard projects storms are given below:

TABLE 1.6.3 Standard Project Storm (Hurricane, Non-Hurricane) and Enveloping) Precipitation Depth

	PRECIPITATION DEPTH (mm)		
DURATION (hrs)	HURRICANE	NON-HURRICANE	ENVELOPING
24	460	255	460
48	493	260	493

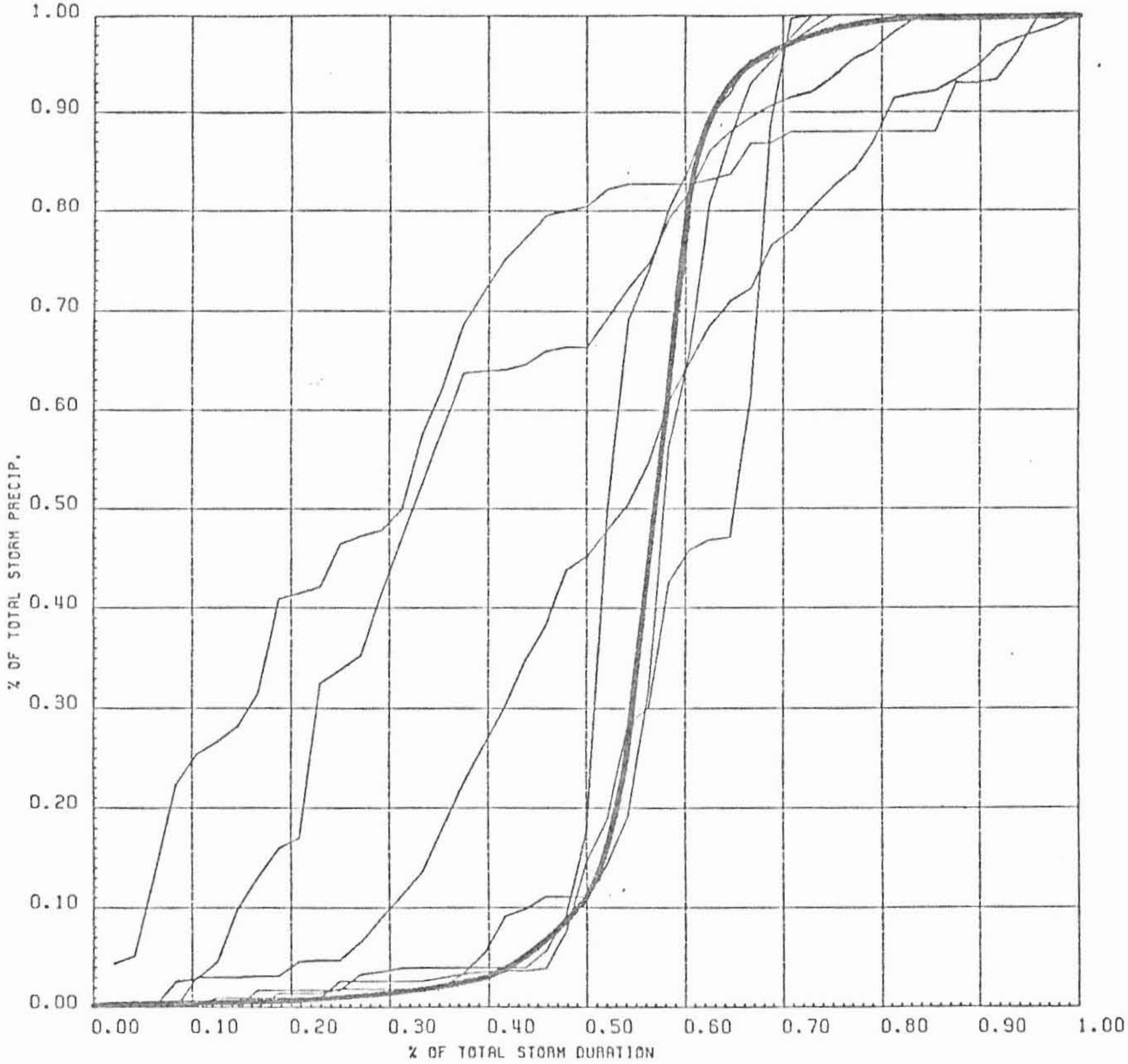


Figure 1.6.4. Historic rainfall patterns and selected design temporal distirubtions.

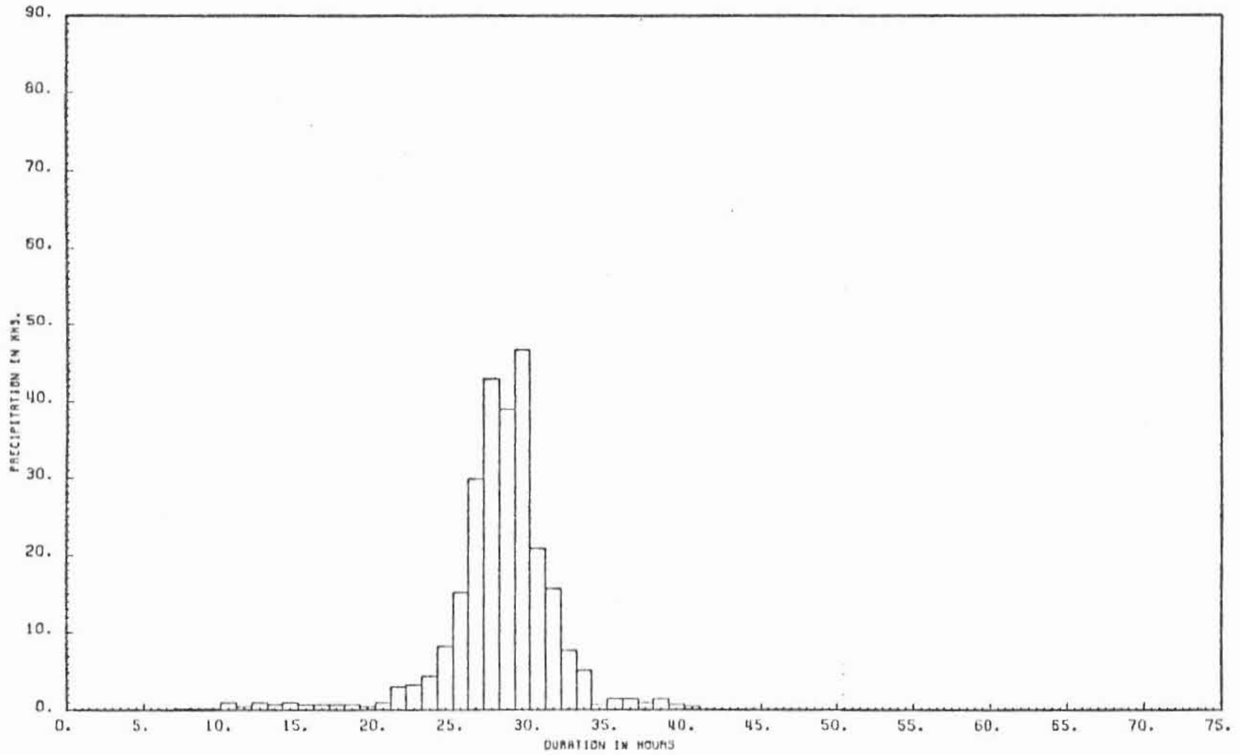


Figure 1.6.5. Non-hurricane standard project storm (48 hours).

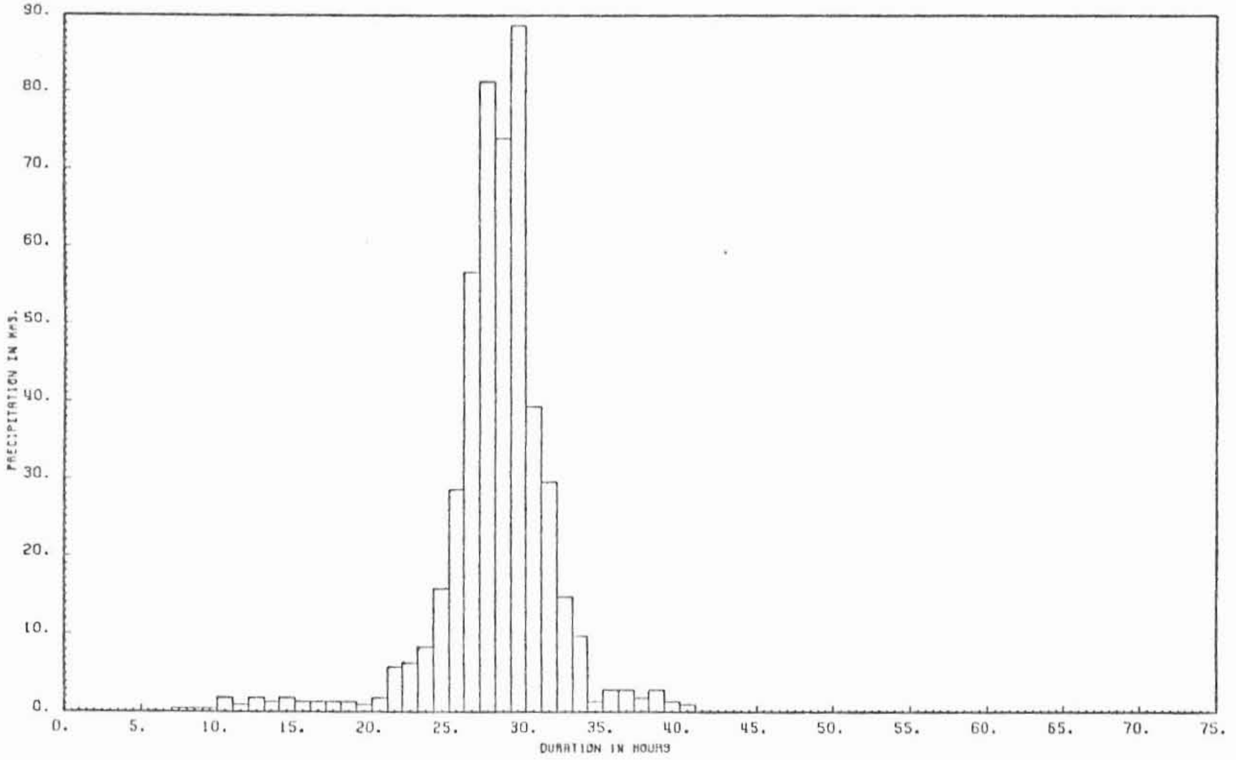


Figure 1.6.6. Hurricane standard project storm (48 hours).

It is seen that precipitation magnitude corresponding to hurricane conditions is almost twice as big as the corresponding depth for non-hurricane conditions from the same storm duration.

1.6.5 Temporal Distribution of SPS

During the course of the study two different criteria have been used for temporal distribution of the total precipitation magnitudes reported in Table 1.6.3. First approach is to select two critical patterns from the 25 historic storms selected for detailed analysis in the derivation of DAD curves. Specifically, the temporal distributions corresponding to hurricane David and tropical storm Frederick were selected. After recognizing the subjective nature of this first approach, a second approach which proved to give a more critical temporal distribution was used as follows. The percentage magnitude versus percentage duration plots were made for all 48 hour storms selected earlier. Then an enveloping curve, which lies below all the curves at small percentage duration, and above all curves for larger durations, was plotted. This exercise is illustrated in Figure 1.6.4.

Combining the enveloping temporal distribution shown in Figure 1.6.4 and the standard project storm magnitudes in Table 1.6.3, the 48 hour standard project storm isohyetal patterns were generated. These design storms are presented in Figure 1.6.5 and 1.6.6.

1.6.6 Probable Maximum Precipitation (PMP)

Given the location of the Nizao basin, a hurricane is most likely to produce the PMP. This is supported by the almost twice the precipitation depths obtained for hurricane conditions than for non-hurricane conditions for a given area and a duration (see DAD analysis). The Hurricane Model of U.S. Weather Bureau (1961) has been used by INDRHI/CDE to produce a hurricane PMP pattern for the Nizao basin. The original model has been modified for conditions existing in the

Dominican Republic and has been applied to compute PMP for the Tavera-Bao Watershed (CDE, personal communication). The precipitation pattern of average PMP over Nizao watershed obtained from the Hurricane model is presented in Figure 1.6.7.

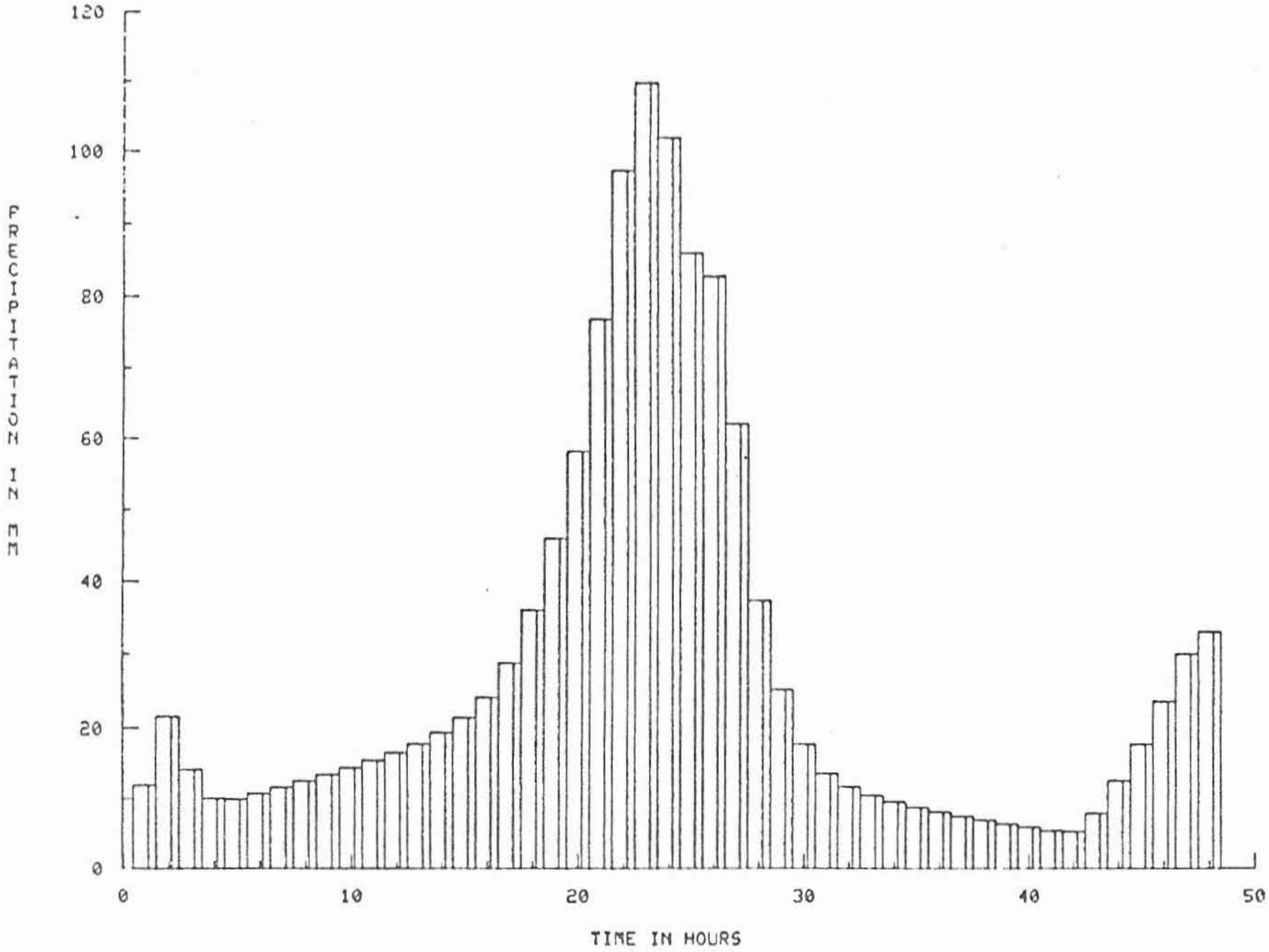
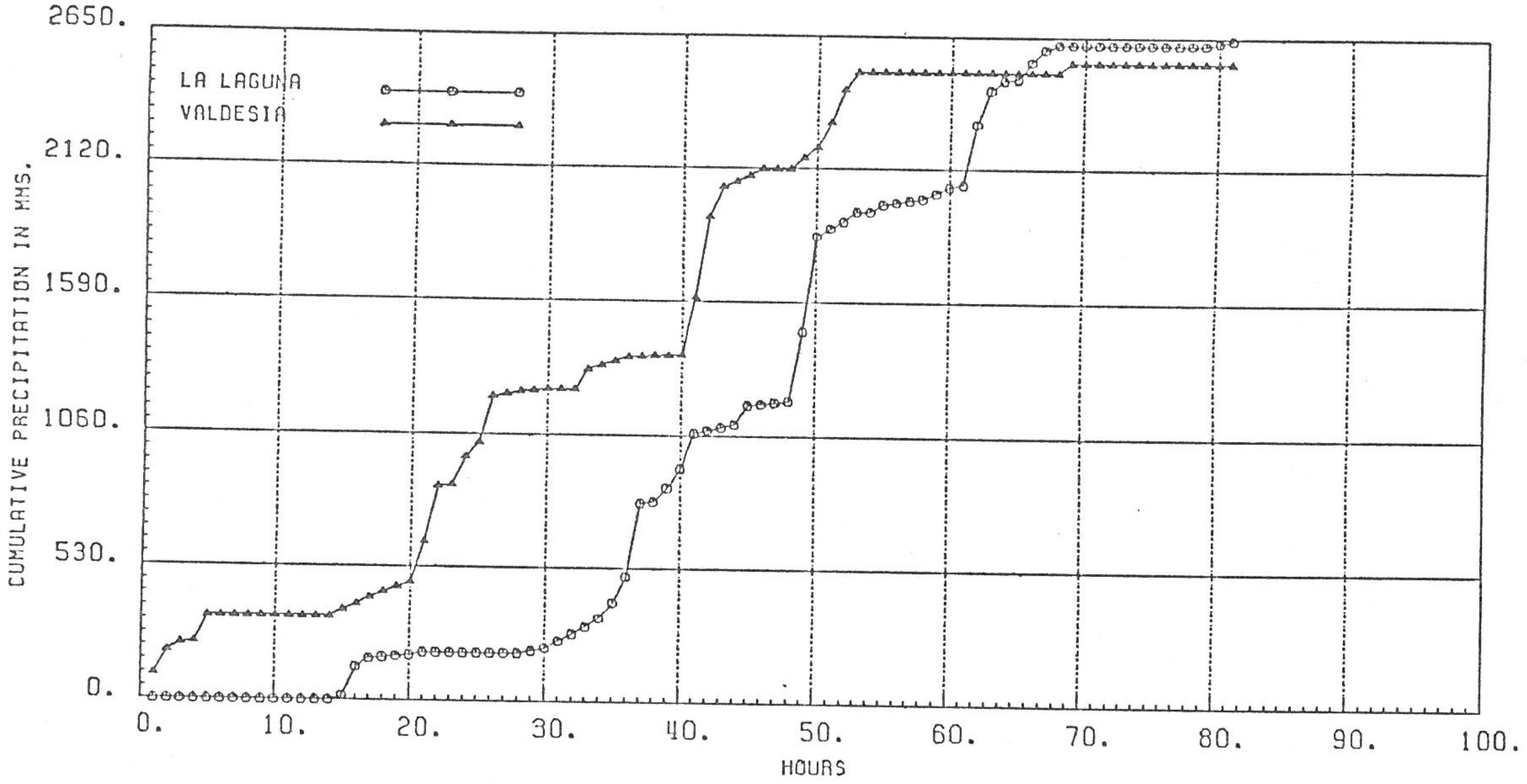


Figure 1.6.7. Precipitation pattern of average Probable Maximum Precipitation over Nizao watershed.

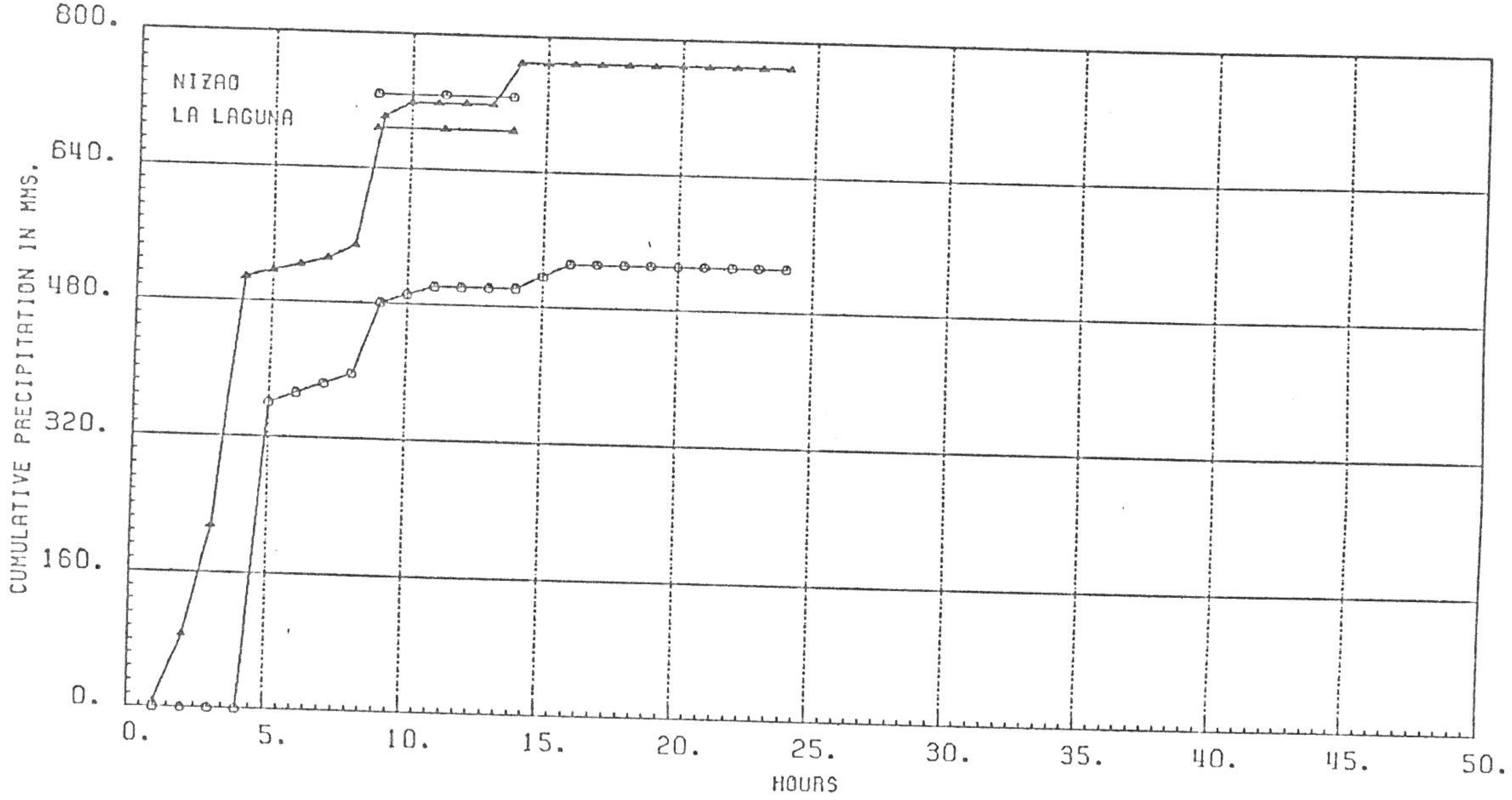
APPENDIX 1.6.A

MASS CURVES OF RAINFALL FOR SELECTED STORMS



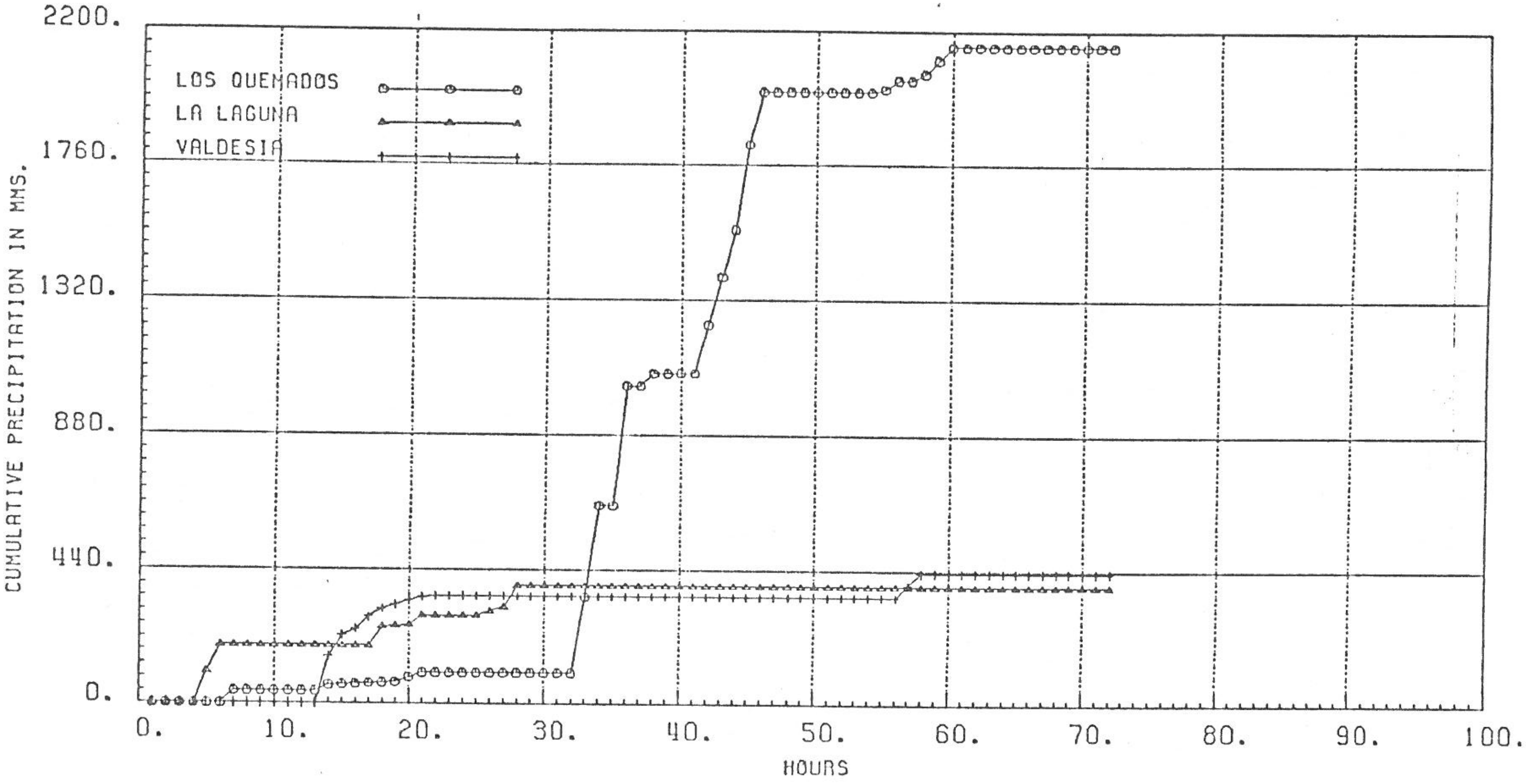
MASS CURVES STORM STARTING 63 OCT 1 20 ENDING 63 OCT 5 5

Figure 1.6.A.1.



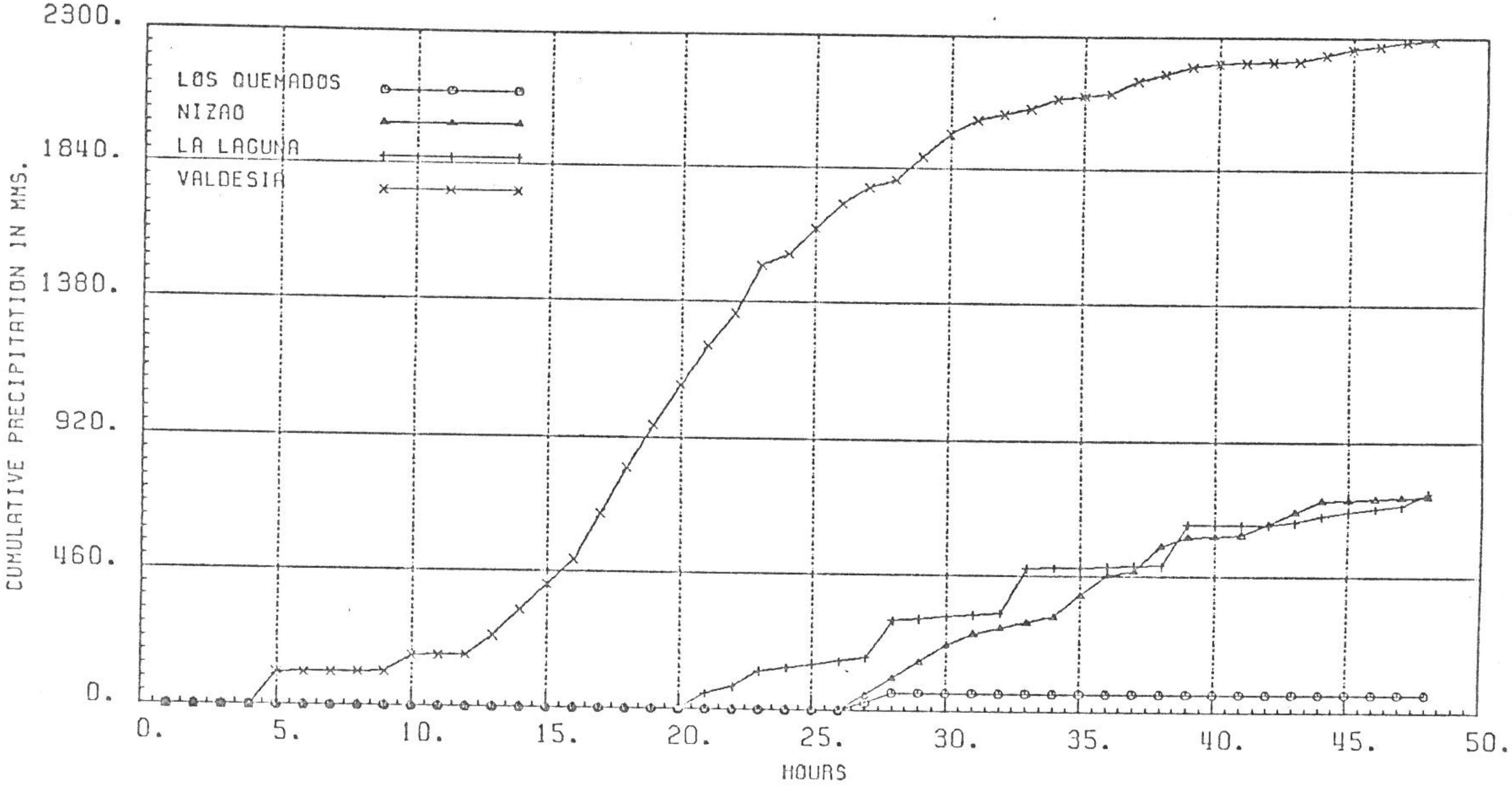
MASS CURVES STORM STARTING 64 AGO 6 8 ENDING 64 AGO 7 8

Figure 1.6.A.2



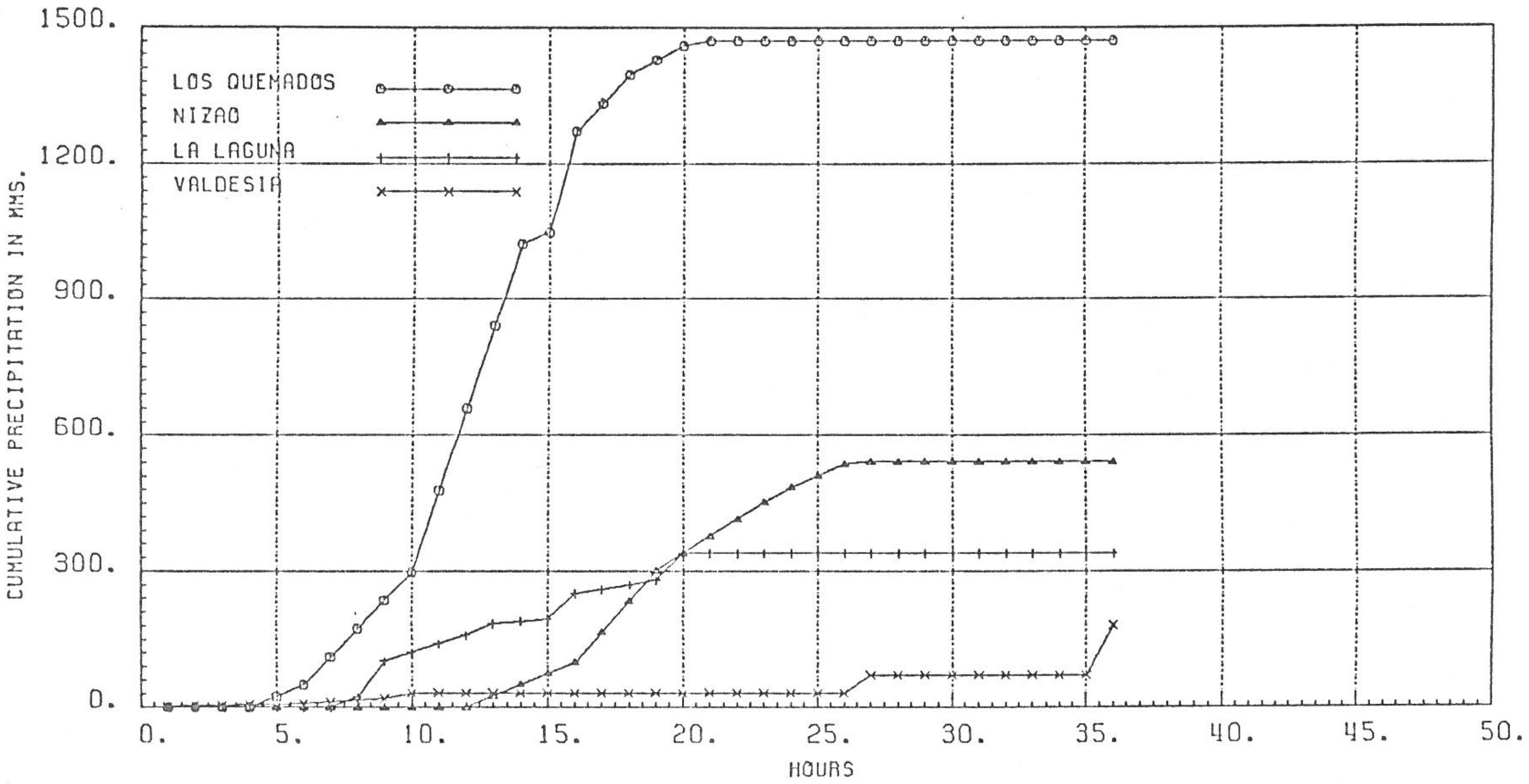
MASS CURVES STORM STARTING 65 MAY 2 8 ENDING 65 MAY 5 8

Figure 1.6.A.3.



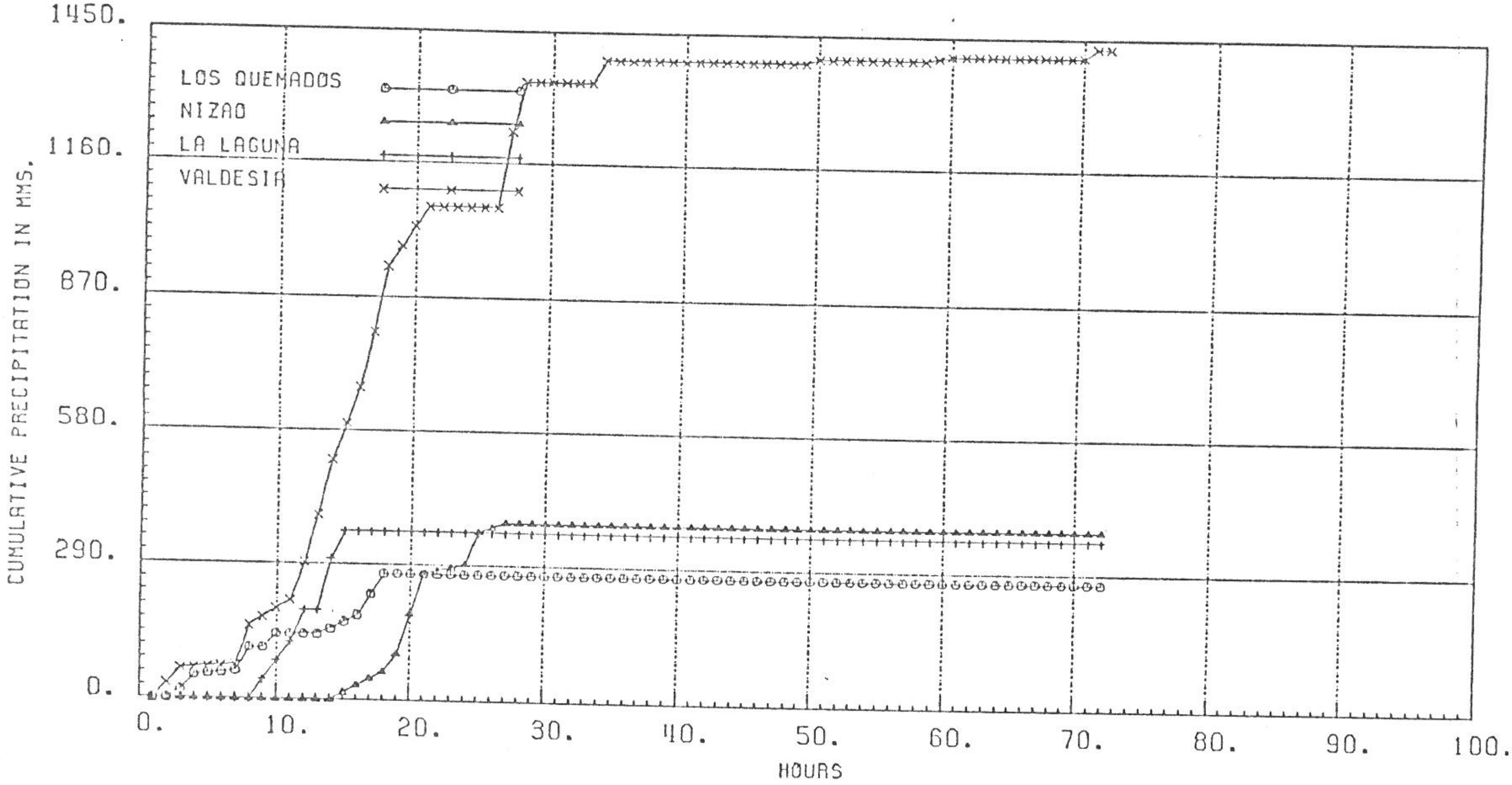
MASS CURVES STORM STARTING 66 MAY 25 8 ENDING 66 MAY 27 8

Figure 1.6.A.4



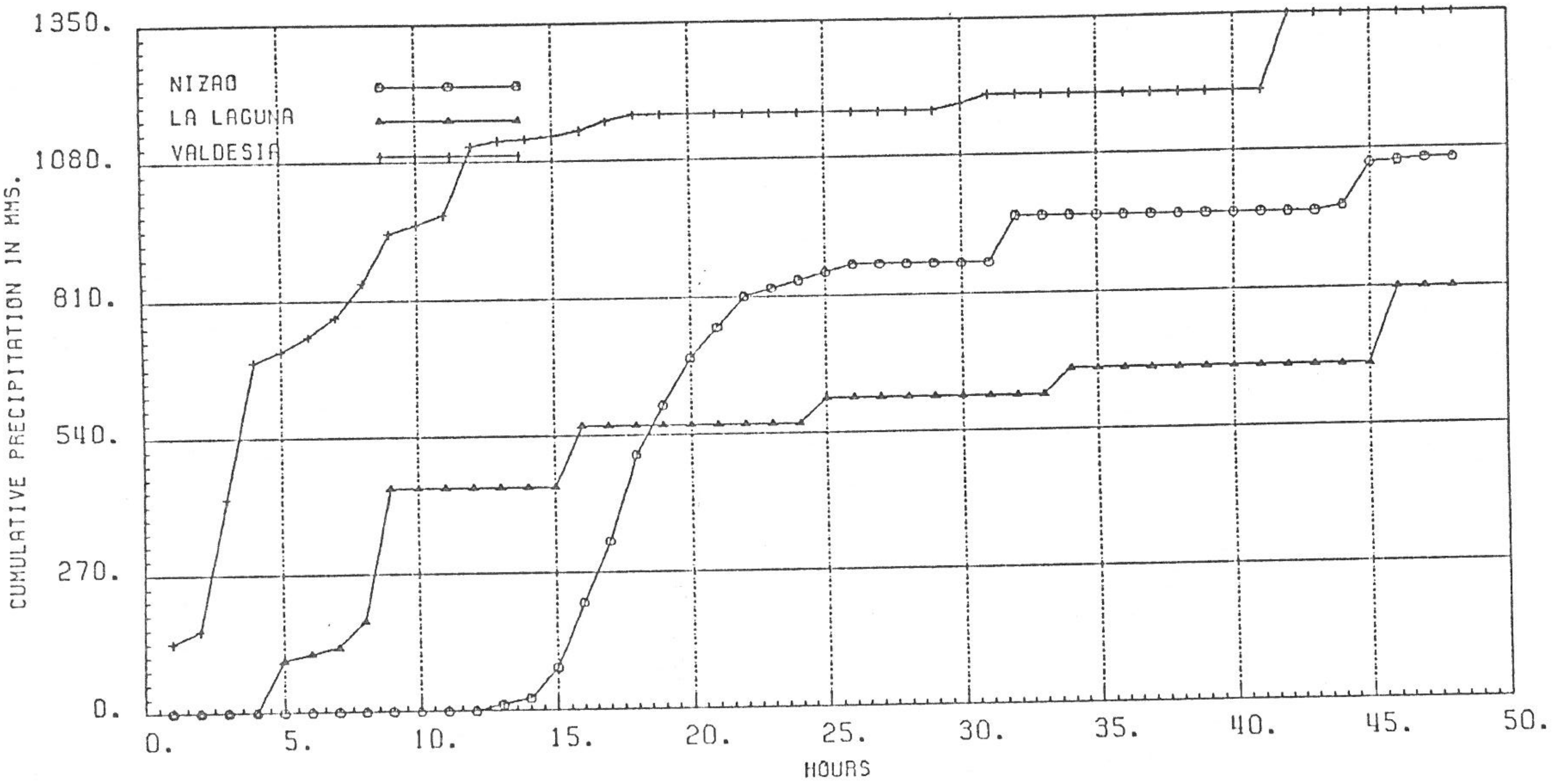
MASS CURVES STØRM STARTING 66 SEP 28 20 ENDING 66 SEP 30 8

Figure 1.6.A.5



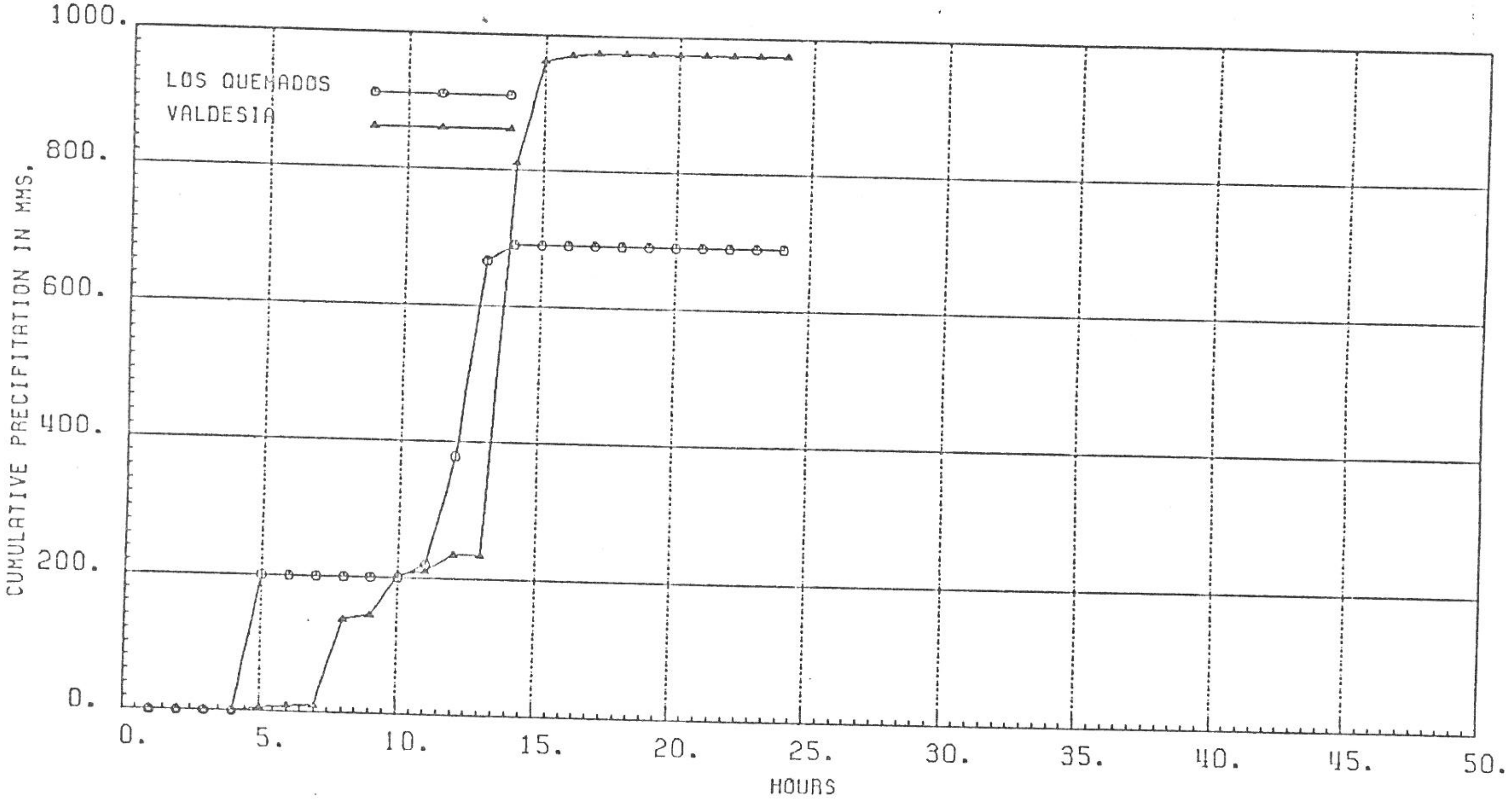
MASS CURVES STORM STARTING 67 SEP 10 8 ENDING 67 SEP 13 8

Figure 1.6.A.6



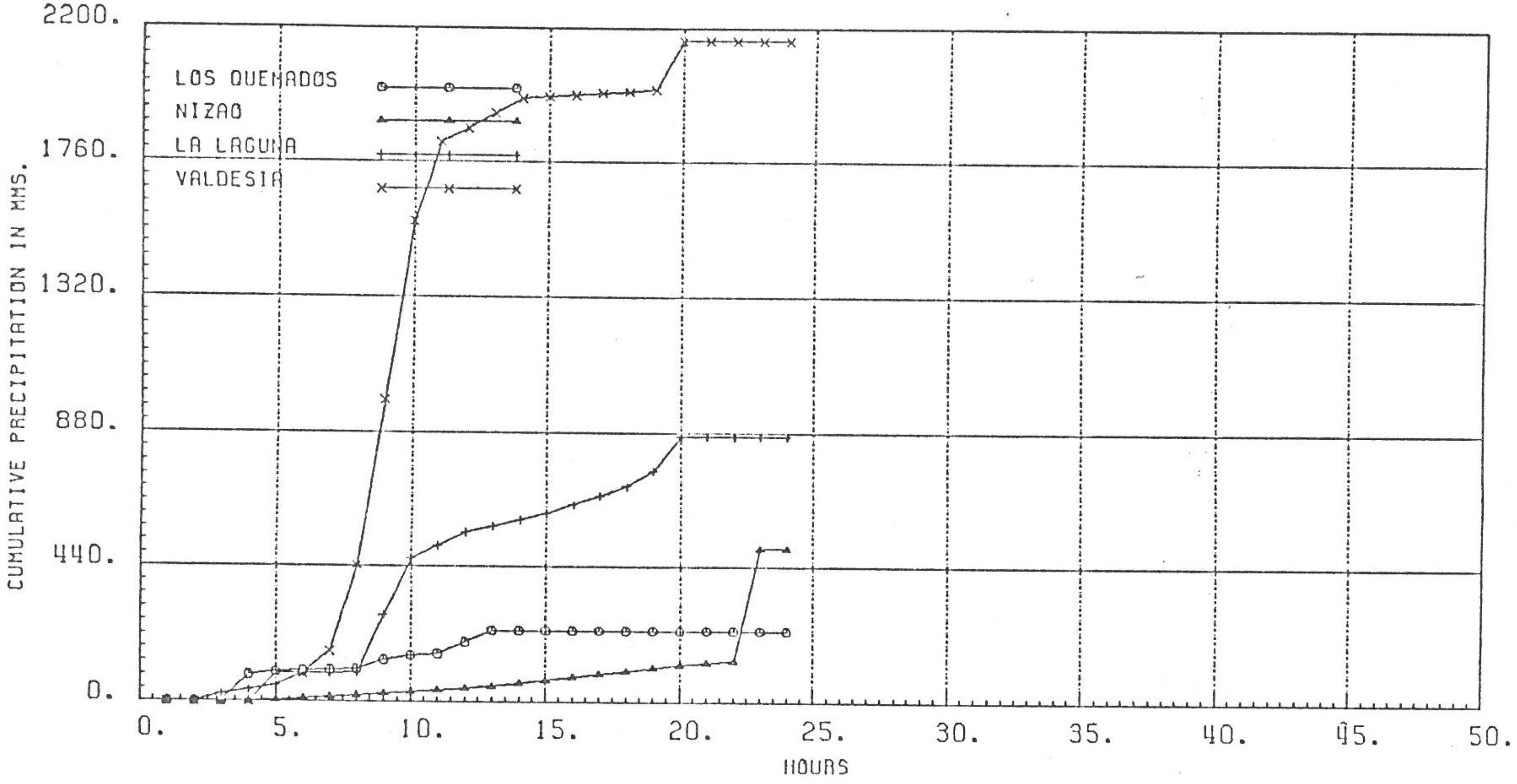
MASS CURVES STØRM STARTING 68 AGØ 8 8 ENDING 68 AGØ 10 8

Figure 1.6.A.7



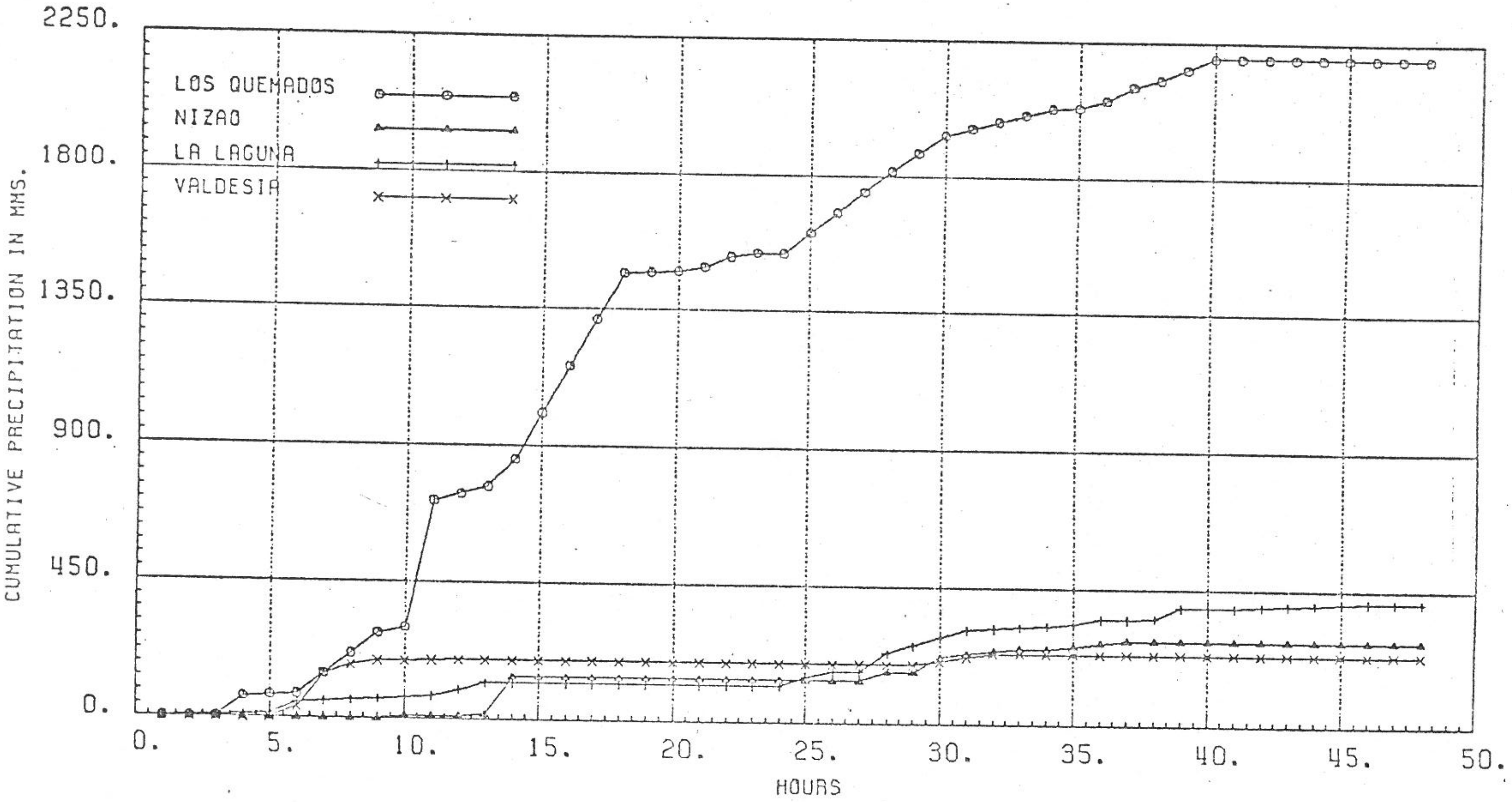
MASS CURVES   STØRM STARTING 69 JUL 19 8 ENDING 69 JUL 20 8

Figure 1.6.A.8



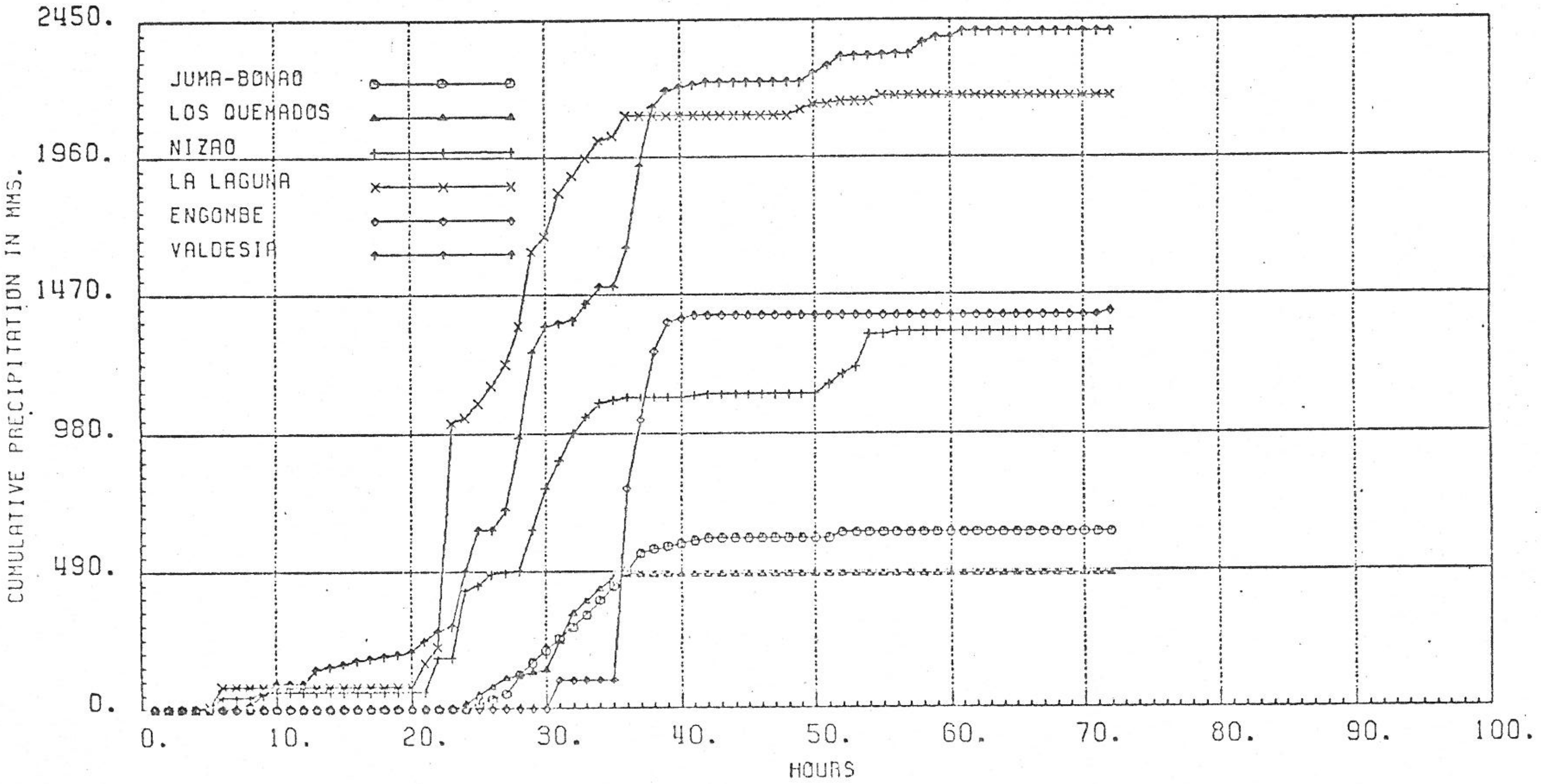
MASS CURVES STØRM STARTING 70 AGØ 22 8 ENDING 70 AGØ 23 8

Figure 1.6.A.9



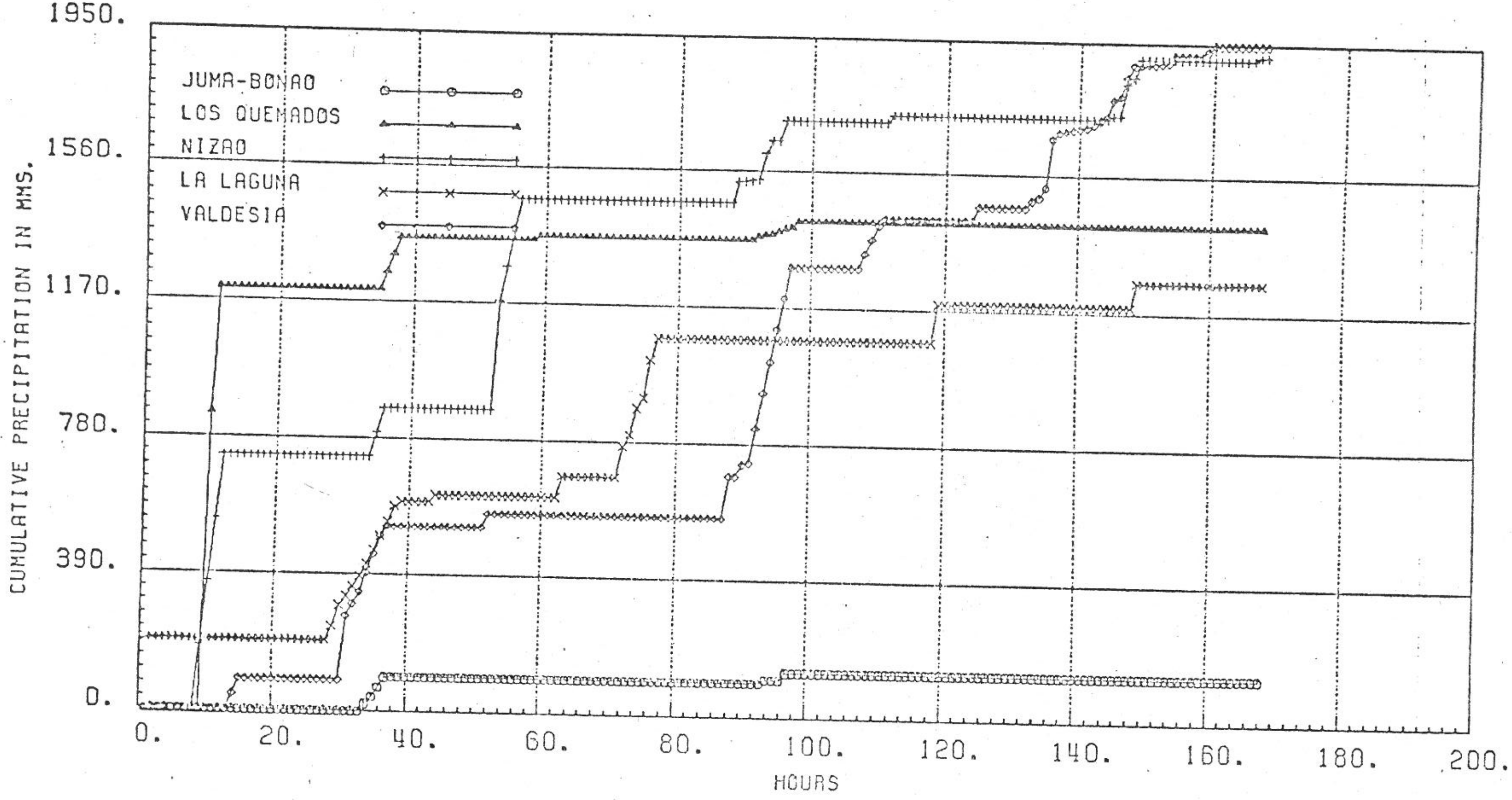
MASS CURVES STORM STARTING 71 FEB 19 8 ENDING 71 FEB 21 8

Figure 1.6.A.10



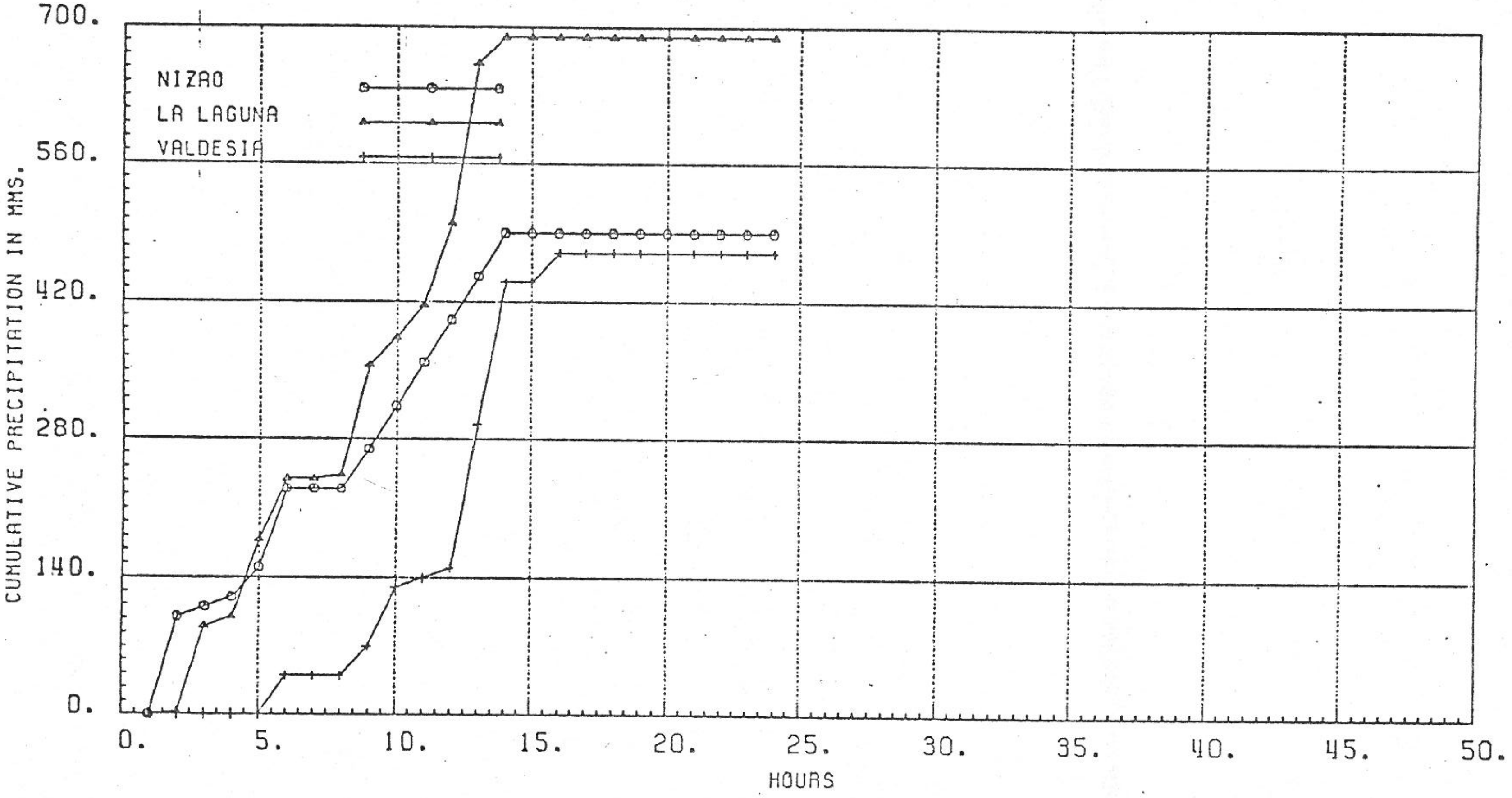
MASS CURVES STORM STARTING 72 MAY 20 8 ENDING 72 MAY 23 8

Figure 1.6.A.11



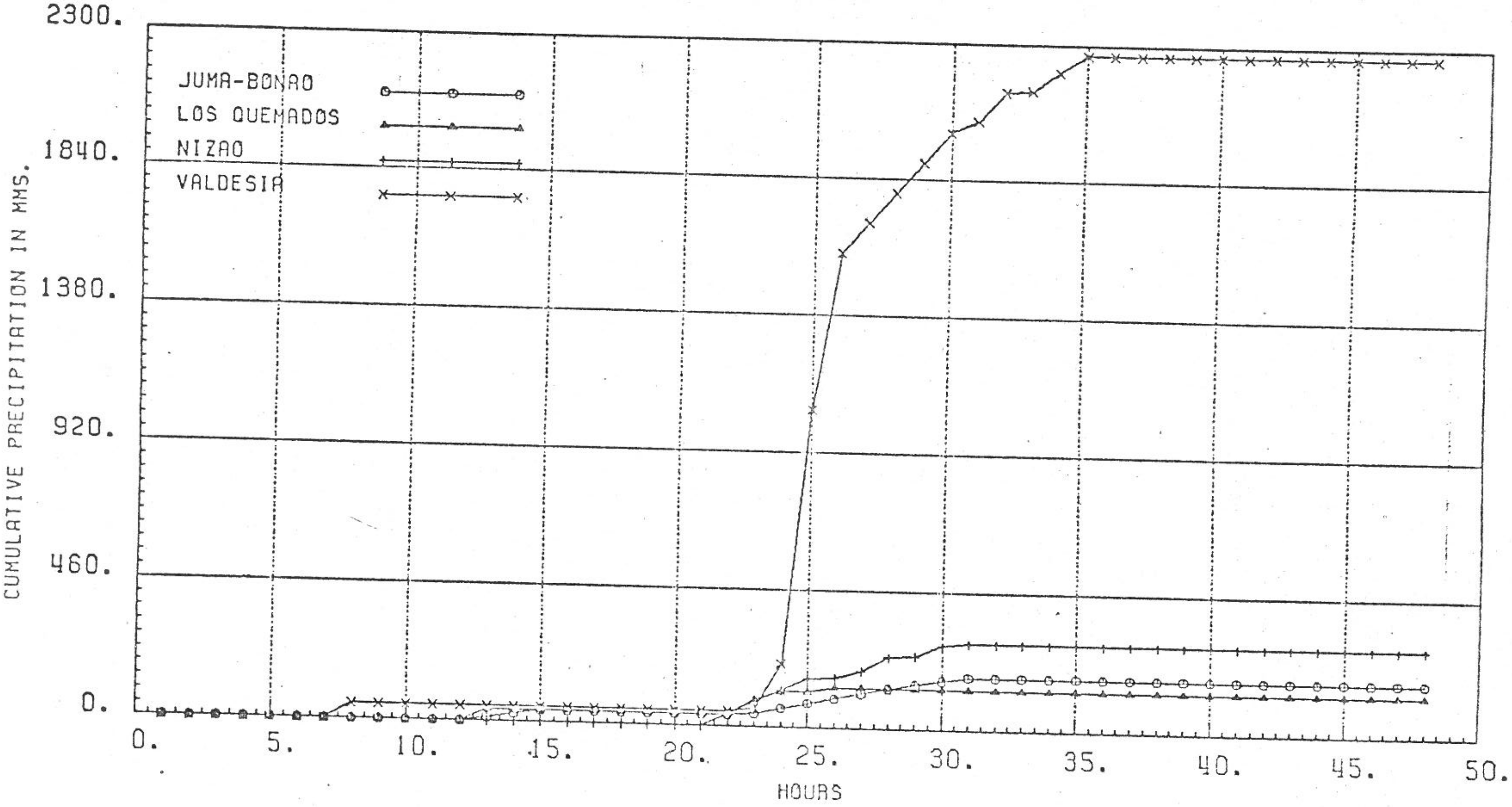
MASS CURVES   STORM STARTING 73 OCT 14 8 ENDING 73 OCT 21 8

Figure 1.6.A.12



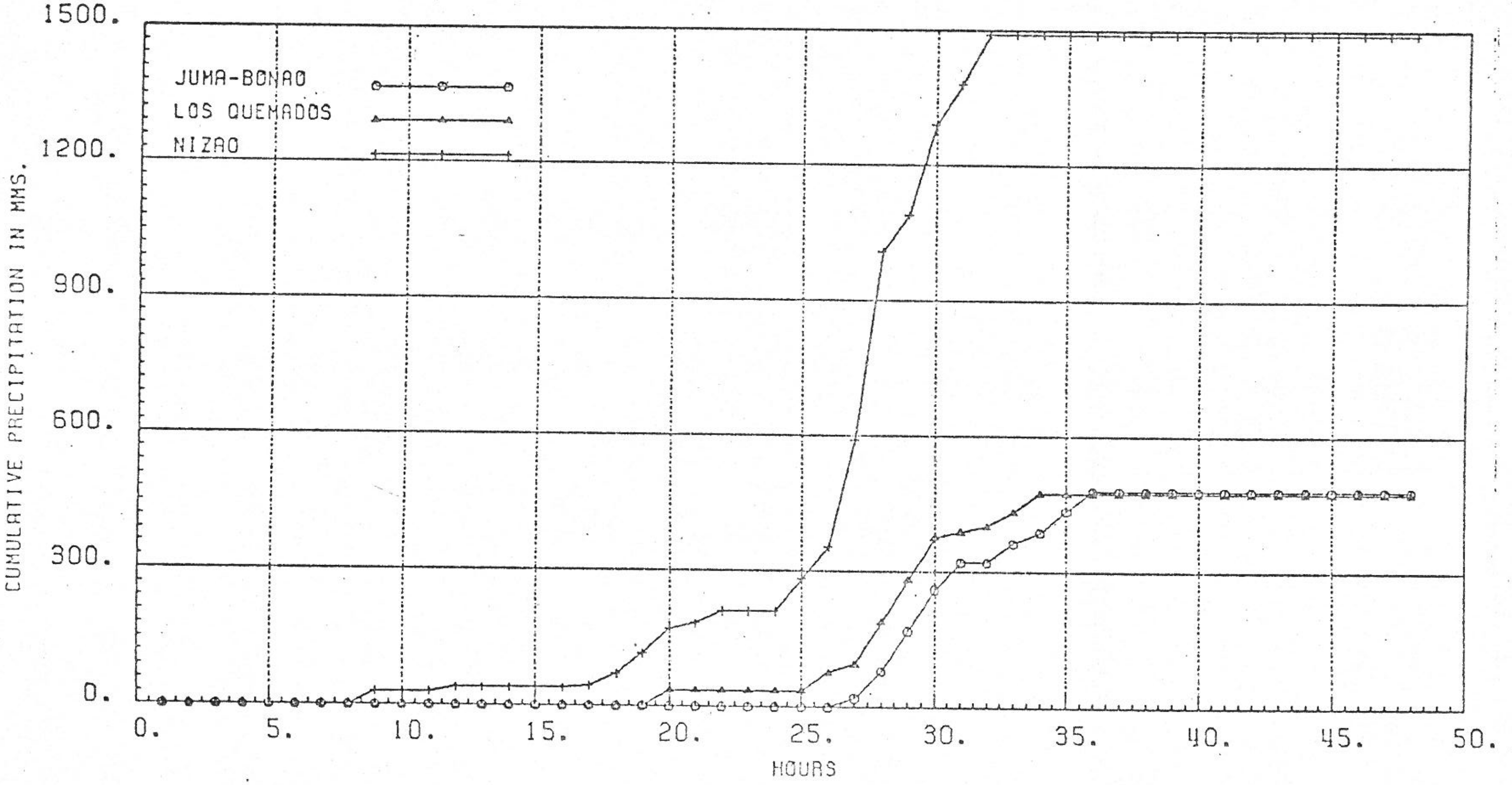
MASS CURVES STORM STARTING 74 AGO 30 8 ENDING 74 AGO 31 8

Figure 1.6.A.13



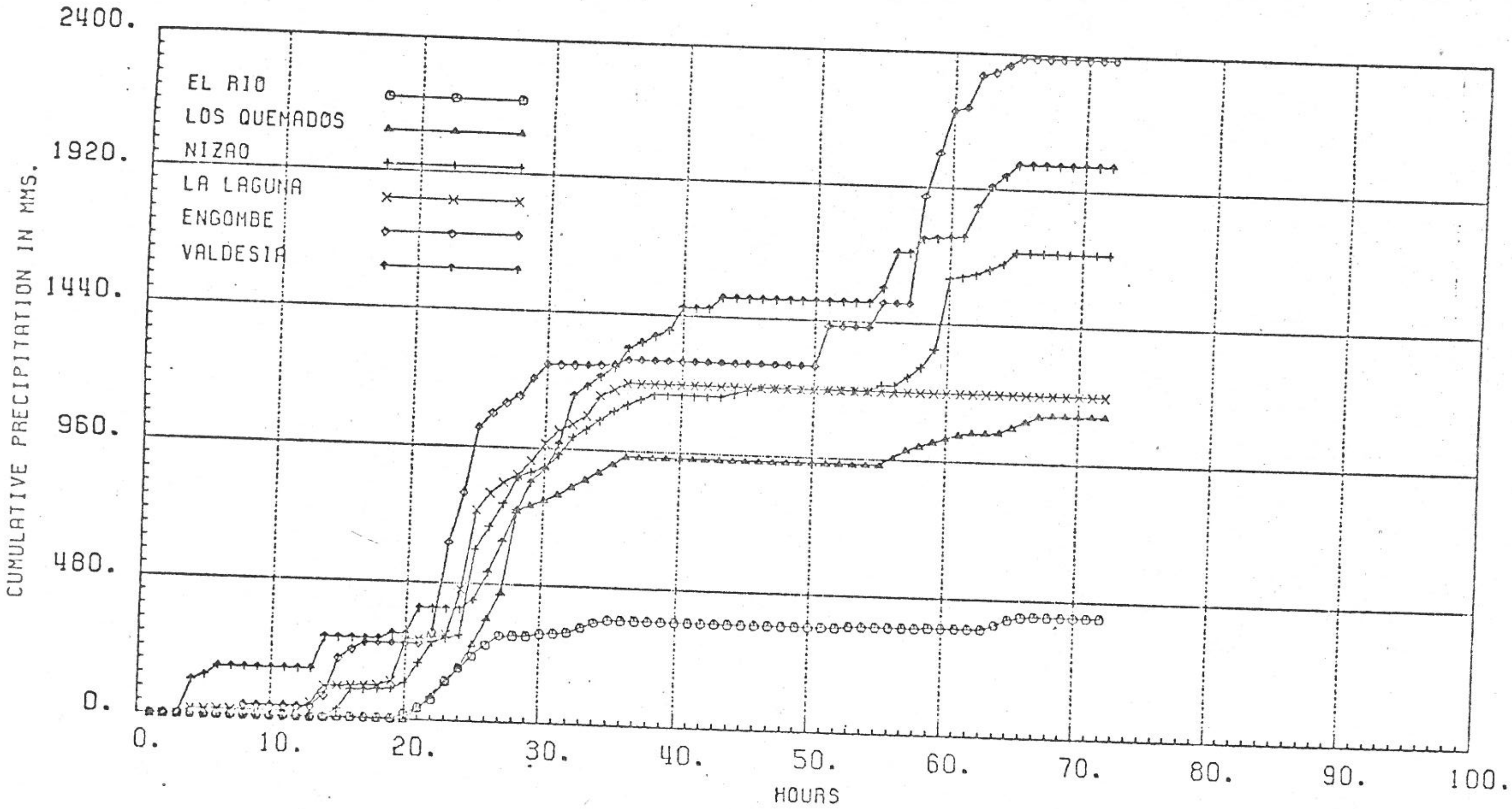
MASS CURVES STORM STARTING 75 SEP 16 8 ENDING 75 SEP 18 8

Figure 1.6.A.14



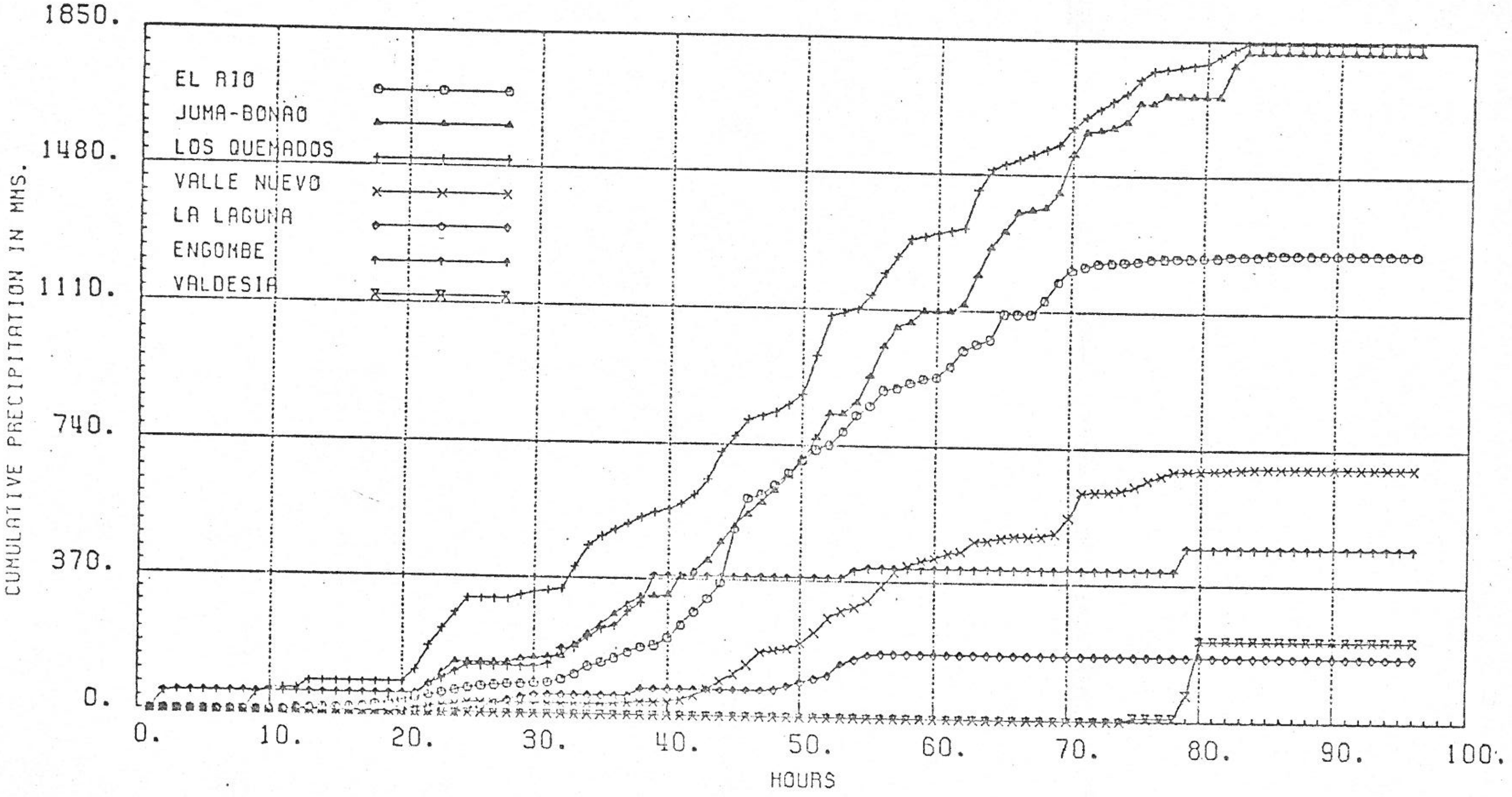
MASS CURVES STORM STARTING 76 OCT 10 8 ENDING 76 OCT 12 8

Figure 1.6.A.15



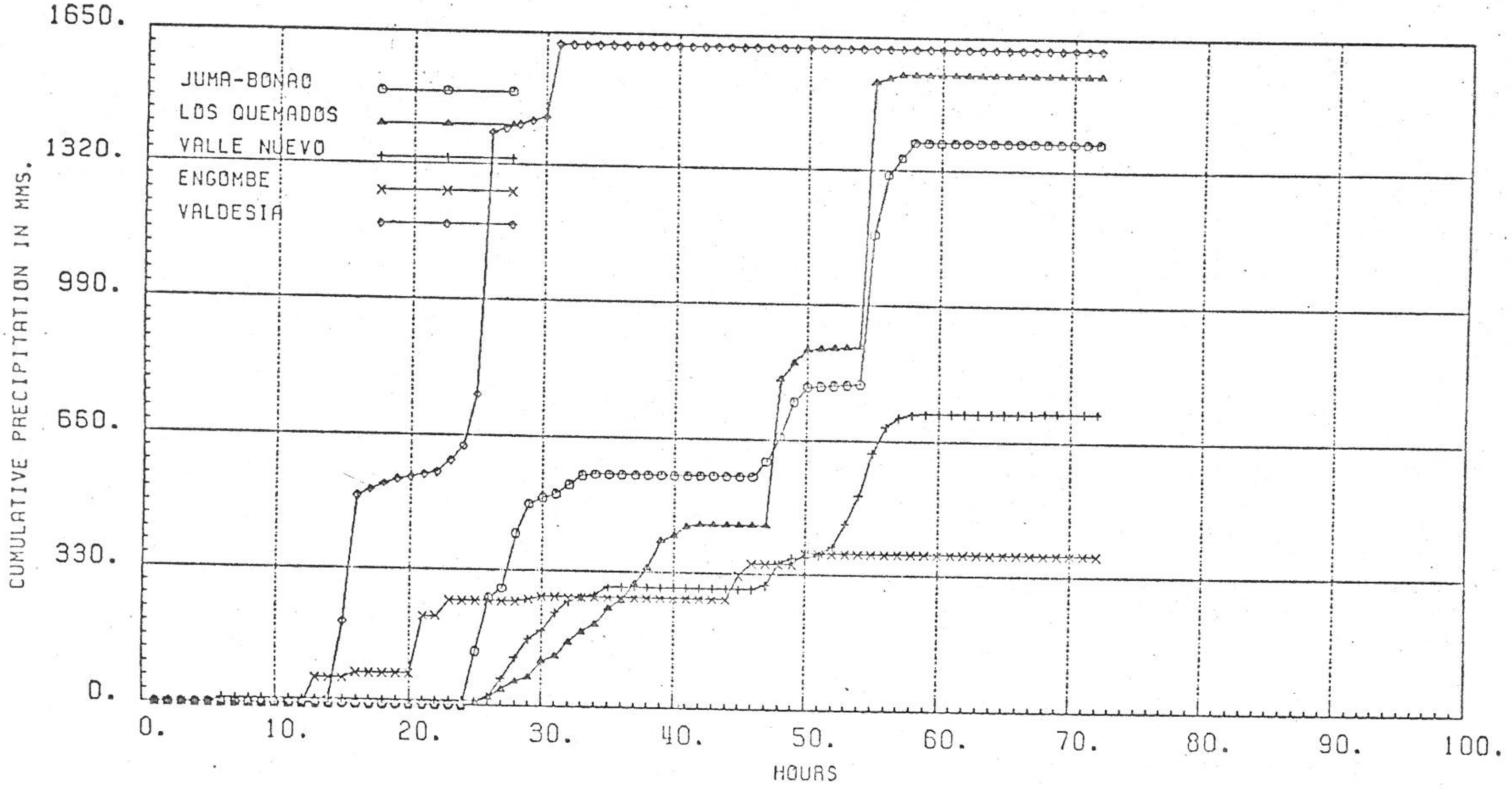
MASS CURVES   STORM STARTING 77 MAY 21 8 ENDING 77 MAY 24 8

Figure 1.6.A.16



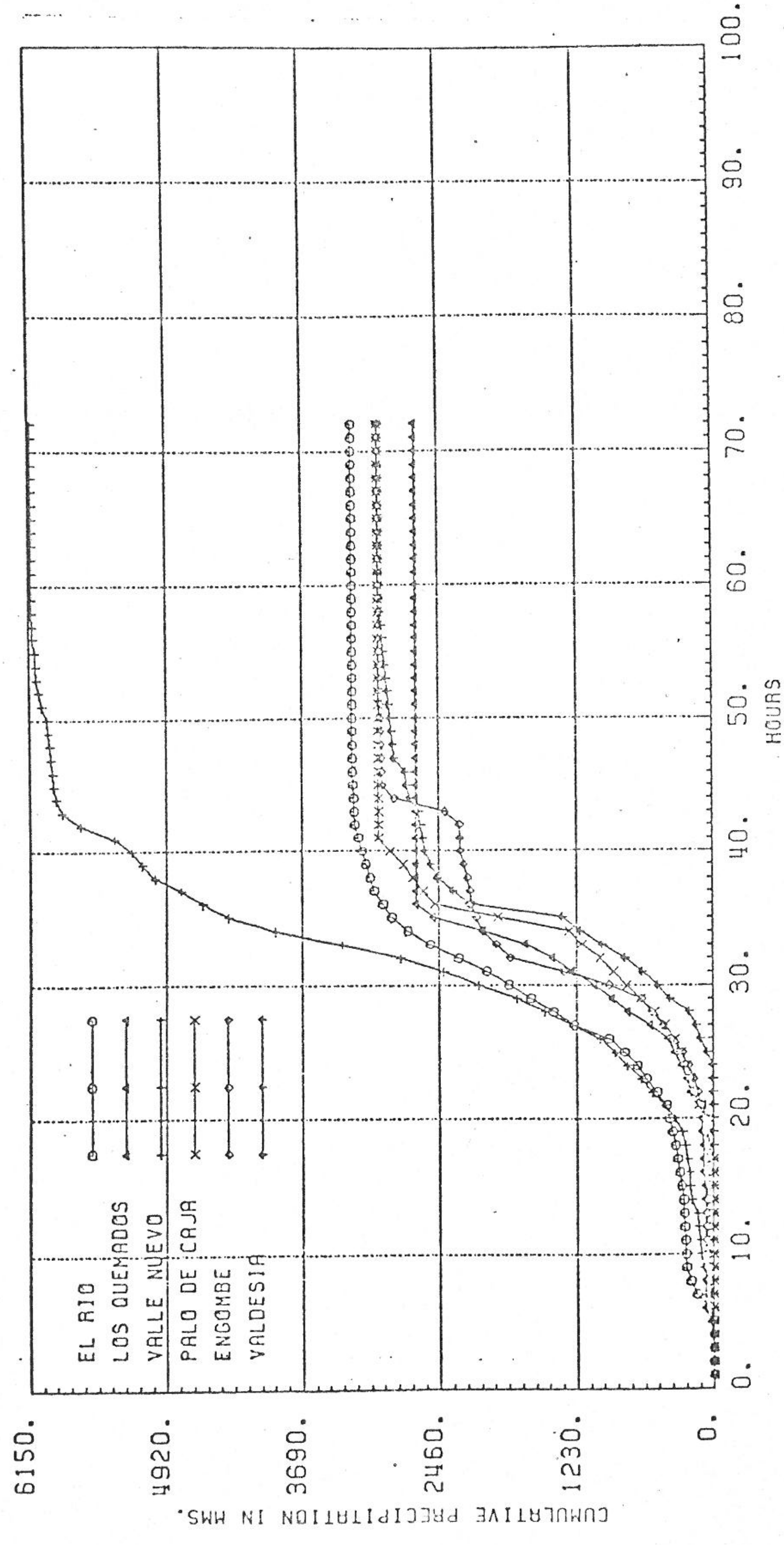
MASS CURVES   STORM STARTING 77 DIC 28 8 ENDING 78 ENE 1 8

Figure 1.6.A.17



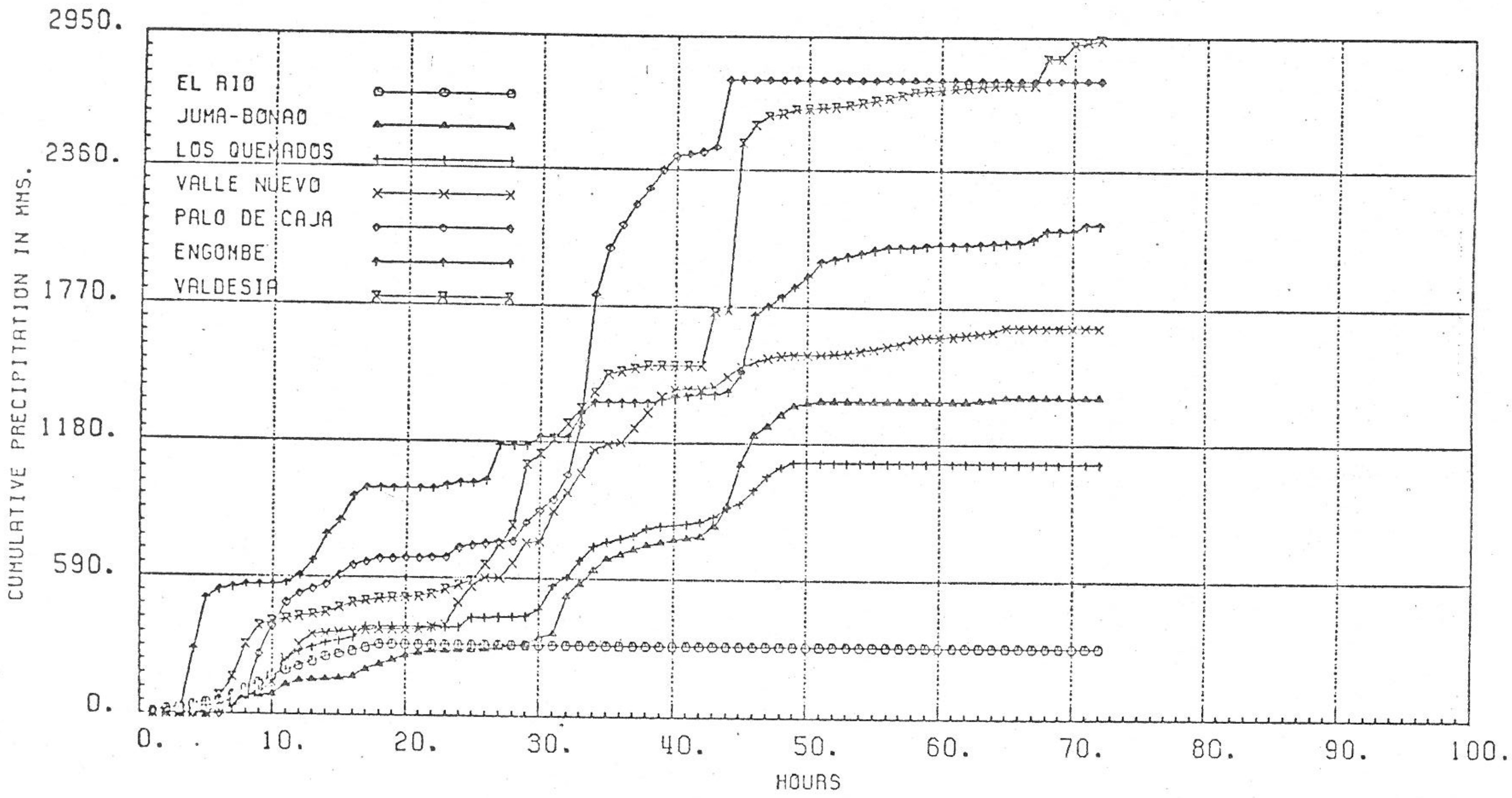
MASS CURVES STORM STARTING 78 AGO 3 8 ENDING 78 AGO 6 8

Figure 1.6.A.18



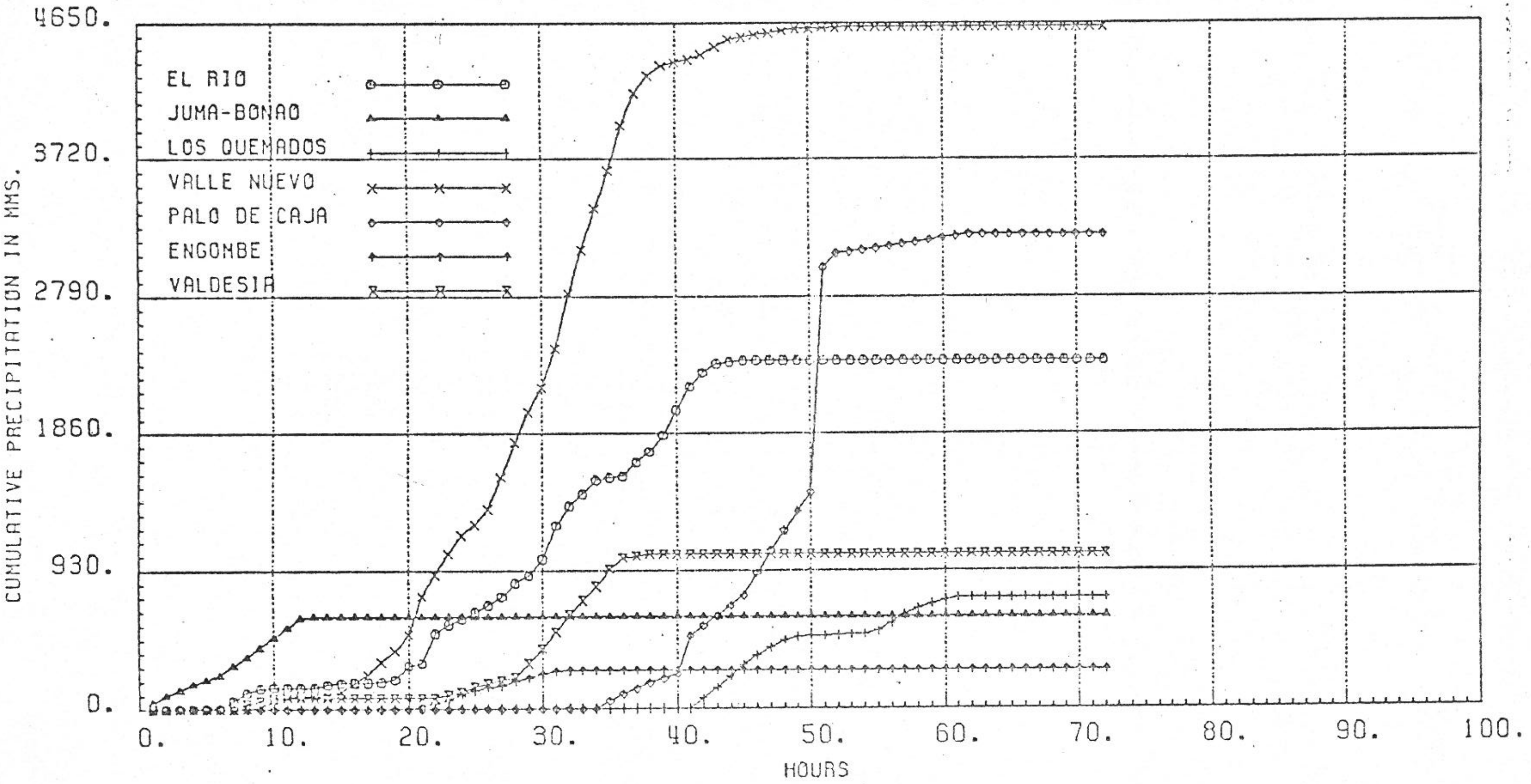
MASS CURVES   STORM STARTING 79 AGO 30 8 ENDING 79 SEP 2 8

Figure 1.6.A.19



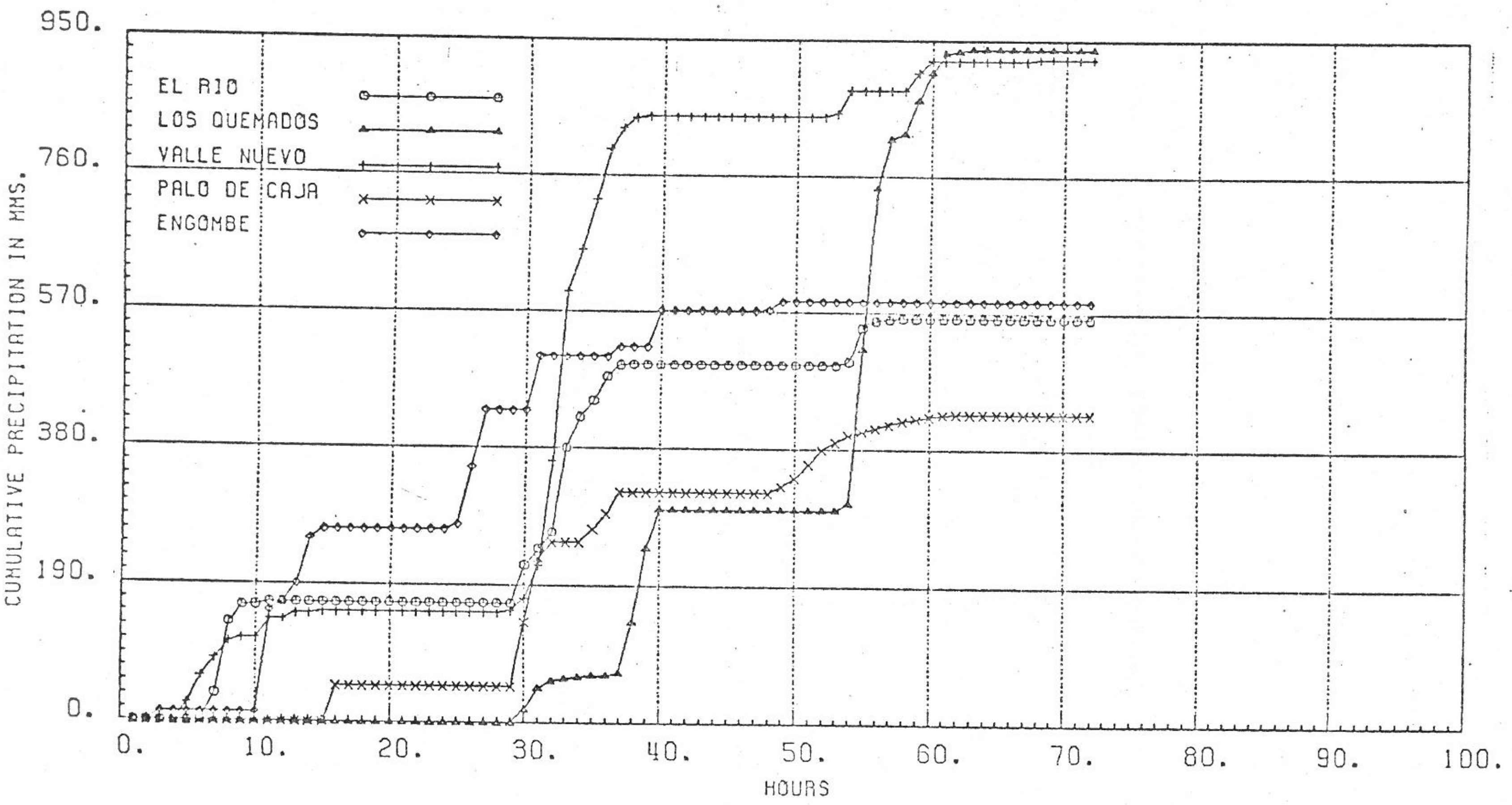
MASS CURVES STORM STARTING 79 SEP 5 8 ENDING 79 SEP 8 8

Figure 1.6.A.20



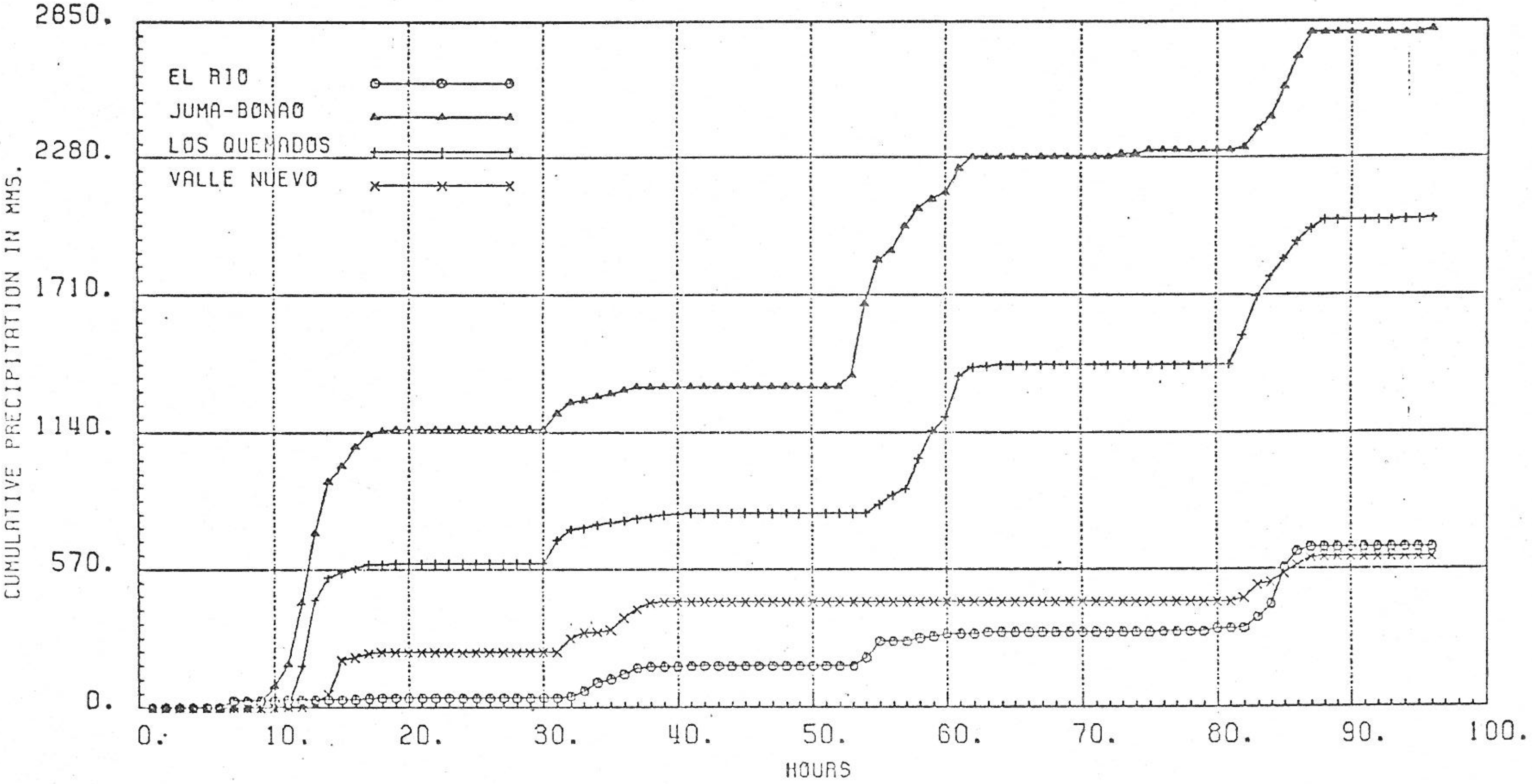
MASS CURVES STORM STARTING 80 AGO 4 8 ENDING 80 AGO 7 8

Figure 1.6.A.21



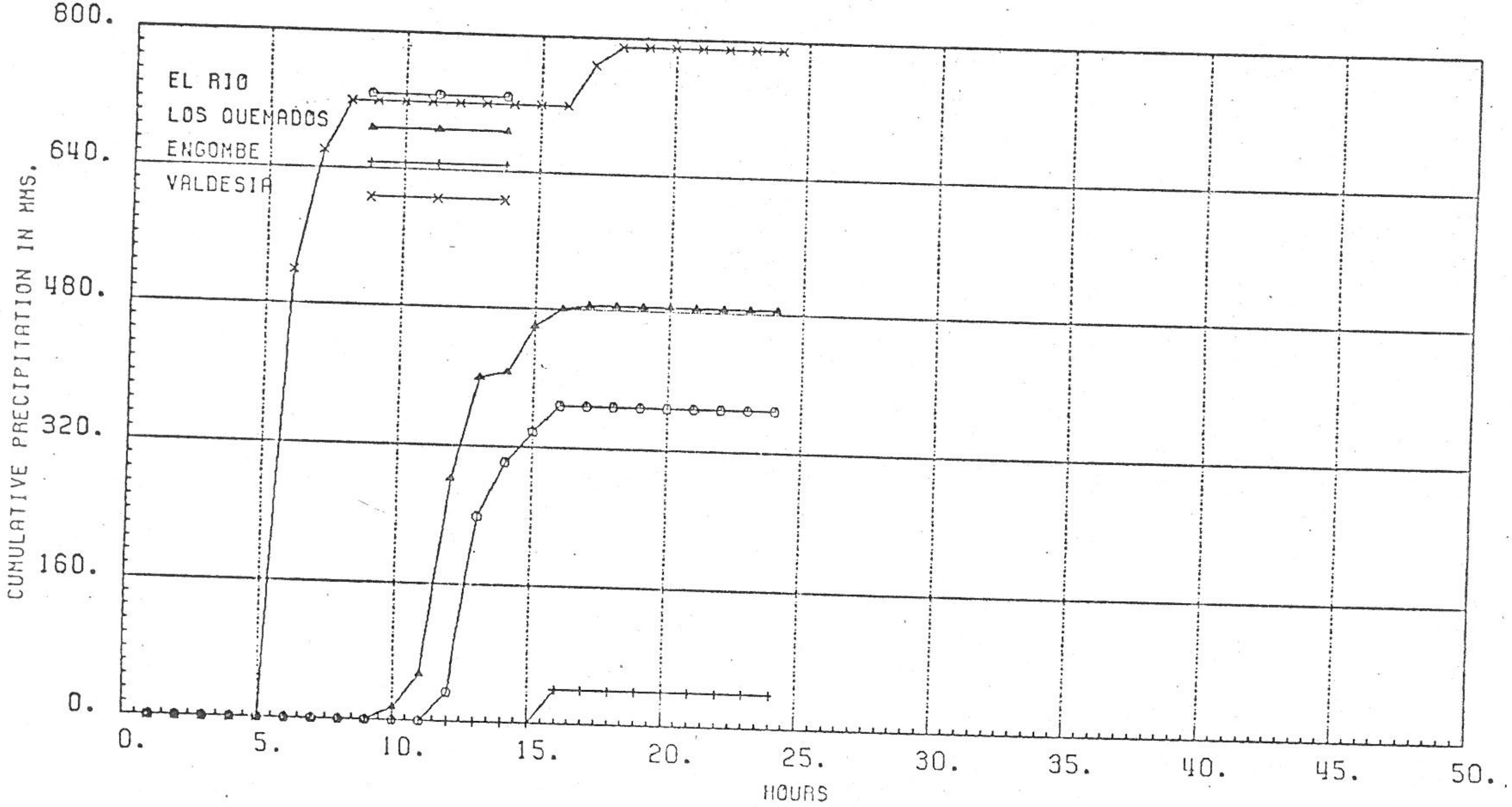
MASS CURVES STORM STARTING 81 MAY 8 8 ENDING 81 MAY 11 8

Figure 1.6.A.22



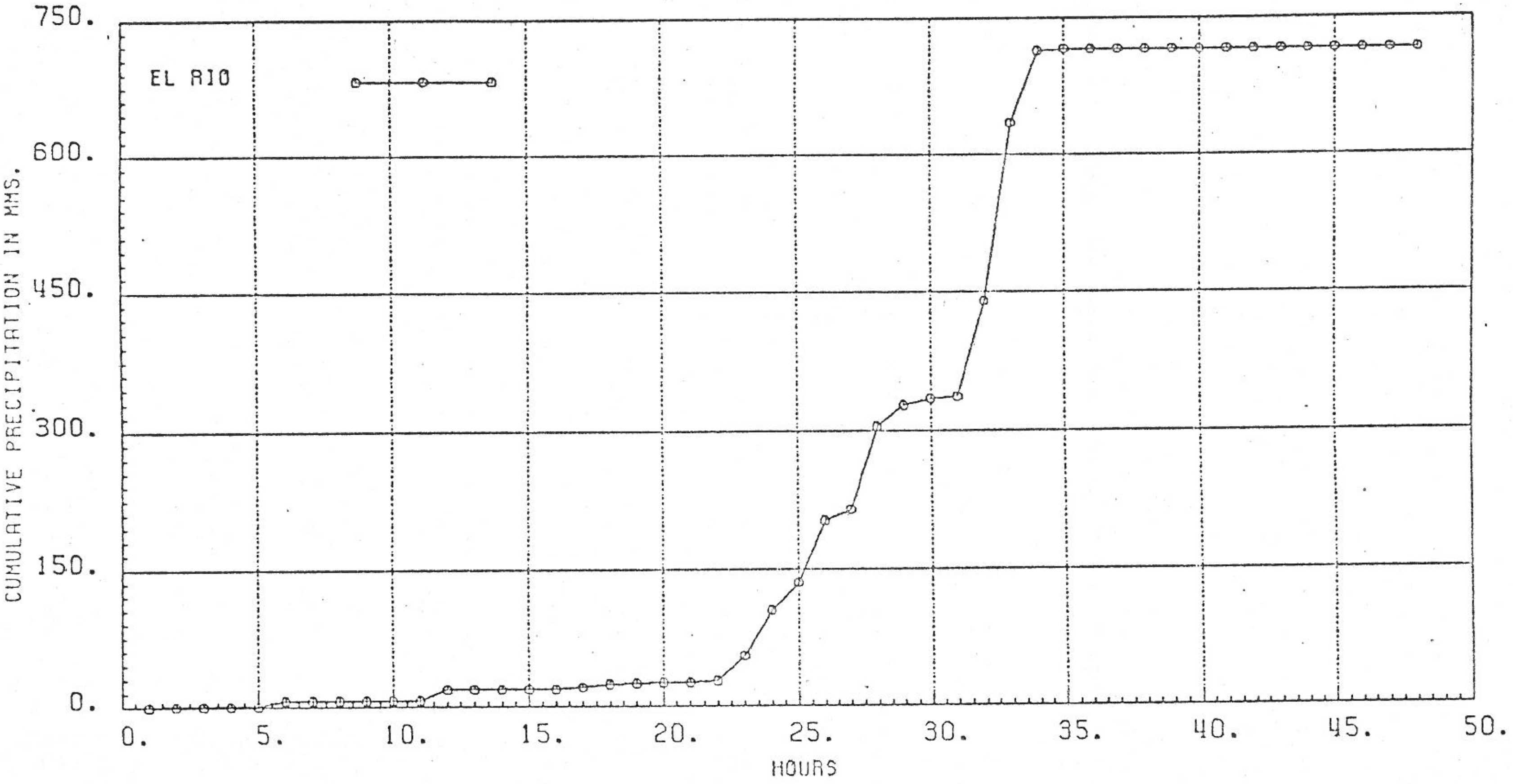
MASS CURVES STORM STARTING 82 MAY 9 8 ENDING 82 MAY 13 8

Figure 1.6.A.23



MASS CURVES STØRM STARTING 83 ABR 12 8 ENDING 83 ABR 13 8

Figure 1.6.A.24



MASS CURVES STORM STARTING 84 AGO 1 8 ENDING 84 AGO 3 8

Figure 1.6.A.25

APPENDIX 1.6.B

PROGRAM LISTING FOR RAINFALL ISOHYETH COMPUTATIONS

```
      PROGRAM PCMAP (INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,
     1 TAPE10)
C
C     PROGRAM FOR MAPPING, INTERPOLATION AND AREAL AVERAGING
C
      CHARACTER*8 LIST,ALFA,PROC,TITLE,SNAME,BL,BLANK,ENDER,SKIP
      CHARACTER*1 STN
      CHARACTER*8 SDNAME
      DIMENSION             ALFA(10)      , PROC(23)      , BL(3)         ,
     1        IND(5)
      COMMON /SYSID/           STORE(400,101)
      COMMON /SYSID2/         TITLE(10),  SNAME(50)
      COMMON /CONST/        IDSC          , NS            , NX            ,
     1        NY          , DX            , DY            , XMAX          ,
     2        XMIN        , YMAX          , YMIN          , HMAX          ,
     3        HMIN        , SMAX          , SMIN
      COMMON /SYSTAT/       AMU           , STD           , STE           ,
     1        RC          , ATC           , CRSCO(50)     , SPAC(50,50)
      COMMON /CVAR/         KVR           , OMEGA         , ALPHA         ,
     1        SVAR(50)    , SMU(50)
      COMMON /SYSDAT/       X(50)         , Y(50)         , H(50)         ,
     1        Z(50)
      COMMON /SBOUND/       NB            , XB(100)       , YB(100)
      COMMON /SBOUN2/       STN(50,8)
      COMMON /AREAL/        AREA          , TAR
      COMMON /CODE/         ID            , VR(5)         , KCOR          ,
     1        KERR
      COMMON /CORP/         NCR           , FA            , FB            ,
     1        AXM         , AYL           , XM
      COMMON /PTP/          NP            , STP(50)       , XP(50)        ,
     1        YP(50)      , KDP(50)
      COMMON /DEPTH1/ SDNAME(50)
      COMMON /DEPTH2/ NRS, XRS(50), YRS(50)
      DATA PROC/'TITLE','RANGE','STATION','BOUNDARY','DATA','STATISTI',
     1 'THIESSEN','HARMONIC','OPTIMAL','POLYNOMI','INVERSE','QUADRIC',
     2 'KRIGING','STOP','TAPE','RETITLE','MASK','SPACOR','VARIOGRA',
     3 'PTDATA','DEPTH','STAMEANS','STADEPTH'/
      DATA BLANK/'        '/,ENDER/'END'/
      IDSC = 200
      RTXY=8.0
      NIG = 23
  100 REWIND 10
      KCOR = 0
      KVR = 0
      NC = 0
      NB=0
      NS=0
      NRS=0
      IND(1) = 0
      IND(2) = 0
      IND(3) = 0
      IND(4) = 0
      IND(5) = 0
  110 READ (5,940,ERR=120,END=120) LIST,ALFA
      NC = NC + 1
      WRITE (10,930) ALFA
```

```
      IF (LIST.EQ.PROC(14)) GO TO 120
      GO TO 110
  120 IF (NC.EQ.0) STOP
      WRITE (10,820) PROC(14)
      REWIND 10
      WRITE (6,800)
      NR = 0
  130 NR = NR + 1
      IF (NR.GT.NC) GO TO 400
      READ (10,940) LIST,ALFA
      DO 140 IG = 1,NIG
         IF (LIST.EQ.PROC(IG)) GO TO 150
  140 CONTINUE
      PNT = NR/1000.
      WRITE (6,950) PNT,ALFA
      GO TO 130
  150 GO TO (160,180,190,220,300,360,370,370,370,370,370,370,380,400,390
     1,170,250,260,270,280,370,300,375), IG
  160 IND(1) = 1
  170 PNT = NR/1000.
      WRITE (6,960) PNT,ALFA
      NR = NR + 1
      READ (10,930) ALFA
      PNT = NR/1000.
      WRITE (6,970) PNT,ALFA
      GO TO 130
  180 IND(2) = 1
      PNT = NR/1000.
      WRITE (6,960) PNT,ALFA
      NR = NR + 1
      READ (10,930) ALFA
      PNT = NR/1000.
      WRITE (6,970) PNT,ALFA
      GO TO 130
  190 IND(3) = 1
      PNT = NR/1000.
      WRITE (6,960) PNT,ALFA
  200 NR = NR + 1
      IF (NR.GT.NC) GO TO 350
      NS = NS + 1
      READ (10,940) LIST,ALFA
      PNT = NR/1000.
      IF (LIST.EQ.ENDER) GO TO 210
      WRITE (6,970) PNT,ALFA
      GO TO 200
  210 WRITE (6,970) PNT,ALFA
      NS = NS - 1
      GO TO 130
  220 PNT = NR/1000.
      WRITE (6,960) PNT,ALFA
  230 NR = NR + 1
      IF (NR.GT.NC) GO TO 350
      NB = NB + 1
      READ (10,940) LIST,ALFA
      PNT = NR/1000.
      IF (LIST.EQ.ENDER) GO TO 240
```

```
      WRITE (6,970) PNT,ALFA
      GO TO 230
  240 WRITE (6,970) PNT,ALFA
      NB = NB - 1
      GO TO 130
  250 PNT = NR/1000.
      WRITE (6,1010) PNT,ALFA
      GO TO 130
  260 PNT = NR/1000.0
      WRITE (6,960) PNT,ALFA
      NR = NR + 1
      READ (10,930) ALFA
      PNT = NR/1000.0
      WRITE (6,970) PNT,ALFA
      GO TO 130
  270 PNT = NR/1000.
      WRITE (6,960) PNT,ALFA
      NR = NR + 1
      READ (10,930) ALFA
      PNT = NR/1000.
      WRITE (6,970) PNT,ALFA
      GO TO 130
  280 PNT = NR/1000.
      WRITE (6,1010) PNT,ALFA
      BACKSPACE 10
      READ (10,1110) KPT
      IF (KPT.EQ.0) GO TO 130
  290 NR = NR + 1
      IF (NR.GT.NC) GO TO 350
      READ (10,940) LIST,ALFA
      PNT = NR/1000.
      WRITE (6,970) PNT,ALFA
      IF (LIST.EQ.ENDER) GO TO 130
      GO TO 290
  300 KND = 4
      IF (IG.NE.5) KND = 5
      NDT = 0
      IND(KND) = 1
      PNT = NR/1000.
      WRITE (6,960) PNT,ALFA
  310 NR = NR + 1
      IF (NR.GT.NC) GO TO 350
      NDT = NDT + 1
      READ (10,940) LIST,ALFA
      PNT = NR/1000.
      IF (LIST.EQ.ENDER) GO TO 320
      WRITE (6,970) PNT,ALFA
      GO TO 310
  320 NDT = NDT - 1
      WRITE (6,970) PNT,ALFA
      IF (NDT.EQ.NS) GO TO 130
      IND(KND) = 0
      IF (KND.EQ.4) WRITE (6,980)
      IF (KND.EQ.5) WRITE (6,990)
  330 WRITE (6,1000)
      NR = NR + 1
```

```
      DO 340 KF = NR,NC
         READ (10,940) LIST,ALFA
         PNT = KF/1000.
  340 WRITE (6,970) PNT,ALFA
      GO TO 790
  350 WRITE (6,1070) PROC(IG)
      WRITE (6,1000)
      WRITE (6,1060)
      GO TO 790
  360 PNT = NR/1000.
      WRITE (6,960) PNT,ALFA
      NR = NR + 1
      READ (10,930) ALFA
      PNT = NR/1000.
      WRITE (6,970) PNT,ALFA
      GO TO 130
  370 PNT = NR/1000.
      WRITE (6,1010) PNT,ALFA
      GO TO 130
  375 PNT = NR/1000.
      WRITE (6,1010) PNT, ALFA
  376 NR = NR + 1
      IF(NR.GT.NC) GO TO 350
      READ (10,940) LIST, ALFA
      PNT = NR/1000.
      IF (LIST.EQ.ENDER) GO TO 377
      WRITE (6,970) PNT, ALFA
      GO TO 376
  377 WRITE (6,970) PNT, ALFA
      GO TO 130
  380 PNT = NR/1000.
      WRITE (6,1010) PNT,ALFA
      BACKSPACE 10
      READ (10,1110) ID
      IF (ID.NE.1) GO TO 130
      IF (IND(5).EQ.1) GO TO 130
      WRITE (6,1050)
      GO TO 330
  390 PNT = NR/1000.
      WRITE (6,1020) PNT
      GO TO 130
  400 KERR = 0
      DO 410 II = 1,4
         IF (IND(II).EQ.1) GO TO 410
         KERR = 1
         WRITE (6,1040) PROC(II)
  410 CONTINUE
      IF (KERR.NE.1) GO TO 420
      WRITE (6,1060)
      GO TO 790
  420 PNT = NR/1000.
      WRITE (6,1030) PNT
      IF (LIST.NE.PROC(14)) WRITE (6,1080)
      REWIND 10
      NR = 0
  430 NR = NR + 1
```

```
    IF (NR.GT.NC) GO TO 790
    KERR = 0
    READ (10,810) LIST,ID,VR
    DO 440 IG = 1,NIG
       IF (LIST.EQ.PROC(IG)) GO TO 450
440 CONTINUE
    GO TO 430
450 IF (IG.LE.6) GO TO 480
    IF (ISIG.EQ.1) GO TO 480
    ISIG = 1
    CALL CHECK (RTXY)
    IF (KERR.EQ.1) GO TO 790
    CALL BOUND (INAME)
    GO TO 480
460 CALL TAPERWR (PROC(ITP),STORE,0)
    GO TO 430
480 GO TO (490,500,510,530,550,570,600,610,620,630,640,650,660,790,680
   1,490,730,740,770,780,670,580,675), IG
490 NR = NR + 1
    READ (10,820) TITLE
    GO TO 430
500 NR = NR + 1
    INAME = ID
    READ (10,810) LIST,ID,VR
    ITP = 4
    ISIG = 0
    NCR = MAX0(ID,0)
    NCR = MIN0(NCR,4)
    XMAX = VR(1)
    XMIN = VR(2)
    YMAX = VR(3)
    YMIN = VR(4)
    GO TO 430
510 DO 520 K = 1,NS
       NR = NR + 1
520 READ (10,830) SNAME(K),(STN(K,L),L = 1,8),X(K),Y(K),Z(K)
    READ (10,1100) SKIP
    NR = NR + 1
    GO TO 430
530 DO 540 L = 1,NB
       NR = NR + 1
540 READ (10,840) XB(L),YB(L)
    READ (10,1100) SKIP
    NR = NR + 1
    GO TO 430
550 AMU = 0.0
    STD = 0.0
    STE = 0.0
    DO 560 K = 1,NS
       NR = NR + 1
       READ (10,850) H(K)
       AMU = AMU + H(K)
560 STD = STD + H(K) * H(K)
    STD = SQRT((STD - AMU * AMU/NS)/(NS - 1.))
    AMU = AMU/NS
    READ (10,1100) SKIP
```

```
      NR = NR + 1
      GO TO 430
  570 NR = NR + 1
      READ (10,860) ID,VR,BL
      IF (BL(1).NE.BLANK) AMU = VR(1)
      IF (BL(2).NE.BLANK) STD = VR(2)
      IF (BL(3).NE.BLANK) STE = VR(3)
      GO TO 430
  580 DO 590 K = 1,NS
         NR = NR + 1
  590 READ (10,850) SMU(K)
      READ (10,1100) SKIP
      NR = NR + 1
      GO TO 430
  600 ITP = 7
      CALL THIESN
      KTP = ID
      GO TO 430
  610 ITP = 8
      CALL HARMON
      KTP = ID
      GO TO 430
  620 ITP = 9
      CALL OPTIM
      KTP = ID
      GO TO 430
  630 ITP = 10
      CALL POLYN
      KTP = ID
      GO TO 430
  640 ITP = 11
      CALL INDISM
      KTP = ID
      GO TO 430
  650 ITP = 12
      CALL QUAD
      KTP = ID
      GO TO 430
  660 ITP = 13
      CALL KRIGING
      KTP = ID
      GO TO 430
  670 CALL DEPTH
      GO TO 430
  675 NRS=0
  676 NR=NR+1
      NRS=NRS+1
      READ (10,815) SDNAME(NRS), XRS(NRS), YRS(NRS)
      IF(SDNAME(NRS).NE.ENDER) GO TO 676
      NRS=NRS-1
      GO TO 430
  680 IF (ITP.NE.0) GO TO 690
      WRITE (6,870)
      GO TO 430
  690 IF (ITP.NE.4) GO TO 700
      GO TO 460
```

```
  700 CALL TAPERWR (PROC(ITP),STORE,0)
      WRITE (6,880) PROC(ITP),KTP
      NTP = ITP
      ITP = 0
      IF (KCOR.EQ.0) GO TO 430
      IF (NTP.LE.8) GO TO 430
      CALL TAPERWR (PROC(ITP),STORE,1)
      GO TO 430
  730 IF (ITP.EQ.8) GO TO 430
      WRITE (6,1090) PROC(ITP),TITLE
      CALL MASK
      GO TO 430
  740 READ (10,860) ID,VR,BL
      RHO = 0.0
      IF (BL(1).NE.BLANK) RAD = VR(1)
      IF (BL(2).NE.BLANK) RHO = VR(2)
      KCOR = MAX0(ID, - 1)
      KCOR = MIN0(KCOR,2)
      RC = RAD
      IF (RHO * (RHO - 1.).GE.0.) GO TO 760
      IF (KCOR.EQ.2) GO TO 750
      RC =  - RAD/ALOG(RHO)
      GO TO 760
  750 RC = RHO * RAD/(1.0 - RHO)
  760 CALL SPACOR
      GO TO 430
  770 READ (10,810) LIST,ID,VR
      CALL VARIO
      GO TO 430
  780 CALL PTDATA (ID)
      GO TO 430
  790 IF (LIST.EQ.PROC(14)) GO TO 100
      STOP
C
C
C
  800 FORMAT (1H1,/T18,1H+,68(1H-),1H+,/T18,1H!,T20,68H   HYDROLOGIC MAP
     1PING, INTERPOLATION AND AREAL AVERAGING SYSTEM     !,/T18,1H+,68(1H
     2-),1H+)
  810 FORMAT (A8,2X,I5,4X,5F10.0)
  815 FORMAT (A8,11X,2F10.0)
  820 FORMAT (10A8)
  830 FORMAT (A8,T1,8A1,T20,3F10.0)
  840 FORMAT (T20,2F10.0)
  850 FORMAT (T20,F10.0)
  860 FORMAT (T14,I2,T20,5F10.0,T20,3(2X,A8))
  870 FORMAT (1H1,/T20,17HDATA SET IS EMPTY)
  880 FORMAT (1H-,T20,26HMAPPED VALUES ON TAPE  -  ,A8,6HCODE =,I3)
  890 FORMAT (1H1,/T20,A8,I3,3X,10A8/T22,2I6,2F15.5)
  900 FORMAT (10F10.3)
  910 FORMAT (8HSTDERROR,2X,10A8)
  920 FORMAT (10I10)
  930 FORMAT (10A8)
  940 FORMAT (A8,T1,10A8)
  950 FORMAT (/T5,1HS,F4.3,T25,10A8/T5,49H***** INVALID STATEMENT/PROCED
     1URE NOT FOUND *****,/)
```

```
  960 FORMAT (/T5,1HS,F4.3,T19,6HINPUT ,10A8)
  970 FORMAT (T5,1HS,F4.3,T25,10A8)
  980 FORMAT (/T5,81H*****  STATION INPUT DATA IS GREATER OR LESS THAN T
     1HE NUMBER OF STATION(S)   *****)
  990 FORMAT (/T5,81H***** STATION INPUT MEANS IS GREATER OR LESS THAN T
     1HE NUMBER OF STATION(S)   *****)
 1000 FORMAT (/T5,58H*****  INPUT STREAM IS FLUSH UP TO STOP/END OF FILE
     1  *****)
 1010 FORMAT (/T5,1HS,F4.3,T20,5HPROC ,10A8)
 1020 FORMAT (T5,1HS,F4.3,T20,25HTAPE PRECEEDING PROCEDURE)
 1030 FORMAT (/T5,1HS,F4.3,T20,4HSTOP)
 1040 FORMAT (//T5,30HNOTE:  INPUT REQUIREMENTS FOR ,A8,17H IS NOT SATIS
     1FIED)
 1050 FORMAT (/T5,63HNOTE:  INPUT REQUIREMENTS FOR KRIGING OPTION 1 IS N
     1OT SATISFIED)
 1060 FORMAT (/T5,35H*****  NO FURTHER PROCESSING  *****)
 1070 FORMAT (/T5,13H*****  END OF,A8,1X,16HNOT FOUND  *****)
 1080 FORMAT (1H+,T25,16H* STMT GENERATED)
 1090 FORMAT (1H1,T20,16HMASKED VALUES - ,A8,3H : ,10A8/)
 1100 FORMAT (A8)
 1110 FORMAT (T14,I2)
      END
      SUBROUTINE CHECK (RTXY)
C
C     DIAGNOSTIC CHECK OF COORDINATE SYSTEM
C
      CHARACTER*8 TITLE, SNAME
      CHARACTER*1 STN
      COMMON /SYSID/           STORE(400,101)
      COMMON /SYSID2/         TITLE(10),  SNAME(50)
      COMMON /CONST/        IDSC          , NS            , NX          ,
     1         NY         , DX            , DY            , XMAX        ,
     2         XMIN       , YMAX          , YMIN          , HMAX        ,
     3         HMIN       , SMAX          , SMIN
      COMMON /SYSDAT/       X(50)         , Y(50)         , H(50)       ,
     1         Z(50)
      COMMON /SYSTAT/       AMU           , STD           , STE         ,
     1         RC         , ATC           , CRSCO(50)     , SPAC(50,50)
      COMMON /SBOUND/       NB            , XB(100)       , YB(100)
      COMMON /SBOUN2/      STN(50,8)
      COMMON /AREAL/        AREA          , TAR
      COMMON /CODE/         ID            , VR(5)         , KCOR        ,
     1         KERR
      COMMON /CORP/         NCR           , FA            , FB          ,
     1         AXM        , AYL           , XM
      BIG = 9999999.0
      TAR = 0.0
      FA = 3.141592654/180.
      FB = 111.
      WRITE (6,230) TITLE
      IF (NCR.EQ.0) GO TO 100
      AXL = ANGLE(XMIN,1)
      AXH = ANGLE(XMAX,1)
      AXM = (AXL + AXH)/2.
      AYL = ANGLE(YMIN,2)
      AYH = ANGLE(YMAX,2)
```

```
    XL = XMIN
    XH = XMAX
    YL = YMIN
    YH = YMAX
    CL = COS(FA * AYL)
    CH = COS(FA * AYH)
    XMAX = FB * (AXH - AXL) * AMAX1(CL,CH)
    XMIN = 0.0
    XM = XMAX/2.
    YMAX = FB * (AYH - AYL)
    YMIN = 0.
    WRITE (6,240) XL,YL,XMIN,YMIN,XH,YH,XMAX,YMAX
    GO TO 110
100 WRITE (6,250) XMIN,YMIN,XMAX,YMAX
110 NX = 101
    DX = (XMAX - XMIN)/100.0
    DY = DX * 10./RTXY
    NY = IFIX((YMAX - YMIN)/DY) + 1
    IF (NS.LE.0) GO TO 220
    DO 150 K = 1,NS
       IF (NCR.EQ.0) GO TO 120
       AX = ANGLE(X(K),1)
       AY = ANGLE(Y(K),2)
       XT = X(K)
       YT = Y(K)
       X(K) = XM + FB * COS(FA * AY) * (AX - AXM)
       Y(K) = FB * (AY - AYL)
       WRITE (6,260) K,SNAME(K),XT,YT,X(K),Y(K),Z(K)
       GO TO 130
120    WRITE (6,270) K,SNAME(K),X(K),Y(K),Z(K)
130    IF ((X(K) - XMIN) * (X(K) - XMAX).GT.0.) GO TO 140
       IF ((Y(K) - YMIN) * (Y(K) - YMAX).GT.0.0) GO TO 140
       WRITE (6,280)
       GO TO 150
140    WRITE (6,290)
150 CONTINUE
    KERR = 0
    IF (NB.GT.0) GO TO 170
    NB = 4
    TAR = BIG
    XB(1) = XMIN
    XB(2) = XMAX
    XB(3) = XMAX
    XB(4) = XMIN
    YB(1) = YMIN
    YB(2) = YMIN
    YB(3) = YMAX
    YB(4) = YMAX
    DO 160 L = 1,NB
160 WRITE (6,300) L,XB(L),YB(L)
    RETURN
170 DO 210 L = 1,NB
       IF (NCR.EQ.0) GO TO 180
       AX = ANGLE(XB(L),1)
       AY = ANGLE(YB(L),2)
       XT = XB(L)
```

```
         YT = YB(L)
         XB(L) = XM + FB * COS(FA * AY) * (AX - AXM)
         YB(L) = FB * (AY - AYL)
         WRITE (6,310) L,XT,YT,XB(L),YB(L)
         GO TO 190
 180     WRITE (6,320) L,XB(L),YB(L)
 190     IF ((XB(L) - XMIN) * (XB(L) - XMAX).GT.0.) GO TO 200
         IF ((YB(L) - YMIN) * (YB(L) - YMAX).GT.0.) GO TO 200
         WRITE (6,280)
         GO TO 210
 200     WRITE (6,290)
         KERR = 1
 210 CONTINUE
      IF (KERR.EQ.1) WRITE (6,330)
      RETURN
 220 KERR = 1
      WRITE (6,340)
      RETURN
C
C
C
 230 FORMAT (1H1,/T12,40HDIAGNOSTIC CHECK OF COORDINATE SYSTEM : ,10A8/
     1/T38,9HSPHERICAL,T68,11HRECTANGULAR,//T10,14HCONTROL POINTS,T30,11
     2HDEG.MIN.SEC,T45,11HDEG.MIN.SEC,T60,12HX-COORDINATE,T75,12HY-COORD
     3INATE,T90,11HZ-ELEVATION,T105,11HDIAGNOSTICS,/T31,9HLONGITUDE,T47,
     48HLATITUDE,//)
 240 FORMAT (T10,7HMINIMUM,T30,F10.0,T45,F10.0,T60,F10.3,T75,F10.3/T10,
     17HMAXIMUM,T30,F10.0,T45,F10.0,T60,F10.3,T75,F10.3/)
 250 FORMAT (T10,7HMINIMUM,T60,F10.3,T75,F10.3/T10,7HMAXIMUM,T60,F10.3,
     1T75,F10.3/)
 260 FORMAT (T10,3HSTA,I4,2X,A8,T30,F10.0,T45,F10.0,T60,F10.3,T75,F10.3
     1,T90,F10.3)
 270 FORMAT (T10,3HSTA,I4,2X,A8,T60,F10.3,T75,F10.3,T90,F10.3)
 280 FORMAT (1H+,T105,15HINSIDE OF RANGE)
 290 FORMAT (1H+,T103,18H*OUTSIDE OF RANGE*)
 300 FORMAT (T10,22HDEFAULT BOUNDARY POINT,I3,T60,F10.3,T75,F10.3,T105,
     115HINSIDE OF RANGE)
 310 FORMAT (T10,14HBOUNDARY POINT,I3,T30,F10.0,T45,F10.0,T60,F10.3,T75
     1,F10.3)
 320 FORMAT (T10,14HBOUNDARY POINT,I3,T60,F10.3,T75,F10.3)
 330 FORMAT (/T40,55HNO FURTHER PROCESSING - BOUNDARY POINT OUTSIDE OF
     1RANGE,/)
 340 FORMAT (T105,17HNO INPUT STATIONS,//)
      END
      FUNCTION ANGLE(A,KL)
C
C     CONVERSION FROM DEGREE-MINUTES-SECONDS TO DEGREE DECIMALS
C     OR FROM DEGREE DECIMALS DO DEGREE-MINUTES-SECONDS
C       NCR=1, DEG-MIN-SEC TO DEG DECIMALS (EAST)
C       NCR=1, DEG-MIN-SEC TO DEG DECIMALS (WEST)
C       NCR=3, DEG DECIMALS TO DEG-MIN-SEC (EAST)
C       NCR=4, DEG DECIMALS TO DEG-MIN-SEC (WEST)
C
      COMMON /CORP/         NCR          , FA            , FB           ,
     1       AXM          , AYL          , XM
      GO TO (100,100,110,110), NCR
```

```
  100 IA = IFIX(A)
      IDEG = IA/10000
      IMIN = IA/100 - 100 * IDEG
      ISEC = IA - 10000 * IDEG - 100 * IMIN
      ANG = FLOAT(IDEG) + FLOAT(IMIN)/60. + FLOAT(ISEC)/3600.
      IF (NCR.EQ.1) GO TO 120
      IF (KL.EQ.2) GO TO 120
      ANG = 180.0 - ANG
      GO TO 120
  110 ANG = A
      IA = A
      DEG = IA
      A = (A - DEG) * 60.0
      IA = A
      AMIN = IA
      A = (A - AMIN) * 60.0
      IA = A
      ASEC = IA
      A = DEG * 10000.0 + AMIN * 100.0 + ASEC
      IF (NCR.EQ.3) GO TO 120
      IF (KL.EQ.2) GO TO 120
      ANG = 180.0 - ANG
  120 ANGLE = ANG
      RETURN
      END
      SUBROUTINE BOUND (INAME)
C
C     DETERMINATION OF BASIN BOUNDARY POINTS
C
      CHARACTER*8 TITLE, SNAME
      CHARACTER*1 STN,PLOTC(200,101),BLK,PLUS,PERD
      COMMON /SYSID/          STORE(400,101)
      COMMON /SYSID2/        TITLE(10),  SNAME(50)
      COMMON /CONST/        IDSC        , NS            , NX            ,
     1        NY          , DX          , DY            , XMAX          ,
     2        XMIN        , YMAX        , YMIN          , HMAX          ,
     3        HMIN        , SMAX        , SMIN
      COMMON /SYSDAT/       X(50)       , Y(50)         , H(50)         ,
     1        Z(50)
      COMMON /SBOUND/       NB          , XB(100)       , YB(100)
      COMMON /SBOUN2/      STN(50,8)
      COMMON /AREAL/        AREA        , TAR
      DATA BLK,PLUS,PERD/' ','+','.'/
      BIG = 9999999.0
      IDR = 0
      IF (TAR.LT.BIG) GO TO 110
      DO 100 I = 1,NY
      DO 100 J = 1,NX
  100 STORE(I,J) = 1.0
      GO TO 240
  110 DO 120 I = 1,NY
      DO 120 J = 1,NX
  120 STORE(I,J) = 0.0
      DO 230 L = 1,NB
         X1 = XB(L)
         Y1 = YB(L)
```

```
         LB = L + 1
         IF (LB.LE.NB) GO TO 130
         LB = 1
130      X2 = XB(LB)
         Y2 = YB(LB)
         IX1 = IFIX((X1 - XMIN)/DX) + 1
         IX2 = IFIX((X2 - XMIN)/DX) + 1
         IF (IX2 - IX1) 140,170,200
140      IX2 = IX2 + 1
         DO 160 IX = IX2,IX1
            XT = XMIN + DX * (IX - 1.0)
            YT = Y2 + (Y1 - Y2) * (XT - X2)/(X1 - X2)
            IYM = IFIX((YT - YMIN)/DY) + 1
            DO 150 IY = 1,IYM
150         STORE(IY,IX) = STORE(IY,IX) + 1.0
160      CONTINUE
         GO TO 230
170      IF (Y2.GE.Y1) GO TO 180
         TP = Y1
         Y1 = Y2
         Y2 = TP
180      IY1 = IFIX((Y1 - YMIN)/DY) + 1
         IY2 = IFIX((Y2 - YMIN)/DY) + 1
         DO 190 IY = IY1,IY2
190      STORE(IY,IX1) = STORE(IY,IX1) + 1.0
         GO TO 230
200      IX1 = IX1 + 1
         DO 220 IX = IX1,IX2
            XT = XMIN + DX * (IX - 1.0)
            YT = Y1 + (Y2 - Y1) * (XT - X1)/(X2 - X1)
            IYM = IFIX((YT - YMIN)/DY)
            IF (IYM.LE.0) GO TO 220
            DO 210 IY = 1,IYM
210         STORE(IY,IX) = STORE(IY,IX) - 1.0
220      CONTINUE
230   CONTINUE
240   TAR = 0.0
      DO 270 IY = 1,NY
         IDS3 = IY + IDR
         DO 260 IX = 1,NX
            IF (STORE(IY,IX).LE.0.0) GO TO 250
            STORE(IY,IX) = 0.0
            TAR = TAR + 1.0
            PLOTC(IDS3,IX) = BLK
            GO TO 260
250         PLOTC(IDS3,IX) = PERD
            STORE(IY,IX) =  - BIG
260      CONTINUE
270   CONTINUE
      AREA = TAR * DX * DY
      DO 340 K = 1,NS
         IF ((X(K) - XMIN) * (X(K) - XMAX).GT.0.0) GO TO 340
         IF ((Y(K) - YMIN) * (Y(K) - YMAX).GT.0.0) GO TO 340
         IX = IFIX((X(K) - XMIN)/DX) + 1
         IY = IFIX((Y(K) - YMIN)/DY) + 1
         IY = IY + IDR
```

```
         PLOTC(IY,IX) = PLUS
         IF (INAME.EQ.1) GO TO 340
         IY = IY - IDR
         IXP = IX - 3
  280    IF (IXP.GT.0) GO TO 290
         IXP = IXP + 1
         GO TO 280
  290    IT = IX + 4
  300    IF (IT.LE.NX) GO TO 310
         IT = IT - 1
         IXP = IXP - 1
         GO TO 300
  310    IYP = IY + 1
         IF (IYP.LE.NY) GO TO 320
         IYP = IY - 1
  320    IYP = IYP + IDR
         KX = 0
         DO 330 IX = IXP,IT
            KX = KX + 1
  330    PLOTC(IYP,IX) = STN(K,KX)
  340 CONTINUE
      WRITE (6,350) TITLE
      CALL GRAPH (PLOTC)
      UA = DX * DY
      WRITE (6,360) AREA,UA,DX,DY
      RETURN
C
C
C
  350 FORMAT (1H1,T22,31HDELINEATION OF BASIN BOUNDARY: ,10A8//)
  360 FORMAT (//  T32,12HTOTAL AREA =,F10.3/T32,11HUNIT AREA =,F10.3//T3
     12,9HDELTA X =,F10.3/T32,9HDELTA Y =,F10.3//T32,7HLEGEND:,/T33,21HI
     2.I  OUTSIDE OF BASIN,/T33,20HI I  INSIDE OF BASIN,/T33,13HI+I   ST
     3ATION)
      END
      SUBROUTINE GRAPH (PLOTC)
C
C     MAPPING OF CHARACTER INFORMATION
C
      CHARACTER*8 TITLE, SNAME
      CHARACTER*1 PLOTC(200,101)
      DIMENSION                 XAX(11)
      COMMON /SYSID/               STORE(400,101)
      COMMON /SYSID2/            TITLE(10),  SNAME(50)
      COMMON /CONST/            IDSC         , NS           , NX           ,
     1        NY          , DX           , DY           , XMAX         ,
     2        XMIN        , YMAX         , YMIN         , HMAX         ,
     3        HMIN        , SMAX         , SMIN
      IDR = 0
      WRITE (6,140)
      AX = DX * 10
      XAX(1) = XMIN
      DO 100 K = 2,11
  100 XAX(K) = XAX(K - 1) + AX
      DO 110 II = 1,NY
         I = NY + 1 - II
```

```
         YAX = YMIN + DY * (I - 1.0)
         IDS = I + IDR
 110  WRITE (6,120) YAX,(PLOTC(IDS,J),J = 1,NX)
      WRITE (6,140)
      WRITE (6,130) XAX
      RETURN
C
C
C
 120  FORMAT (5X,F8.2,1X,1HI,101A1,1HI)
 130  FORMAT (9X,3HY/X,F6.2,10(3X,F7.2))
 140  FORMAT (14X,2HI+,10(9(1H-),1H+),1HI)
      END
      SUBROUTINE MAP (KDSK)
C
C     MAPPING OF CONTOURS
C
      CHARACTER*8 TITLE, SNAME
      CHARACTER*1 PLOTC(200,101),PT,BLK,PERD,PLUS
      COMMON /SYSID/            STORE(400,101)
      COMMON /SYSID2/          TITLE(10),  SNAME(50)
      DIMENSION               HG(21)       , PT(21)
      COMMON /CONST/          IDSC         , NS           , NX           ,
     1        NY            , DX           , DY           , XMAX         ,
     2        XMIN          , YMAX         , YMIN         , HMAX         ,
     3        HMIN          , SMAX         , SMIN
      COMMON /SYSDAT/         X(50)        , Y(50)        , H(50)        ,
     1        Z(50)
      COMMON /CODE/           ID           , VR(5)        , KCOR         ,
     1        KERR
      DATA BLK,PERD,PLUS/' ','.','+'/
      DATA PT/'0','1','2','3','4','5','6','7','8','9','A','B','C','D',
     1 'E','F','G','H','I','J','K'/
      BIG = 9999999.0
      KD = IDSC * (KDSK - 1)
      IDR = 0
      HMX = HMAX
      HMN = HMIN
      IF (KDSK.EQ.1) GO TO 100
      HMX = SMAX
      HMN = SMIN
 100  RH = ABS(HMX - HMN)
      IF (RH.EQ.0.0) RETURN
      IF (ID.NE. - 99) GO TO 110
      DH = RH/20.0
      TOL = DH * VR(1)
      GO TO 150
 110  BS = 0.001
 120  DO 130 K = 1,9
         DH = BS * K
         IF (RH/DH.LE.18.0) GO TO 140
 130  CONTINUE
      BS = BS * 10.0
      GO TO 120
 140  NL = IFIX(HMN/DH) - 1
      HMN = NL * DH
```

```
      TOL = DH * 0.25
  150 DO 160 K = 1,21
         HG(K) = HMN + DH * (K - 1.0)
         HH = HG(K) * 10000.
         HT = HH - IFIX(HH)
         IF (HT.LT.6.) HG(K) = HG(K) + .0003
  160 CONTINUE
      DO 230 I = 1,NY
         KDD = KD + I
         IDS3 = IDR + I
         DO 220 J = 1,NX
            PL = STORE(KDD,J)
            PLOTC(IDS3,J) = BLK
            IF (STORE(I,J).EQ.-BIG) GO TO 220
            K = IFIX((PL - HMN)/DH) + 1
            IF (K - 1) 170,190,180
  170       PLOTC(IDS3,J) = PT(1)
            GO TO 220
  180       IF (K.LT.21) GO TO 190
            PLOTC(IDS3,J) = PT(21)
            GO TO 220
  190       IF ((PL - HG(K) + TOL) * (PL - HG(K) - TOL).LE.0.0) GO TO 20
     1      0
            K = K + 1
            IF ((PL - HG(K) + TOL) * (PL - HG(K) - TOL).GT.0.0) GO TO 21
     1      0
  200       PLOTC(IDS3,J) = PT(K)
            GO TO 220
  210       PLOTC(IDS3,J) = PERD
  220    CONTINUE
  230 CONTINUE
      IF (NS.EQ.0) GO TO 250
      DO 240 K = 1,NS
         IF ((X(K) - XMIN) * (X(K) - XMAX).GT.0.0) GO TO 240
         IF ((Y(K) - YMIN) * (Y(K) - YMAX).GT.0.0) GO TO 240
         J = IFIX((X(K) - XMIN)/DX) + 1
         I = IFIX((Y(K) - YMIN)/DY) + 1
         IDS3 = I + IDR
         PLOTC(IDS3,J) = PLUS
  240 CONTINUE
  250 CONTINUE
      CALL GRAPH (PLOTC)
      WRITE (6,270)
      DO 260 K = 1,21
  260 WRITE (6,280) PT(K),HG(K),TOL
      RETURN
C
C
C
  270 FORMAT (//  T27,8HLEGEND :,//T28,7HSYMBOLS,T40,8HCONTOURS,T54,9HTO
     1LERANCE,/)
  280 FORMAT (T31,A1,T37,F10.3,T53,3H+/-,T58,F6.3)
      END
      SUBROUTINE GEPCON (AI,N)
C
C     MATRIX INVERSION USING GAUSSIAN ELIMINATION
```

```
C     WITH PIVOTAL CONDENSATION
C
      COMMON /CODE/          ID            , VR(5)         , KCOR          ,
     1        KERR
      DIMENSION              AI(52,52)     , A(52,104)     , W(52)
C
      KERR = 0
      NM = N - 1
      IM = N + 1
      NDL = N + N
      DO 110 I = 1,N
         DO 100 J = 1,N
            A(I,J) = AI(I,J)
            M = N + J
  100    A(I,M) = 0.0
         M = N + I
  110 A(I,M) = 1.0
      DO 170 I = 1,NM
         MX = I
         AMX = ABS(A(I,I))
         IN = I + 1
         DO 120 K = IN,N
            IF (ABS(A(K,I)).LE.AMX) GO TO 120
            MX = K
            AMX = ABS(A(K,I))
  120    CONTINUE
         IF (MX.EQ.I) GO TO 140
         DO 130 L = I,NDL
            TT = A(I,L)
            A(I,L) = A(MX,L)
  130    A(MX,L) = TT
  140    DV = A(I,I)
         IF (ABS(DV).LE.0.00000001) GO TO 220
         DO 160 J = IN,N
            IF (A(J,I).EQ.0.0) GO TO 160
            CN =  - A(J,I)/DV
            DO 150 L = I,NDL
  150       A(J,L) = A(J,L) + CN * A(I,L)
  160    CONTINUE
  170 CONTINUE
      IK = 0
      IF (ABS(A(N,N)).LE.0.00000001) GO TO 220
      DO 210 II = IM,NDL
         W(N) = A(N,II)/A(N,N)
         DO 190 I = 1,NM
            K = N - I
            JK = K + 1
            WW = A(K,II)
            DO 180 J = JK,N
  180       WW = WW - A(K,J) * W(J)
         IF (ABS(A(K,K)).LE.0.00000001) GO TO 220
  190    W(K) = WW/A(K,K)
         IK = IK + 1
         DO 200 L = 1,N
  200    AI(L,IK) = W(L)
  210 CONTINUE
```

```
      RETURN
  220 KERR = 1
      WRITE (6,230)
      RETURN
C
C
  230 FORMAT (/5X, 44HPROCESSING STOPPED - MATRIX DETERMINANT ZERO,/5X,
     120HIN SUBROUTINE GEPCON,/)
      END
      SUBROUTINE THIESN
C
C     THIESSEN METHOD AND AREAL AVERAGING
C
      CHARACTER*8 TITLE, SNAME
      CHARACTER*1 PLOTC(200,101),PT,BLK,PLUS
      DIMENSION            DST(50)     , W(50)       , ISM(50)     ,
     1        PT(30)
      COMMON /SYSID/          STORE(400,101)
      COMMON /SYSID2/        TITLE(10), SNAME(50)
      COMMON /CONST/       IDSC        , NS          , NX          ,
     1        NY         , DX          , DY          , XMAX        ,
     2        XMIN       , YMAX        , YMIN        , HMAX        ,
     3        HMIN       , SMAX        , SMIN
      COMMON /SYSDAT/      X(50)       , Y(50)       , H(50)       ,
     1        Z(50)
      COMMON /SYSTAT/      AMU         , STD         , STE         ,
     1        RC         , ATC         , CRSCO(50)   , SPAC(50,50) ,
      COMMON /AREAL/       AREA        , TAR
      COMMON /CODE/        KOD         , VR(5)       , KCOR        ,
     1        KERR
      DATA BLK,PLUS/' ','+'/
      DATA PT/'0','1','2','3','4','5','6','7','8','9','A','B','C','D',
     1 'E','F','G','H','I','J','K','L','M','N','O','P','Q','R','S','T'/
      WRITE (6,380) TITLE
      BIG = 9999999.0
      KOD1 = MAX0(KOD,1)
      KOD1 = MIN0(KOD1,6)
      IF (KOD1.NE.5) GO TO 100
      IF (KCOR.NE.0) GO TO 100
      WRITE (6,490)
      RETURN
  100 HM = 0.0
      ATM = 0.0
      DO 110 K = 1,NS
         ATM = ATM + H(K)
  110 W(K) = 0.0
      TOL = SQRT(DX * DX + DY * DY)
      IF (KOD1.EQ.5) TOL = ABS(ATM/NS) * TOL
      IF (KOD1.EQ.6) TOL = STD * TOL/RC
      DO 310 I = 1,NY
         YT = YMIN + DY * (I - 1.0)
         DO 300 J = 1,NX
            IF (STORE(I,J).EQ.-BIG) GO TO 290
            XT = XMIN + DX * (J - 1.0)
            DO 120 K = 1,NS
               ISM(K) = K
```

```
120        DST(K) = BIG
           DO 220 K = 1,NS
              GO TO (130,140,150,160,170,190), KOD1
130           DST(K) = SQRT((XT - X(K)) *  * 2 + (YT - Y(K)) *  * 2)
              GO TO 220
140           DST(K) = (XT - X(K)) *  * 2 + (YT - Y(K)) *  * 2
              GO TO 220
150           DST(K) = ABS(XT - X(K)) + ABS(YT - Y(K))
              GO TO 220
160           DST(K) = AMAX1(ABS(XT - X(K)),ABS(YT - Y(K)))
              GO TO 220
170           DIS = SQRT((XT - X(K)) *  * 2 + (YT - Y(K)) *  * 2)
              IF (DIS.GT.0.0) GO TO 180
              DST(K) = 0.0
              GO TO 220
180           IF (H(K).EQ.0.0) GO TO 220
              DST(K) = ABS(H(K)) * DIS
              GO TO 220
190           DIS = SQRT((XT - X(K)) * (XT - X(K)) + (YT - Y(K)) * (YT
  1           - Y(K)))
              IF (KCOR.EQ.2) GO TO 200
              RHO = EXP( - DIS/RC)
              GO TO 210
200           RHO = 1.0/(1.0 + DIS/RC)
210           DST(K) =  - ABS(RHO * (H(K) - AMU))
220        CONTINUE
           IF (NS.GT.2) GO TO 230
           K = 1
           IF (NS.EQ.1) GO TO 270
           IF (DST(1).GT.DST(2)) GO TO 260
           K = 2
           GO TO 260
230        DO 250 K = 1,2
              IS = K + 1
              DO 240 L = IS,NS
                 IF (DST(K).LE.DST(L)) GO TO 240
                 TMP = DST(K)
                 DST(K) = DST(L)
                 DST(L) = TMP
                 IT = ISM(K)
                 ISM(K) = ISM(L)
                 ISM(L) = IT
240           CONTINUE
250        CONTINUE
           K = ISM(1)
260        IF (ABS(DST(2) - DST(1)).GT.TOL) GO TO 270
           PLOTC(I,J) = BLK
           GO TO 280
270        PLOTC(I,J) = PT(K)
280        W(K) = W(K) + 1.0
           STORE(I,J) = H(K)
           HM = HM + H(K)
           GO TO 300
290        PLOTC(I,J) = BLK
300     CONTINUE
310 CONTINUE
```

```
      DO 320 K = 1,NS
         IF ((X(K) - XMIN) * (X(K) - XMAX).GT.0.0) GO TO 320
         IF ((Y(K) - YMIN) * (Y(K) - YMAX).GT.0.0) GO TO 320
         J = 1 + IFIX((X(K) - XMIN)/DX)
         I = 1 + IFIX((Y(K) - YMIN)/DY)
         I = I + IDR
         PLOTC(I,J) = PLUS
  320 CONTINUE
      CALL GRAPH (PLOTC)
      WRITE (6,390)
      DO 330 K = 1,NS
         W(K) = W(K)/TAR
         ART = W(K) * AREA
  330 WRITE (6,400) K,SNAME(K),PT(K),W(K),ART,H(K)
      HM = HM/TAR
      IF (KCOR.NE.0) GO TO 340
      WRITE (6,480) HM
      GO TO 370
  340 SD2 = STD * STD
      SE2 = STE * STE
      SE = ATC * SD2
      DO 360 K = 1,NS
         WT = W(K)
         SE = SE + WT * WT * SE2 - 2. * WT * CRSCO(K) * SD2
         DO 350 L = 1,NS
  350    SE = SE + WT * W(L) * SD2
  360 CONTINUE
      IF (SE.LE.0.0) SE = 0.0
      SE = SQRT(SE)
      WRITE (6,410) HM,SE
  370 WRITE(6,500) KOD1
      RETURN
C
  380 FORMAT (1H1,T20,28HMAPPING BY THIESSEN POLYGON:,10A8//)
  390 FORMAT (//  T20,7HSTA.NO.,6X,9HSTA. NAME,6X,6HSYMBOL,4X,15HTHIESSE
     1N WEIGHT,5X,12HPOLYGON AREA,T96,9HSTA. DATA,/)
  400 FORMAT (1H ,T21,I3,10X,A8,8X,A1,7X,F10.5,8X,F10.2,T95,F9.3)
  410 FORMAT (//  T40,23HAREAL AVERAGE OF DATA =,F16.4/T40,24HERROR OF A
     1REAL AVERAGE =,F15.4/)
  480 FORMAT (//  T40,23HAREAL AVERAGE OF DATA =,F16.4/)
  490 FORMAT (1H1,//T40,41HTHIESSEN METHOD - OPTION 5 NOT APPLICABLE,//T
     140,42HSPATIAL CORRELATION FUNCTION NOT SPECIFIED)
  500 FORMAT(/20X,'THIESSEN METHOD OPTION CODE =',I3//
     1 23X,'1  MIN STRAIGHT DISTANCE'/
     2 23X,'2  MIN SQUARE DISTANCE'/
     3 23X,'3  MIN ORTHOGONAL DISTANCE'/
     4 23X,'4  MIN MAX LEG DISTANCE'/
     5 23X,'5  MIN ABS (DATA) X STRAIGHT DISTANCE'/
     6 23X,'6  MAX ABS (DEVIATE) X SPATIAL CORRELATION COEFF'/)
      END
      SUBROUTINE QUAD
C
C     MULTIQUADRIC INTERPOLATION
C
      CHARACTER*8 TITLE, SNAME
      DIMENSION            C(50)        , A(52,52)     , RAD(50)       ,
```

```
   1        COR(50)     , W(50)
    COMMON /SYSID/           STORE(400,101)
    COMMON /SYSID2/        TITLE(10),  SNAME(50)
    COMMON /CONST/        IDSC        , NS          , NX          ,
   1        NY          , DX          , DY          , XMAX        ,
   2        XMIN        , YMAX        , YMIN        , HMAX        ,
   3        HMIN        , SMAX        , SMIN
    COMMON /SYSDAT/       X(50)       , Y(50)       , H(50)       ,
   1        DAS(50)
    COMMON /SYSTAT/       AMU         , STD         , STE         ,
   1        RC          , ATC         , CRSCO(50)   , SPAC(50,50)
    COMMON /AREAL/        AREA        , TAR
    COMMON /CODE/         KOD         , VR(5)       , KCOR        ,
   1        KERR
    BIG = 9999999.0
    SD2 = STD * STD
    SE2 = STE * STE
    KD = MAX0(1,KOD)
    KD = MIN0(KD,4)
    WRITE (6,370) TITLE
    A(1,1) = 0.
    DO 160 K = 2,NS
       X1 = X(K)
       Y1 = Y(K)
       KL = K - 1
       A(K,K) = 0.
       DO 150 J = 1,KL
          X2 = X(J)
          Y2 = Y(J)
          DSX = ABS(X1 - X2)
          DSY = ABS(Y1 - Y2)
          GO TO (100,110,120,130), KD
100       DST = SQRT(DSX * DSX + DSY * DSY)
          GO TO 140
110       DST = DSX * DSX + DSY * DSY
          GO TO 140
120       DST = DSX + DSY
          GO TO 140
130       DST = AMAX1(DSX,DSY)
140       A(K,J) = DST
          A(J,K) = DST
150    CONTINUE
160 CONTINUE
    IF (KD.NE.2) GO TO 190
    DO 180 K = 1,NS
       IF (DAS(K).LE.0.0) GO TO 180
       RG2 = DAS(K)/6.2832
       DO 170 J = 1,NS
170    A(K,J) = A(K,J) + RG2
180 CONTINUE
190 NSH = NS/2
    DO 210 K = 1,NSH
       IS = NS - K + 1
       DO 200 J = 1,NS
          TEMP = A(K,J)
          A(K,J) = A(IS,J)
```

```
200      A(IS,J) = TEMP
210   CONTINUE
      CALL GEPCON (A,NS)
      HM = 0.0
      IF (KERR.EQ.1) WRITE (6,380) KD,HM
      IF (KERR.EQ.1) RETURN
      DO 230 J = 1,NS
         SUM = 0.
         DO 220 K = 1,NS
            IS = NS + 1 - K
220      SUM = SUM + A(J,K) * H(IS)
230   C(J) = SUM
      HMAX =  - BIG
      HMIN = BIG
      SMAX =  - BIG
      SMIN = BIG
      DO 360 I = 1,NY
         YT = YMIN + DY * (I - 1.0)
         IDS2 = I + IDSC
         DO 350 J = 1,NX
            IF (STORE(I,J).EQ.-BIG) GO TO 350
            XT = XMIN + DX * (J - 1.0)
            HH = 0.
            SW = 0.
            DO 280 K = 1,NS
               DSX = ABS(XT - X(K))
               DSY = ABS(YT - Y(K))
               GO TO (240,250,260,270), KD
240            RAD(K) = SQRT(DSX * DSX + DSY * DSY)
               GO TO 280
250            RAD(K) = DSX * DSX + DSY * DSY
               GO TO 280
260            RAD(K) = DSX + DSY
               GO TO 280
270            RAD(K) = AMAX1(DSX,DSY)
280         CONTINUE
            DO 300 K = 1,NS
               SUM = 0.
               IS = NS + 1 - K
               DO 290 N = 1,NS
290            SUM = SUM + RAD(N) * A(N,IS)
               W(K) = SUM
               SW = SW + SUM
300         HH = HH + C(K) * RAD(K)
            STORE(I,J) = HH
            HMAX = AMAX1(HMAX,HH)
            HMIN = AMIN1(HMIN,HH)
            HM = HM + HH
            IF (KCOR.EQ.0) GO TO 350
            DO 320 K = 1,NS
               DS = SQRT((XT - X(K)) *  * 2 + (YT - Y(K)) *  * 2)
               IF (KCOR.EQ.2) GO TO 310
               COR(K) = EXP( - DS/RC)
               GO TO 320
310            COR(K) = 1./(1. + DS/RC)
320         CONTINUE
```

```
          SE = ((1. - SW) * AMU) *  * 2 + SD2
          DO 340 K = 1,NS
            WT = W(K)
            SE = SE + WT * WT * SE2 - 2. * WT * COR(K) * SD2
            DO 330 IS = 1,NS
 330        SE = SE + WT * W(IS) * SPAC(K,IS) * SD2
 340      CONTINUE
          IF (SE.LE.0.0) SE = 0.0
          SE = SQRT(SE)
          STORE(IDS2,J) = SE
          SMAX = AMAX1(SE,SMAX)
          SMIN = AMIN1(SE,SMIN)
 350    CONTINUE
 360  CONTINUE
      HM = HM/TAR
      CALL MAP (1)
      WRITE (6,380) KD,HM
      IF (KCOR.EQ.0) RETURN
      WRITE (6,390) TITLE
      CALL MAP (2)
      RETURN
C
C
C
 370  FORMAT (1H1,/T20,28HMULTIQUADRIC INTERPOLATION :,10A8//)
 380  FORMAT (//  T20,26HMULTIQUADRIC OPTION CODE =,I4/T23,28H1  SQRT((X
     1-XS)**2+(Y-YS)**2),/T23,24H2  (X-XS)**2 + (Y-YS)**2,/T23,24H3  ABS
     2(X-XS) + ABS(Y-YS),/T23,27H4  MAX(ABS(X-XS),ABS(Y-YS)),//T20,35HAR
     3EAL MEAN OF INTERPOLATED VALUES =,F12.5)
 390  FORMAT (1H1,/T20,23HERROR OF INTERPOLATION:,10A8//)
      END
      SUBROUTINE DEPTH
C
C     DEPTH-AREA CURVE COMPUTATIONS
C
      DIMENSION             CSA(50)     , CSB(50), WT(50,50)
      CHARACTER*8 TITLE, SNAME, SDNAME
      COMMON /SYSID/          STORE(400,101)
      COMMON /SYSID2/        TITLE(10),  SNAME(50)
      COMMON /CONST/        IDSC        , NS        , NX        ,
     1     NY        , DX          , DY        , XMAX      ,
     2     XMIN      , YMAX        , YMIN      , HMAX      ,
     3     HMIN      , SMAX        , SMIN
      COMMON /AREAL/        AREA        , TAR
      COMMON /CODE/         KOD         , VR(5)     , KCOR      ,
     1     KERR
      COMMON /DEPTH1/ SDNAME(50)
      COMMON /DEPTH2/ NRS, XRS(50), YRS(50)
      BIG = 9999999.0
      NC = MIN0(KOD,50)
      NC = MAX0(2,NC)
      CMIN = VR(1)
      CMAX = VR(2)
      IF (CMAX.NE.CMIN) GO TO 100
      CMIN = HMIN
      CMAX = HMAX
```

```
100 DC = (CMAX - CMIN)/NC
    DO 110 K = 1,NC
       CSA(K) = 0.0
    CSB(K) = 0.0
    IF(NRS.EQ.0) GO TO 110
    DO 106 N=1,NRS
106 WT(N,K) = 0.0
110 CONTINUE
    NC1 = NC - 1
    DO 150 I = 1,NY
    YT = YMIN + DY * (I-1.0)
       DO 140 J = 1,NX
          IF (STORE(I,J).EQ.-BIG) GO TO 140
          XT = XMIN + DX * (J-1.0)
          DO 120 K = 1,NC1
             KC = K
             CL = CMIN + (K - 1.0) * DC
             CH = CL + DC
             CV = STORE(I,J)
             IF (CV.GE.CL.AND.CV.LT.CH) GO TO 130
120       CONTINUE
          KC = NC
          IF (CV.LT.CMIN.AND.CV.GT.CMAX) GO TO 140
130       CSA(KC) = CSA(KC) + 1.0
          CSB(KC) = CSB(KC) + CV
          IF (NRS.EQ.0) GO TO 140
          DSM = BIG
          ISM = 1
          DO 135 N=1,NRS
          DST = SQRT ((XRS(N) - XT)**2 + (YRS(N)- YT) **2)
          IF (DST.GE.DSM) GO TO 135
          DSM = DST
          ISM = N
135       CONTINUE
          WT(ISM,KC) = WT(ISM,KC) + 1.0
140    CONTINUE
150 CONTINUE
    WRITE (6,170) TITLE
    UAREA = DX * DY
    SA = 0.0
    SB = 0.0
    DO 160 L = 1,NC
       K = NC - L + 1
       CL = CMIN + (K - 1.0) * DC
       SA = SA + CSA(K)
       SAP = SA * UAREA
       SB = SB + CSB(K)
       SBP = 0.0
       IF (SA.NE.0.0) SBP = SB/SA
160 WRITE (6,180) K,CL,CMAX,SAP,SBP
    IF (NRS.EQ.0) RETURN
    WRITE (6,185) (SDNAME(N),N=1,NRS)
    WRITE(6,186)
    SA= 0.0
    DO 165 L=1,NC
    K=NC-L+1
```

```
      CL= CMIN+DC*(K-1.0)
      SA=SA+CSA(K)
      IF (SA.LE.0.0) SA=1.0
      DO 166 N=1,NRS
      IF(K.NE.NC) WT(N,K)=WT(N,K)+WT(N,K+1)
  166 CSB(N)=WT(N,K)/SA
  165 WRITE (6,190) K,CL,CMAX,(CSB(N),N=1,NRS)
      RETURN
C
C
C
  170 FORMAT (1H1/5X,31HDEPTH-AREA CURVE COMPUTATIONS: ,10A8//10X,6HNUMB
     1ER,4X,11HLOWER LIMIT,4X,11HUPPER LIMIT,4X,8HCUM.AREA,4X,9HAVE.DEPT
     2H,/)
  180 FORMAT (11X,I3,6X,F10.3,5X,F10.3,2X,F10.2,3X,F10.3)
  185 FORMAT (///5X,'STATION WEIGHTS USING THIESSEN POLYGON METHOD (STRA
     1IGHT DISTANCE FORMULA)'//6X,'NUMBER',2X,'LOWER LIMIT',2X,'UPPER LI
     2MIT',2X,8(2X,A8)/2X,12(2X,A8)/2X,12(2X,A8))
  186 FORMAT(/)
  190 FORMAT (7X,I3,4X,F10.3,3X,F10.3,3X,8F10.4/2X,12F10.4/2X,12F10.4)
      END
      SUBROUTINE SPACOR
C
C     DETERMINATION OF SYSTEM STATISTICS
C
      DIMENSION              DST(50,50)
      CHARACTER*8 TITLE, SNAME
      COMMON /SYSID2/ TITLE(10), SNAME(50)
      COMMON /SYSID/ STORE(400,101)
      COMMON /CONST/         IDSC         , NS          , NX          ,
     1           NY          , DX           , DY          , XMAX        ,
     2           XMIN        , YMAX         , YMIN        , HMAX        ,
     3           HMIN        , SMAX         , SMIN
      COMMON /SYSDAT/        X(50)        , Y(50)       , H(50)       ,
     1           Z(50)
      COMMON /SYSTAT/        AMU          , STD         , STE         ,
     1           RC          , ATC          , CRSCO(50)   , SPAC(50,50)
      COMMON /SBOUND/        NB           , XB(100)     , YB(100)
      COMMON /AREAL/         AREA         , TAR
      COMMON /CODE/          ID           , VR(5)       , KCOR        ,
     1           KERR
      BIG = 9999999.0
      KRTN = 0
      IF (KCOR.NE. - 1) GO TO 100
      KRTN =  - 1
      READ (5,290) KCOR,ATC
      READ (5,280) (CRSCO(I),I = 1,NS)
  100 DO 130 K = 1,NS
         DO 120 L = 1,NS
            RAD = SQRT((X(L) - X(K)) *  * 2 + (Y(L) - Y(K)) *  * 2)
            DST(K,L) = RAD
            IF (KCOR.EQ.2) GO TO 110
            SPAC(K,L) = EXP( - RAD/RC)
            GO TO 120
  110       SPAC(K,L) = 1.0/(1.0 + RAD/RC)
            DST(K,K) = 0.0
```

```
120       CONTINUE
130   SPAC(K,K) = 1.0
      IF (KRTN.EQ. - 1) RETURN
      SX = 0.0
      SY = 0.0
      DO 150 I = 1,NY
         YT = YMIN + DY * (I - 1.0)
         DO 140 J = 1,NX
            IF (STORE(I,J).EQ.-BIG) GO TO 140
            XT = XMIN + DX * (J - 1.0)
            SX = SX + XT
            SY = SY + YT
140      CONTINUE
150   CONTINUE
      XC = SX/TAR
      YC = SY/TAR
      DO 190 K = 1,NS
         SUM = 0.0
         DO 180 I = 1,NY
            YT = YMIN + DY * (I - 1.0)
            DO 170 J = 1,NX
               IF (STORE(I,J).EQ.-BIG) GO TO 170
               XT = XMIN + DX * (J - 1.0)
               RAD = SQRT((XT - X(K)) *  * 2 + (YT - Y(K)) *  * 2)
               IF (KCOR.EQ.2) GO TO 160
               SUM = SUM + EXP( - RAD/RC)
               GO TO 170
160            SUM = SUM + 1.0/(1.0 + RAD/RC)
170         CONTINUE
180      CONTINUE
190   CRSCO(K) = SUM/TAR
      SUM = 0.0
      DO 220 I = 1,NY
         YT = YMIN + DY * (I - 1.0)
         DO 210 J = 1,NX
            IF (STORE(I,J).EQ.-BIG) GO TO 210
            XT = XMIN + DX * (J - 1.0)
            RAD = SQRT((XT - XC) * (XT - XC) + (YT - YC) * (YT - YC))
            IF (KCOR.EQ.2) GO TO 200
            SUM = SUM + EXP( - RAD/RC)
            GO TO 210
200         SUM = SUM + 1./(1. + RAD/RC)
210      CONTINUE
220   CONTINUE
      CROC = SUM/TAR
      CROC2 = CROC * CROC
      PERM = 0.0
      DO 240 L = 1,NB
         X1 = XB(L)
         Y1 = YB(L)
         LB = L + 1
         IF (LB.LE.NB) GO TO 230
         LB = 1
230      X2 = XB(LB)
         Y2 = YB(LB)
240   PERM = PERM + SQRT((X2 - X1) * (X2 - X1) + (Y2 - Y1) * (Y2 - Y1))
```

```
      REQ = 2. * AREA/PERM
      RR = REQ/RC
      R2 = RR * RR
      R3 = R2 * RR
      R4 = R3 * RR
      IF (KCOR.EQ.2) GO TO 250
      ATCLO = 4.0 * ( - EXP( - RR)/RR + (1.0 - EXP( - RR))/R2) *  * 2
      ATCHI = 8.0 * (1./(3. * RR) - .5/R2 - EXP( - RR)/R3 + (1. - EXP( -
     1 RR))/R4)
      GO TO 260
  250 ATCLO = 4.0 * ( - 2./(3. * RR) - 1./R2 + 1./(6. * R4)) * ALOG(1. +
     1 2. * RR) + 4.0 * (2./(3. * RR) + 1./R2 - 1./(3. * R4)) * ALOG(1.
     2+ RR) + 4. * (2./(3. * RR) + 1./(6. * R2))
      ATCHI = 8. * (1./(3. * RR) + .5/R2 - 1./(6. * R4)) * ALOG(1. + RR)
     1 + 8. * ( - 4./(9. * RR) - 1./(12. * R2) + 1./(6. * R3))
  260 ATC = AMIN1(1.,(ATCHI + ATCLO)/2.)
      WRITE (6,300) AMU,STD,STE,ATC,ATCHI,ATCLO,CROC2,CROC,AREA,PERM,REQ
     1,XC,YC
      WRITE (6,340)
      IF (KCOR.EQ.1) WRITE (6,370)
      WRITE (6,350)
      IF (KCOR.EQ.2) WRITE (6,370)
      WRITE (6,360) RC
      WRITE (6,310) (SNAME(K),K = 1,NS)
      DO 270 K = 1,NS
         WRITE (6,320) SNAME(K),CRSCO(K),(SPAC(K,L),L = 1,NS)
  270 WRITE (6,330) (DST(K,L),L = 1,NS)
      RETURN
C
C
C
  280 FORMAT (10F10.0)
  290 FORMAT (I2,F10.0)
  300 FORMAT (1H1,T30,34HS Y S T E M   S T A T I S T I C S :,//T25,38HSPA
     1TIAL MEAN ..........................,F10.3/T25,38HSPATIAL STANDARD
     2DEVIATION ...........,F10.3/T25,38HSTANDARD MEASUREMENT ERROR ....
     3.......,F10.3//T25,38HAREAL AUTOCORRELATION COEFFICIENT ....,F10.5
     4/T25,38H       UPPER LIMIT ......................,F10.5/T25,38H
     5HIGH LOWER LIMIT ................,F10.5/T25,38H       LOW LOWER LIMI
     6T .................,F10.5/T25,31HCENTROID-AREA CROSS CORRELATION,/T
     725,38H       COEFFICIENT .....................,F10.5//T25,38HBASIN A
     8REA ..........................,F10.3/T25,38HBASIN PERIMETER .....
     9..................,F10.3/T25,38HBASIN EQUIVALENT RADIUS ...........
     0...,F10.3/T25,14HBASIN CENTROID,/T25,38H       X - AXIS ...........
     1............,F10.3/T25,38H       Y - AXIS ........................,F
     210.3)
  310 FORMAT (/T6,22HSTATION    AREAL CROSS,T45,36H   STATION-STATION CR
     1OSS CORRELATION,/T6,22H NAME       CORR.COEFF.,T39,T52,26HCOEFFICIE
     2NTS AND DISTANCES,//(T31,10(2X,A8)))
  320 FORMAT (/T5,A8,T16,F10.5,(T31,10F10.5))
  330 FORMAT (T5,11H(DISTANCES),(T31,10F10.3))
  340 FORMAT (1H1,T30,61HS Y S T E M   C O R R E L A T I O N   C O E F F I
     1 C I E N T S :,/T28,65H( S T A T I O N   C O R R E L A T I O N   C O
     2 E F F I C I E N T S ),//T35,29HSPATIAL CORRELATION FUNCTION:,/T38
     3,21HRHO = EXP(-RADIUS/RC))
  350 FORMAT (1H ,T38,25HRHO = 1.0/(1.0+RADIUS/RC))
```

```
  360 FORMAT (1H ,T35,28H CHARACTERISTIC RADIUS, RC =,F10.3)
  370 FORMAT (1H+,T34,3H==>)
      END
      SUBROUTINE OPTIM
C
C     OPTIMAL INTERPOLATION AND AREAL AVERAGING
C
      DIMENSION                W(52)         , COR(52)       , B(52)        ,
     1          A(52,52)
      CHARACTER*8 TITLE, SNAME
      COMMON /SYSID2/ TITLE(10), SNAME(50)
      COMMON /SYSID/ STORE(400,101)
      COMMON /CONST/           IDSC          , NS            , NX           ,
     1          NY           , DX            , DY            , XMAX         ,
     2          XMIN         , YMAX          , YMIN          , HMAX         ,
     3          HMIN         , SMAX          , SMIN
      COMMON /SYSDAT/          X(50)         , Y(50)         , H(50)        ,
     1          Z(50)
      COMMON /SYSTAT/          AMU           , STD           , STE          ,
     1          RC           , ATC           , CRSCO(50)     , SPAC(50,50)
      COMMON /AREAL/           AREA          , TAR
      COMMON /CODE/            KOD           , VR(5)         , KCOR         ,
     1          KERR
      BIG = 9999999.0
      KOPT = MAX0(KOD,1)
      KOPT = MIN0(KOPT,2)
      IF (KOPT.EQ.2) GO TO 100
      WRITE (6,350) (TITLE(LT),LT = 1,9)
      GO TO 110
  100 WRITE (6,360) (TITLE(LT),LT = 1,9)
  110 CONTINUE
      HMAX =  - BIG
      HMIN = BIG
      SMAX =  - BIG
      SMIN = BIG
      SD2 = STD * STD
      SE2 = STE * STE
      MS = NS + 2 - KOPT
      HM = 0.0
      DO 130 K = 1,NS
         HMAX = AMAX1(H(K),HMAX)
         HMIN = AMIN1(H(K),HMIN)
         DO 120 L = 1,NS
  120    A(K,L) = SD2 * SPAC(K,L)
  130 A(K,K) = A(K,K) + SE2
      NSS = NS + 1
      IF (KOPT.EQ.2) GO TO 150
      DO 140 K = 1,NS
         A(K,NSS) = 1.0
  140 A(NSS,K) = 1.0
      A(NSS,NSS) = 0.0
      B(NSS) = 1.0
  150 CALL GEPCON (A,MS)
      IF (KERR.EQ.1) RETURN
      DO 260 I = 1,NY
         YT = YMIN + DY * (I - 1.0)
```

```
       IDS2 = I + IDSC
       DO 250 J = 1,NX
          IF (STORE(I,J).EQ.-BIG) GO TO 250
          XT = XMIN + DX * (J - 1.0)
          DO 170 K = 1,NS
             RAD = SQRT((XT - X(K)) *  * 2 + (YT - Y(K)) *  * 2)
             IF (KCOR.EQ.2) GO TO 160
             COR(K) = EXP( - RAD/RC)
             GO TO 170
160          COR(K) = 1.0/(1.0 + RAD/RC)
170       B(K) = SD2 * COR(K)
          IF (KOPT.EQ.2) GO TO 190
          WL = 0.0
          DO 180 K = 1,MS
180       WL = WL + A(MS,K) * B(K)
190       SUM = 0.0
          DO 210 K = 1,NS
             W(K) = 0.0
             DO 200 L = 1,MS
200          W(K) = W(K) + A(K,L) * B(L)
210       SUM = SUM + W(K)
          IF (KOPT.EQ.2) GO TO 220
          HH = 0.0
          SE = SD2 - WL
          GO TO 230
220       HH = (1.0 - SUM) * AMU
          SE = SD2
230       DO 240 K = 1,NS
             HH = HH + W(K) * H(K)
240       SE = SE - W(K) * SD2 * COR(K)
          STORE(I,J) = HH
          IF (SE.LE.0.0) SE = 0.0
          SE = SQRT(SE)
          STORE(IDS2,J) = SE
          SMAX = AMAX1(SE,SMAX)
          SMIN = AMIN1(SE,SMIN)
          HM = HM + HH
250    CONTINUE
260 CONTINUE
    HM = HM/TAR
    CALL MAP (1)
    WRITE (6,410) HM
    WRITE (6,370) (TITLE(LT),LT = 1,9)
    CALL MAP (2)
    DO 270 K = 1,NS
270 B(K) = SD2 * CRSCO(K)
    IF (KOPT.EQ.2) GO TO 290
    WL = 0.0
    DO 280 K = 1,MS
280 WL = WL + A(MS,K) * B(K)
290 SUM = 0.0
    DO 310 K = 1,NS
       W(K) = 0.0
       DO 300 L = 1,MS
300    W(K) = W(K) + A(K,L) * B(L)
310 SUM = SUM + W(K)
```

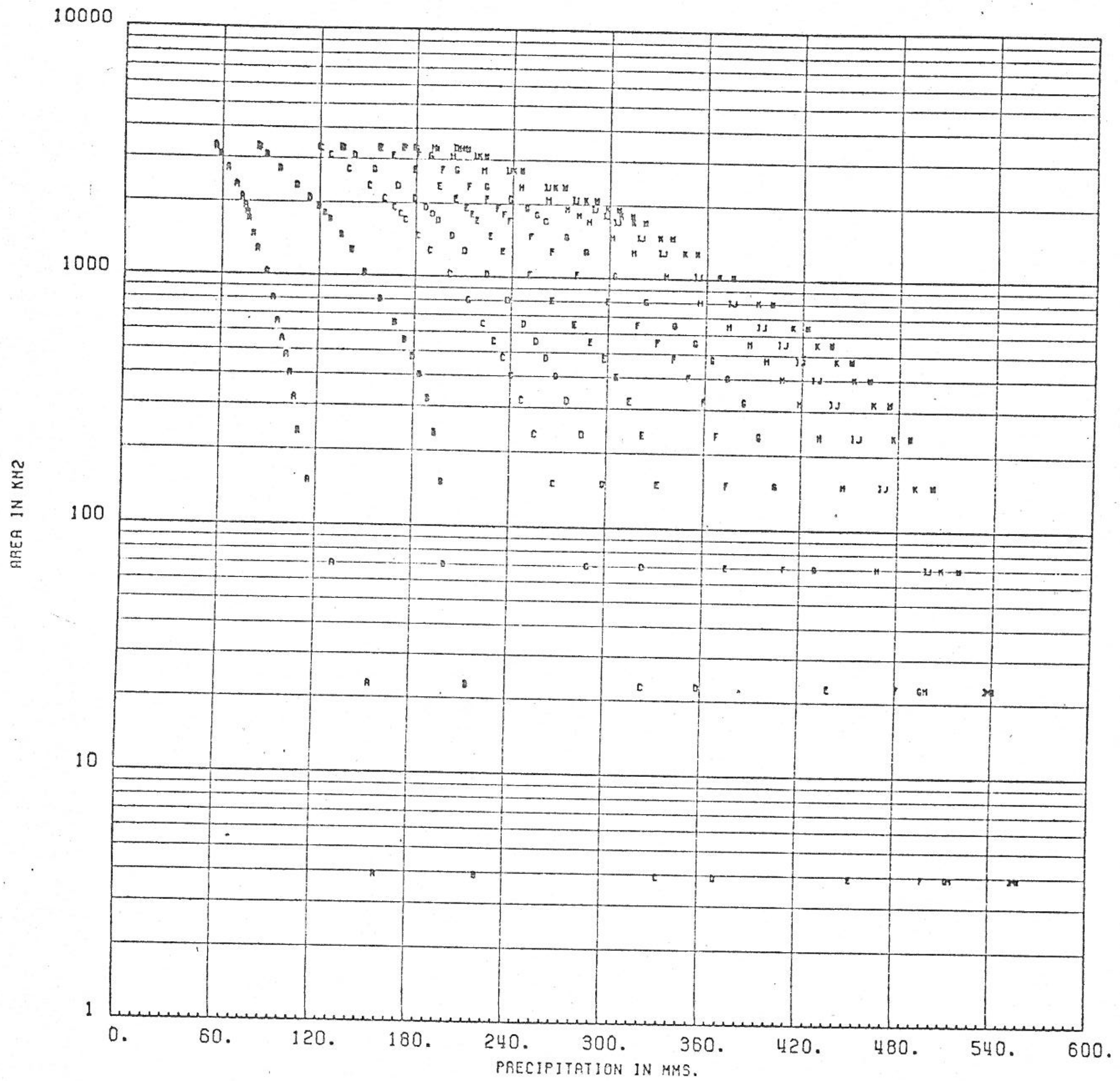
```
      IF (KOPT.EQ.2) GO TO 320
      HH = 0.0
      SE = SD2 * ATC - WL
      GO TO 330
  320 HH = (1.0 - SUM) * AMU
      SE = SD2 * ATC
  330 DO 340 K = 1,NS
         HH = HH + W(K) * H(K)
  340 SE = SE - W(K) * SD2 * CRSCO(K)
      HM = HH
      IF (SE.LE.0.0) SE = 0.0
      SE = SQRT(SE)
      WRITE (6,380)
      WRITE (6,400) (K,SNAME(K),H(K),W(K),K = 1,NS)
      WRITE (6,390) SUM,HM,SE
      RETURN
C
C
C
  350 FORMAT (1H1,/T14,46HOPTIMAL INTERPOLATION BASED ON STRAIGHT DATA
     1,9A8//)
  360 FORMAT (1H1,/T17,41HOPTIMAL INTERPOLATION BASED ON DEVIATES: ,9A8/
     1/)
  370 FORMAT (1H1,T17,41HOPTIMAL STANDARD ERROR OF INTERPOLATION: ,9A8//
     1)
  380 FORMAT (//  T35,23HOPTIMAL AREAL AVERAGING,//T20,7HSTA.NO.,T30,9HS
     1TA. NAME,T43,10HINPUT DATA,T58,14HOPTIMAL WEIGHT,/)
  390 FORMAT (//  T25,23HSUM OF OPTIMAL WEIGHT =,F10.5/T25,23HOPTIMAL AR
     1EAL MEAN    =,F10.3/T25,26HSTD. ERROR OF AREAL MEAN =,F10.4/)
  400 FORMAT (T22,I2,T31,A8,T44,F8.3,T59,F8.4)
  410 FORMAT (//  T15,35HAREAL MEAN OF INTERPOLATED VALUES =,F12.4)
      END
~eor
```

```
      PROGRAM DAD2 (INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,TAPE10=TAPE10)
      CHARACTER TITL*80
      DIMENSION A(30),DUR(200),DADD(30,200),W(7),XM(8,200),SN(7),
     1  IFOR(11),WM(200)
      DATA IFOR /4H(13X,9*1H ,6H,F8.0)/
      DO 1000 IC=1,25
        READ (10,10) TITL
        WRITE (6,10) TITL
   10 FORMAT (A80)
      READ (5,20) DUM
   20 FORMAT (A1)
      READ (5,30) (SN(I),I=1,7)
   30 FORMAT (16X,7F8.3)
      DO 100 I=1,7
        IF (SN(I).EQ.0.) GO TO 110
  100   CONTINUE
  110 NST=I-1
      NCPL=I
      J=1
      DO 200 I=1,9
        W(I)=0.
        IF(I.NE.SN(J)) GO TO 200
        W(I)=1.
        J=J+1
  200   CONTINUE
      DO 210 I=2,10
        IF(W(I-1).EQ.0.) GO TO 220
        IFOR(I)=5H,F6.0
        GO TO 210
  220   IFOR(I)=5H,6X
  210   CONTINUE
      DO 230 I=1,2
  230   READ (10,20) DUM
      DO 300 I=1,200
      READ (10,IFOR) (XM(J,I),J=1,NCPL)
      IF (XM(NCPL,I).EQ.-100.) GO TO 310
  300 CONTINUE
  310 CONTINUE
      NPTS = I-1
      DO 400 NA=1,30
        READ (5,40) D,A(NA),(W(I),I=1,NST)
        IF (D.EQ.-100.) GO TO 500
      DO 320 I=1,NPTS
        WM(I)=0.
        DO 320 J=1,NST
  320     WM(I)=WM(I)+W(J)*XM(J,I)
      CALL MDEPTH (WM,NPTS,DUR)
        DO 330 I=1,NPTS
  330     DADD(NA,I) = D*DUR(I)
  400   CONTINUE
  500 IAMAX=NA-1
      IT=(NPTS-1)/12 + 1
      DO 600 I=1,IT
        INIT = 12*(I-1) + 1
        IEND = INIT + 11
        IF(IEND.GT.NPTS) IEND=NPTS
```

```
       WRITE (6,50) (J,J=INIT,IEND)
  50 FORMAT('    AREA   ',12(' DUR.',I3,' H'))
       DO 410 J=1,IAMAX
 410     WRITE (6,60) A(J), (DADD(J,K),K=INIT,IEND)
 600   CONTINUE
1000 CONTINUE
  60 FORMAT (13F10.3)
  40 FORMAT (9F8.2)
     END
     SUBROUTINE MDEPTH (WM,NPTS,DUR)
     DIMENSION WM(200), DUR(200)
     DO 100 I=1,NPTS
 100   WM(I)=WM(I)/WM(NPTS)
     IM=NPTS-1
     DO 430 I=1,IM
       AVMAX=WM(I)
       IMI=NPTS-I
       DO 440 J=1,IMI
         SUM=WM(I+J)-WM(J)
 440     AVMAX=AMAX1(AVMAX,SUM)
 430   DUR(I) = AVMAX
     DUR(NPTS)=1.
     RETURN
     END
~eor
```

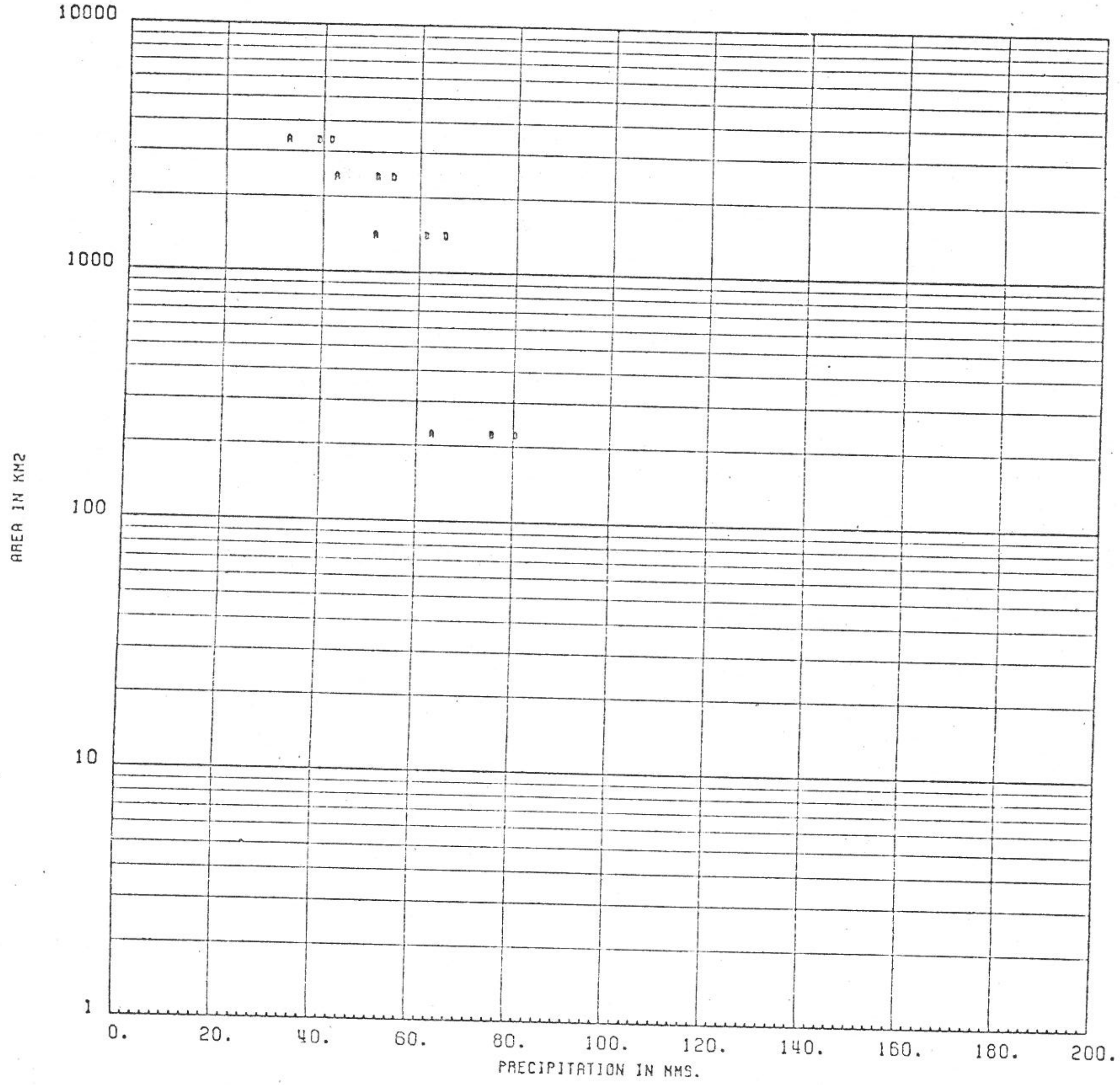
APPENDIX 1.6.C

DEPTH-AREA-DURATION CURVES FOR SELECTED STORMS



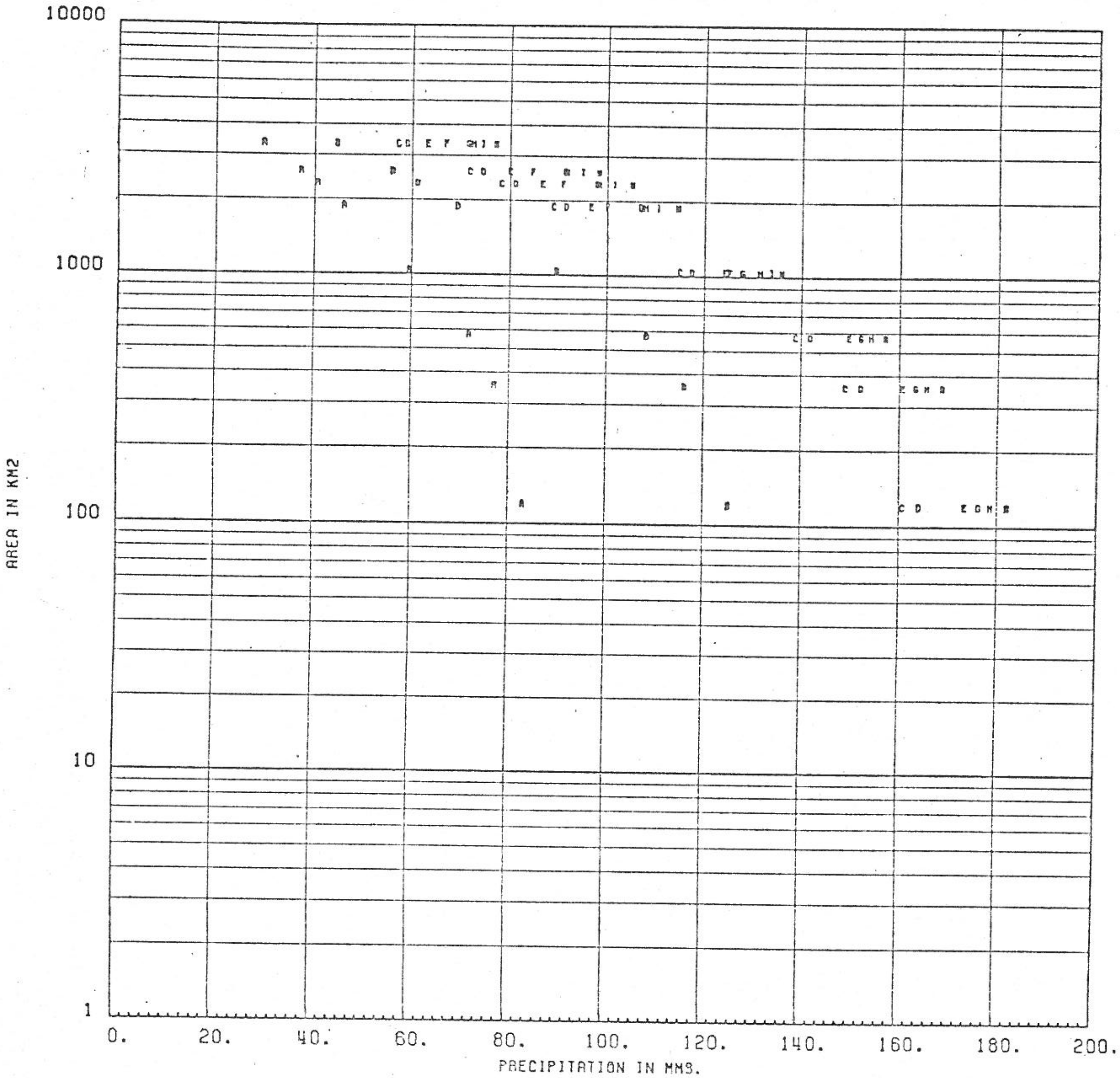
DEPTH AREA DURATION STORM STARTING 63 OCT 1 20 ENDING 63 OCT 5 5

Figure 1.6.C.1



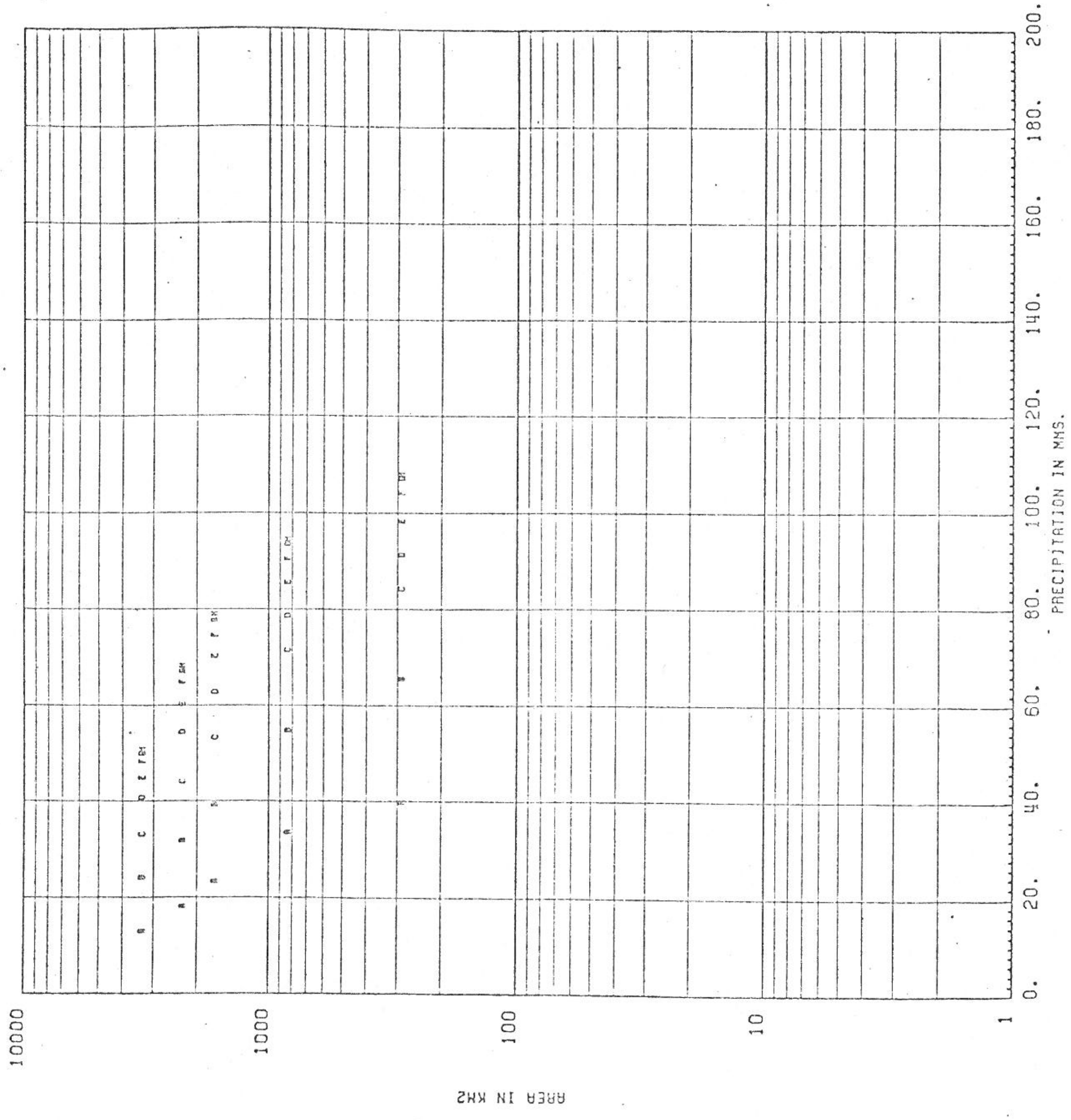
DEPTH AREA DURATION STORM STARTING 64 AGO 6 8 ENDING 64 AGO 7 8

Figure 1.6.C.2.



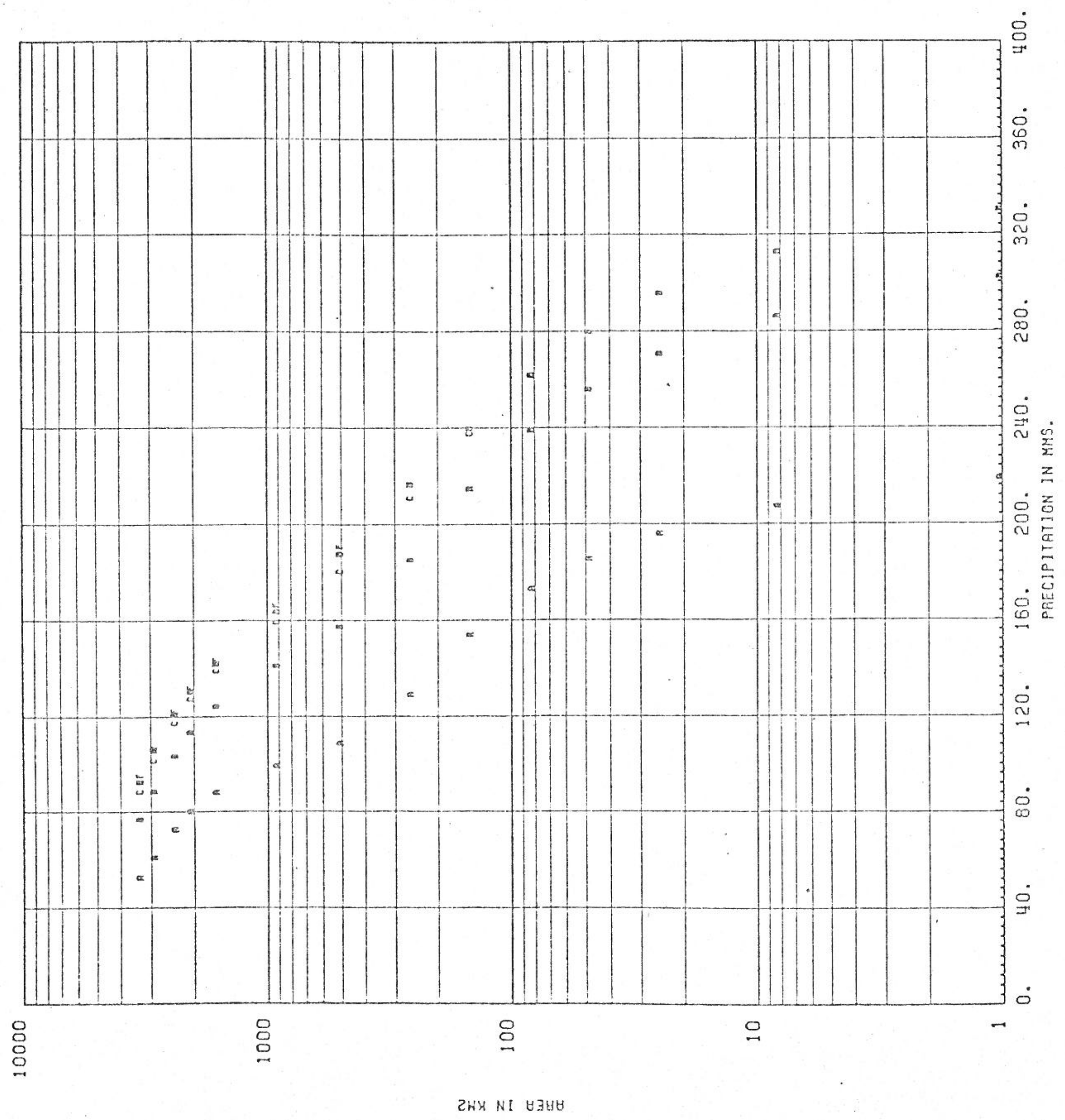
DEPTH AREA DURATION STORM STARTING 65 MAY 2 8 ENDING 65 MAY 5 8

Figure 1.6.C.3.



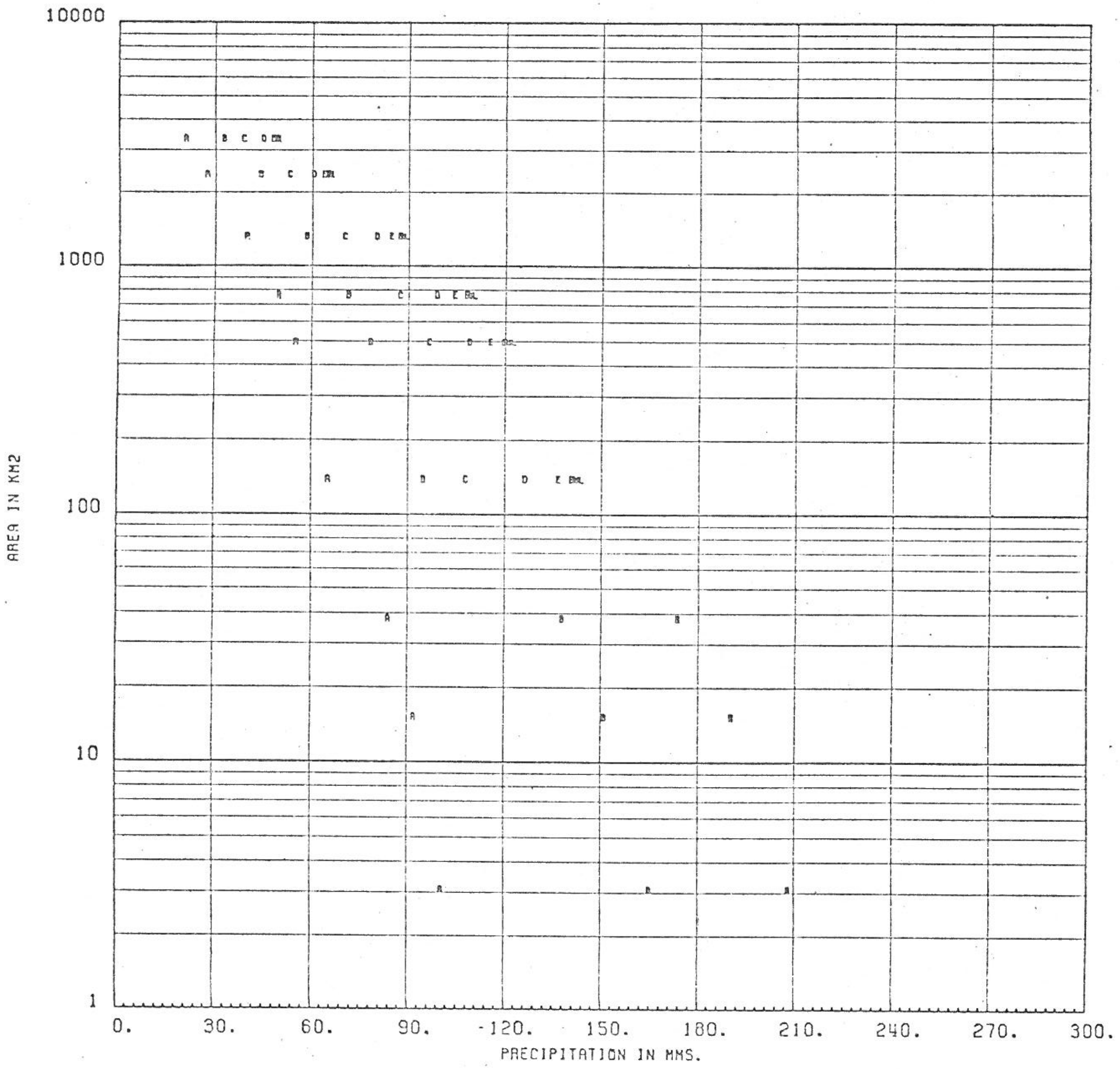
DEPTH AREA DURATION STORM STARTING 66 MAY 25 8 ENDING 66 MAY 27 8

Figure 1.6.C.4.



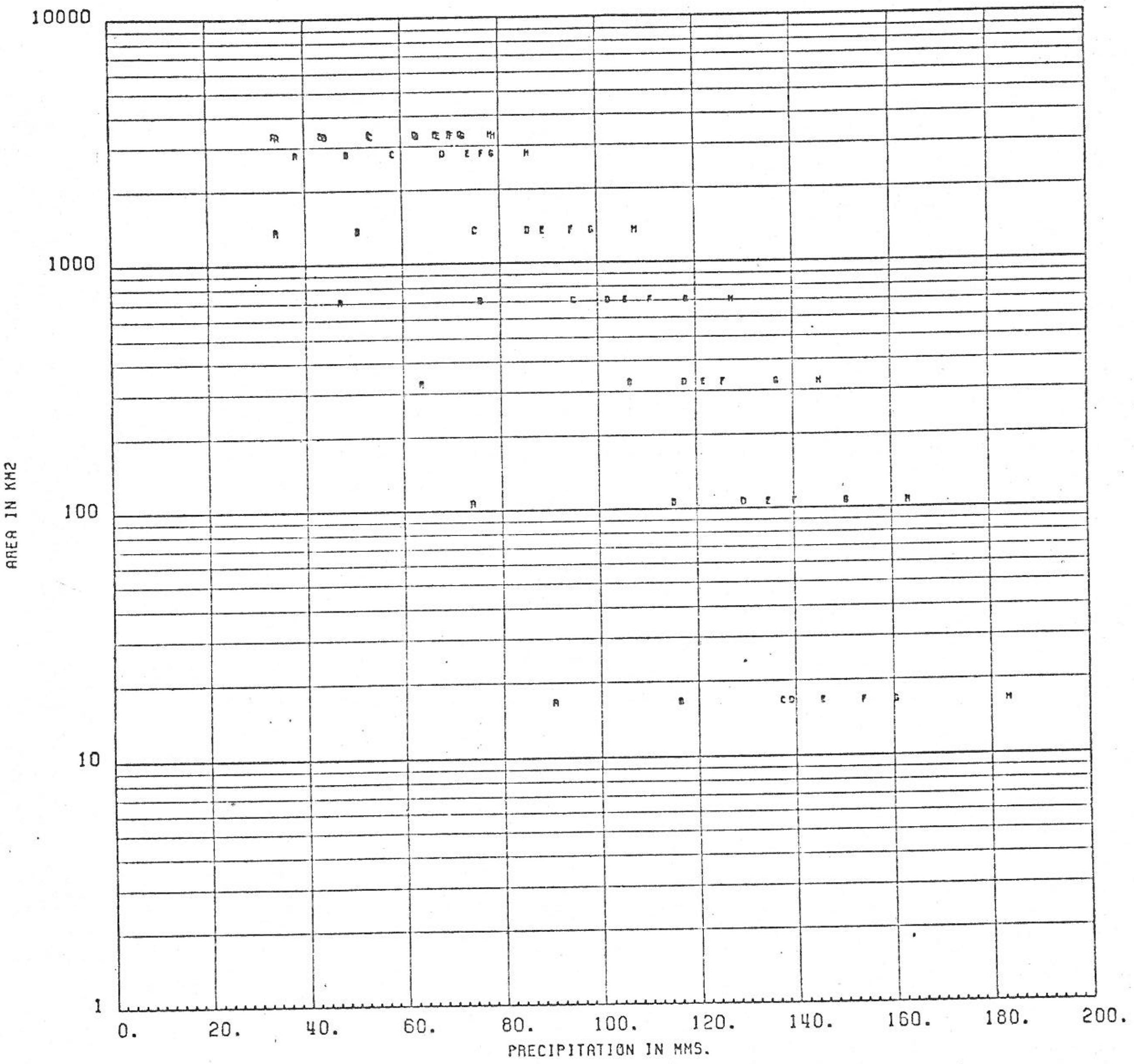
DEPTH AREA DURATION STORM STARTING 66 SEP 28 20 ENDING 66 SEP 30 8

Figure 1.6.C.5.



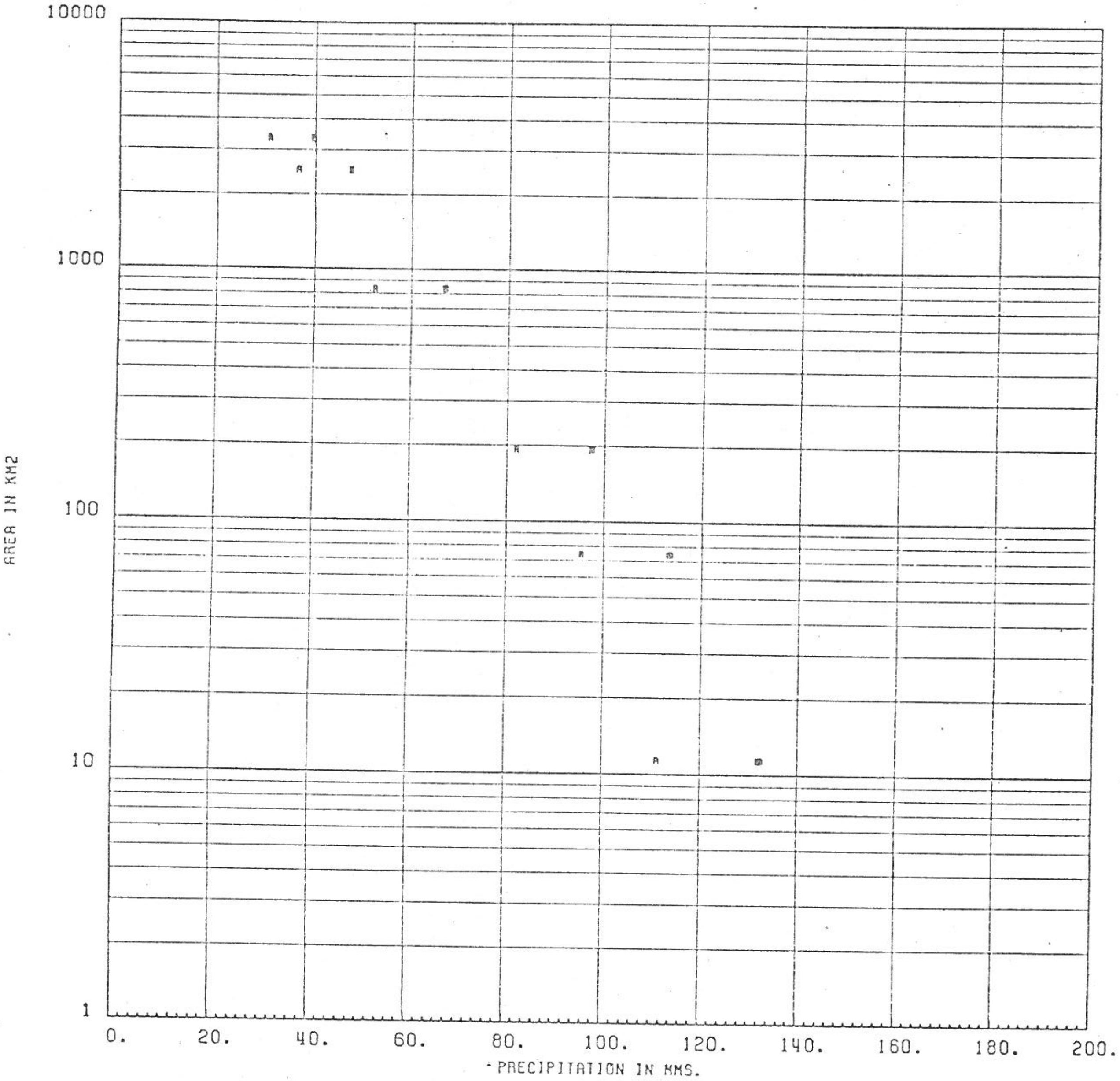
DEPTH AREA DURATION STORM STARTING 67 SEP 10 8 ENDING 67 SEP 13 8

Figure 1.6.C.6.



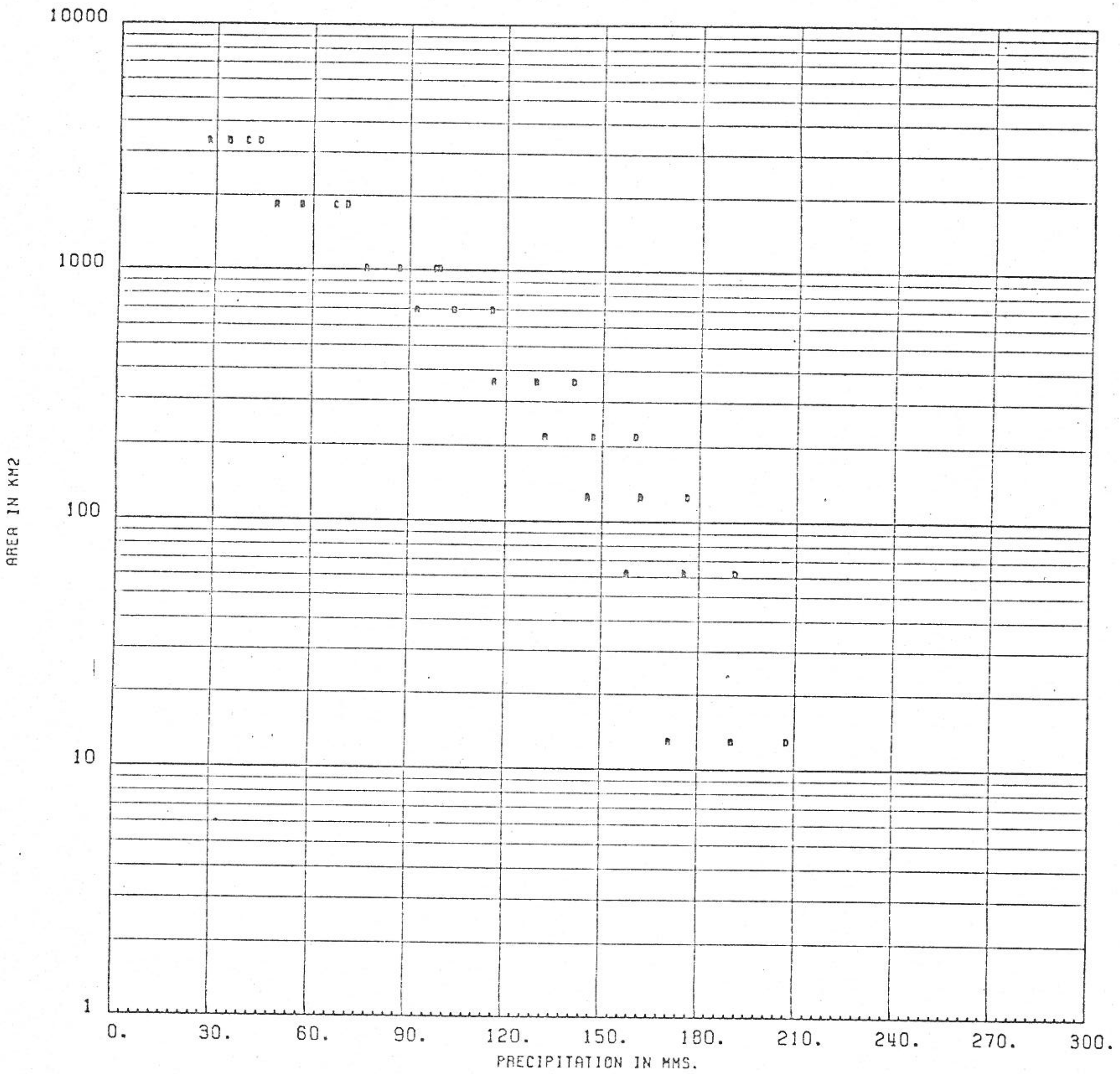
DEPTH AREA DURATION STORM STARTING 68 AGO 8 8 ENDING 68 AGO 10 8

Figure 1.6.C.7.



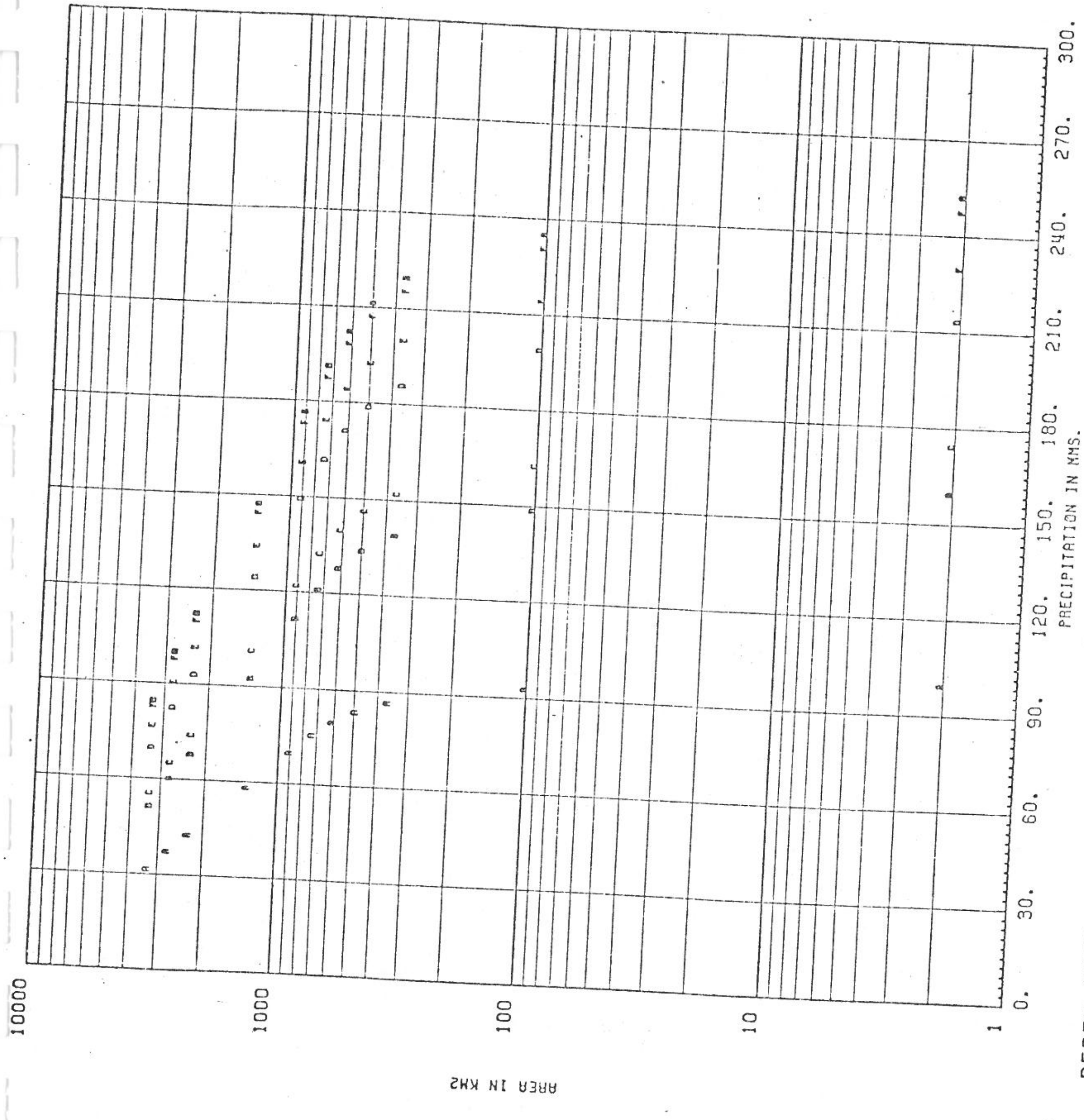
DEPTH AREA DURATION STØRM STARTING 69 JUL 19 8 ENDING 69 JUL 20 8

Figure 1.6.C.8.



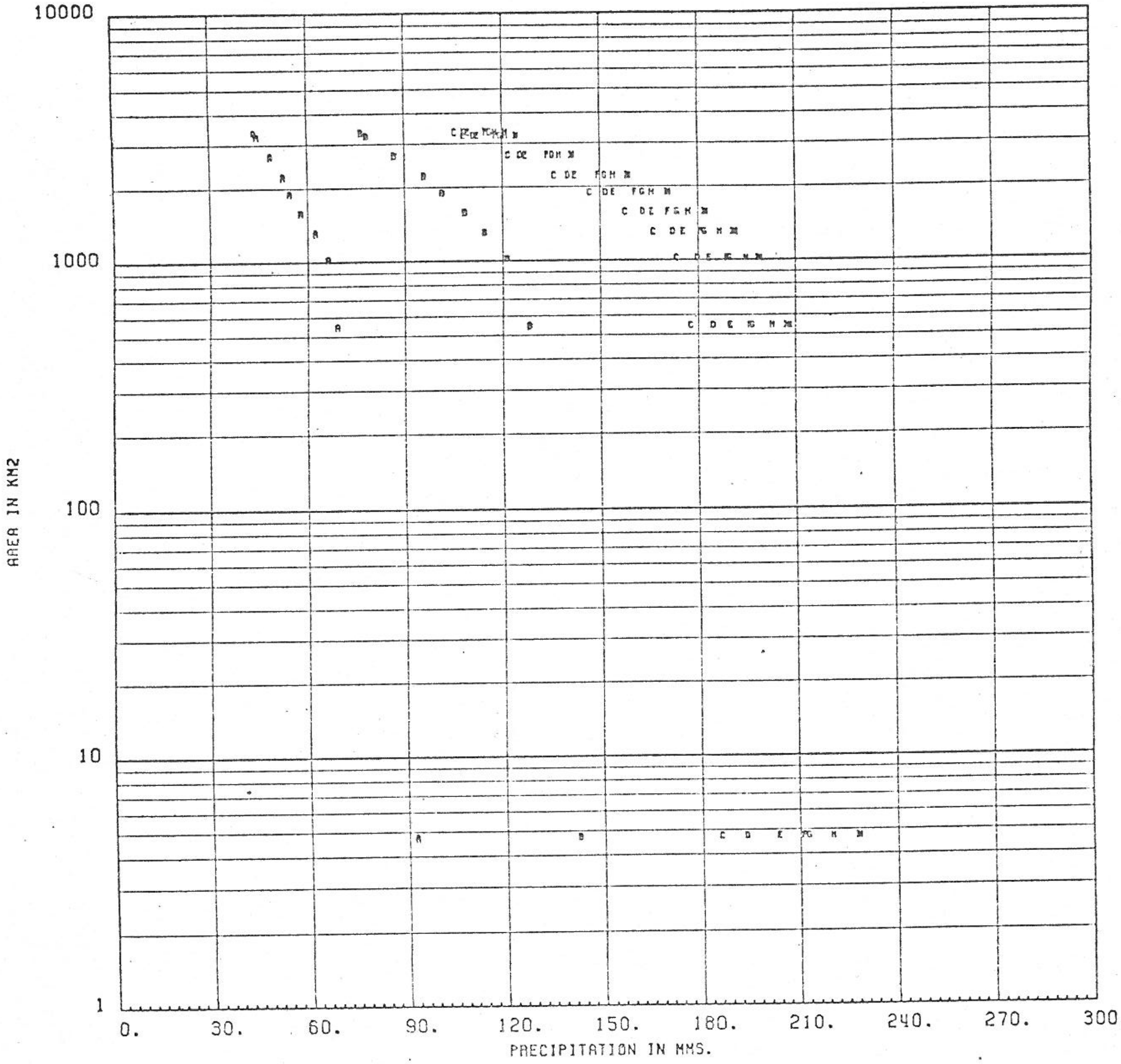
DEPTH AREA DURATION STORM STARTING 70 AGO 22 8 ENDING 70 AGO 23 8

Figure 1.6.C.9.



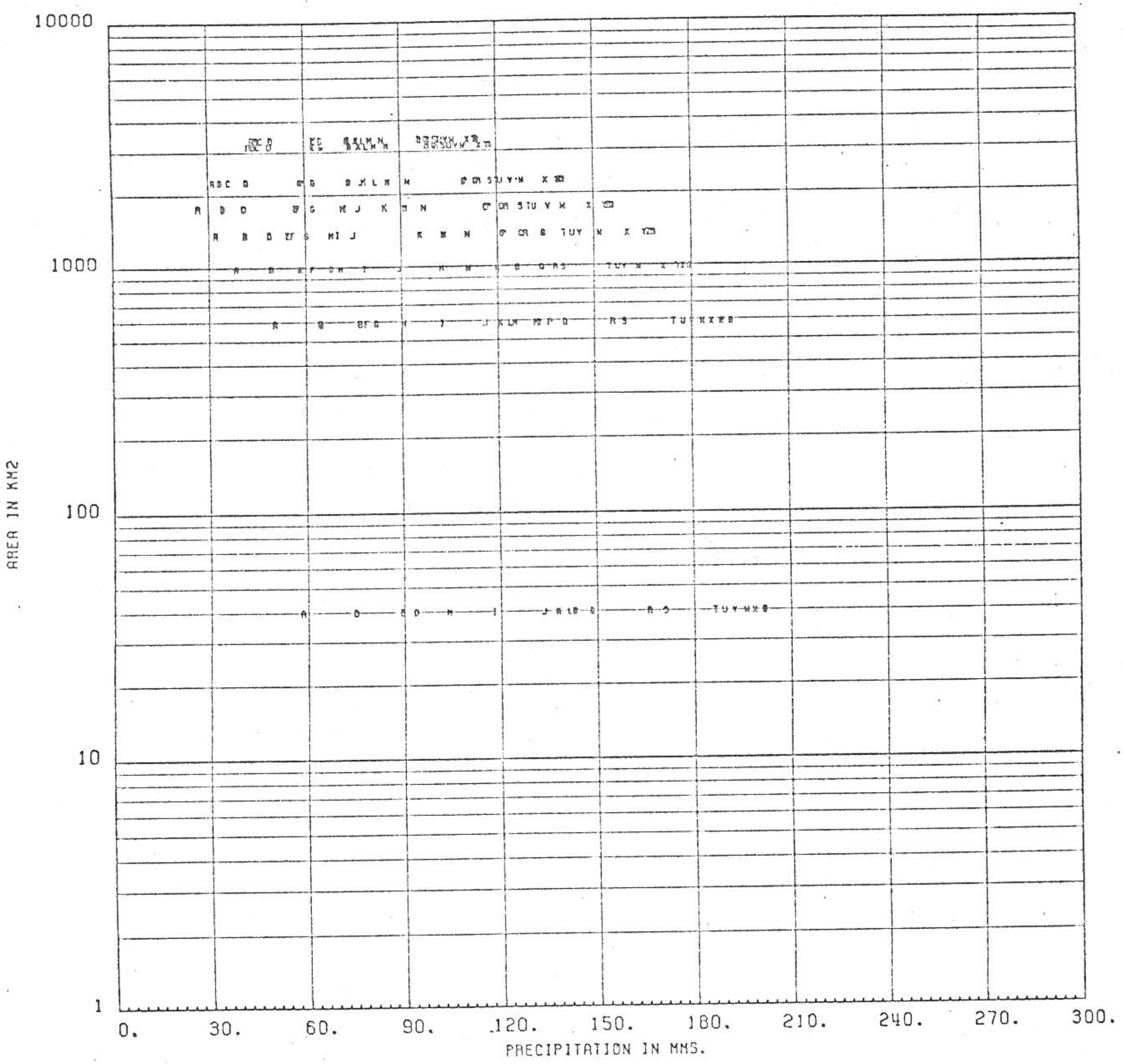
DEPTH AREA DURATION STORM STARTING 71 FEB 19 8 ENDING 71 FEB 21 8

Figure 1.6.C.10



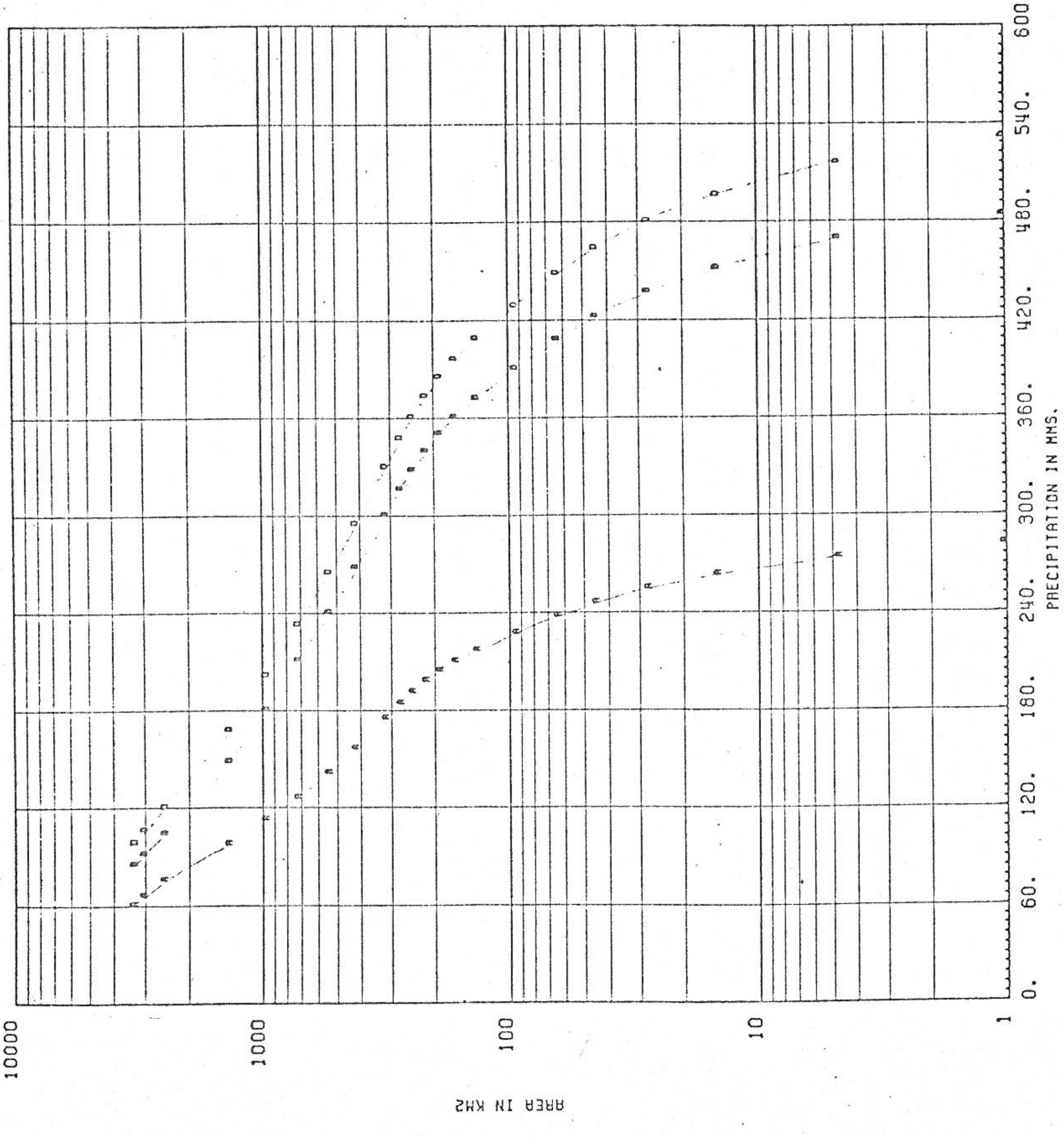
DEPTH AREA DURATION STORM STARTING 72 MAY 20 8 ENDING 72 MAY 23 8

Figure 1.6.C.11.



DEPTH AREA DURATION STORM STARTING 73 OCT 14 8 ENDING 73 OCT 21 8

Figure 1.6.C.12



DEPTH AREA DURATION STORM STARTING 74 AGO 30 8 ENDING 74 AGO 31 8

Figure 1.6.C.13.

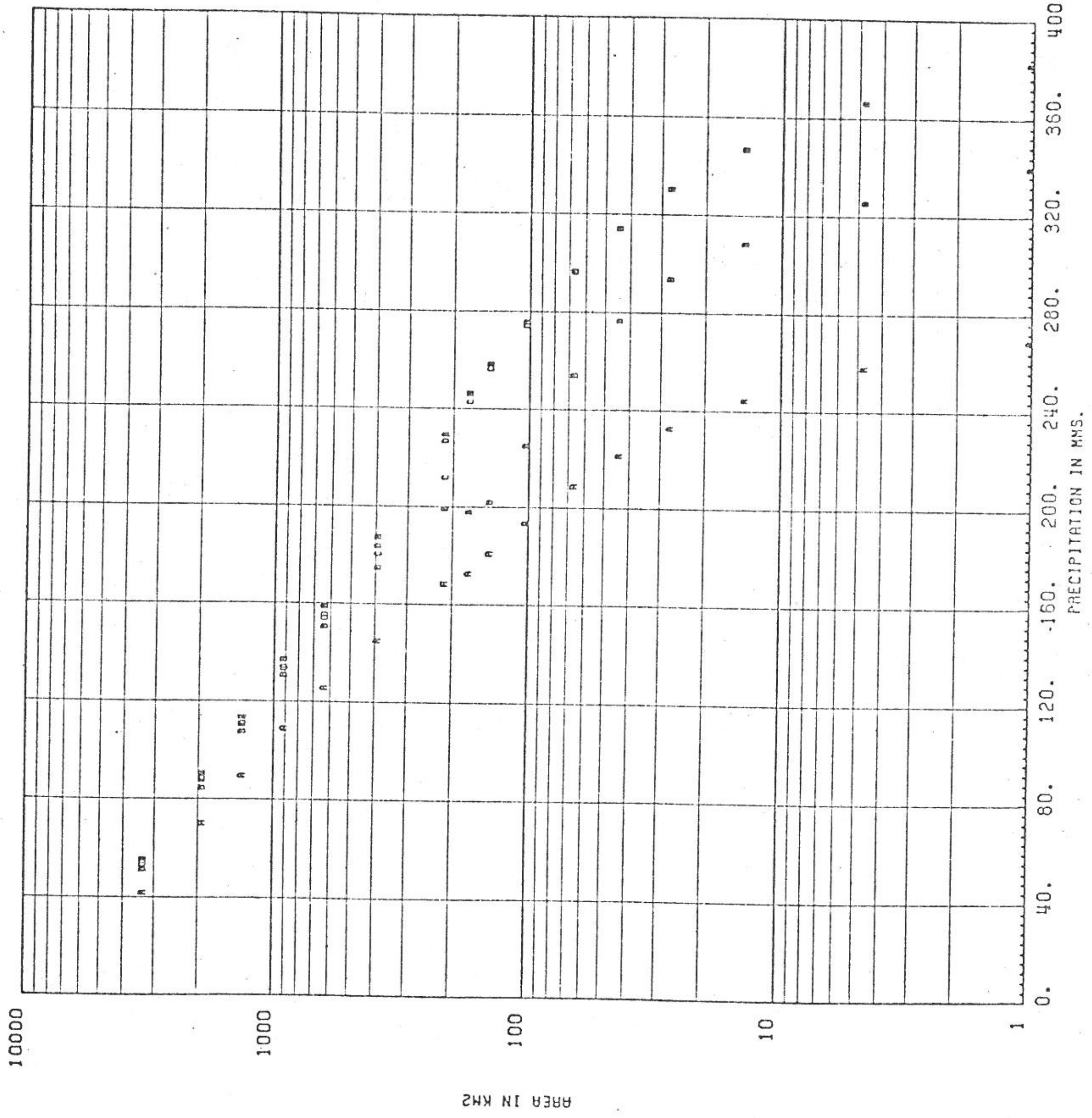


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Figure 1.6.C.14

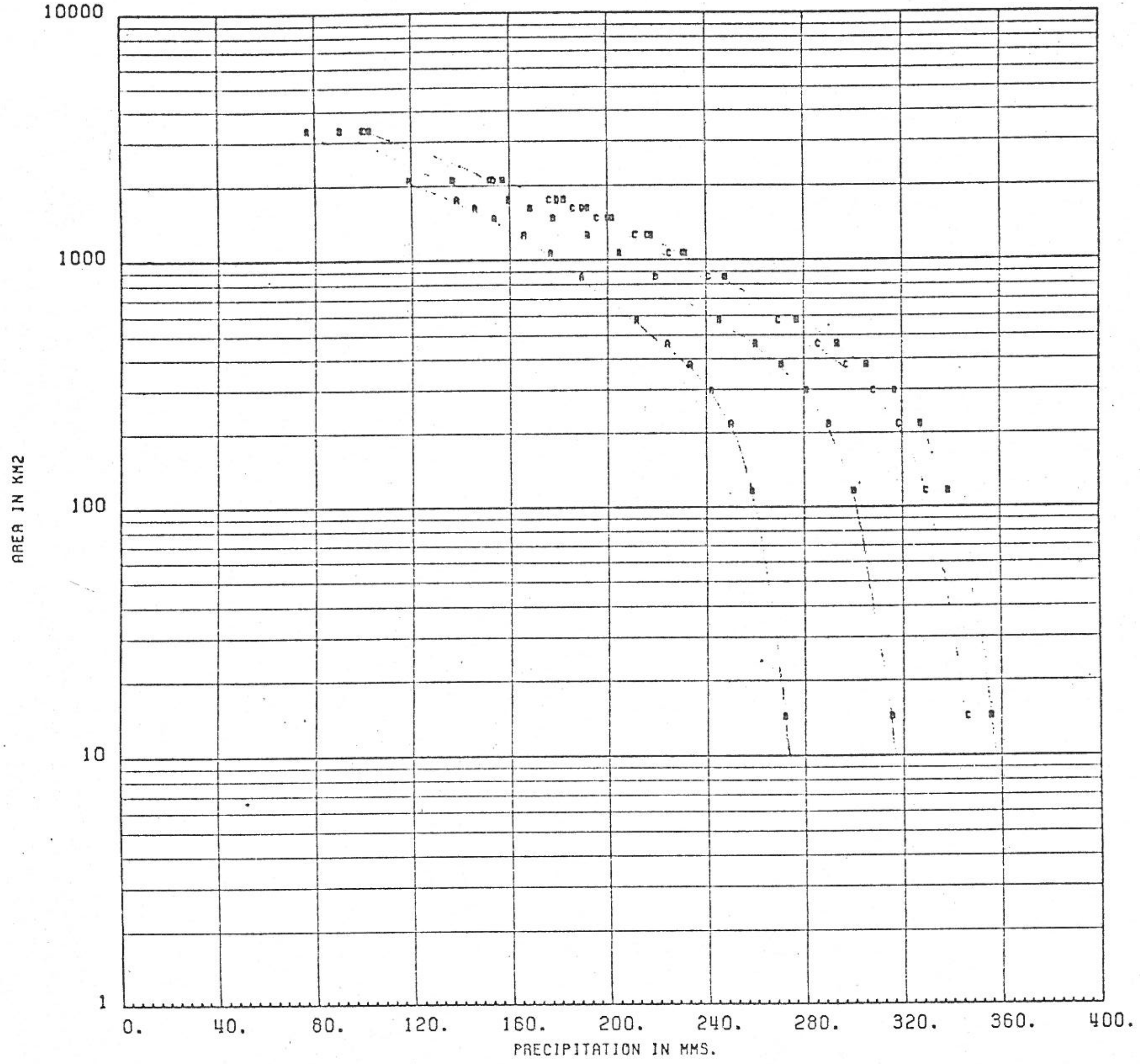

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Figure 1.6.C.15

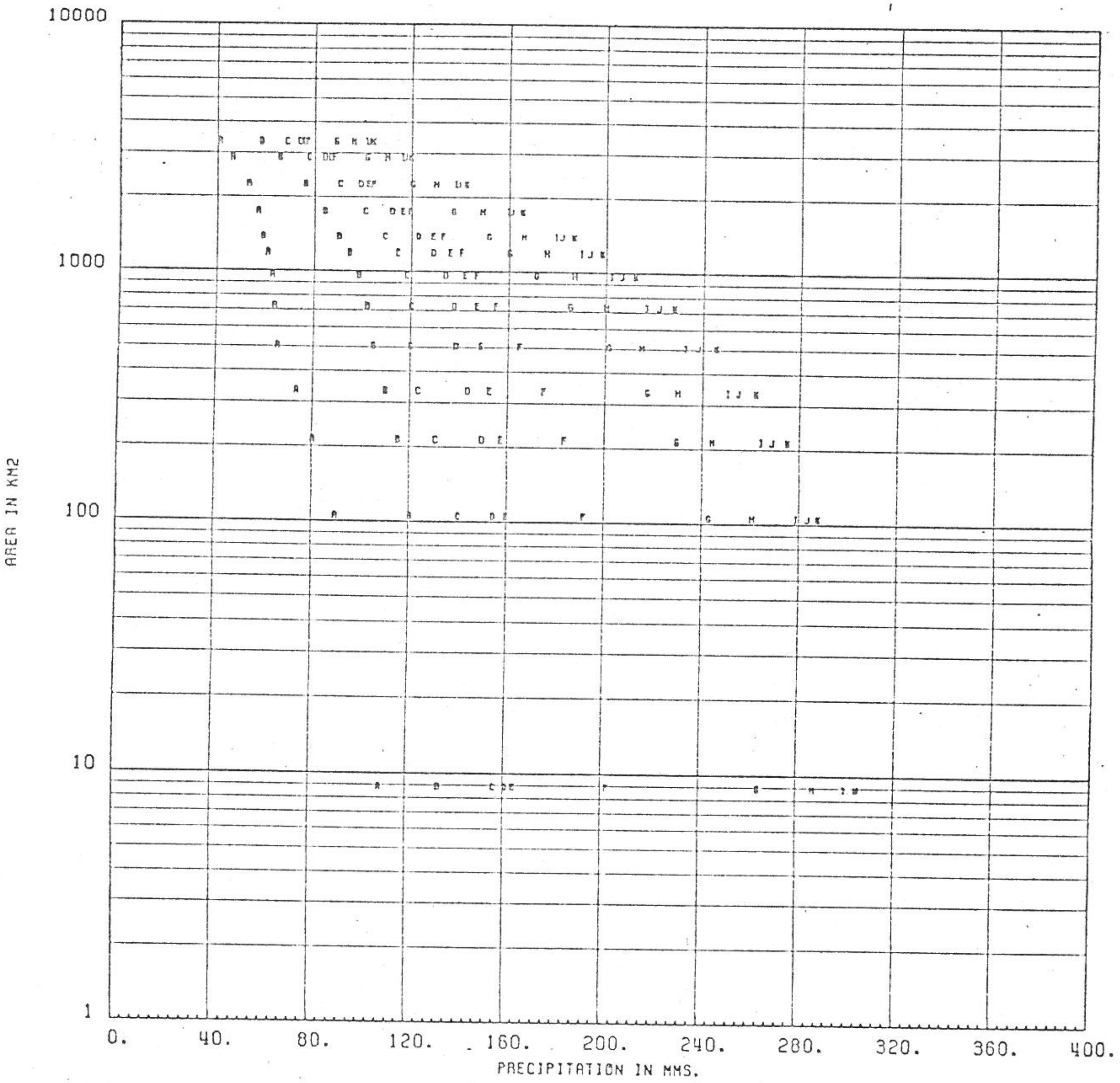

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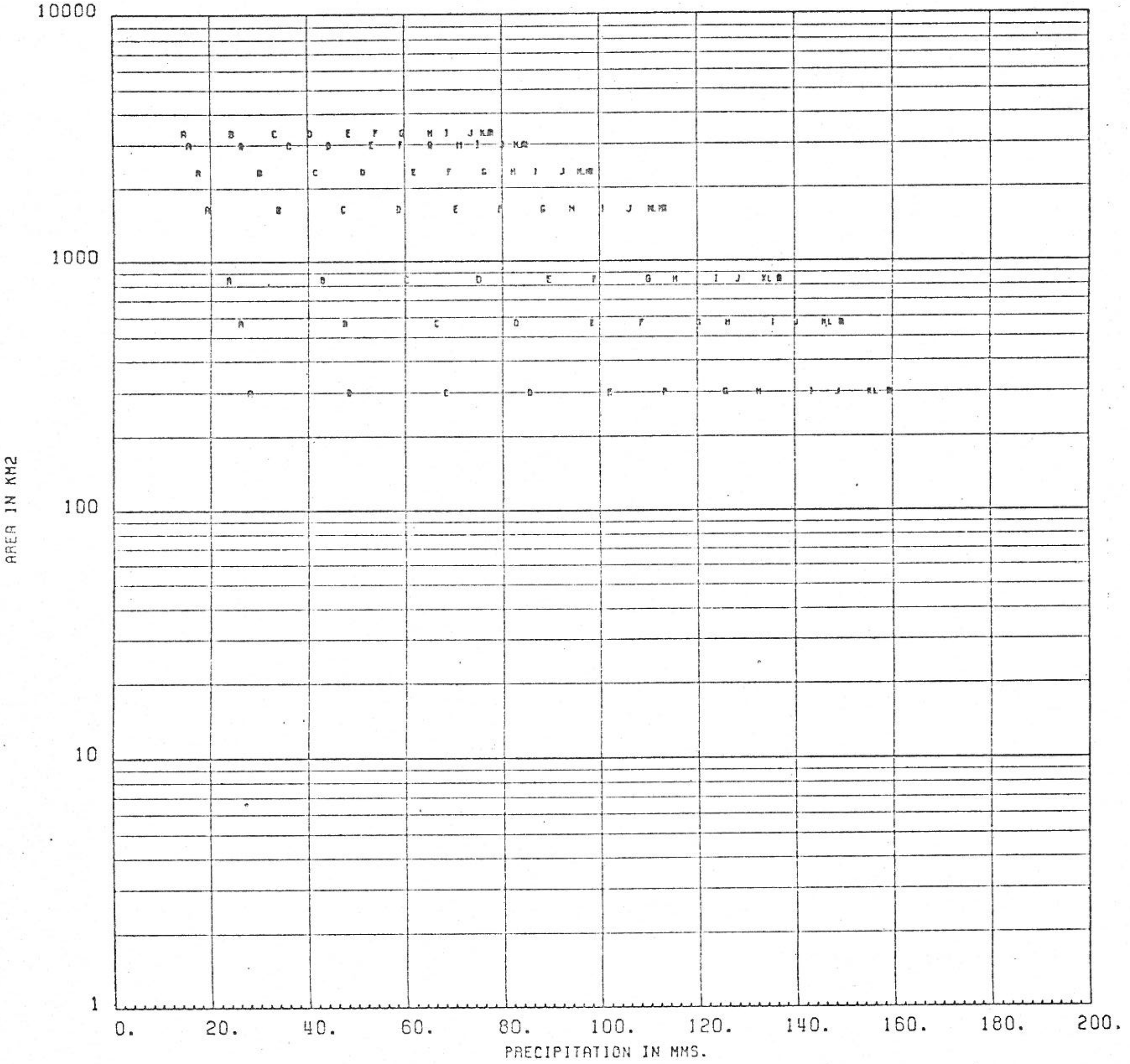
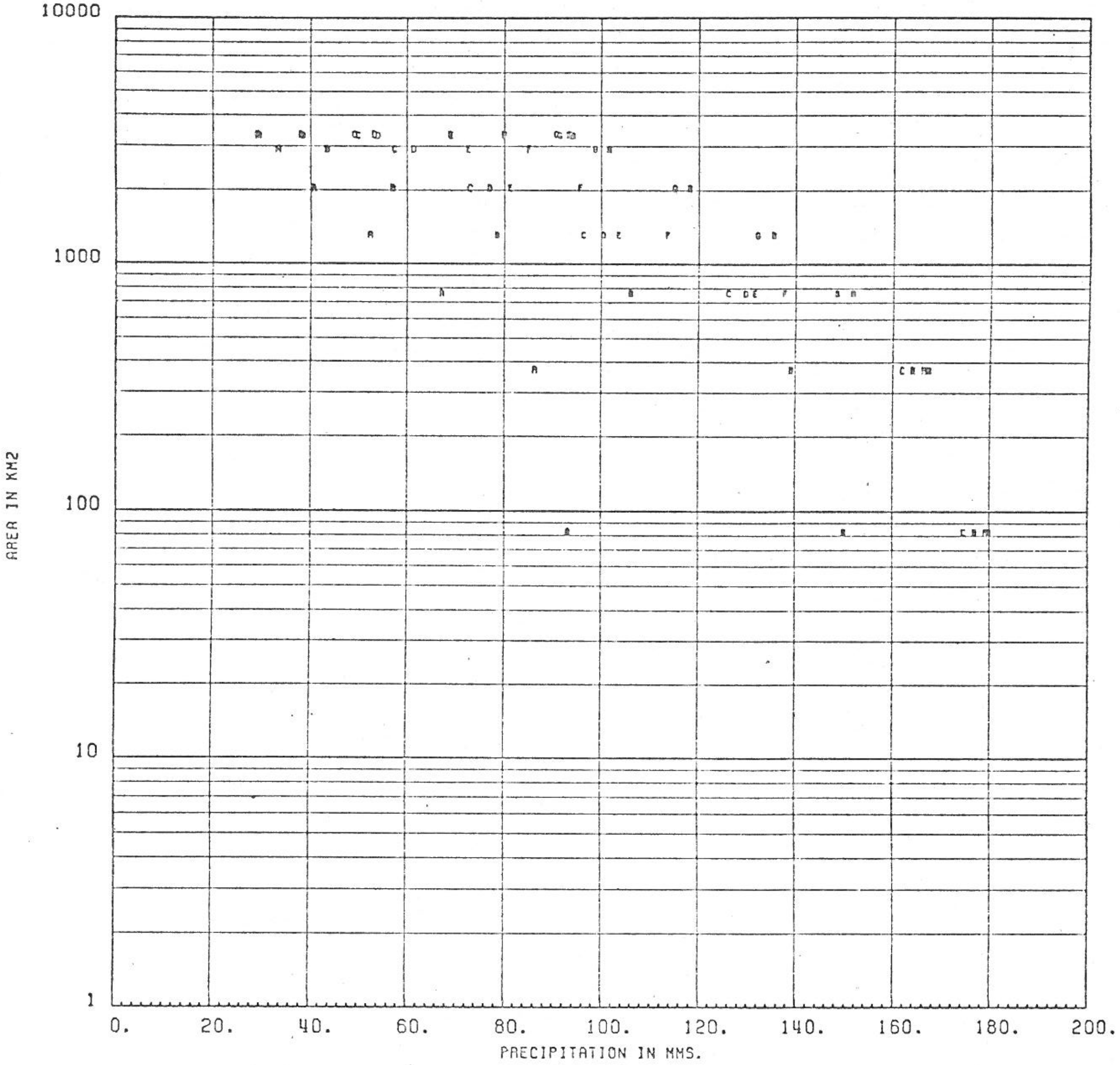
Figure 1.6.C.16



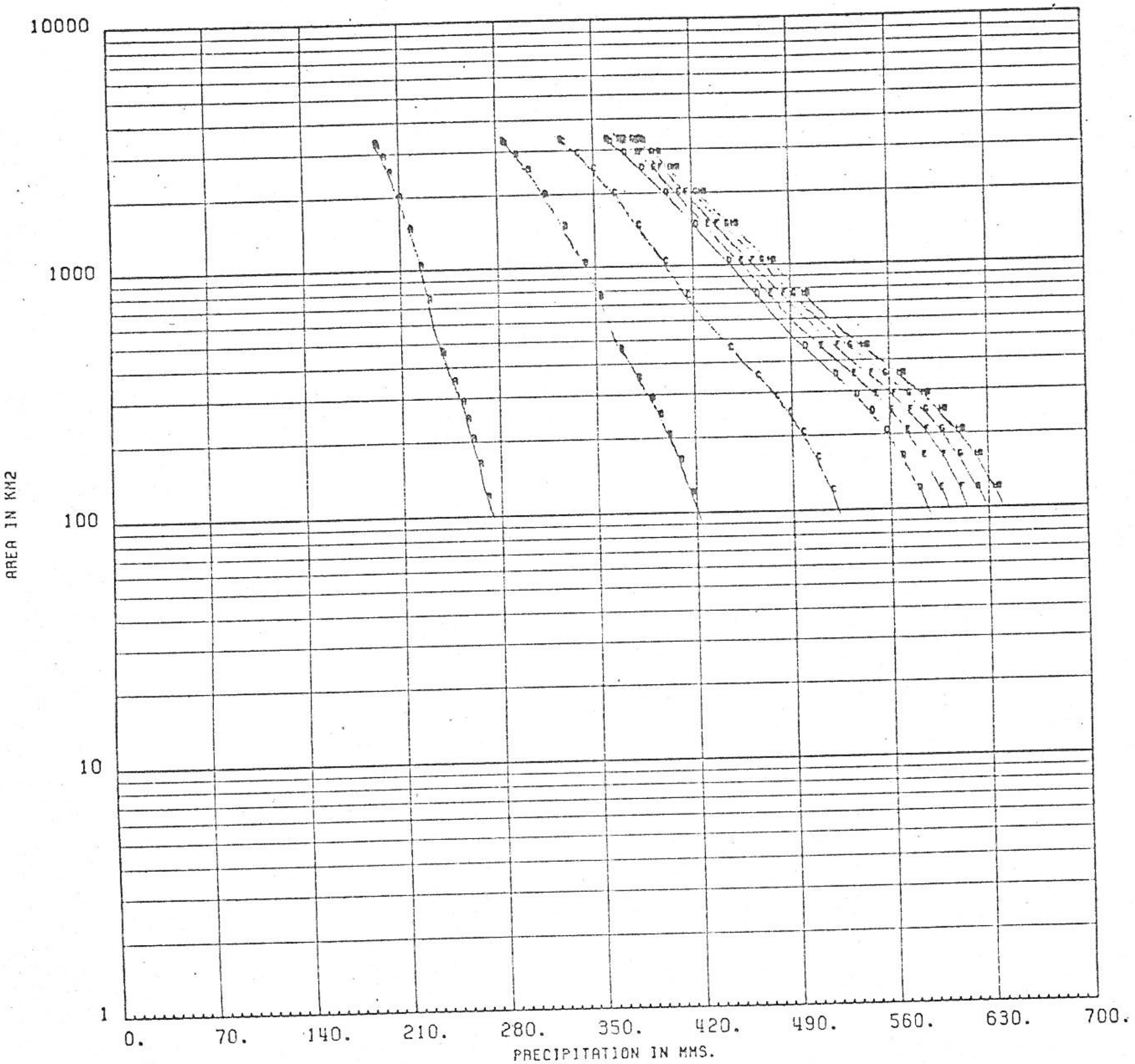
DEPTH AREA DURATION STORM STARTING 77 DIC 28 8 ENDING 78 ENE 1 8

Figure 1.6.C.17



DEPTH AREA DURATION STORM STARTING 78 AGO 3 8 ENDING 78 AGO 6 8

Figure 1.6.C.18



DEPTH AREA DURATION STORM STARTING 79 AGO 30 8 ENDING 79 SEP 2 8

Figure 1.6.C.19

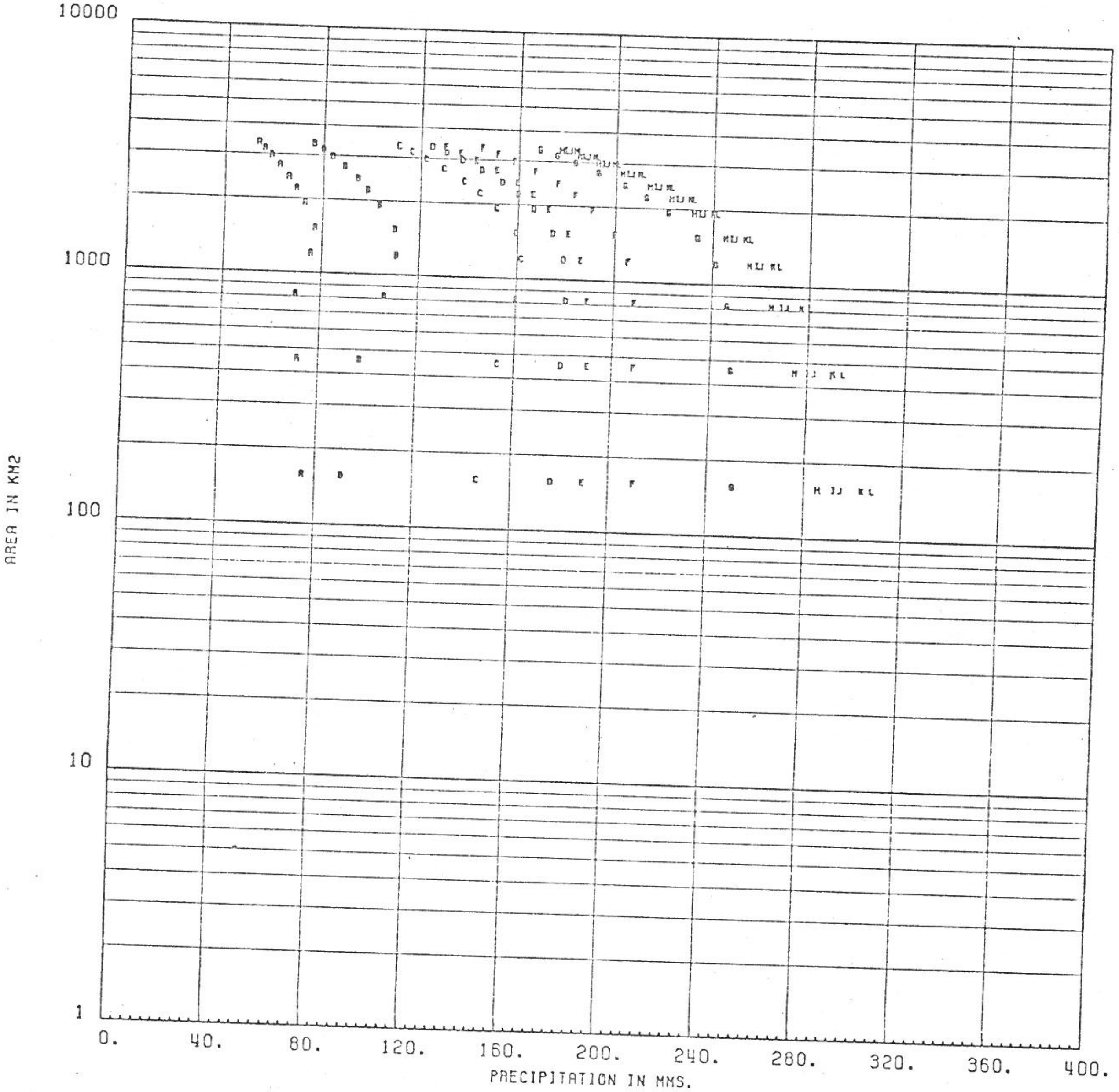


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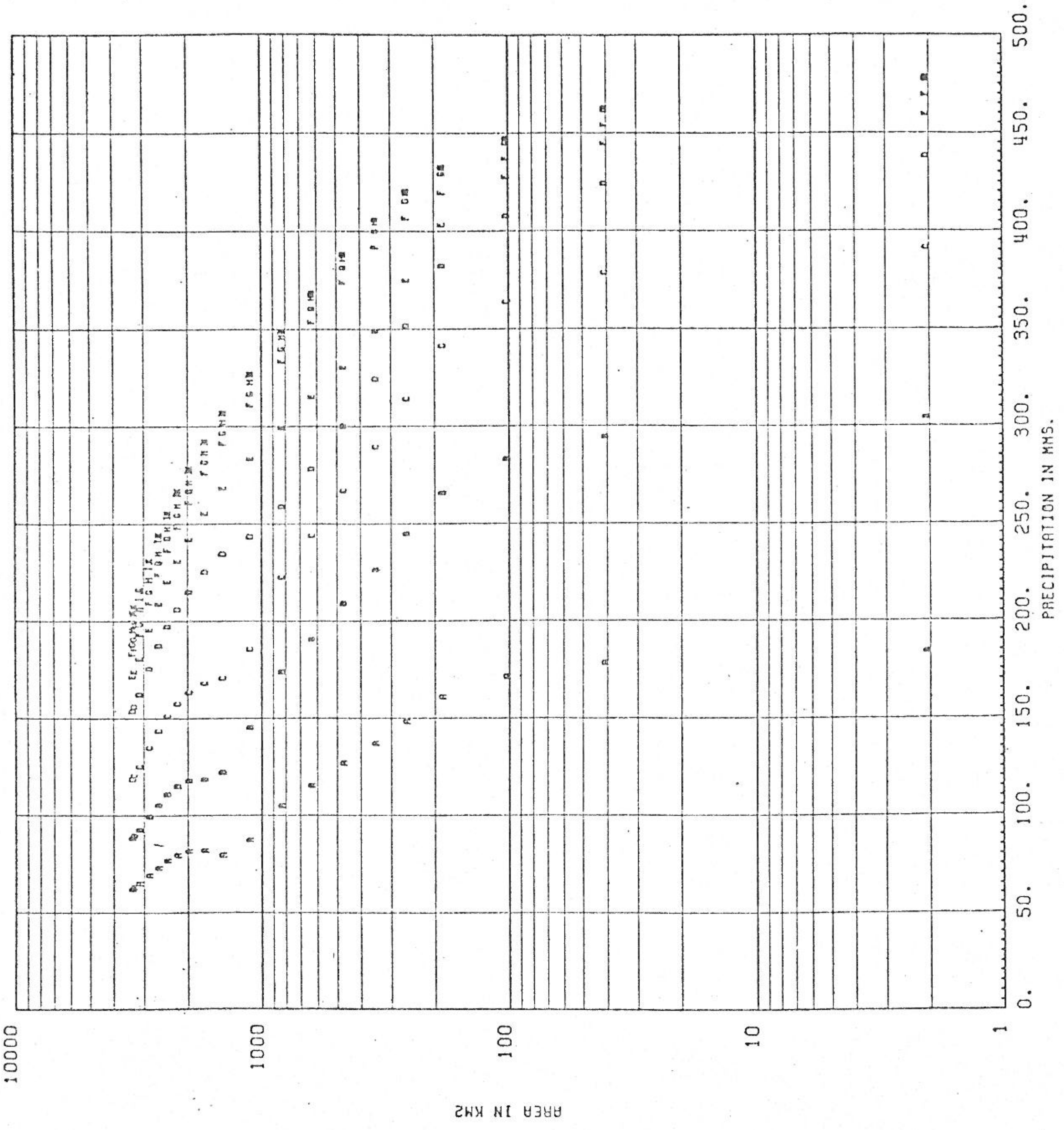
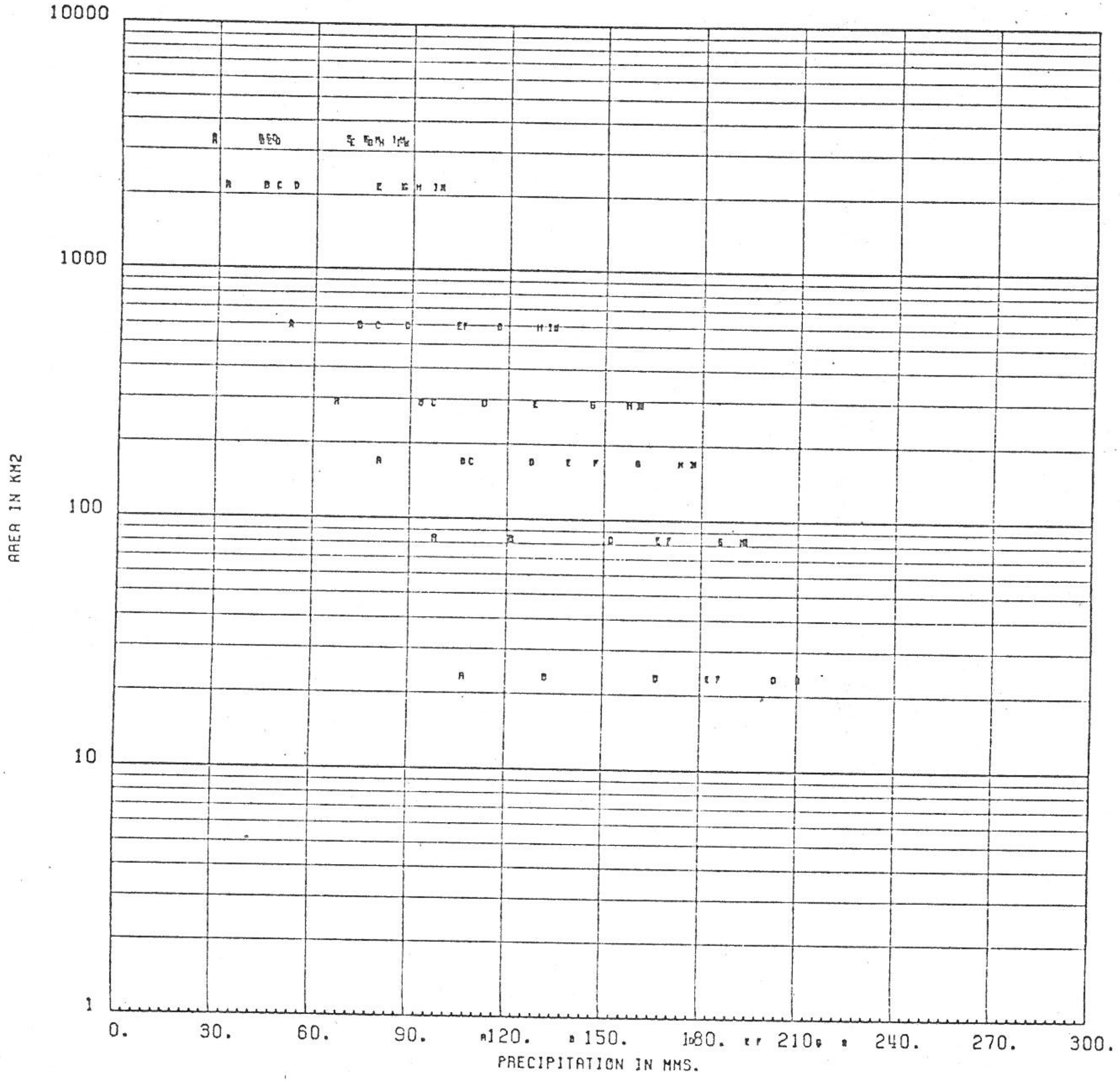
Figure 1.6.C.20



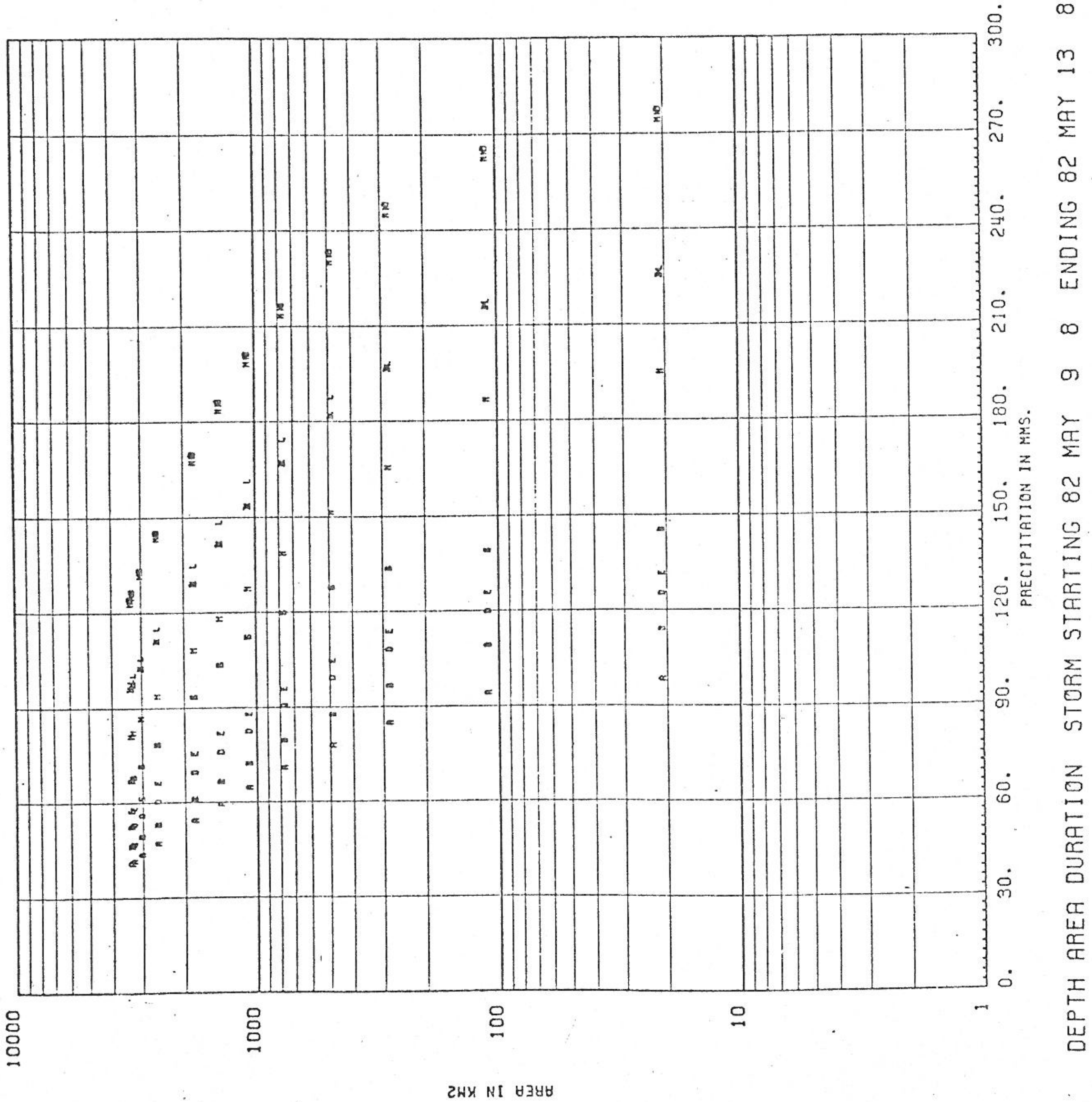
DEPTH AREA DURATION STORM STARTING 80 AGO 4 8 ENDING 80 AGO 7 8

Figure 1.6.C.21



DEPTH AREA DURATION STØRM STARTING 81 MAY 8 8 ENDING 81 MAY 11 8

Figure 1.6.C.22



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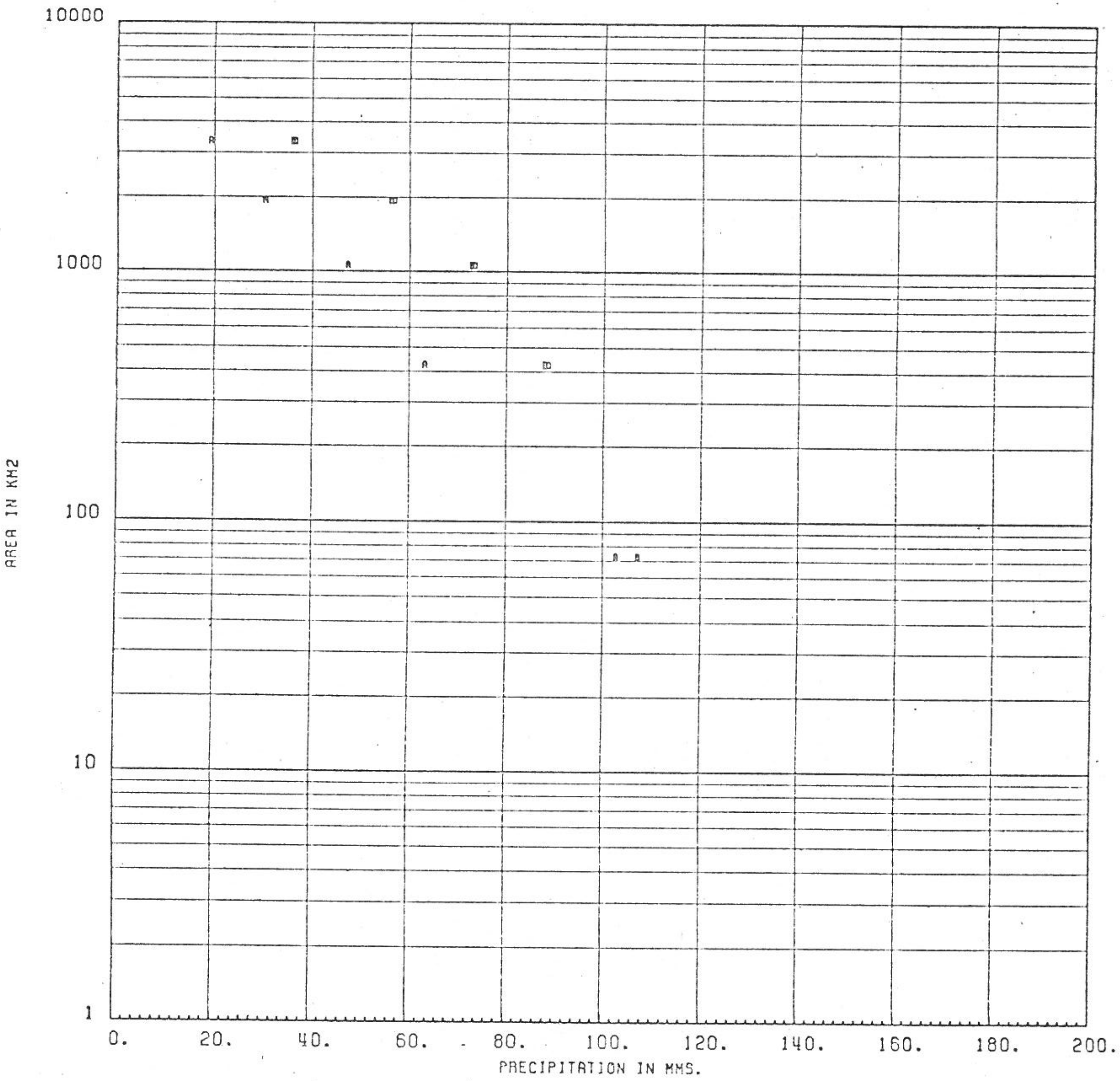
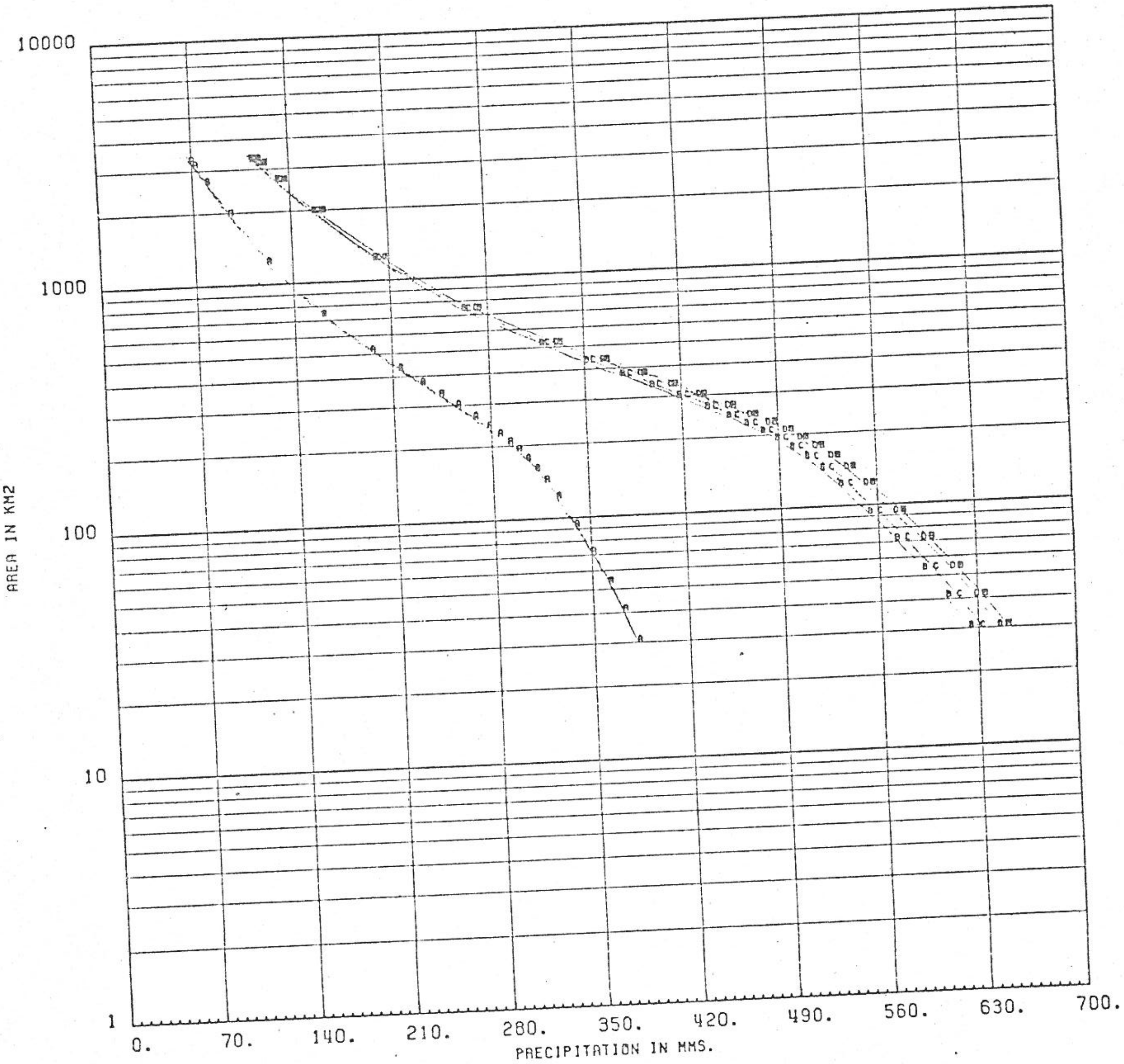


DEPTH AREA DURATION STORM STARTING 83 ABR 12 8 ENDING 83 ABR 13 8

Figure 1.6.C.24



DEPTH AREA DURATION STORM STARTING 84 AGO 1 8 ENDING 84 AGO 3 8

Figure 1.6.C.25

1.7 Rainfall-Runoff Modeling

1.7.1 Selection of Model

Several existing simulation models were considered for various applications in this project. In particular, a close scrutiny was exercised for models Flood Hydrograph Package (HEC-1) of U.S. Army Corps of Engineers, National Weather Service River Forecast System (NWSRFS), Hydrologic Simulation Program-Fortran (HSPF), and Simulation of Flood Control and Conservation Systems (HEC5). Most of these models obtained by Colorado State University require a large computer memory and storage and they cannot be implemented readily in the IBM System 34 or in the personal computers available at INDRHI or CDE. Moreover, the available data for Nizao basin do not satisfy the requirements of some of the models.

Since flood hydrographs entering Valdesia reservoir are to be simulated from historic and hypothetical storms, an event type rainfall-runoff model is needed. From all the event models considered, the HEC-1 was chosen based on the data availability and ease of implementation. A version of HEC-1 which fits into an IBM personal computer (PC) has been obtained and installed in the IBM-PC at INDRHI.

1.7.2 HEC-1 Model Calibration

Clark Unit Hydrograph and Muskingum Routing: The HEC-1 rainfall-runoff model has many options for computing rainfall excess, watershed routing, and channel routing. Many of these options can be used with the optimization model which computes the "best" parameters on basis of "best fit" of the observed and computed flood hydrographs. A common approach is to use the HEC-1 exponential loss rate function with the Clark unit hydrograph to compute subbasin flood hydrographs and then to use Muskingum method to route flood hydrographs to the basin outlet. Naturally, this was our initial approach to calibrate HEC-1 for Nizao watershed. Unfortunately, the results obtained by this method were unacceptable. The poor quality of rainfall and runoff data used in our optimization runs was partly responsible for this poor initial calibration results. The variation of parameters from one storm event to another was too large to be acceptable (see Table 1.7.1).

The particular topography of Nizao basin (high slopes with no significant flood plains) is thought to be another reason for the failure of storage routing techniques such as Clark Unit hydrograph and Muskingum method. Consequently, the kinematic wave approach of overland flow routing and channel routing was deemed to be more appropriate for rainfall-runoff modeling in Nizao basin.

<u>Kinematic wave model:</u> The first step taken in the Kinematic Wave Model formulation was to subdivide the basin into 10 subbasins, in an effort to simulate each important tributary of the Nizao basin independently. Also, one additional subdivision was included at gaging station La Estrechura, to be able to compare simulated and observed hydrographs at that point. Other two subbasing limits coincide with gaging stations Palo de Caja and Paso del Ermitano. The general configuration is shown in Figure 1.7.1.

The physical characteristics of the basin, such as channel lengths, slopes, widths, areas, etc., as well as the land use was estimated from available maps of the area. Mannings's N was obtained by calibration.

The loss rate method that was chosen was the SCS (Soil Conservation Service) loss rate function. Since very little data on soil type was available it was judged convenient to reduce the number of unknown

TABLE 1.7.1 INITIAL HEC-1 CALIBRATION FOR EXPONENTIAL LOSS RATE AND CLARK UNIT HYDROGRAPH PARAMETERS

*	1st RUN	STRKR	DLTKR	RTIOL	TC	R	ERAIN
	Storm E	12.76	24.82	7.99	11.03	11.25	.44
	Storm F	14.69	95.04	2.76	1.09	12.35	.13
	Storm H	4.05	11.46	1.90	9.12	12.64	.81
	Storm M	19.53	96.78	4.33	16.83	18.09	.28
	Storm N	1.90	7.37	1.26	17.01	18.34	.10
**	2nd RUN						
	Storm E	13.70	26.89	1.98	11.04	10.80	.44
	Storm F	24.00	94.37	2.91	7.03	5.71	.22
	Storm H	4.53	12.59	1.98	6.00	18.01	.50
	Storm M	6.96	88.38	2.15	11.26	10.47	.13
	Storm N	3.20	11.04	1.50	16.83	18.08	.10
***	Storm E	10.75	5.89	1.39	1.36	32.06	.08
	Storm F	3.68	93.94	11.52	4.66	14.73	.06
	Storm H	4.26	10.59	1.73	10.12	12.74	.38
	Storm M	9.66	86.96	2.14	11.24	10.28	.13
	Storm N	6.03	16.77	1.67	11.55	13.91	.31

* Using all precipitation stations (recording and non-recording) all hydrograph ordinates

** Range of optimization limited to period around peak outflow

*** Inconsistent precipitation data removed from record.

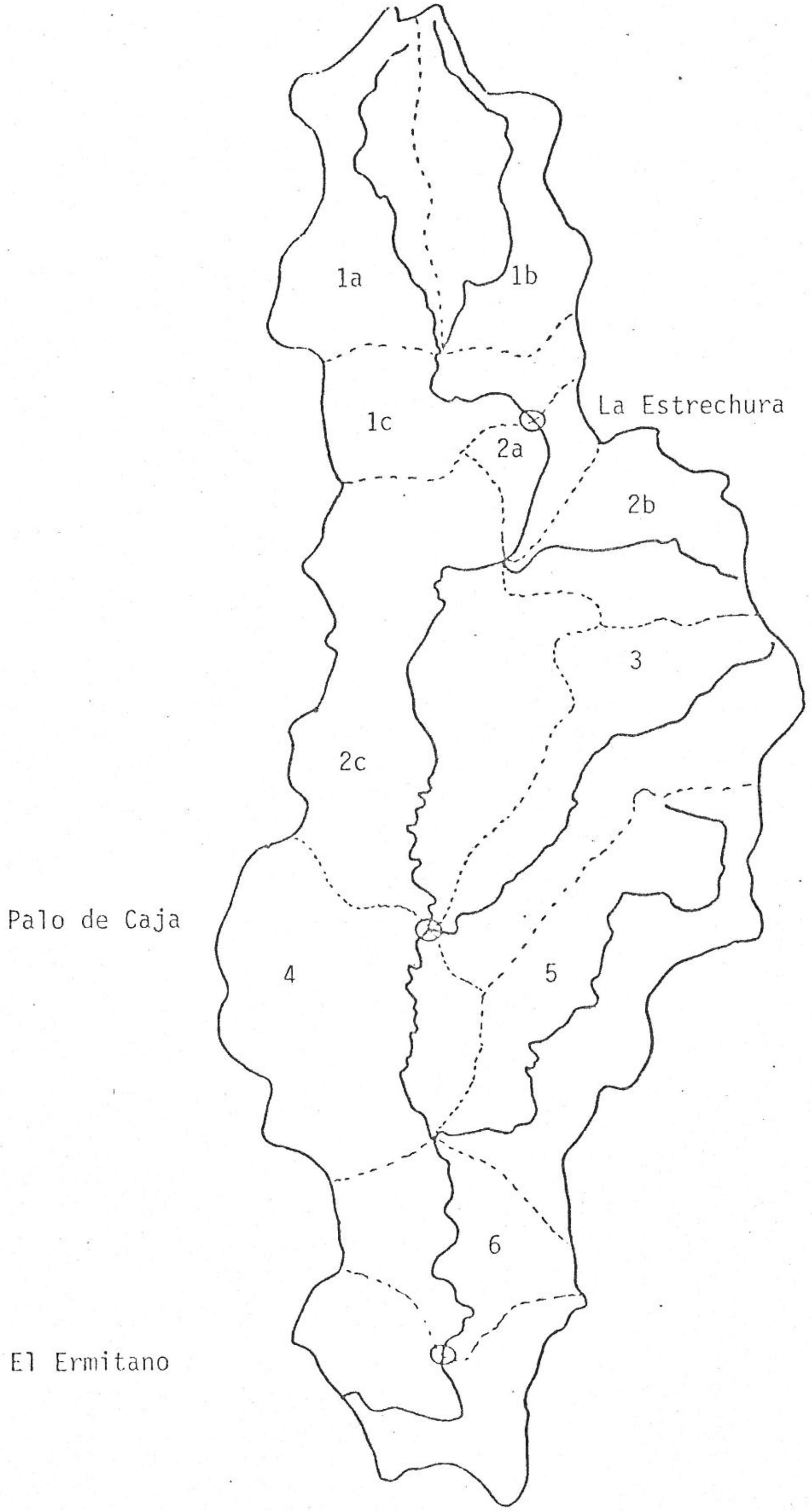


Figure 1.7.1. Nizao river basin configuration used in kinematic wave routing model.

parameters in the model to a minimum, and the SCS method only uses the Curve Number as input (once we assume that the initial abstraction is 20% of the storage capacity). The SCS method has proven to give very good results in similar situations.

The selection of the storms used for the calibration was a little difficult. After the revision of the stage-discharge relations and the computation of the new hydrographs, very carefully the plots of precipitation and runoff of all the available storms were inspected. Most of them showed dramatic inconsistencies in terms of timing and volume of water. In many cases the hydrographs show a peak before the stations show any record of precipitation. This is why only four storms were selected for calibration. The corresponding hydrographs are shown in Figures 1.7.2 through 1.7.5.

The creation of each storm file starts by assigning weights to each of the precipitation stations with available data for each storm. The HEC-1 model computes an average total storm depth based on given weights and storm values for each precipitation station. Then an average time distribution is computed based on given weights and precipitation patterns of the recording stations. The weights were assigned by using program PCMAPS to map the Thiessen polygons which were superimposed on the basin subdivision. In this way, each subbasin has an individual average storm depth and an individual time distribution pattern. The weights assigned to each station for each subbasin and storm are included in the HEC-1 input files printed as part of the output. A computer output of the Thiessen polygons is included in Appendix 1.7.A.

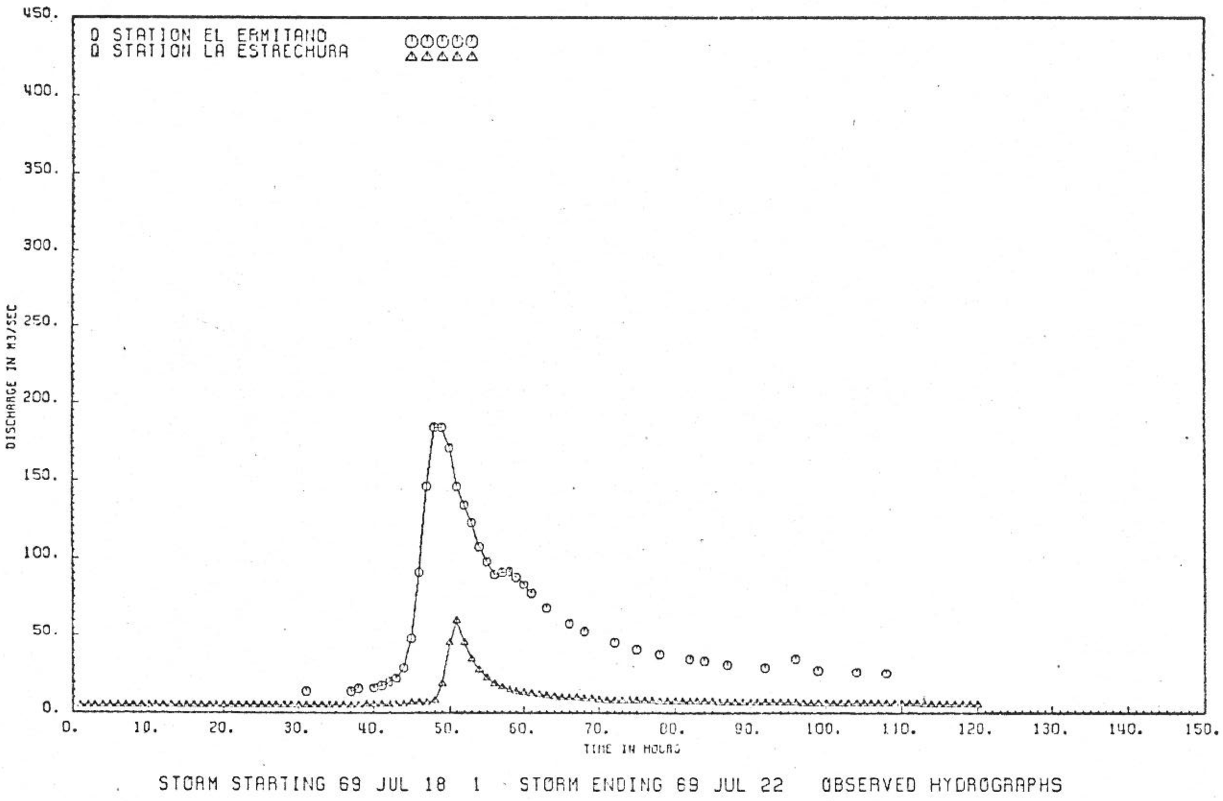


Figure 1.7.2. Streamflow hydrographs for period July 18-22, 1969 (storm A).

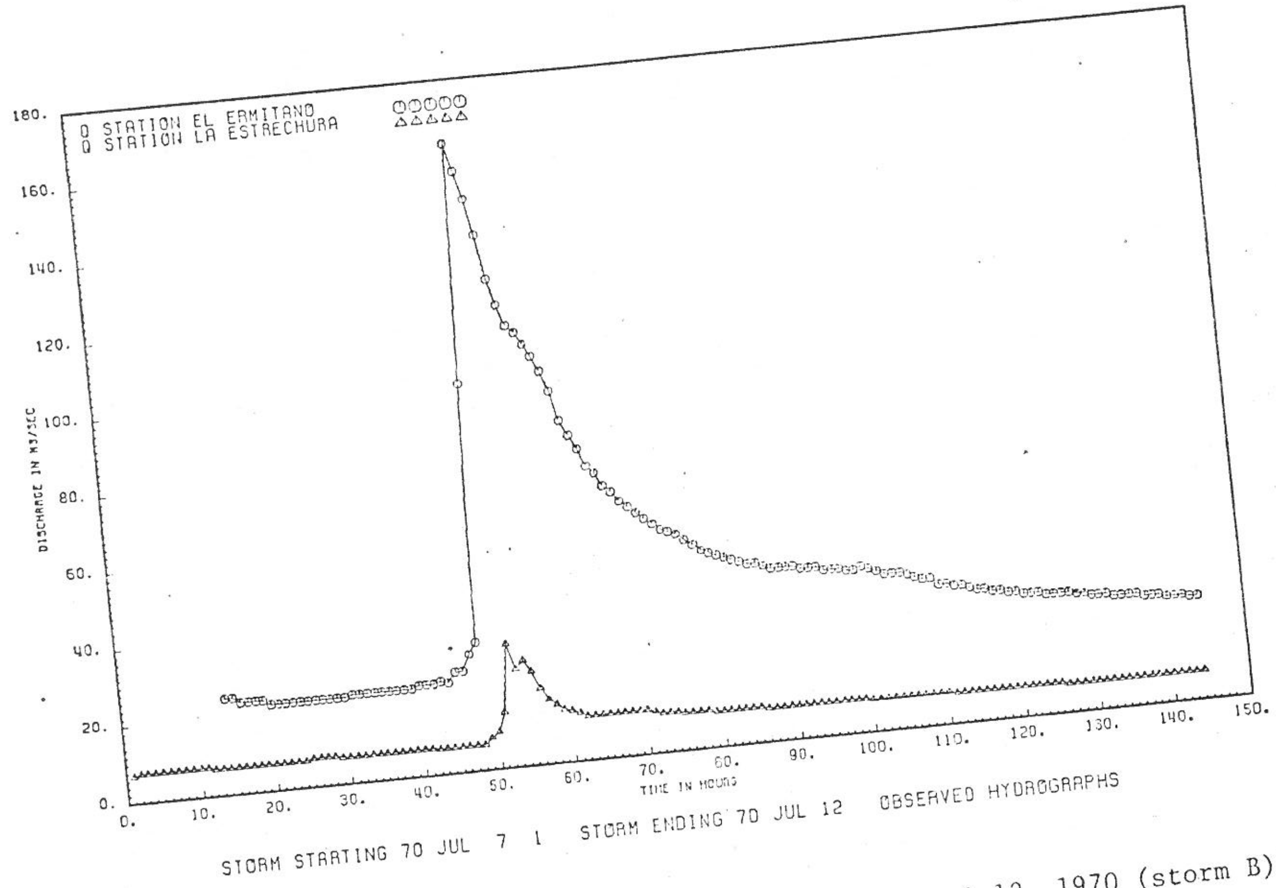


Figure 1.7.3. Streamflow hydrographs for period July 1-12, 1970 (storm B).

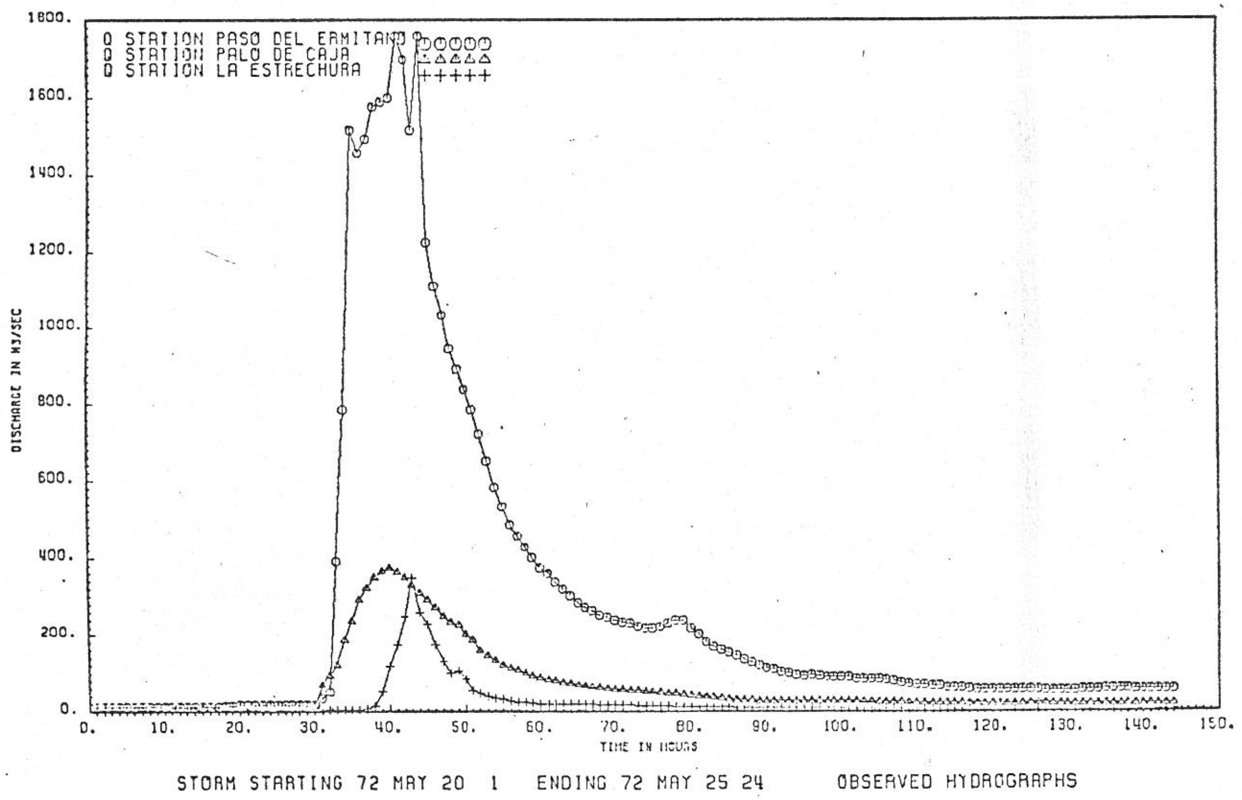


Figure 1.7.4. Streamflow hydrographs for period May 20-25, 1972 (storm F).

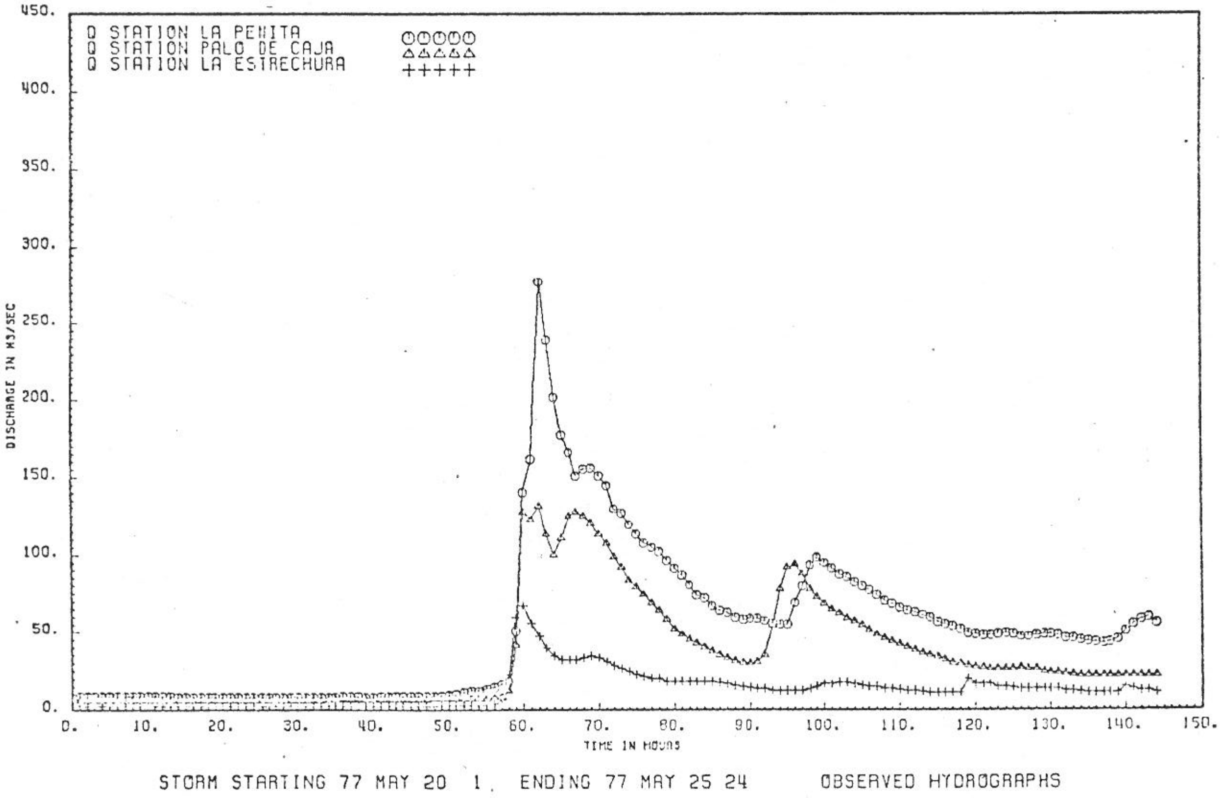


Figure 1.7.5. Streamflow hydrographs for period May 20-25, 1977 (storm M).

The calibration procedure starts by trying to adjust the volume under the computed hydrograph to the volume under the observed hydrograph. In most of the cases the curve number fall in the range 60 to 80 which is reasonable for the vegetation cover and expected soil type in the area. Some extremes as low as 45 and high as 100 are observed in case of storms F and M. The low of 45 could be reasonable for a very dry antecedent condition but in the case of CN = 100 (see storm F and La Penita), i.e. with practically no infiltration, in the lower subbasins there is a deficit of 45% of the observed volume. It is concluded that some errors are present in the data.

Once the runoff volumes are matched, next step is to change the Manning's N, within reasonable values, to try to adjust the timing of the hydrographs. The best set of parameters so obtained is shown in Tables 1.7.2 and 1.7.3. Unfortunately, the computer outputs showed that the match is not too good in most of the cases. Since, in some cases, the observed peak comes before the computed, and in other cases is the opposite, it was not possible to arrive at a unique set of parameters that will fit all the storms. Suspecting errors in data, additional data consisting of reservoir levels and operation records of the Valdesia reservoir,during certain major storm events were requested. The data for two reasonably large storms in September and October 1985 were received which proved to be very useful. The calibration results for the September storm are illustrated in Figure 1.7.6. The timing of the reconstructed inflow hydrographs to the reservoir matches reasonably well those computed with the calibrated model.

TABLE 1.7.2 . KINEMATIC WAVE MODEL SUBBASIN CHARACTERISTICS

SUBBASIN	OVERLAND FLOW PLANE LENGTH	OVERLAND FLOW PLANE SLOPE	MANNING N	DRAINAGE AREA (sq km)	LAND USE
1a	2500	0.60	0.400	70	Forest
1b	2500	0.60	0.400	70	Forest
1c	4500	0.50	0.300	45	Pasture
2a	2000	0.40	0.300	24	Pasture/Forest
2b	3500	0.20	0.300	56	Agriculture/Forest
2c	4500	0.40	0.300	164	Pasture/Forest
3	2000	0.40	0.300	106	Pasture/Forest
4	5000	0.50	0.300	103	Pasture/Forest
5	3000	0.40	0.300	109	Forest
6	5000	0.60	0.300	53	Forest

TABLE 1.7.3 KINEMATIC WAVE MODEL CHANNEL CHARACTERISTICS

SUBBASIN	LENGTH (m)	SLOPE (m/m)	MANNING N	WIDTH	SIDE SLOPE (m/m)	UPSTREAM INFLOW
1a	16000	0.1050	0.060	45	1	no
1b	20000	0.0837	0.060	45	1	no
1c	8500	0.0133	0.040	85	1	yes
2a	7500	0.0108	0.040	85	1	yes
2b	13500	0.0452	0.050	45	1	no
2c	33500	0.0086	0.040	70	1	yes
3	33000	0.0293	0.050	45	1	no
4	18000	0.0148	0.040	80	1	yes
5	34000	0.0323	0.050	45	1	no
6	18000	0.0119	0.040	80	1	yes

Figure 1.7.6. Comparison of computed (from reservoir levels) and calibrated (HEC-1) inflow hydrographs to Valdesia Reservoir due to storm on September 13-14, 1985.

1.7.3 Design Flood Hydrographs

The primary use of the calibrated HEC-1 model is in computing design flood hydrographs from hypothetical design storm events. The hypothetical storms under consideration are (a) Standard Project storm for non-hurricane conditions; (b) Standard Project storm for hurricane conditions; and (c) probable maximum precipitation. The calibrated HEC-1 model was used to compute hydrographs corresponding to all three design storms.

An important consideration in computing design flood hydrographs is the antecedent moisture condition of the basin under consideration. Since the SCS curve number method of HEC-1 model is being used for computing losses, the antecedent basin condition is reflected in the curve numbers corresponding to each subbasin. The actual curve number magnitudes depend on three types of basin conditions: (a) Antecedent Moisture Condition type-I (AMC-I). This corresponds to the dry soil conditions; (b) Antecedent Moisture Condition type-II (AMC II). This corresponds to average soil moisture conditions; and (c) Antecedent Moisture Condition type-III (AMC-III). This corresponds to the nearly saturated soil condition. The soil conservation service provides the Curve Numbers for AMC II conditions for a variety of land uses and four types of soil cover complexes. Based on a past study on soil types and land uses in Nizao basin (Perez, 1982), the curve numbers were identified for various subbasins in the watershed subdivision made for kinematic wave model. These curve numbers correspond to AMC II. The curve numbers for AMC I and AMC III were identified from another table provided by soil conservation service. These results are summarized in Table 1.7.4.

TABLE 1.7.4 CURVE NUMBERS USED IN HEC-1 MODEL

SUB-BASIN	AMC-I	AMC-II	AMC-III
1a	40	60	78
1b	40	60	78
1c	51	70	85
2a	51	70	85
2b	51	70	85
2c	45	65	82
3	45	65	82
4	45	65	82
5	45	65	82
6	40	60	78

Finally, by using the curve numbers corresponding to AMC I, AMC II and AMC III in the calibrated HEC-1 model three design flood hydrographs were computed for each of the three hypothetical design storms mentioned above. The resulting hydrographs are presented in Figures 1.7.7 through 1.7.9.

1.7.4 Reconstruction of Hydrographs for Hurricane DAVID

Hurricane DAVID constitutes the largest storm event recorded in Nizao. Unfortunately, the hydrograph corresponding to this event is not available due to failure of equipment during the hurricane. The HEC-1 model was used to reconstruct the hydrograph corresponding to recorded precipitation pattern of hurricane DAVID. Since the antecedent basin condition prior to the hurricane is unknown, the hydrograph corresponding to all three antecedent moisture conditions AMC I, AMC II, and AMC III were computed. These results are presented in Figure 1.7.10. It is noted that the peak flow corresponding to even AMC I is considerably larger than the peak discharge of about 3800 m^3/D reported in some documents obtained from INDRHI. For the present study however, exact reproduction of the actual peak discharge of flood due to hurricane DAVID is not critical.

1.7.5 Effects of Natural Storages in the Watershed

It is noted here that the kinematic wave approach of HEC-1 does not have a facility to attenuate a flood hydrograph due to natural storages such as those present in flood plains. However, it is important to account for such storages wherever they exist since the hydrograph can be greatly modified by attenuation due to storage effects. A study was undertaken to investigate the presence of natural storage which may have

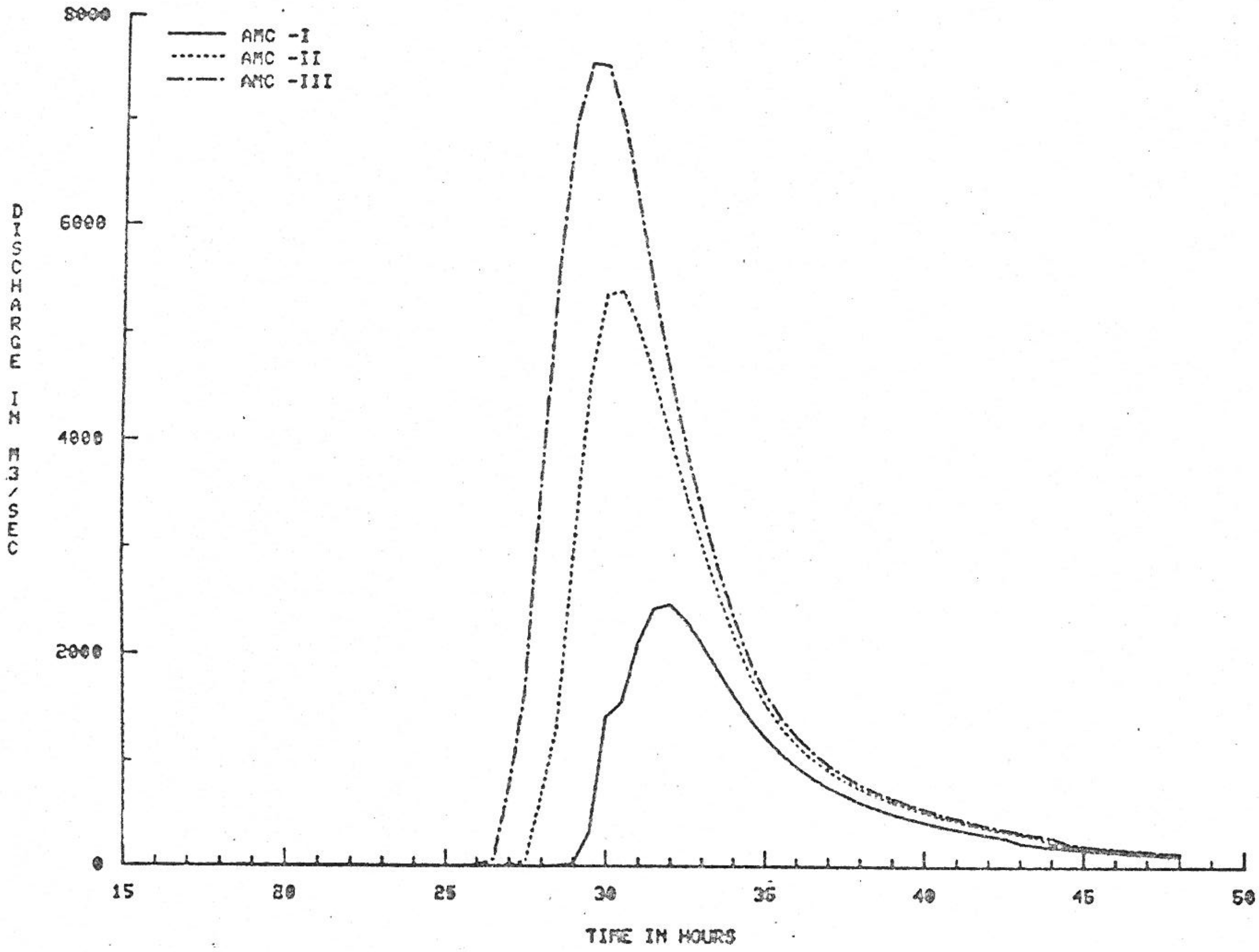


Figure 1.7.7. Non-hurricane standard project flood.

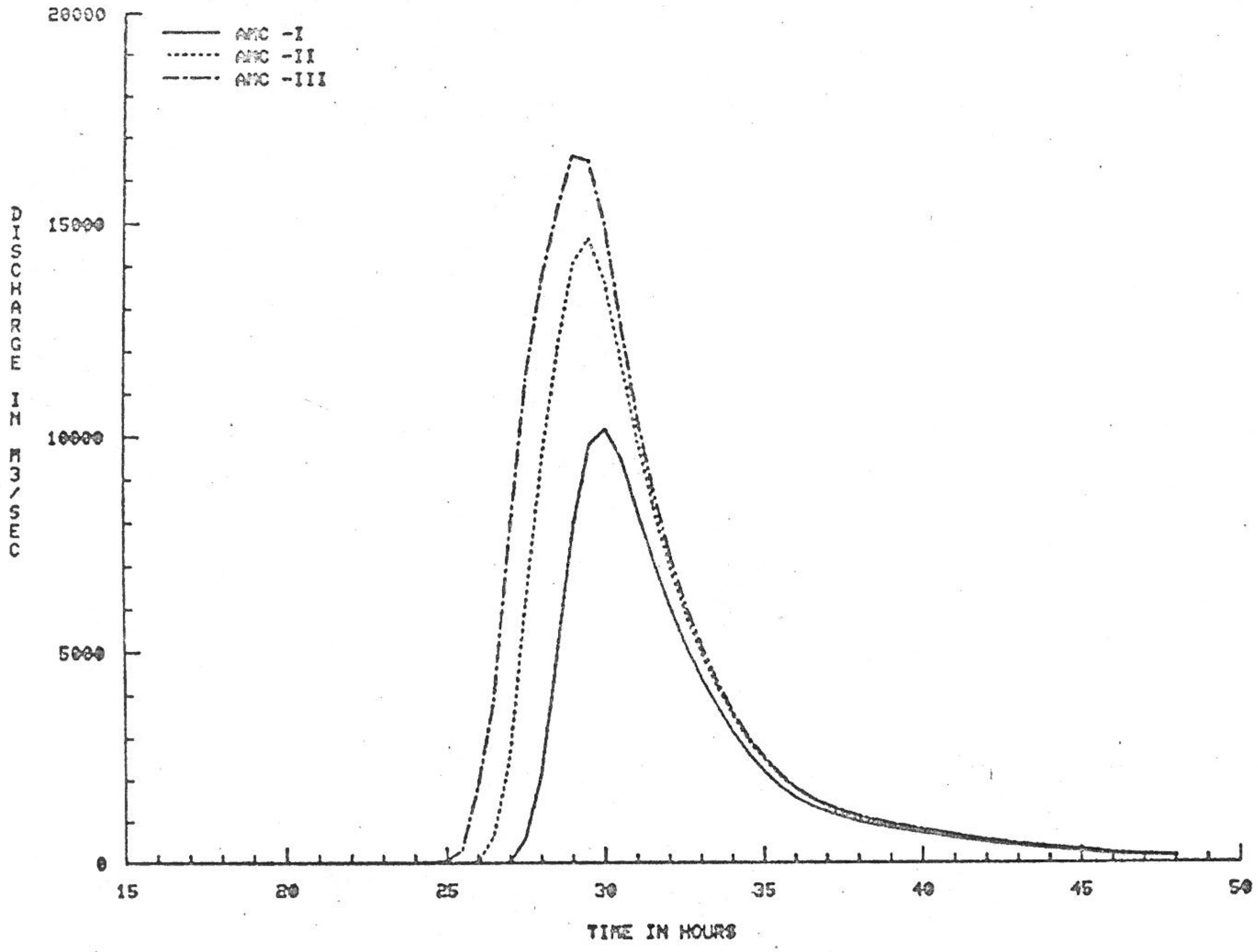


Figure 1.7.8. Hurricane standard project flood.

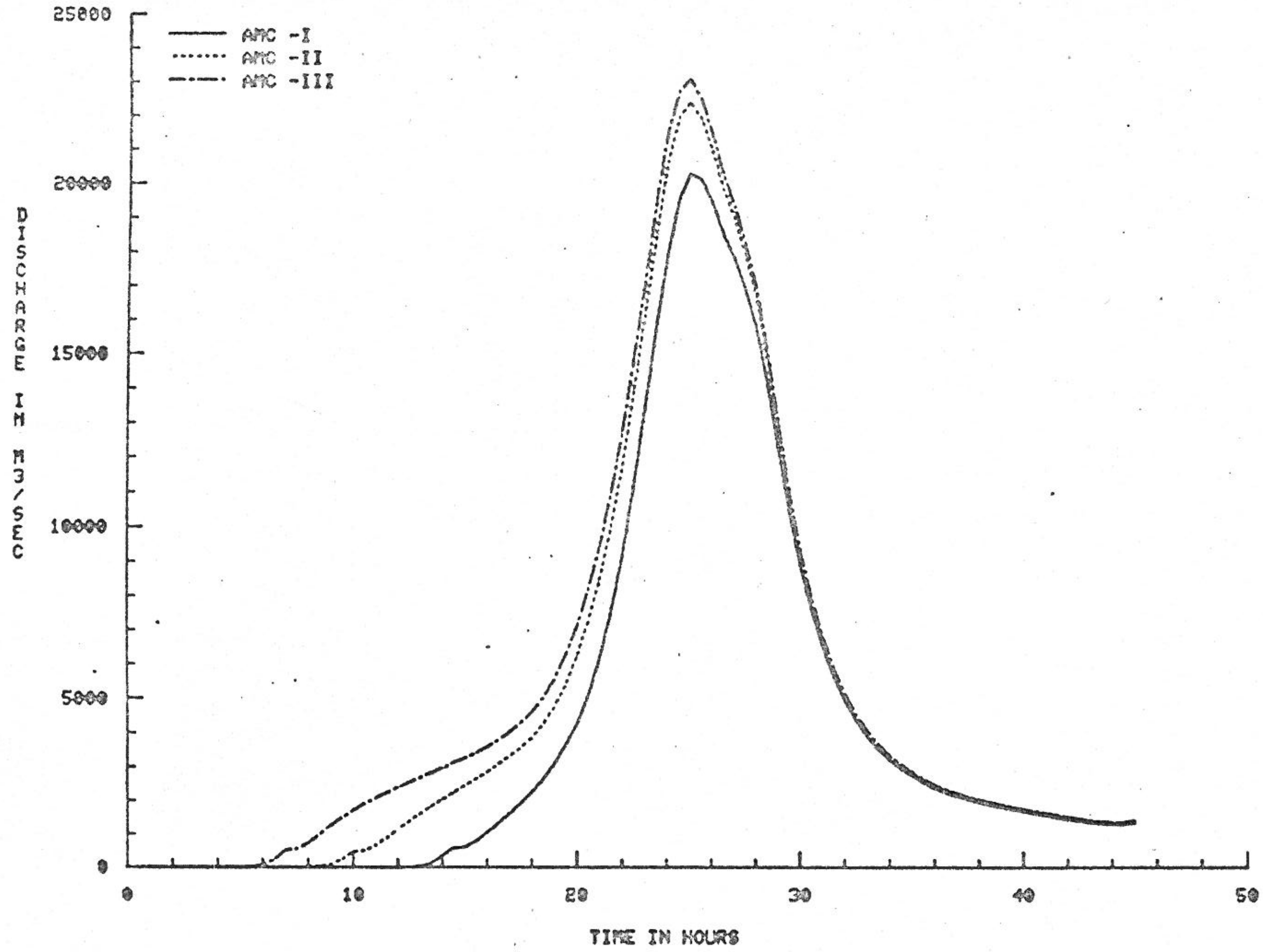


Figure 1.7.9. Simulated probable maximum flood.

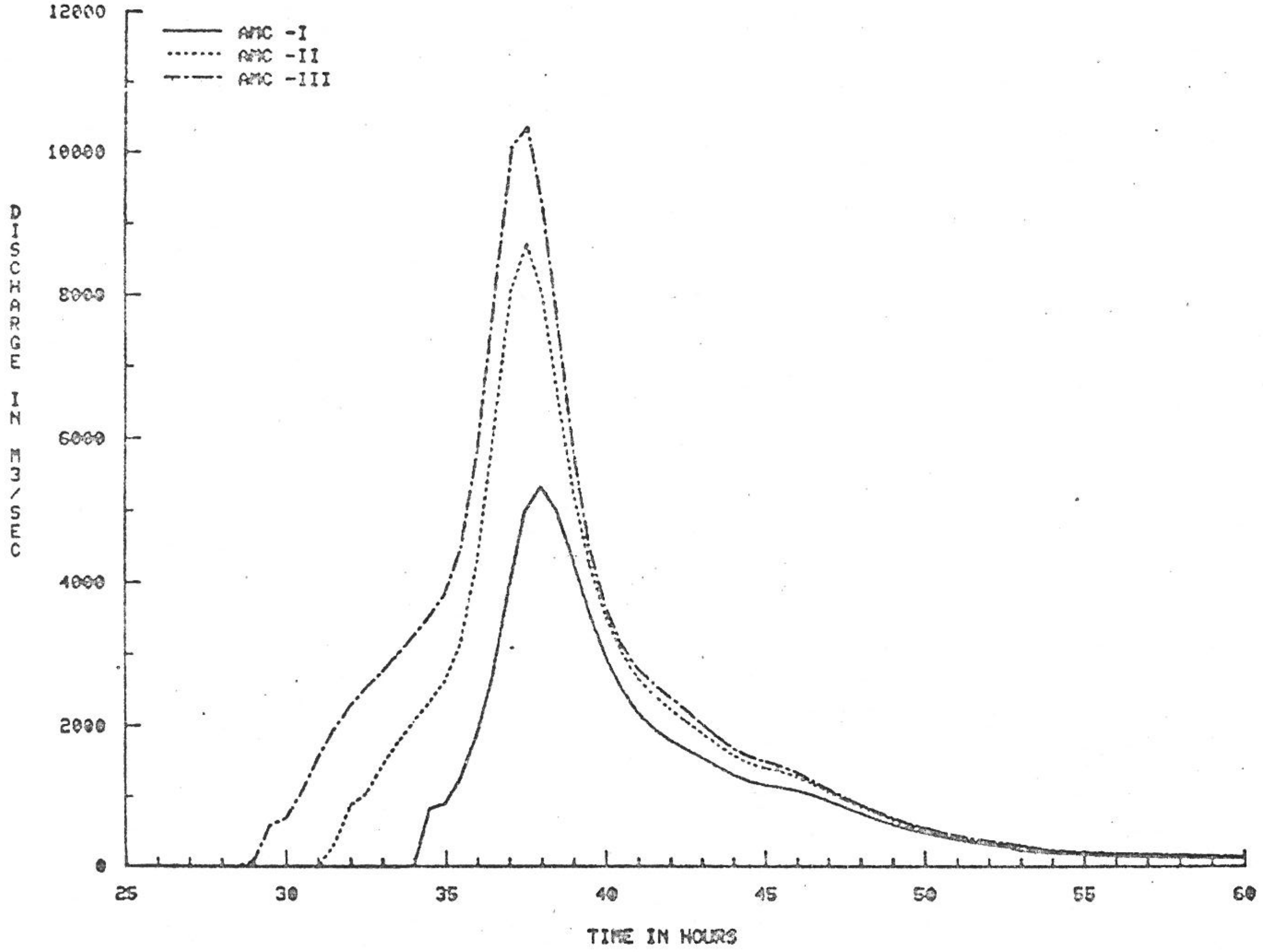


Figure 1.7.10. Simulated hydrograph for hurricane David (August, 1979).

the potential to substantially attenuate the flood hydrograph computed by the kinematic wave model.

Two possible storage areas were identified in the main channel of the Nizao River. The first one is located upstream of Rio Abajo and the second one upstream the junction of Banilejo River and the main channel.

Based on the new information made available by INDRHI (cross sections and map scale 1:20000) for the area upstream of Rio Abajo, it was concluded that the storage in the channal is not significant even for very high flows. Because a detailed map for the area upstream the junction of Banilejo and Nizao is not available a definite conclusion about the effect of storage in this location during high flows could not be made. However an approximate sensitivity analysis was conducted to see the effect of different storages on the peak discharge.

An estimate of elevation-discharge relation was obtained by using Manning's equation in the narrowest section downstream the junction. The values used for this estimation are:

Slope = = 0.0055

Manning's N = 0.04

Base width = 85 m

z (side slope) = $\frac{11}{40}$ = 0.275

Using the parameters the following table was obtained.

Depth	A	R	Q	V
0.5	42.6	0.49	49.4	1.16
1.0	85.3	0.98	156	1.83
1.5	128.1	1.45	305	2.38
2.0	171.1	1.92	490	2.86
2.5	214.0	2.38	707	3.30
3.0	257.0	2.82	953	3.70
3.5	301.0	3.26	1227	4.08
4.0	344.0	3.69	1525	4.43
4.5	388.0	4.11	1847	4.76
5.0	432.0	4.53	2192	5.07
5.5	476.0	4.94	2557	5.37
6.0	520.0	5.34	2943	5.66

From the maps scale 1:50000 one can estimate the volume of storage for different depths. Two runs with different storage values were made to see their effect on the hydrograph at Paso del Ermitano.

(a) FIRST RUN: (Upper Limit)

For a maximum stage level of 6.0 m assume a maximum average flooded area of 3 km^2. The storage for this stage is $\frac{1}{3} \times 3 \times 10^6 \times 6 = 6 \times 10^6$ m^3. Assuming storage S is related to stage ,d, in the form, $S = ad^3$ the stage-storage data are obtained as given below:

Depth (m)	STORAGE x 10^3 m^3
0.5	3.5
1.0	27.8
1.5	93.8
2.0	222.2
2.5	434.0
3.0	750.0
3.5	1191.0
4.0	1777.8
4.5	2531.3
5.0	3472.2
5.5	4621.5
6.0	6000.0

(b) SECOND RUN

Assume that the maximum storage for a stage of 6 m is 2000 x 10^3m^3. Then the storage ordinate in the storage-elevation curve will be one third of the one used in the first run.

These two assumed reservoirs were incorporated into the Hurricane David HEC-file. The corresponding results for the larger reservoir are included in Appendix 1.7.B. It was seen that the effect of the storage on the peak discharge is insignificant in both cases and therefore it was not considered in subsequent analysis.

APPENDIX 1.7.A

SAMPLE OUTPUT OF RAINFALL WEIGHTING USING THIESSEN POLYGON METHOD

```
S.059              54              27.70    77.70
S.060              55              26.60    75.70
S.061              56              27.20    74.80
S.062              57              29.00    74.40
S.063              58              31.00    72.70
S.064              59              31.20    71.00
S.065              60              30.90    69.80
S.066              61              31.80    68.70
S.067              62              32.20    67.50
S.068              63              33.00    66.80
S.069              64              33.80    67.10
S.070              65              35.20    67.40
S.071              66              37.10    65.70
S.072              67              39.30    64.10
S.073              68              40.40    60.20
S.074              69              43.10    59.70
S.075              70              43.20    58.60
S.076              71              43.80    58.50
S.077              72              44.80    56.00
S.078              73              44.30    54.70
S.079              74              45.40    54.00
S.080              75              45.80    53.00
S.081              76              47.30    52.80
S.082              77              47.70    51.20
S.083              78              47.00    50.20
S.084              79              46.80    49.00
S.085              80              47.70    45.80
S.086              81              49.70    44.60
S.087              82              49.80    43.80
S.088              83              51.20    42.60
S.089              84              54.30    42.50
S.090              85              54.30    41.50
S.091              86              55.00    40.80
S.092              87              57.60    41.20
S.093              88              58.80    40.80
S.094              89              59.80    39.80
S.095              90              61.20    38.70
S.096              91              60.70    36.80
S.097              92              61.20    34.80
S.098              93              62.50    34.90
S.099              94              64.70    34.30
S.100           END

S.101      INPUT STATION
S.102           VALDESIA           64.80    35.40
S.103           EL RIO             28.70    99.30
S.104           QUEMADOS           46.40    89.20
S.105           VALLENUEVO         22.70    80.10
S.106           CONSTANZA          19.20    91.80
S.107           BANI               59.50    21.10
S.108           VILLA ALTAGRACIA   76.20    64.90
S.109           AZUA               16.60    41.20
S.110           PALO DE CAJA       52.20    49.20
S.111           MEDINA             79.20    49.60
S.112           JUMA-BONAO         54.00    90.20
S.113           ENGOMBE            94.20    40.20
S.114           AZUA HATILLO       37.40    34.30
S.115           END

S.116      INPUT DATA
S.117           VALDESIA           313.7
S.118           EL RIO             18.8
S.119           QUEMADOS         47.3
S.120           VALLENUEVO       35.7
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S.121                 CONSTANZA             12.2
S.122                 BANI                  331.5
S.123                 VILLA ALTAGRACIA      173.8
S.124                 AZUA                  182.4
S.125                 PALO DE CAJA          153.7
S.126                 MEDINA                 263.7
S.127                 JUMA-BONAO              50.5
S.128                 ENCOMBE                487.1
S.129                 AZUA HATILLO          63.2
S.130                 END

S.131            PROC THIESSEN

S.132            STOP
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DIAGNOSTIC CHECK OF COORDINATE SYSTEM :      NIZAO BASIN - DOMINICAN REPUBLIC   NON-RECORDING WEIGHTS SEP.85

                               SPHERICAL                        RECTANGULAR

CONTROL POINTS        DEG.MIN.SEC    DEG.MIN.SEC    X-COORDINATE   Y-COORDINATE   Z-ELEVATION    DIAGNOSTICS
                       LONGITUDE      LATITUDE


MINIMUM                                                25.000         30.000
MAXIMUM                                                75.000         85.000

STA    1  VALDESIA                                     64.800         35.400           .000       INSIDE OF RANGE
STA    2  EL RIO                                       28.700         99.300           .000     *OUTSIDE OF RANGE*
STA    3  QUEMADOS                                     46.400         89.200           .000     *OUTSIDE OF RANGE*
STA    4  VALLENUE                                     22.700         80.100           .000     *OUTSIDE OF RANGE*
STA    5  CONSTANZ                                     19.200         91.800           .000     *OUTSIDE OF RANGE*
STA    6  BANI                                         59.500         21.100           .000     *OUTSIDE OF RANGE*
STA    7  VILLA AL                                     76.200         64.900           .000     *OUTSIDE OF RANGE*
STA    8  AZUA                                         16.600         41.200           .000     *OUTSIDE OF RANGE*
STA    9  PALO DE                                      52.200         49.200           .000       INSIDE OF RANGE
STA   10  MEDINA                                       79.200         49.600           .000     *OUTSIDE OF RANGE*
STA   11  JUMA-BON                                     54.000         90.200           .000     *OUTSIDE OF RANGE*
STA   12  ENCOMBE                                      94.200         40.200           .000     *OUTSIDE OF RANGE*
STA   13  AZUA HAT                                     37.400         34.300           .000       INSIDE OF RANGE
BOUNDARY POINT  1                                      65.700         34.200                      INSIDE OF RANGE
BOUNDARY POINT  2                                      68.500         32.900                      INSIDE OF RANGE
BOUNDARY POINT  3                                      68.800         34.000                      INSIDE OF RANGE
BOUNDARY POINT  4                                      70.000         35.100                      INSIDE OF RANGE
BOUNDARY POINT  5                                      71.000         35.200                      INSIDE OF RANGE
BOUNDARY POINT  6                                      72.500         35.000                      INSIDE OF RANGE
BOUNDARY POINT  7                                      73.000         36.000                      INSIDE OF RANGE
BOUNDARY POINT  8                                      72.500         37.000                      INSIDE OF RANGE
BOUNDARY POINT  9                                      71.500         38.000                      INSIDE OF RANGE
BOUNDARY POINT 10                                      70.800         39.000                      INSIDE OF RANGE
BOUNDARY POINT 11                                      70.000         40.000                      INSIDE OF RANGE
BOUNDARY POINT 12                                      69.300         41.800                      INSIDE OF RANGE
BOUNDARY POINT 13                                      69.700         42.500                      INSIDE OF RANGE
BOUNDARY POINT 14                                      69.500         43.300                      INSIDE OF RANGE
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BOUNDARY POINT 15        69.700     44.200      INSIDE OF RANGE
BOUNDARY POINT 16        69.000     44.300      INSIDE OF RANGE
BOUNDARY POINT 17        65.300     48.000      INSIDE OF RANGE
BOUNDARY POINT 18        65.000     49.800      INSIDE OF RANGE
BOUNDARY POINT 19        64.200     51.600      INSIDE OF RANGE
BOUNDARY POINT 20        65.000     52.000      INSIDE OF RANGE
BOUNDARY POINT 21        65.200     53.000      INSIDE OF RANGE
BOUNDARY POINT 22        65.000     54.000      INSIDE OF RANGE
BOUNDARY POINT 23        64.000     55.000      INSIDE OF RANGE
BOUNDARY POINT 24        63.300     56.000      INSIDE OF RANGE
BOUNDARY POINT 25        63.200     58.000      INSIDE OF RANGE
BOUNDARY POINT 26        63.900     59.000      INSIDE OF RANGE
BOUNDARY POINT 27        65.200     61.000      INSIDE OF RANGE
BOUNDARY POINT 28        62.500     63.000      INSIDE OF RANGE
BOUNDARY POINT 29        62.300     64.600      INSIDE OF RANGE
BOUNDARY POINT 30        60.800     65.800      INSIDE OF RANGE
BOUNDARY POINT 31        60.200     67.000      INSIDE OF RANGE
BOUNDARY POINT 32        60.000     69.800      INSIDE OF RANGE
BOUNDARY POINT 33        58.300     70.900      INSIDE OF RANGE
BOUNDARY POINT 34        55.200     71.600      INSIDE OF RANGE
BOUNDARY POINT 35        53.600     72.000      INSIDE OF RANGE
BOUNDARY POINT 36        53.000     73.900      INSIDE OF RANGE
BOUNDARY POINT 37        51.500     74.200      INSIDE OF RANGE
BOUNDARY POINT 38        51.300     75.000      INSIDE OF RANGE
BOUNDARY POINT 39        49.300     74.000      INSIDE OF RANGE
BOUNDARY POINT 40        48.200     74.500      INSIDE OF RANGE
BOUNDARY POINT 41        47.600     74.500      INSIDE OF RANGE
BOUNDARY POINT 42        46.600     73.500      INSIDE OF RANGE
BOUNDARY POINT 43        46.300     72.800      INSIDE OF RANGE
BOUNDARY POINT 44        45.000     72.900      INSIDE OF RANGE
BOUNDARY POINT 45        43.700     73.800      INSIDE OF RANGE
BOUNDARY POINT 46        41.800     76.000      INSIDE OF RANGE
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BOUNDARY POINT 47        40.000     78.800     INSIDE OF RANGE
BOUNDARY POINT 48        37.200     79.500     INSIDE OF RANGE
BOUNDARY POINT 49        35.500     82.100     INSIDE OF RANGE
BOUNDARY POINT 50        33.000     80.600     INSIDE OF RANGE
BOUNDARY POINT 51        29.000     82.200     INSIDE OF RANGE
BOUNDARY POINT 52        28.500     80.700     INSIDE OF RANGE
BOUNDARY POINT 53        27.500     80.400     INSIDE OF RANGE
BOUNDARY POINT 54        27.700     77.700     INSIDE OF RANGE
BOUNDARY POINT 55        26.600     75.700     INSIDE OF RANGE
BOUNDARY POINT 56        27.200     74.800     INSIDE OF RANGE
BOUNDARY POINT 57        29.000     74.400     INSIDE OF RANGE
BOUNDARY POINT 58        31.000     72.700     INSIDE OF RANGE
BOUNDARY POINT 59        31.200     71.000     INSIDE OF RANGE
BOUNDARY POINT 60        30.900     69.800     INSIDE OF RANGE
BOUNDARY POINT 61        31.800     68.700     INSIDE OF RANGE
BOUNDARY POINT 62        32.200     67.500     INSIDE OF RANGE
BOUNDARY POINT 63        33.000     66.800     INSIDE OF RANGE
BOUNDARY POINT 64        33.800     67.100     INSIDE OF RANGE
BOUNDARY POINT 65        35.200     67.400     INSIDE OF RANGE
BOUNDARY POINT 66        37.100     65.700     INSIDE OF RANGE
BOUNDARY POINT 67        39.300     64.100     INSIDE OF RANGE
BOUNDARY POINT 68        40.400     60.200     INSIDE OF RANGE
BOUNDARY POINT 69        43.100     59.700     INSIDE OF RANGE
BOUNDARY POINT 70        43.200     58.600     INSIDE OF RANGE
BOUNDARY POINT 71        43.800     58.500     INSIDE OF RANGE
BOUNDARY POINT 72        44.800     56.000     INSIDE OF RANGE
BOUNDARY POINT 73        44.300     54.700     INSIDE OF RANGE
BOUNDARY POINT 74        45.400     54.000     INSIDE OF RANGE
BOUNDARY POINT 75        45.800     53.000     INSIDE OF RANGE
BOUNDARY POINT 76        47.300     52.800     INSIDE OF RANGE
BOUNDARY POINT 77        47.700     51.200     INSIDE OF RANGE
BOUNDARY POINT 78        47.000     50.200     INSIDE OF RANGE
```
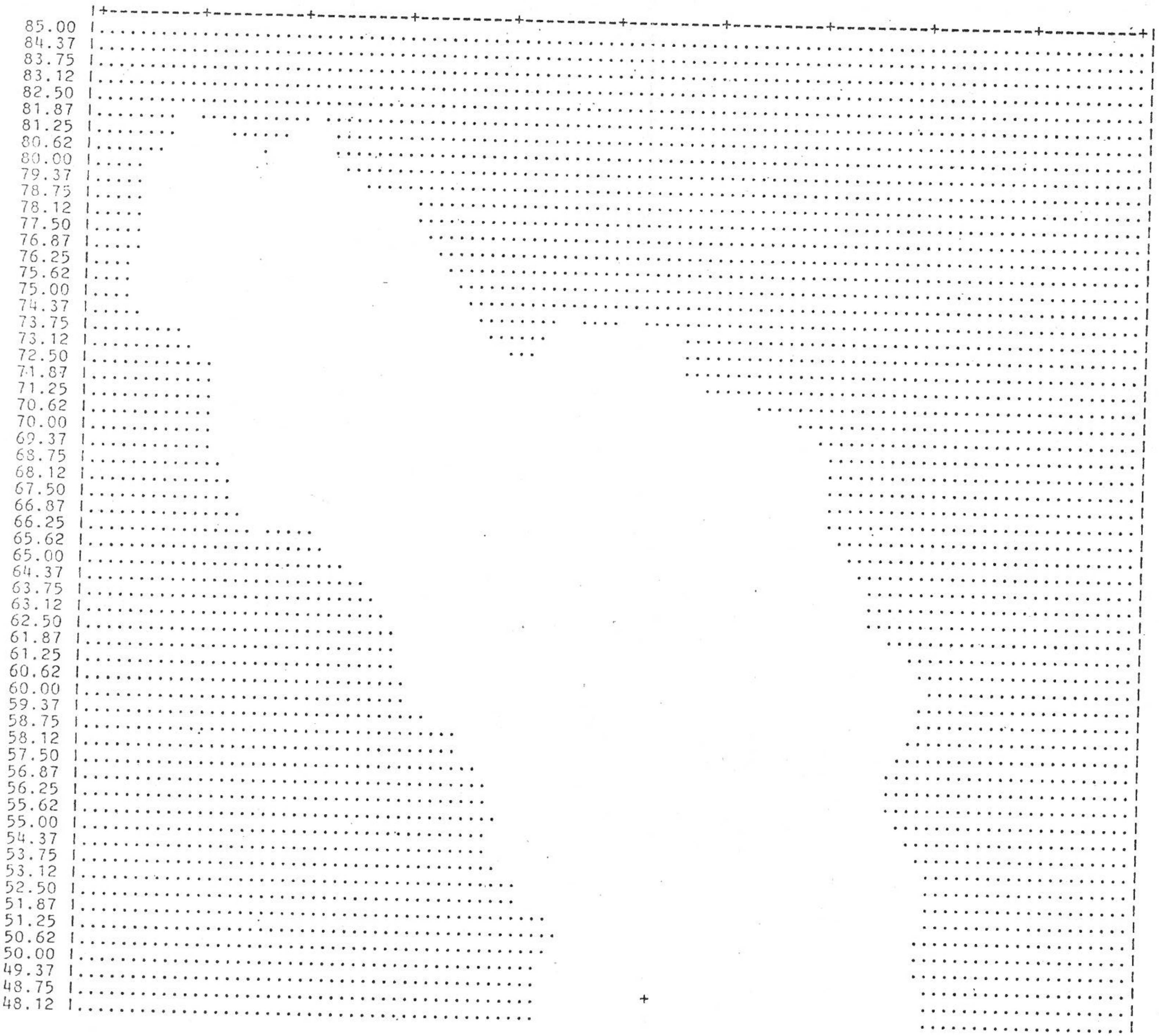
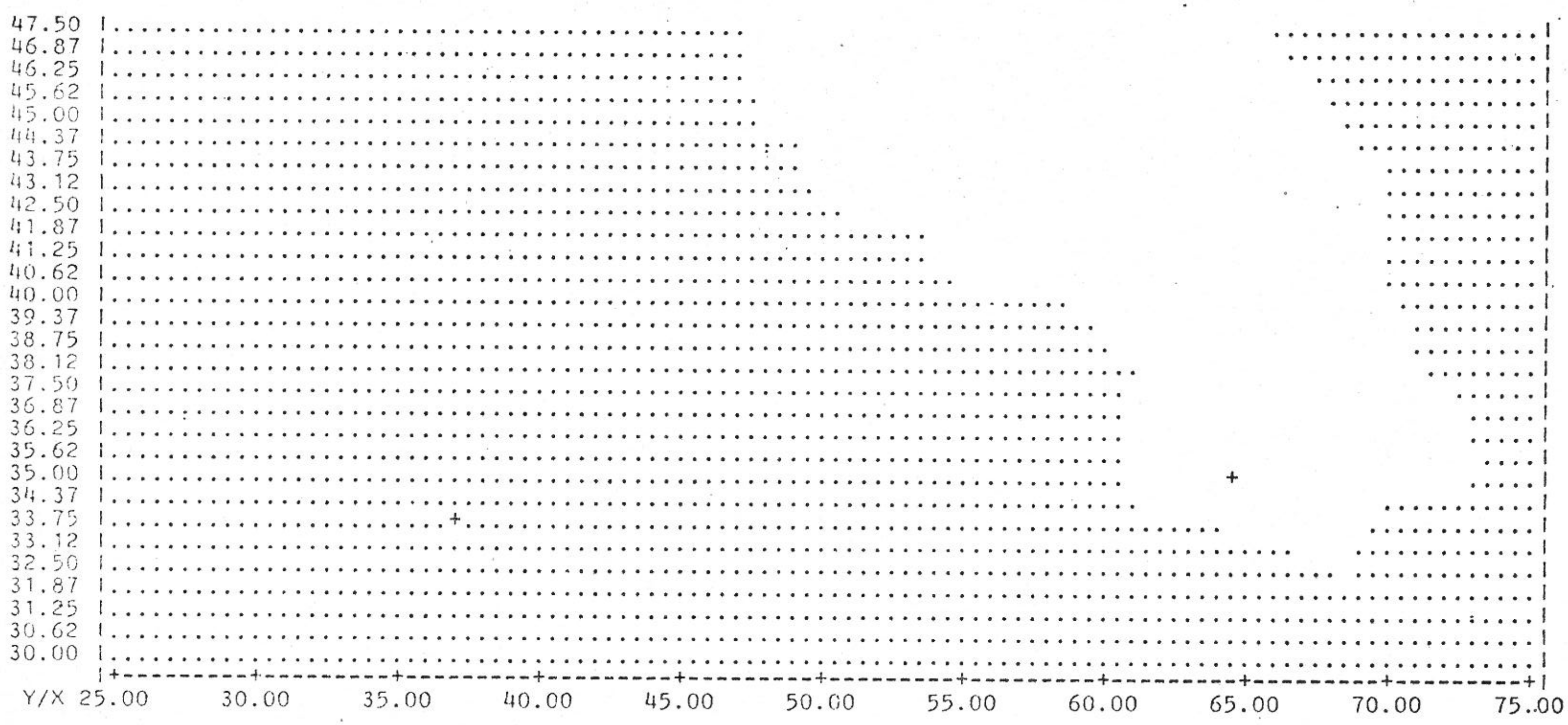

```
BOUNDARY POINT 79                    46.800      49.000      INSIDE OF RANGE
BOUNDARY POINT 80                    47.700      45.800      INSIDE OF RANGE
BOUNDARY POINT 81                    49.700      44.600      INSIDE OF RANGE
BOUNDARY POINT 82                    49.800      43.800      INSIDE OF RANGE
BOUNDARY POINT 83                    51.200      42.600      INSIDE OF RANGE
BOUNDARY POINT 84                    54.300      42.500      INSIDE OF RANGE
BOUNDARY POINT 85                    54.300      41.500      INSIDE OF RANGE
BOUNDARY POINT 86                    55.000      40.800      INSIDE OF RANGE
BOUNDARY POINT 87                    57.600      41.200      INSIDE OF RANGE
BOUNDARY POINT 88                    58.800      40.800      INSIDE OF RANGE
BOUNDARY POINT 89                    59.800      39.800      INSIDE OF RANGE
BOUNDARY POINT 90                    61.200      38.700      INSIDE OF RANGE
BOUNDARY POINT 91                    60.700      36.800      INSIDE OF RANGE
BOUNDARY POINT 92                    61.200      34.800      INSIDE OF RANGE
BOUNDARY POINT 93                    62.500      34.900      INSIDE OF RANGE
BOUNDARY POINT 94                    64.700      34.300      INSIDE OF RANGE
                                                             INSIDE OF RANGE
```

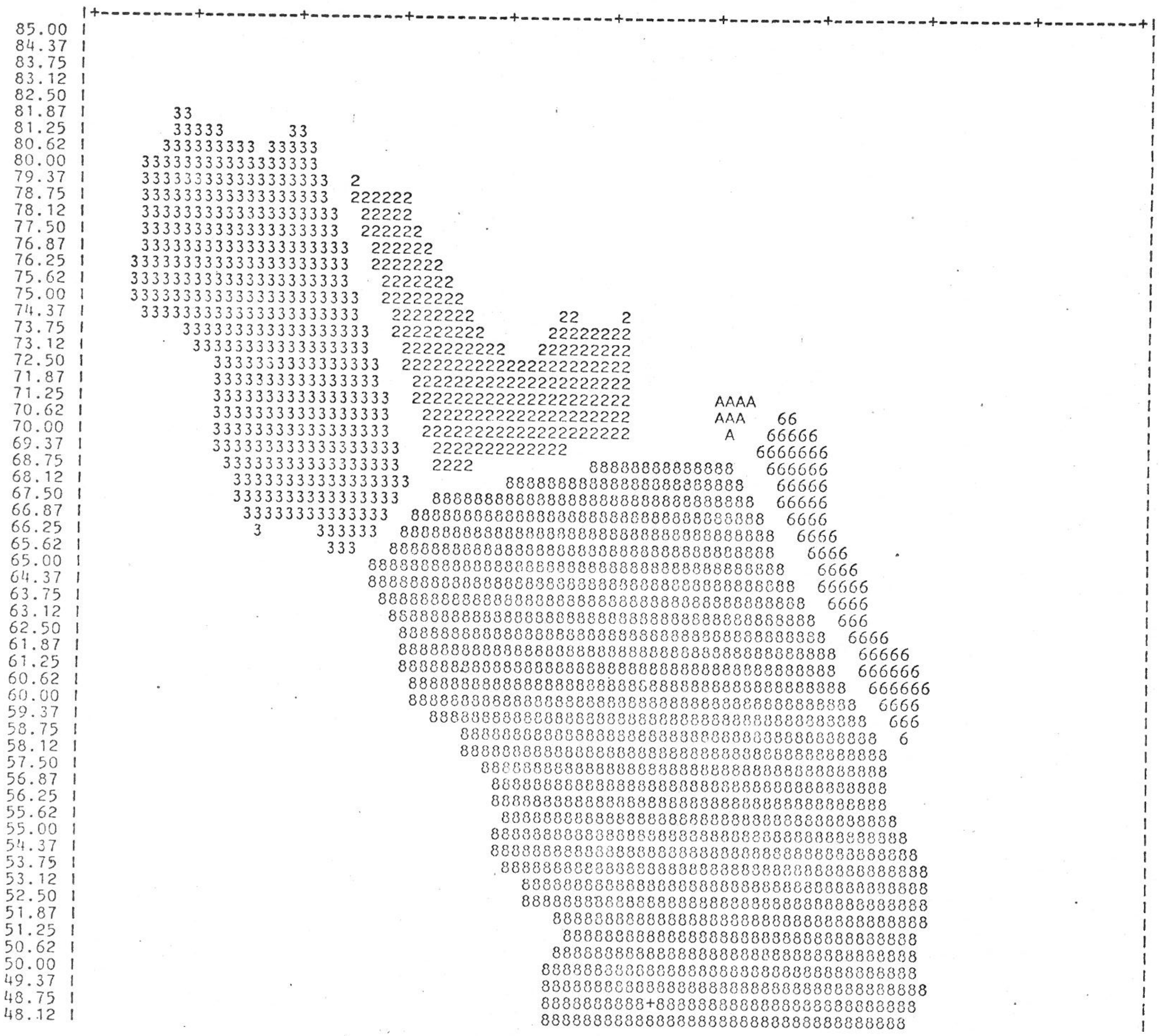
DELINEATION OF BASIN BOUNDARY: NIZAO BASIN - DOMINICAN REPUBLIC NON-RECORDING WEIGHTS SEP.85





```
TOTAL AREA =   904.062
UNIT AREA =      .312

DELTA X =       .500
DELTA Y =       .625

LEGEND:
 I.I  OUTSIDE OF BASIN
 I I  INSIDE OF BASIN
 I+I   STATION
```

MAPPING BY THIESSEN POLYGON: NIZAO BASIN - DOMINICAN REPUBLIC NON-RECORDING WEIGHTS SEP.85



```
47.50 I                                             88888888888888888888888888888888   00                   I
46.87 I                                             8888888888888888888888888888888   0000                  I
46.25 I                                             888888888888888888888888888888   0000000                I
45.62 I                                              888888888888888888888888888   0000000000               I
45.00 I                                              88888888888888888888888888   000000000000              I
44.37 I                                                 8888888888888888888888  000000000000000             I
43.75 I                                                 88888888888888888888   000000000000000000           I
43.12 I                                                  888888888888888888   0000000000000000000           I
42.50 I                                                    888888888888888  000000000000000000000           I
41.87 I                                                          8888888   0000000000000000000000           I
41.25 I                                                          888888  000000000000000000000000           I
40.62 I                                                            888  0000000000000000000000000           I
40.00 I                                                                    00000000000000000000000          I
39.37 I                                                                      0000000000000000000000         I
38.75 I                                                                       000000000000000000000         I
38.12 I                                                                         00000000000000000000        I
37.50 I                                                                        00000000000000000000000      I
36.87 I                                                                        000000000000000000000000     I
36.25 I                                                                        000000000000000000000000     I
35.62 I                                                                        0000000000000000000000000    I
35.00 I                                                                        0000000+0000000000000000     I
34.37 I                                                                         00000000000000000           I
33.75 I                        +                                                      0000000000            I
33.12 I                                                                                    0000             I
32.50 I                                                                                       0             I
31.87 I                                                                                                     I
31.25 I                                                                                                     I
30.62 I                                                                                                     I
30.00 I                                                                                                     I
      |+---------+---------+---------+---------+---------+---------+---------+---------+---------+---------+|
Y/X 25.00      30.00     35.00     40.00     45.00     50.00     55.00     60.00     65.00     70.00     75.00

           STA.NO.      STA. NAME      SYMBOL    THIESSEN WEIGHT     POLYGON AREA      STA. DATA

              1          VALDESIA        0           .14967            135.31           313.700
              2          EL RIO          1           .00000               .00            18.800
              3          QUEMADOS        2           .09644             87.19            47.300
              4          VALLENUE        3           .15900            143.75            35.700
              5          CONSTANZ        4           .00000               .00            12.200
              6          BANI            5           .00000               .00           331.500
              7          VILLA AL        6           .03837             34.69           173.800
              8          AZUA            7           .00000               .00           182.400
              9          PALO DE         8           .54511            492.81           153.700
             10          MEDINA          9           .00000               .00           263.700
             11          JUMA-BON        A           .01141             10.31            50.500
             12          ENGOMBE         B           .00000               .00           487.100
             13          AZUA HAT        C           .00000               .00            63.200

                               AREAL AVERAGE OF DATA =        148.2178

            THIESSEN METHOD OPTION CODE =  1

               1  MIN STRAIGHT DISTANCE
               2  MIN SQUARE DISTANCE
               3  MIN ORTHOGONAL DISTANCE
               4  MIN MAX LEG DISTANCE
               5  MIN ABS (DATA) X STRAIGHT DISTANCE
               6  MAX ABS (DEVIATE) X SPATIAL CORRELATION COEFF
```

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           +----------------------------------------------------------------------+
           !    HYDROLOGIC MAPPING, INTERPOLATION AND AREAL AVERAGING SYSTEM      !
           +----------------------------------------------------------------------+

S.001      INPUT TITLE
S.002              NIZAO BASIN - DOMINICAN REPUBLIC   RECORDING STATIONS WEIGHTS SEP.85

S.003      INPUT RANGE          1
S.004                           0     75.00      25.00      85.00      30.00

S.005      INPUT BOUNDARY
S.006                 1                   65.70     34.20
S.007                 2                   68.50     32.90
S.008                 3                   68.80     34.00
S.009                 4                   70.00     35.10
S.010                 5                   71.00     35.20
S.011                 6                   72.50     35.00
S.012                 7                   73.00     36.00
S.013                 8                   72.50     37.00
S.014                 9                   71.50     38.00
S.015                10                   70.80     39.00
S.016                11                   70.00     40.00
S.017                12                   69.30     41.80
S.018                13                   69.70     42.50
S.019                14                   69.50     43.30
S.020                15                   69.70     44.20
S.021                16                   69.00     44.30
S.022                17                   65.30     48.00
S.023                18                   65.00     49.80
S.024                19                   64.20     51.60
S.025                20                   65.00     52.00
S.026                21                   65.20     53.00
S.027                22                   65.00     54.00
S.028                23                   64.00     55.00
S.029                24                   63.30     56.00
S.030                25                   63.20     58.00
S.031                26                   63.90     59.00
S.032                27                   65.20     61.00
S.033                28                   62.50     63.00
S.034                29                   62.30     64.60
S.035                30                   60.80     65.80
S.036                31                   60.20     67.00
S.037                32                   60.00     69.80
S.038                33                   58.30     70.90
S.039                34                   55.20     71.60
S.040                35                   53.60     72.00
S.041                36                   53.00     73.90
S.042                37                   51.50     74.20
S.043                38                   51.30     75.00
S.044                39                   49.30     74.00
S.045                40                   48.20     74.50
S.046                41                   47.60     74.50
S.047                42                   46.60     73.50
S.048                43                   46.30     72.80
S.049                44                   45.00     72.90
S.050                45                   43.70     73.80
S.051                46                   41.80     76.00
S.052                47                   40.00     78.80
S.053                48                   37.20     79.50
S.054                49                   35.50     82.10
S.055                50                   33.00     80.60
S.056                51                   29.00     82.20
S.057                52                   28.50     80.70
S.                   53                   27.50     80.40
```

```
S.059             54             27.70    77.70
S.060             55             26.60    75.70
S.061             56             27.20    74.80
S.062             57             29.00    74.40
S.063             58             31.00    72.70
S.064             59             31.20    71.00
S.065             60             30.90    69.80
S.066             61             31.80    68.70
S.067             62             32.20    67.50
S.068             63             33.00    66.80
S.069             64             33.80    67.10
S.070             65             35.20    67.40
S.071             66             37.10    65.70
S.072             67             39.30    64.10
S.073             68             40.40    60.20
S.074             69             43.10    59.70
S.075             70             43.20    58.60
S.076             71             43.80    58.50
S.077             72             44.80    56.00
S.078             73             44.30    54.70
S.079             74             45.40    54.00
S.080             75             45.80    53.00
S.081             76             47.30    52.80
S.082             77             47.70    51.20
S.083             78             47.00    50.20
S.084             79             46.80    49.00
S.085             80             47.70    45.80
S.086             81             49.70    44.60
S.087             82             49.80    43.80
S.088             83             51.20    42.60
S.089             84             54.30    42.50
S.090             85             54.30    41.50
S.091             86             55.00    40.80
S.092             87             57.60    41.20
S.093             88             58.80    40.80
S.094             89             59.80    39.80
S.095             90             61.20    38.70
S.096             91             60.70    36.80
S.097             92             61.20    34.80
S.098             93             62.50    34.90
S.099             94             64.70    34.30
S.100           END

S.101     INPUT STATION
                VALDESIA         64.80    35.40
                JUMA BONAO       54.00    90.20
                VALLENUEVO       22.70    80.10
S.105           END

S.106     INPUT DATA
S.107           VALDESIA         30.00
S.108           JUMA BONAO       80.00
S.109           VALLENUEVO       10.00
S.110           END

S.111      PROC THIESSEN

S.112      STOP
             * STMT GENERATED
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DIAGNOSTIC CHECK OF COORDINATE SYSTEM :    NIZAO BASIN - DOMINICAN REPUBLIC    RECORDING STATIONS WEIGHTS SEP.85
                                SPHERICAL                      RECTANGULAR
CONTROL POINTS          DEG.MIN.SEC    DEG.MIN.SEC    X-COORDINATE  Y-COORDINATE  Z-ELEVATION   DIAGNOSTICS
                         LONGITUDE      LATITUDE

MINIMUM                                                  25.000        30.000
MAXIMUM                                                  75.000        85.000
STA    1   VALDESIA                                      64.800        35.400         .000     INSIDE OF RANGE
STA    2   JUMA BON                                      54.000        90.200         .000    *OUTSIDE OF RANGE*
STA    3   VALLENUE                                      22.700        80.100         .000    *OUTSIDE OF RANGE*
BOUNDARY POINT  1                                        65.700        34.200                  INSIDE OF RANGE
BOUNDARY POINT  2                                        68.500        32.900                  INSIDE OF RANGE
BOUNDARY POINT  3                                        68.800        34.000                  INSIDE OF RANGE
BOUNDARY POINT  4                                        70.000        35.100                  INSIDE OF RANGE
BOUNDARY POINT  5                                        71.000        35.200                  INSIDE OF RANGE
BOUNDARY POINT  6                                        72.500        35.000                  INSIDE OF RANGE
BOUNDARY POINT  7                                        73.000        36.000                  INSIDE OF RANGE
BOUNDARY POINT  8                                        72.500        37.000                  INSIDE OF RANGE
BOUNDARY POINT  9                                        71.500        38.000                  INSIDE OF RANGE
BOUNDARY POINT 10                                        70.800        39.000                  INSIDE OF RANGE
BOUNDARY POINT 11                                        70.000        40.000                  INSIDE OF RANGE
BOUNDARY POINT 12                                        69.300        41.800                  INSIDE OF RANGE
BOUNDARY POINT 13                                        69.700        42.500                  INSIDE OF RANGE
BOUNDARY POINT 14                                        69.500        43.300                  INSIDE OF RANGE
BOUNDARY POINT 15                                        69.700        44.200                  INSIDE OF RANGE
BOUNDARY POINT 16                                        69.000        44.300                  INSIDE OF RANGE
BOUNDARY POINT 17                                        65.300        48.000                  INSIDE OF RANGE
BOUNDARY POINT 18                                        65.000        49.800                  INSIDE OF RANGE
BOUNDARY POINT 19                                        64.200        51.600                  INSIDE OF RANGE
BOUNDARY POINT 20                                        65.000        52.000                  INSIDE OF RANGE
BOUNDARY POINT 21                                        65.200        53.000                  INSIDE OF RANGE
BOUNDARY POINT 22                                        65.000        54.000                  INSIDE OF RANGE
BOUNDARY POINT 23                                        64.000        55.000                  INSIDE OF RANGE
BOUNDARY POINT 24                                        63.300        56.000                  INSIDE OF RANGE
```

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BOUNDARY POINT 25          63.200     58.000          INSIDE OF RANGE
BOUNDARY POINT 26          63.900     59.000          INSIDE OF RANGE
BOUNDARY POINT 27          65.200     61.000          INSIDE OF RANGE
BOUNDARY POINT 28          62.500     63.000          INSIDE OF RANGE
BOUNDARY POINT 29          62.300     64.600          INSIDE OF RANGE
BOUNDARY POINT 30          60.800     65.800          INSIDE OF RANGE
BOUNDARY POINT 31          60.200     67.000          INSIDE OF RANGE
BOUNDARY POINT 32          60.000     69.800          INSIDE OF RANGE
BOUNDARY POINT 33          58.300     70.900          INSIDE OF RANGE
BOUNDARY POINT 34          55.200     71.600          INSIDE OF RANGE
BOUNDARY POINT 35          53.600     72.000          INSIDE OF RANGE
BOUNDARY POINT 36          53.000     73.900          INSIDE OF RANGE
BOUNDARY POINT 37          51.500     74.200          INSIDE OF RANGE
BOUNDARY POINT 38          51.300     75.000          INSIDE OF RANGE
BOUNDARY POINT 39          49.300     74.000          INSIDE OF RANGE
BOUNDARY POINT 40          48.200     74.500          INSIDE OF RANGE
BOUNDARY POINT 41          47.600     74.500          INSIDE OF RANGE
BOUNDARY POINT 42          46.600     73.500          INSIDE OF RANGE
BOUNDARY POINT 43          46.300     72.800          INSIDE OF RANGE
BOUNDARY POINT 44          45.000     72.900          INSIDE OF RANGE
BOUNDARY POINT 45          43.700     73.800          INSIDE OF RANGE
BOUNDARY POINT 46          41.800     76.000          INSIDE OF RANGE
BOUNDARY POINT 47          40.000     78.800          INSIDE OF RANGE
BOUNDARY POINT 48          37.200     79.500          INSIDE OF RANGE
BOUNDARY POINT 49          35.500     82.100          INSIDE OF RANGE
BOUNDARY POINT 50          33.000     80.600          INSIDE OF RANGE
BOUNDARY POINT 51          29.000     82.200          INSIDE OF RANGE
BOUNDARY POINT 52          28.500     80.700          INSIDE OF RANGE
BOUNDARY POINT 53          27.500     80.400          INSIDE OF RANGE
BOUNDARY POINT 54          27.700     77.700          INSIDE OF RANGE
BOUNDARY POINT 55          26.600     75.700          INSIDE OF RANGE
BOUNDARY POINT 56          27.200     74.800          INSIDE OF RANGE
```

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BOUNDARY POINT 57                 29.000      74.400          INSIDE OF RANGE
BOUNDARY POINT 58                 31.000      72.700          INSIDE OF RANGE
BOUNDARY POINT 59                 31.200      71.000          INSIDE OF RANGE
BOUNDARY POINT 60                 30.900      69.800          INSIDE OF RANGE
BOUNDARY POINT 61                 31.800      68.700          INSIDE OF RANGE
BOUNDARY POINT 62                 32.200      67.500          INSIDE OF RANGE
BOUNDARY POINT 63                 33.000      66.800          INSIDE OF RANGE
BOUNDARY POINT 64                 33.800      67.100          INSIDE OF RANGE
BOUNDARY POINT 65                 35.200      67.400          INSIDE OF RANGE
BOUNDARY POINT 66                 37.100      65.700          INSIDE OF RANGE
BOUNDARY POINT 67                 39.300      64.100          INSIDE OF RANGE
BOUNDARY POINT 68                 40.400      60.200          INSIDE OF RANGE
BOUNDARY POINT 69                 43.100      59.700          INSIDE OF RANGE
BOUNDARY POINT 70                 43.200      58.600          INSIDE OF RANGE
BOUNDARY POINT 71                 43.800      58.500          INSIDE OF RANGE
BOUNDARY POINT 72                 44.800      56.000          INSIDE OF RANGE
BOUNDARY POINT 73                 44.300      54.700          INSIDE OF RANGE
BOUNDARY POINT 74                 45.400      54.000          INSIDE OF RANGE
BOUNDARY POINT 75                 45.800      53.000          INSIDE OF RANGE
BOUNDARY POINT 76                 47.300      52.800          INSIDE OF RANGE
BOUNDARY POINT 77                 47.700      51.200          INSIDE OF RANGE
BOUNDARY POINT 78                 47.000      50.200          INSIDE OF RANGE
BOUNDARY POINT 79                 46.800      49.000          INSIDE OF RANGE
BOUNDARY POINT 80                 47.700      45.800          INSIDE OF RANGE
BOUNDARY POINT 81                 49.700      44.600          INSIDE OF RANGE
BOUNDARY POINT 82                 49.800      43.800          INSIDE OF RANGE
BOUNDARY POINT 83                 51.200      42.600          INSIDE OF RANGE
BOUNDARY POINT 84                 54.300      42.500          INSIDE OF RANGE
BOUNDARY POINT 85                 54.300      41.500          INSIDE OF RANGE
BOUNDARY POINT 86                 55.000      40.800          INSIDE OF RANGE
BOUNDARY POINT 87                 57.600      41.200          INSIDE OF RANGE
BOUNDARY POINT 88                 58.800      40.800          INSIDE OF RANGE
```

```
                                                                                    INSIDE OF RANGE
BOUNDARY POINT 89                                 59.800          39.800
                                                                                    INSIDE OF RANGE
BOUNDARY POINT 90                                 61.200          38.700
                                                                                    INSIDE OF RANGE
BOUNDARY POINT 91                                 60.700          36.800
                                                                                    INSIDE OF RANGE
BOUNDARY POINT 92                                 61.200          34.800
                                                                                    INSIDE OF RANGE
BOUNDARY POINT 93                                 62.500          34.900
                                                                                    INSIDE OF RANGE
BOUNDARY POINT 94                                 64.700          34.300
                                                                                    INSIDE OF RANGE
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BOUNDARY POINT 57          29.000     74.400          INSIDE OF RANGE
BOUNDARY POINT 58          31.000     72.700          INSIDE OF RANGE
BOUNDARY POINT 59          31.200     71.000          INSIDE OF RANGE
BOUNDARY POINT 60          30.900     69.800          INSIDE OF RANGE
BOUNDARY POINT 61          31.800     68.700          INSIDE OF RANGE
BOUNDARY POINT 62          32.200     67.500          INSIDE OF RANGE
BOUNDARY POINT 63          33.000     66.800          INSIDE OF RANGE
BOUNDARY POINT 64          33.800     67.100          INSIDE OF RANGE
BOUNDARY POINT 65          35.200     67.400          INSIDE OF RANGE
BOUNDARY POINT 66          37.100     65.700          INSIDE OF RANGE
BOUNDARY POINT 67          39.300     64.100          INSIDE OF RANGE
BOUNDARY POINT 68          40.400     60.200          INSIDE OF RANGE
BOUNDARY POINT 69          43.100     59.700          INSIDE OF RANGE
BOUNDARY POINT 70          43.200     58.600          INSIDE OF RANGE
BOUNDARY POINT 71          43.800     58.500          INSIDE OF RANGE
BOUNDARY POINT 72          44.800     56.000          INSIDE OF RANGE
BOUNDARY POINT 73          44.300     54.700          INSIDE OF RANGE
BOUNDARY POINT 74          45.400     54.000          INSIDE OF RANGE
BOUNDARY POINT 75          45.800     53.000          INSIDE OF RANGE
BOUNDARY POINT 76          47.300     52.800          INSIDE OF RANGE
BOUNDARY POINT 77          47.700     51.200          INSIDE OF RANGE
BOUNDARY POINT 78          47.000     50.200          INSIDE OF RANGE
BOUNDARY POINT 79          46.800     49.000          INSIDE OF RANGE
BOUNDARY POINT 80          47.700     45.800          INSIDE OF RANGE
BOUNDARY POINT 81          49.700     44.600          INSIDE OF RANGE
BOUNDARY POINT 82          49.800     43.800          INSIDE OF RANGE
BOUNDARY POINT 83          51.200     42.600          INSIDE OF RANGE
BOUNDARY POINT 84          54.300     42.500          INSIDE OF RANGE
BOUNDARY POINT 85          54.300     41.500          INSIDE OF RANGE
BOUNDARY POINT 86          55.000     40.800          INSIDE OF RANGE
BOUNDARY POINT 87          57.600     41.200          INSIDE OF RANGE
BOUNDARY POINT 88          58.800     40.800          INSIDE OF RANGE
```

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                                                                            INSIDE OF RANGE
BOUNDARY POINT 89                          59.800      39.800
                                                                            INSIDE OF RANGE
BOUNDARY POINT 90                          61.200      38.700
                                                                            INSIDE OF RANGE
BOUNDARY POINT 91                          60.700      36.800
                                                                            INSIDE OF RANGE
BOUNDARY POINT 92                          61.200      34.800
                                                                            INSIDE OF RANGE
BOUNDARY POINT 93                          62.500      34.900
                                                                            INSIDE OF RANGE
BOUNDARY POINT 94                          64.700      34.300
                                                                            INSIDE OF RANGE
```
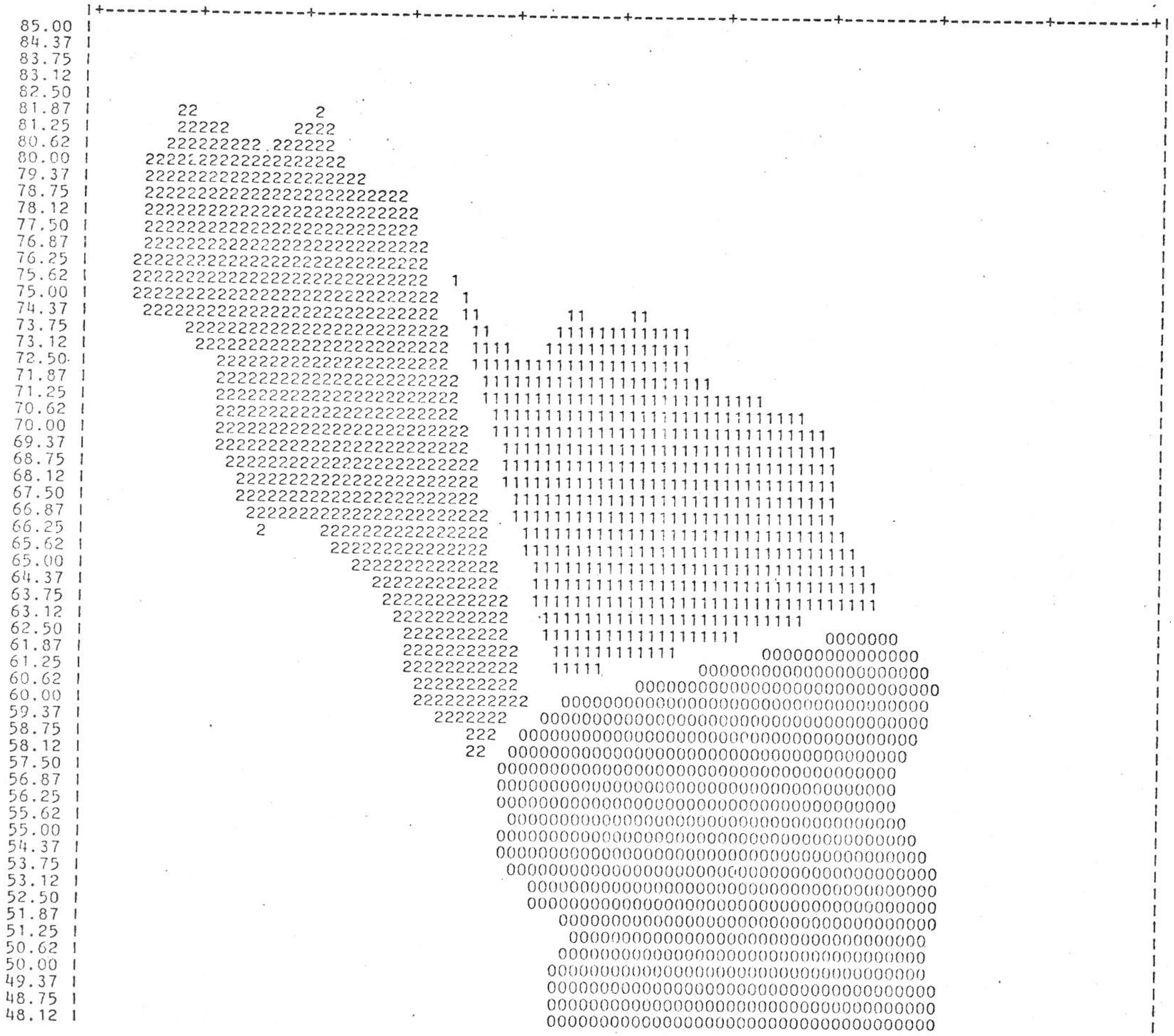
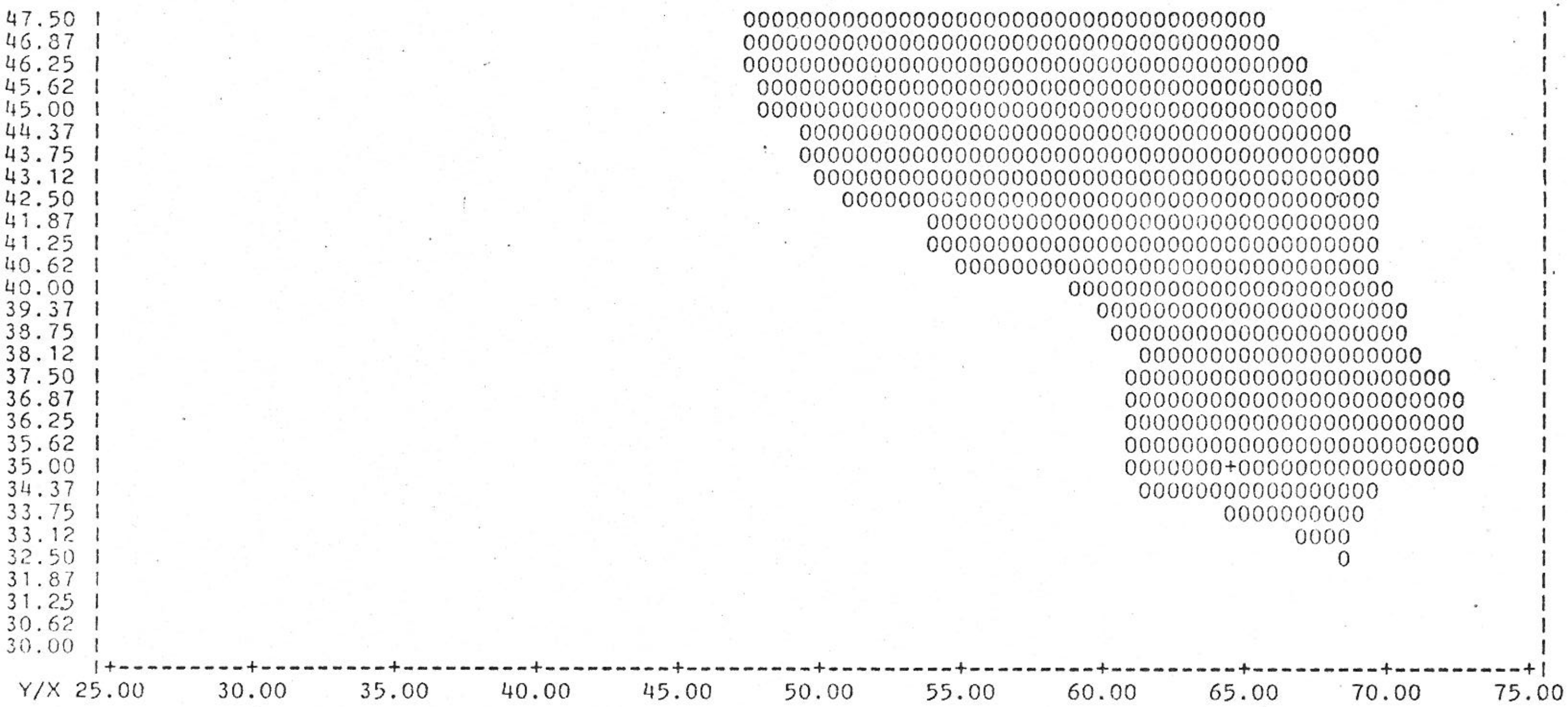
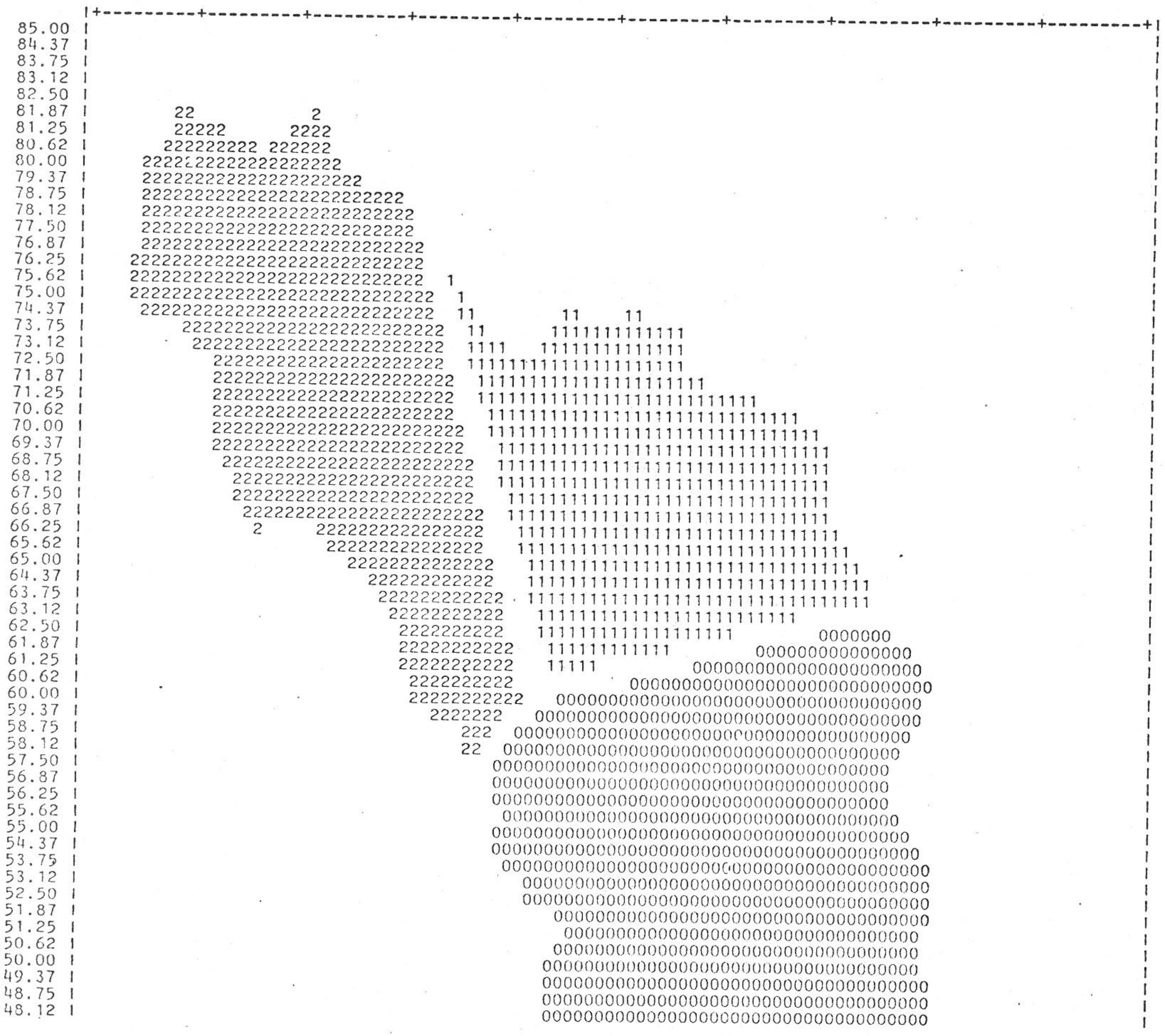

MAPPING BY THIESSEN POLYGON: NIZAO BASIN - DOMINICAN REPUBLIC RECORDING STATIONS WEIGHTS SEP.85

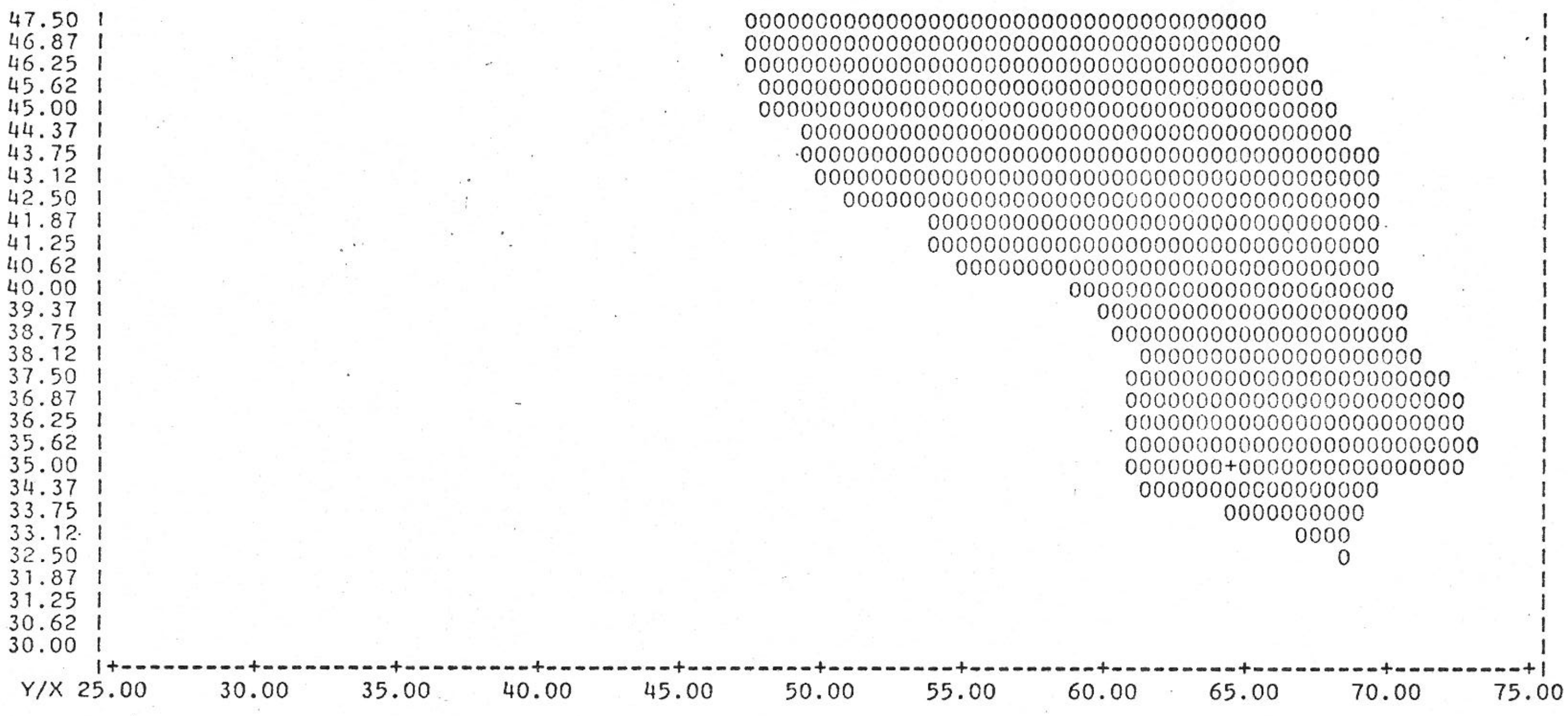




```
     STA.NO.      STA. NAME     SYMBOL   THIESSEN WEIGHT     POLYGON AREA      STA. DATA

        1          VALDESIA        0          .53128            480.31           30.000
        2          JUMA BON        1          .20913            189.06           80.000
        3          VALLENUE        2          .25959            234.69           10.000

                         AREAL AVERAGE OF DATA =          35.2644

      THIESSEN METHOD OPTION CODE =  1

         1  MIN STRAIGHT DISTANCE
         2  MIN SQUARE DISTANCE
         3  MIN ORTHOGONAL DISTANCE
         4  MIN MAX LEG DISTANCE
         5  MIN ABS (DATA) X STRAIGHT DISTANCE
         6  MAX ABS (DEVIATE) X SPATIAL CORRELATION COEFF
```

MAPPING BY THIESSEN POLYGON: NIZAO BASIN - DOMINICAN REPUBLIC   RECORDING STATIONS WEIGHTS.SEP:85





```
     STA.NO.      STA. NAME      SYMBOL   THIESSEN WEIGHT     POLYGON AREA       STA. DATA

        1          VALDESIA         0          .53128            480.31            30.000
        2          JUMA BON         1          .20913            189.06            80.000
        3          VALLENUE         2          .25959            234.69            10.000

                       AREAL AVERAGE OF DATA =          35.2644

     THIESSEN METHOD OPTION CODE =  1

        1  MIN STRAIGHT DISTANCE
        2  MIN SQUARE DISTANCE
        3  MIN ORTHOGONAL DISTANCE
        4  MIN MAX LEG DISTANCE
        5  MIN ABS (DATA) X STRAIGHT DISTANCE
        6  MAX ABS (DEVIATE) X SPATIAL CORRELATION COEFF
```

APPENDIX 1.7.B

RESULTS OF HEC-1 MODEL RUN USING HURRICANE DAVID DATA TO ASSESS EFFECTS OF UPSTREAM NATURAL STORAGES

```
****************************************                                                  ****************************************
*                                      *                                                  *                                      *
*  FLOOD HYDROGRAPH PACKAGE  (HEC-1)   *                                                  *   U.S. ARMY CORPS OF ENGINEERS       *
*           FEBRUARY 1981              *                                                  * THE HYDROLOGIC ENGINEERING CENTER    *
*         REVISED 31 JAN 85            *                                                  *        609 SECOND STREET             *
*                                      *                                                  *      DAVIS, CALIFORNIA 95616         *
* RUN DATE  02/27/86    TIME  22.24.50 *                                                  * (916) 440-3285 OR (FTS) 448-3285     *
*                                      *                                                  *                                      *
****************************************                                                  ****************************************




                                       X     X  XXXXXXX   XXXXX         X
                                       X     X  X        X     X       XX
                                       X     X  X        X              X
                                       XXXXXXX  XXXX     X       XXXXX  X
                                       X     X  X        X              X
                                       X     X  X        X     X        X
                                       X     X  XXXXXXX   XXXXX        XXX



          THIS PROGRAM REPLACES ALL PREVIOUS VERSIONS OF HEC-1 KNOWN AS HEC1 (JAN 73), HEC1GS, HEC1DB, AND HEC1KW.

          THE DEFINITIONS OF VARIABLES -RTIMP- AND -RTIOR- HAVE CHANGED FROM THOSE USED WITH THE 1973-STYLE INPUT STRUCTURE.
          THE DEFINITION OF -AMSKK- ON RM-CARD WAS CHANGED WITH REVISIONS DATED 28 SEP 81.  THE VERSION RELEASED 31JAN85
          CONTAINS NEW OPTIONS ON RL AND BA RECORDS, AND ADDS THE HL RECORD. SEE JANUARY 1985 INPUT
          DESCRIPTION FOR NEW DEFINITIONS.
```

```
                                  HEC-1 INPUT
 LINE      ID.......1.......2.......3.......4.......5.......6.......7.......8.......9......10

   1       ID        NIZAO BASIN - DOMINICAN REPUBLIC
   2       ID        KINEMATIC WAVE MODEL  HURRICANE DAVID  W/STORAGE
           *DIAGRAM
   3       IT      60 30AUG79    0900       0  3SEP79    0800
   4       IO       1       2
   5       IM
   6       PG      10  300.10
   7       PG      20  300.00
   8       PG      30  251.30
   9       PG      40  450.10
  10       PG      50  611.90
  11       PG      60  359.50
  12       PG       3
  13       PI     .00     .00     .00     .30    1.70    1.00     .30     .30     .30    1.00
  14       PI    1.00     .00     .00     .00     .00     .00     .00     .00    1.00    1.00
  15       PI    1.00   12.00    3.00    5.00    6.00    6.00   16.00   20.00   14.00   16.00
  16       PI   20.00   18.00   24.00   38.00   44.00   16.00     .00     .00     .00     .00
  17       PI     .00     .00     .00     .00     .00     .00     .00     .00     .00     .00
  18       PI     .00     .00     .00     .00     .00     .00     .00     .00     .00     .00
  19       PI     .00     .00     .00     .00     .00     .00     .00     .00     .00     .00
  20       PI     .00     .00     .00     .00     .00     .00     .00     .00     .00     .00
  21       PI     .00     .00     .00     .00     .00     .00     .00     .00     .00     .00
  22       PI     .00     .00     .00     .00     .00     .00     .00     .00     .00     .00
  23       PG       4
  24       PI     .00     .00     .00     .00     .10     .10     .10    4.20    4.40    2.00
  25       PI    1.20    1.30     .80    5.40    1.60     .30    1.90    1.90    3.00    6.50
  26       PI    8.50   11.60   10.20   12.40   10.70   13.40   25.00   25.00   25.00   34.40
  27       PI   31.20   38.60   52.10   60.50   42.70   23.40   19.30   23.90   11.50    9.40
  28       PI   15.60   30.60   16.60    5.00    2.60     .50    1.50     .90    1.30    1.30
  29       PI    4.40    2.70    2.00     .50     .70    1.90     .40     .10     .00     .00
  30       PI     .00     .00     .00     .00     .00     .00     .00     .00     .00     .00
  31       PI     .00     .00     .00     .00     .00     .00     .00     .00     .00     .00
  32       PI     .00     .00     .00     .00     .00     .00     .00     .00     .00     .00
  33       PI     .00     .00     .00     .00     .00     .00     .00     .00     .00     .00
  34       PG       7
  35       PI     .00     .00     .00     .00     .00     .00     .00     .00     .00     .00
  36       PI     .00     .00     .00     .00     .00     .00     .00    4.00    1.00    1.00
  37       PI    8.00    3.00    3.50    3.50    5.00    5.00   10.00    9.00   13.00   12.00
  38       PI   12.00   12.00   16.00   12.00   64.00   56.00   10.00   10.00    8.00   12.00
  39       PI   10.00     .00     .00     .00     .00     .00     .00     .00     .00     .00
  40       PI     .00     .00     .00     .00     .00     .00     .00     .00     .00     .00
  41       PI     .00     .00     .00     .00     .00     .00     .00     .00     .00     .00
  42       PI     .00     .00     .00     .00     .00     .00     .00     .00     .00     .00
  43       PI     .00     .00     .00     .00     .00     .00     .00     .00     .00     .00
  44       PI     .00     .00     .00     .00     .00     .00     .00     .00     .00     .00
  45       PG       9
  46       PI     .00     .00     .00     .00     .00     .00     .00     .00     .00     .00
  47       PI     .00     .00     .00     .00     .00     .00     .00     .00     .00     .00
  48       PI     .00     .00     .00     .50    5.50    6.00    4.00    6.00   16.90   11.10
  49       PI   14.00   16.00   20.00   20.00   16.00   84.00   14.00   14.00    5.50    5.50
  50       PI    1.70    1.70    1.70    8.00    2.90    1.10   10.20     .80    1.00    1.20
  51       PI    1.20    1.20    1.20    1.20    1.00    1.00    1.00    1.50    1.50     .00
  52       PI     .00     .00     .00     .00     .00     .00     .00     .00     .00     .00
  53       PI     .00     .00     .00     .00     .00     .00     .00     .00     .00     .00
  54       PI     .00     .00     .00     .00     .00     .00     .00     .00     .00     .00
```

```
                                                     HEC-1 INPUT                                            PAGE 2

LINE        ID.......1.......2.......3.......4.......5.......6.......7.......8.......9......10

  55        PI     .00     .00     .00     .00     .00     .00

  56        KK   SUB1A
  57        KM        RUNOFF FROM SUBBASIN 1A
  58        PR       4
  59        PW     1.0
  60        PT      50
  61        PW    1.00
  62        BA      70
  63        LS              80
  64        UK    2500    0.60   0.400     100
  65        RK   16000  0.1050   0.040            TRAP      45      10

  66        KK   SUB1B
  67        KM        RUNOFF FROM SUBBASIN 1B
  68        PR       3       4
  69        PW    0.30    0.70
  70        PT      40      50
  71        PW    0.30    0.70
  72        BA      70
  73        LS              80
  74        UK    2500    0.60   0.400     100
  75        RK   19000  0.0837   0.040            TRAP      45      10

  76        KK   SUB1C
  77        KM        COMBINE RUNOFF FROM SUB1A AND SUB1B
  78        HC       2

  79        KK   SUB1C
  80        KM        RUNOFF FROM SUBBASIN 1C
  81        PR       3       4       7
  82        PW    0.40    0.40    0.20
  83        PT      20      40      50
  84        PW    0.20    0.40    0.40
  85        BA      45
  86        LS              80
  87        UK    4500    0.50   0.300     100
  88        RK    7500  0.0133   0.026            TRAP      85      10     YES

  89        KK   SUB2A
  90        KM        RUNOFF FROM SUBBASIN 2A
  91        PR       3       7
  92        PW    0.80    0.20
  93        PT      20      40
  94        PW     0.2     0.8
  95        BA      24
  96        LS              80
  97        UK    2000    0.40   0.300     100
  98        RK    6500  0.0108   0.022            TRAP      85      10     YES
```

```
                                              HEC-1 INPUT                                             PAGE 3
  LINE           ID.......1.......2.......3.......4.......5.......6.......7.......8.......9......10

    99           KK   SUB2B
   100           KM        RUNOFF FROM SUBBASIN 2B
   101           PR       3       7
   102           PW    0.65    0.35
   103           PT      20      30      40
   104           PW    0.35    0.10    0.55
   105           BA      56
   106           LS              80
   107           UK    3500    0.20   0.300     100
   108           RK   11500  0.0452   0.030            TRAP      45      10

   109           KK   SUB2C
   110           KM        COMBINE RUNOFF FROM SUB2A AND SUB2B
   111           HC       2

   112           KK   RESER
   113           KM        ROUTE FLOW THROUGH RESERVOIR
   114           RS     1.0     0.0     0.0     0.0
   115           SV     0.0     3.5    27.8    93.8   222.2   434.0   750.0  1191.0  1777.8  2531.3
   116           SV  3472.2  4621.5  6000.0
   117           SE    0.00    0.50    1.00    1.50    2.00    2.50    3.00    3.50    4.00    4.50
   118           SE    5.00    5.50    6.00
   119           SQ    0.00    49.4   156.0   305.0   490.0   707.0   953.0   1227.   1525.   1847.
   120           SQ   2192.   2557.   2943.

   121           KK   SUB2C
   122           KM        RUNOFF FROM SUBBASIN 2C
   123           PR       7
   124           PW    1.00
   125           PT      20
   126           PW    1.00
   127           BA     164
   128           LS              80
   129           UK    4500    0.40   0.300     100
   130           RK   21000  0.0086   0.022            TRAP      70      10     YES

   131           KK    SUB3
   132           KM        RUNOFF FROM SUBBASIN 3
   133           PR       3       7
   134           PW    0.05    0.95
   135           PT      20      30      60
   136           PW    0.75    0.05    0.20
   137           BA     106
   138           LS              80
   139           UK    2000    0.40   0.300     100
   140           RK   21500  0.0293   0.030            TRAP      45      10

   141           KK    SUB4
   142           KM        COMBINE RUNOFF FROM SUB2C AND SUB3
   143           HC       2
```

```
                                             HEC-1 INPUT                                            PAGE 4

LINE           ID......1.......2.......3.......4.......5.......6.......7.......8.......9......10

 144           KK   SUB4
 145           KM       RUNOFF FROM SUBBASIN 4
 146           PR      7       9
 147           PW   0.90    0.10
 148           PT     10      20
 149           PW   0.10    0.90
 150           BA    103
 151           LS             80
 152           UK   5000    0.50   0.300     100
 153           RK  11500  0.0148   0.030            TRAP      80      10     YES

 154           KK   SUB5
 155           KM       RUNOFF FROM SUBBASIN 5
 156           PR      7       9
 157           PW   0.90    0.10
 158           PT     10      20      60
 159           PW    0.1    0.80    0.10
 160           BA    109
 161           LS             80
 162           UK   3000    0.40   0.300     100
 163           RK  31000  0.0323   0.040            TRAP      45      10

 164           KK   SUB6
 165           KM       COMBINE RUNOFF FROM SUB4 AND SUB5
 166           HC      2

 167           KK   SUB6
 168           KM       RUNOFF FROM SUBBASIN 6
 169           PR      9
 170           PW     1.
 171           PT     10
 172           PW     1.
 173           BA     53
 174           LS             80
 175           UK   5000    0.40   0.300     100
 176           RK  13500  0.0119   0.030            TRAP      80      10     YES
 177           ZZ
```

```
                   SCHEMATIC DIAGRAM OF STREAM NETWORK
INPUT
LINE       (V) ROUTING              (--->) DIVERSION OR PUMP FLOW

 NO.       (.) CONNECTOR            (<---) RETURN OF DIVERTED OR PUMPED FLOW

  56        SUB1A
              .
              .
  66          .        SUB1B
              .          .
              .          .
  76        SUB1C.........
              V
              V
  79        SUB1C ***
              V
              V
  89        SUB2A ***
              .
              .
  99          .        SUB2B
              .          .
              .          .
 109        SUB2C.........
              V
              V
 112        RESER
              V
              V
 121        SUB2C ***
              .
              .
 131          .        SUB3
              .          .
              .          .
 141        SUB4..........
              V
              V
 144        SUB4 ***
              .
              .
 154          .        SUB5
              .          .
              .          .
 164        SUB6..........
              V
              V
 167        SUB6 ***

(***) RUNOFF ALSO COMPUTED AT THIS LOCATION
```

```
**************************************                                                         **************************************
*                                    *                                                         *                                    *
*  FLOOD HYDROGRAPH PACKAGE  (HEC-1) *                                                         *     U.S. ARMY CORPS OF ENGINEERS   *
*            FEBRUARY 1981           *                                                         * THE HYDROLOGIC ENGINEERING CENTER  *
*         REVISED 31 JAN 85          *                                                         *         609 SECOND STREET          *
*                                    *                                                         *      DAVIS, CALIFORNIA 95616       *
* RUN DATE  02/27/86    TIME  22.24.50 *                                                       * (916) 440-3285 OR (FTS) 448-3285   *
*                                    *                                                         *                                    *
**************************************                                                         **************************************




                                  NIZAO BASIN - DOMINICAN REPUBLIC
                                  KINEMATIC WAVE MODEL  HURRICANE DAVID  W/STORAGE

   4 IO          OUTPUT CONTROL VARIABLES
                       IPRNT          1  PRINT CONTROL
                       IPLOT          2  PLOT CONTROL
                       QSCAL         0.  HYDROGRAPH PLOT SCALE

     IT          HYDROGRAPH TIME DATA
                        NMIN         60  MINUTES IN COMPUTATION INTERVAL
                       IDATE    30AUG79  STARTING DATE
                       ITIME       0900  STARTING TIME
                          NQ         96  NUMBER OF HYDROGRAPH ORDINATES
                      NDDATE     3SEP79  ENDING DATE
                      NDTIME       0800  ENDING TIME

                   COMPUTATION INTERVAL   1.00 HOURS
                        TOTAL TIME BASE  95.00 HOURS

             METRIC UNITS
                  DRAINAGE AREA          SQUARE KILOMETERS
                  PRECIPITATION DEPTH    MILLIMETERS
                  LENGTH, ELEVATION      METERS
                  FLOW                   CUBIC METERS PER SECOND
                  STORAGE VOLUME         CUBIC METERS
                  SURFACE AREA           SQUARE METERS
                  TEMPERATURE            DEGREES CELSIUS

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


               *************
               *           *
  56 KK        *   SUB1A   *
               *           *
               *************
                                  RUNOFF FROM SUBBASIN 1A

                  SUBBASIN RUNOFF DATA

  62 BA            SUBBASIN CHARACTERISTICS
                        TAREA       70.00  SUBBASIN AREA

                   PRECIPITATION DATA

  60 PT             TOTAL STORM STATIONS        50
  61 PW                          WEIGHTS      1.00
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58 PR            RECORDING STATIONS        4
59 PW                       WEIGHTS     1.00

63 LS          SCS LOSS RATE
                     STRTL       12.70  INITIAL ABSTRACTION
                    CRVNBR       80.00  CURVE NUMBER
                     RTIMP         .00  PERCENT IMPERVIOUS AREA

               KINEMATIC WAVE
64 UK            OVERLAND-FLOW ELEMENT NO. 1
                         L       2500.  OVERLAND FLOW LENGTH
                         S       .6000  SLOPE
                         N        .400  ROUGHNESS COEFFICIENT
                        PA       100.0  PERCENT OF SUBBASIN
65 RK            MAIN CHANNEL
                         L      16000.  CHANNEL LENGTH
                         S       .1050  SLOPE
                         N        .040  CHANNEL ROUGHNESS COEFFICIENT
                        CA       70.00  CONTRIBUTING AREA
                     SHAPE        TRAP  CHANNEL SHAPE
                        WD       45.00  BOTTOM WIDTH OR DIAMETER
                         Z       10.00  SIDE SLOPE
                    RUPSTQ          NO  ROUTE UPSTREAM HYDROGRAPH

                                                       ***

            PRECIPITATION STATION DATA

                  STATION    TOTAL    AVG. ANNUAL    WEIGHT
                       50   611.90           .00      1.00

              TEMPORAL DISTRIBUTIONS

              STATION       4, WEIGHT =    1.00
                   .00       .00       .00       .00       .10       .10       .10      4.20      4.40      2.00
                  1.20      1.30       .80      5.40      1.60       .30      1.90      1.90      3.00      6.50
                  8.50     11.60     10.20     12.40     10.70     13.40     25.00     25.00     25.00     34.40
                 31.20     38.60     52.10     60.50     42.70     23.40     19.30     23.90     11.50      9.40
                 15.60     30.60     16.60      5.00      2.60       .50      1.50       .90      1.30      1.30
                  4.40      2.70      2.00       .50       .70      1.90       .40       .10       .00

         COMPUTED KINEMATIC PARAMETERS
            ELEMENT     ALPHA         M       DT (MIN)    DX (FT)
                  1    2.8854     1.667        60.00     4101.05
                  3     .6898     1.549        60.00    26246.72

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

                                         HYDROGRAPH AT STATION     SUB1A

******************************************************************************************************************************
                                                       *
     DA MON HRMN  ORD     RAIN    LOSS  EXCESS    COMP Q    *      DA MON HRMN  ORD     RAIN    LOSS  EXCESS    COMP Q
                                                       *
     30 AUG 0900    1      .00     .00     .00        0.    *       1 SEP 0900   49      .90     .01     .89       52.
     30 AUG 1000    2      .00     .00     .00        0.    *       1 SEP 1000   50     1.30     .01    1.29       40.
     30 AUG 1100    3      .00     .00     .00        0.    *       1 SEP 1100   51     1.30     .01    1.29       34.
     30 AUG 1200    4      .00     .00     .00        0.    *       1 SEP 1200   52     4.40     .04    4.36       30.
     30 AUG 1300    5      .00     .00     .00        0.    *       1 SEP 1300   53     2.70     .03    2.67       38.
     30 AUG 1400    6      .10     .10     .00        0.    *       1 SEP 1400   54     2.00     .02    1.98       45.
     30 AUG 1500    7      .10     .10     .00        0.    *       1 SEP 1500   55      .50     .00     .50       45.
     30 AUG 1600    8      .10     .10     .00        0.    *       1 SEP 1600   56      .70     .01     .69       38.
     30 AUG 1700    9     4.20    4.20     .00        0.    *       1 SEP 1700   57     1.90     .02    1.88       31.
     30 AUG 1800   10     4.40    4.40     .00        0.    *       1 SEP 1800   58      .40     .00     .40       29.
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30 AUG 1900   11     2.00     2.00      .00         0.       *      1 SEP 1900   59     .10     .00     .10       26.
30 AUG 2000   12     1.20     1.20      .00         0.       *      1 SEP 2000   60     .00     .00     .00       21.
30 AUG 2100   13     1.30     1.29      .01         0.       *      1 SEP 2100   61     .00     .00     .00       16.
30 AUG 2200   14      .80      .77      .03         0.       *      1 SEP 2200   62     .00     .00     .00       13.
30 AUG 2300   15     5.40     4.76      .64         0.       *      1 SEP 2300   63     .00     .00     .00       10.
31 AUG 0000   16     1.60     1.27      .33         0.       *      2 SEP 0000   64     .00     .00     .00        9.
31 AUG 0100   17      .30      .23      .07         0.       *      2 SEP 0100   65     .00     .00     .00        7.
31 AUG 0200   18     1.90     1.43      .47         0.       *      2 SEP 0200   66     .00     .00     .00        6.
31 AUG 0300   19     1.90     1.36      .54         0.       *      2 SEP 0300   67     .00     .00     .00        5.
31 AUG 0400   20     3.00     2.01      .99         1.       *      2 SEP 0400   68     .00     .00     .00        4.
31 AUG 0500   21     6.50     3.87     2.63         2.       *      2 SEP 0500   69     .00     .00     .00        4.
31 AUG 0600   22     8.50     4.25     4.24         5.       *      2 SEP 0600   70     .00     .00     .00        3.
31 AUG 0700   23    11.59     4.70     6.89        18.       *      2 SEP 0700   71     .00     .00     .00        3.
31 AUG 0800   24    10.20     3.36     6.84        46.       *      2 SEP 0800   72     .00     .00     .00        3.
31 AUG 0900   25    12.39     3.36     9.03        81.       *      2 SEP 0900   73     .00     .00     .00        2.
31 AUG 1000   26    10.69     2.42     8.28       121.       *      2 SEP 1000   74     .00     .00     .00        2.
31 AUG 1100   27    13.39     2.55    10.84       146.       *      2 SEP 1100   75     .00     .00     .00        2.
31 AUG 1200   28    24.99     3.73    21.26       173.       *      2 SEP 1200   76     .00     .00     .00        2.
31 AUG 1300   29    24.99     2.81    22.18       267.       *      2 SEP 1300   77     .00     .00     .00        2.
31 AUG 1400   30    24.99     2.19    22.80       404.       *      2 SEP 1400   78     .00     .00     .00        1.
31 AUG 1500   31    34.38     2.33    32.05       436.       *      2 SEP 1500   79     .00     .00     .00        1.
31 AUG 1600   32    31.18     1.64    29.54       529.       *      2 SEP 1600   80     .00     .00     .00        1.
31 AUG 1700   33    38.58     1.60    36.98       589.       *      2 SEP 1700   81     .00     .00     .00        1.
31 AUG 1800   34    52.07     1.65    50.42       652.       *      2 SEP 1800   82     .00     .00     .00        1.
31 AUG 1900   35    60.47     1.43    59.04       860.       *      2 SEP 1900   83     .00     .00     .00        1.
31 AUG 2000   36    42.68      .80    41.88      1071.       *      2 SEP 2000   84     .00     .00     .00        1.
31 AUG 2100   37    23.39      .38    23.01       947.       *      2 SEP 2100   85     .00     .00     .00        1.
31 AUG 2200   38    19.29      .29    19.00       637.       *      2 SEP 2200   86     .00     .00     .00        1.
31 AUG 2300   39    23.89      .33    23.56       432.       *      2 SEP 2300   87     .00     .00     .00        1.
 1 SEP 0000   40    11.49      .15    11.35       413.       *      3 SEP 0000   88     .00     .00     .00        1.
 1 SEP 0100   41     9.40      .12     9.28       359.       *      3 SEP 0100   89     .00     .00     .00        1.
 1 SEP 0200   42    15.59      .19    15.41       209.       *      3 SEP 0200   90     .00     .00     .00        1.
 1 SEP 0300   43    30.59      .34    30.25       232.       *      3 SEP 0300   91     .00     .00     .00        1.
 1 SEP 0400   44    16.59      .17    16.42       402.       *      3 SEP 0400   92     .00     .00     .00        1.
 1 SEP 0500   45     5.00      .05     4.95       447.       *      3 SEP 0500   93     .00     .00     .00        0.
 1 SEP 0600   46     2.60      .03     2.57       210.       *      3 SEP 0600   94     .00     .00     .00        0.
 1 SEP 0700   47      .50      .00      .49       116.       *      3 SEP 0700   95     .00     .00     .00        0.
 1 SEP 0800   48     1.50      .01     1.48        72.       *      3 SEP 0800   96     .00     .00     .00        0.
                                                             *
*****************************************************************************************************************************

  TOTAL RAINFALL =  611.90, TOTAL LOSS =    70.12, TOTAL EXCESS =  541.78

PEAK FLOW       TIME                          MAXIMUM AVERAGE FLOW
                                     6-HR        24-HR       72-HR      95.00-HR
(CU M/S)        (HR)
                         (CU M/S)
  1071.        35.00                 784.        408.         145.        110.
                              (MM) 241.823     503.625     535.463     535.601
                       (1000 CU M)  16928.      35254.      37482.      37492.

                         CUMULATIVE AREA =    70.00 SQ KM
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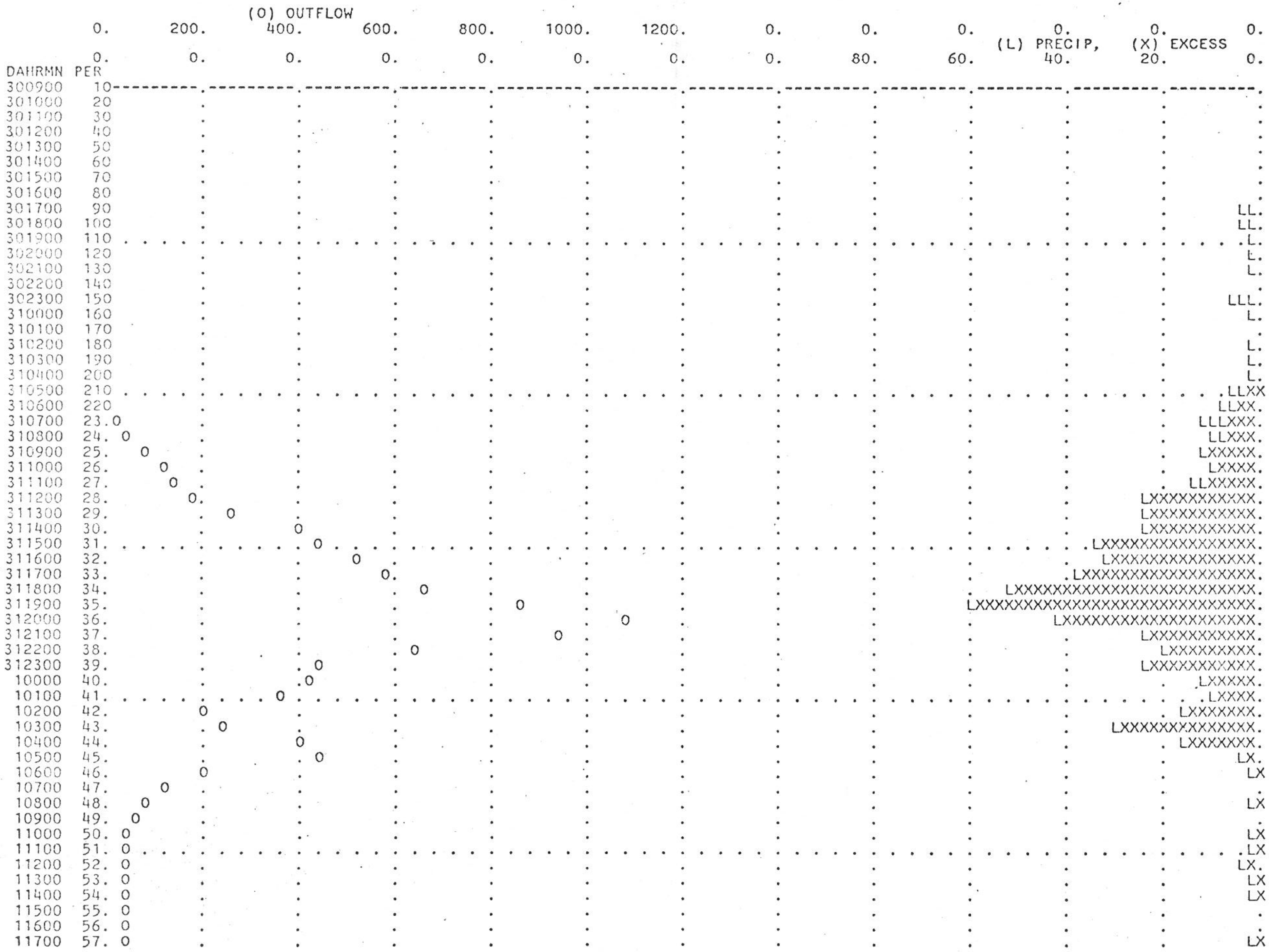
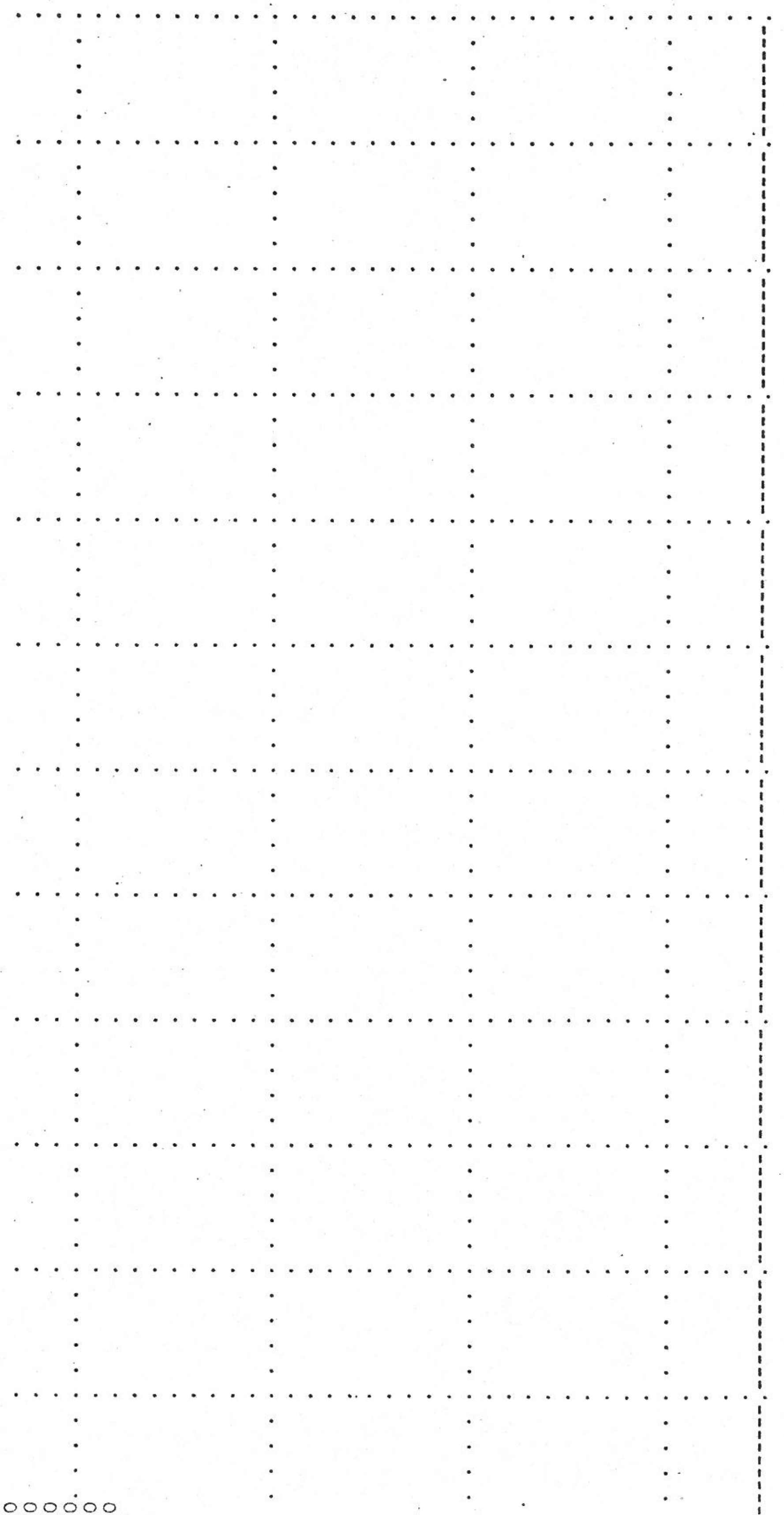
STATION SUB1A

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11900 59.0
12000 60.0
12100 61.0
12200 62.0
12300 63.0
20000 640
20100 650
20200 660
20300 670
20400 680
20500 690
20600 700
20700 710
20800 720
20900 730
21000 740
21100 750
21200 760
21300 770
21400 780
21500 790
21600 800
21700 810
21800 820
21900 830
22000 840
22100 850
22200 860
22300 870
30000 880
30100 890
30200 900
30300 910
30400 920
30500 930
30600 940
30700 950
30800 960

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

             **************
             *            *
  66 KK      *    SUB1B   *
             *            *
             **************
                            RUNOFF FROM SUBBASIN 1B

               SUBBASIN RUNOFF DATA

  72 BA          SUBBASIN CHARACTERISTICS
                      TAREA      70.00  SUBBASIN AREA

                 PRECIPITATION DATA

  70 PT           TOTAL STORM STATIONS        40        50
  71 PW                        WEIGHTS       .30       .70

  68 PR             RECORDING STATIONS         3         4
  69 PW                        WEIGHTS       .30       .70

  73 LS          SCS LOSS RATE
                      STRTL      12.70  INITIAL ABSTRACTION
                     CRVNBR      80.00  CURVE NUMBER
                      RTIMP        .00  PERCENT IMPERVIOUS AREA

                 KINEMATIC WAVE
  74 UK            OVERLAND-FLOW ELEMENT NO. 1
                          L      2500.  OVERLAND FLOW LENGTH
                          S      .6000  SLOPE
                          N       .400  ROUGHNESS COEFFICIENT
                         PA      100.0  PERCENT OF SUBBASIN
  75 RK            MAIN CHANNEL
                          L     19000.  CHANNEL LENGTH
                          S      .0837  SLOPE
                          N       .040  CHANNEL ROUGHNESS COEFFICIENT
                         CA      70.00  CONTRIBUTING AREA
                      SHAPE       TRAP  CHANNEL SHAPE
                         WD      45.00  BOTTOM WIDTH OR DIAMETER
                          Z      10.00  SIDE SLOPE
                     RUPSTQ         NO  ROUTE UPSTREAM HYDROGRAPH

                                                       ***

               PRECIPITATION STATION DATA

                     STATION     TOTAL    AVG. ANNUAL    WEIGHT
                          40    450.10         .00         .30
                          50    611.90         .00         .70

                 TEMPORAL DISTRIBUTIONS

                 STATION        3,  WEIGHT =    .30
                      .00       .00       .00       .30      1.70      1.00       .30       .30       .30      1.00
                     1.00       .00       .00       .00       .00       .00       .00       .00      1.00      1.00
                     1.00     12.00      3.00      5.00      6.00      6.00     16.00     20.00     14.00     16.00
                    20.00     18.00     24.00     38.00     44.00     16.00       .00       .00       .00       .00
                      .00       .00       .00       .00       .00       .00       .00       .00       .00       .00
                      .00       .00       .00       .00       .00       .00       .00       .00
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          STATION        4,  WEIGHT =     .70
                 .00       .00       .00       .00       .10       .10       .10      4.20      4.40      2.00
                1.20      1.30       .80      5.40      1.60       .30      1.90      1.90      3.00      6.50
                8.50     11.60     10.20     12.40     10.70     13.40     25.00     25.00     25.00     34.40
               31.20     38.60     52.10     60.50     42.70     23.40     19.30     23.90     11.50      9.40
               15.60     30.60     16.60      5.00      2.60       .50      1.50       .90      1.30      1.30
                4.40      2.70      2.00       .50       .70      1.90       .40       .10

      COMPUTED KINEMATIC PARAMETERS
         ELEMENT       ALPHA         M        DT (MIN)    DX (FT)
               1      2.8854     1.667        60.00      4101.05
               3       .6159     1.549        60.00     31167.98

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

                                                HYDROGRAPH AT STATION     SUB1B

*******************************************************************************************************************************
                                                                  *
    DA MON HRMN  ORD     RAIN    LOSS  EXCESS     COMP Q          *      DA MON HRMN  ORD     RAIN    LOSS  EXCESS       COMP Q
                                                                  *
    30 AUG 0900    1      .00     .00     .00         0.          *       1 SEP 0900   49      .70     .01     .69          47.
    30 AUG 1000    2      .00     .00     .00         0.          *       1 SEP 1000   50     1.01     .01    1.00          36.
    30 AUG 1100    3      .00     .00     .00         0.          *       1 SEP 1100   51     1.01     .01    1.00          30.
    30 AUG 1200    4      .00     .00     .00         0.          *       1 SEP 1200   52     3.41     .04    3.37          26.
    30 AUG 1300    5      .10     .10     .00         0.          *       1 SEP 1300   53     2.09     .02    2.07          30.
    30 AUG 1400    6      .64     .64     .00         0.          *       1 SEP 1400   54     1.55     .02    1.53          35.
    30 AUG 1500    7      .41     .41     .00         0.          *       1 SEP 1500   55      .39     .00     .38          35.
    30 AUG 1600    8      .18     .18     .00         0.          *       1 SEP 1600   56      .54     .01     .54          31.
    30 AUG 1700    9     3.36    3.36     .00         0.          *       1 SEP 1700   57     1.47     .02    1.46          25.
    30 AUG 1800   10     3.51    3.51     .00         0.          *       1 SEP 1800   58      .31     .00     .31          23.
    30 AUG 1900   11     1.88    1.88     .00         0.          *       1 SEP 1900   59      .08     .00     .08          21.
    30 AUG 2000   12     1.26    1.26     .00         0.          *       1 SEP 2000   60      .00     .00     .00          18.
    30 AUG 2100   13     1.01    1.01     .00         0.          *       1 SEP 2100   61      .00     .00     .00          14.
    30 AUG 2200   14      .62     .62     .00         0.          *       1 SEP 2200   62      .00     .00     .00          11.
    30 AUG 2300   15     4.19    3.90     .29         0.          *       1 SEP 2300   63      .00     .00     .00           9.
    31 AUG 0000   16     1.24    1.06     .18         0.          *       2 SEP 0000   64      .00     .00     .00           7.
    31 AUG 0100   17      .23     .20     .04         0.          *       2 SEP 0100   65      .00     .00     .00           6.
    31 AUG 0200   18     1.47    1.21     .27         0.          *       2 SEP 0200   66      .00     .00     .00           5.
    31 AUG 0300   19     1.47    1.16     .32         0.          *       2 SEP 0300   67      .00     .00     .00           5.
    31 AUG 0400   20     2.66    1.97     .68         0.          *       2 SEP 0400   68      .00     .00     .00           4.
    31 AUG 0500   21     5.37    3.59    1.78         0.          *       2 SEP 0500   69      .00     .00     .00           4.
    31 AUG 0600   22     6.92    3.98    2.95         1.          *       2 SEP 0600   70      .00     .00     .00           3.
    31 AUG 0700   23    12.98    5.98    7.01         5.          *       2 SEP 0700   71      .00     .00     .00           3.
    31 AUG 0800   24     8.91    3.28    5.63        25.          *       2 SEP 0800   72      .00     .00     .00           3.
    31 AUG 0900   25    11.28    3.45    7.82        59.          *       2 SEP 0900   73      .00     .00     .00           2.
    31 AUG 1000   26    10.29    2.63    7.66        94.          *       2 SEP 1000   74      .00     .00     .00           2.
    31 AUG 1100   27    12.38    2.67    9.72       122.          *       2 SEP 1100   75      .00     .00     .00           2.
    31 AUG 1200   28    24.70    4.14   20.56       151.          *       2 SEP 1200   76      .00     .00     .00           2.
    31 AUG 1300   29    26.03    3.22   22.81       240.          *       2 SEP 1300   77      .00     .00     .00           2.
    31 AUG 1400   30    24.04    2.29   21.74       394.          *       2 SEP 1400   78      .00     .00     .00           1.
    31 AUG 1500   31    31.99    2.37   29.62       431.          *       2 SEP 1500   79      .00     .00     .00           1.
    31 AUG 1600   32    30.84    1.77   29.06       494.          *       2 SEP 1600   80      .00     .00     .00           1.
    31 AUG 1700   33    35.91    1.63   34.28       560.          *       2 SEP 1700   81      .00     .00     .00           1.
    31 AUG 1800   34    48.37    1.69   46.68       616.          *       2 SEP 1800   82      .00     .00     .00           1.
    31 AUG 1900   35    59.54    1.55   57.99       789.          *       2 SEP 1900   83      .00     .00     .00           1.
    31 AUG 2000   36    47.73     .96   46.77      1022.          *       2 SEP 2000   84      .00     .00     .00           1.
    31 AUG 2100   37    23.46     .40   23.06       993.          *       2 SEP 2100   85      .00     .00     .00           1.
    31 AUG 2200   38    14.96     .24   14.73       684.          *       2 SEP 2200   86      .00     .00     .00           1.
    31 AUG 2300   39    18.53     .28   18.25       412.          *       2 SEP 2300   87      .00     .00     .00           1.
     1 SEP 0000   40     8.92     .13    8.79       327.          *       3 SEP 0000   88      .00     .00     .00           1.
     1 SEP 0100   41     7.29     .10    7.19       267.          *       3 SEP 0100   89      .00     .00     .00           1.
     1 SEP 0200   42    12.10     .16   11.94       182.          *       3 SEP 0200   90      .00     .00     .00           1.
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  1 SEP 0300   43   23.73    .30   23.43      182.      *    3 SEP 0300   91    .00     .00     .00      1.
  1 SEP 0400   44   12.87    .15   12.72      290.      *    3 SEP 0400   92    .00     .00     .00      1.
  1 SEP 0500   45    3.88    .04    3.83      351.      *    3 SEP 0500   93    .00     .00     .00      0.
  1 SEP 0600   46    2.02    .02    1.99      188.      *    3 SEP 0600   94    .00     .00     .00      0.
  1 SEP 0700   47     .39    .00     .38      105.      *    3 SEP 0700   95    .00     .00     .00      0.
  1 SEP 0800   48    1.16    .01    1.15       67.      *    3 SEP 0800   96    .00     .00     .00      0.
                                                        *
************************************************************************************************************************************

    TOTAL RAINFALL =  563.36, TOTAL LOSS =    69.64, TOTAL EXCESS =  493.72

 PEAK FLOW     TIME                             MAXIMUM AVERAGE FLOW
                                       6-HR        24-HR        72-HR       95.00-HR
 (CU M/S)      (HR)
                           (CU M/S)
   1022.      35.00                    765.         376.         132.          100.
                              (MM)   236.041      463.529      488.875       488.959
                         (1000 CU M)  16523.       32447.       34221.        34227.

                          CUMULATIVE AREA =    70.00 SQ KM
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                                                           STATION    SUB1B

                         (O) OUTFLOW
         0.      200.      400.      600.      800.     1000.     1200.        0.        0.        0.        0.        0.        0.
                                                                                                       (L) PRECIP,   (X) EXCESS
         0.        0.        0.        0.        0.        0.        0.        0.        0.       60.       40.       20.        0.
DAHRMN PER
300900   10---------.---------.---------.---------.---------.---------.---------.---------.---------.---------.---------.---------.
301000   20         .         .         .         .         .         .         .         .         .         .         .         .
301100   30         .         .         .         .         .         .         .         .         .         .         .         .
301200   40         .         .         .         .         .         .         .         .         .         .         .         .
301300   50         .         .         .         .         .         .         .         .         .         .         .         .
301400   60         .         .         .         .         .         .         .         .         .         .         .         .
301500   70         .         .         .         .         .         .         .         .         .         .         .         .
301600   80         .         .         .         .         .         .         .         .         .         .         .         .
301700   90         .         .         .         .         .         .         .         .         .         .         .       LL.
301800  100         .         .         .         .         .         .         .         .         .         .         .       LL.
301900  110 . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .L.
302000  120         .         .         .         .         .         .         .         .         .         .         .        L.
302100  130         .         .         .         .         .         .         .         .         .         .         .        L.
302200  140         .         .         .         .         .         .         .         .         .         .         .         .
302300  150         .         .         .         .         .         .         .         .         .         .         .       LL.
310000  160         .         .         .         .         .         .         .         .         .         .         .        L.
310100  170         .         .         .         .         .         .         .         .         .         .         .         .
310200  180         .         .         .         .         .         .         .         .         .         .         .        L.
310300  190         .         .         .         .         .         .         .         .         .         .         .        L.
310400  200.        .         .         .         .         .         .         .         .         .         .         .        L.
310500  210 . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .LLXX
310600  220         .         .         .         .         .         .         .         .         .         .         .      LLXX
310700  230         .         .         .         .         .         .         .         .         .         .         .   LLXXXX.
310800  24.O        .         .         .         .         .         .         .         .         .         .         .     LXXX.
310900  25.  O      .         .         .         .         .         .         .         .         .         .         .   LLXXXX.
311000  26.    O    .         .         .         .         .         .         .         .         .         .         .    LXXXX.
311100  27.     O   .         .         .         .         .         .         .         .         .         .         .   LXXXXX.
311200  28.       O .         .         .         .         .         .         .         .         .         .       LLXXXXXXXXXXX.
311300  29.         . O       .         .         .         .         .         .         .         .         .      LLXXXXXXXXXXXX.
311400  30.         .         O         .         .         .         .         .         .         .         .       LXXXXXXXXXXXX.
311500  31. . . . . . . . . . . O . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . LXXXXXXXXXXXXXXX.
311600  32.         .         .    O    .         .         .         .         .         .         .    LXXXXXXXXXXXXXX.
311700  33.         .         .       O .         .         .         .         .         .         . LXXXXXXXXXXXXXXXXX.
311800  34.         .         .         .O        .         .         .         .         .     LXXXXXXXXXXXXXXXXXXXXXXX.
311900  35.         .         .         .        O.         .         .         .         .         LXXXXXXXXXXXXXXXXXXXXXXXXXXXXX.
312000  36.         .         .         .         .         .O        .         .         .     LXXXXXXXXXXXXXXXXXXXXXXX.
312100  37.         .         .         .         .         O         .         .         .         .       LXXXXXXXXXXXX.
312200  38.         .         .         .   O     .         .         .         .         .         .         .  LXXXXXXX.
312300  39.         .         .O        .         .         .         .         .         .         .         .LXXXXXXXXX.
 10000  40.         .     O   .         .         .         .         .         .         .         .         .         .     LXXX.
 10100  41. . . . . . .O. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . LXXX.
 10200  42.        O.         .         .         .         .         .         .         .         .         .         .   LXXXXX.
 10300  43.        O.         .         .         .         .         .         .         .         .         .       LXXXXXXXXXXXX.
 10400  44.         .    O    .         .         .         .         .         .         .         .         .         .   LXXXXX.
 10500  45.         .       O .         .         .         .         .         .         .         .         .         .       LX.
 10600  46.        O.         .         .         .         .         .         .         .         .         .         .        LX
 10700  47.    O    .         .         .         .         .         .         .         .         .         .         .         .
 10800  48.  O      .         .         .         .         .         .         .         .         .         .         .        LX
 10900  49. O       .         .         .         .         .         .         .         .         .         .         .         .
 11000  50. O       .         .         .         .         .         .         .         .         .         .         .        L.
 11100  51.O. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .L.
 11200  52.O        .         .         .         .         .         .         .         .         .         .         .       LX.
 11300  53.O        .         .         .         .         .         .         .         .         .         .         .        LX
 11400  54. O       .         .         .         .         .         .         .         .         .         .         .        LX
 11500  55. O       .         .         .         .         .         .         .         .         .         .         .         .
 11600  56. O       .         .         .         .         .         .         .         .         .         .         .         .
 11700  57.O        .         .         .         .         .         .         .         .         .         .         .        LX
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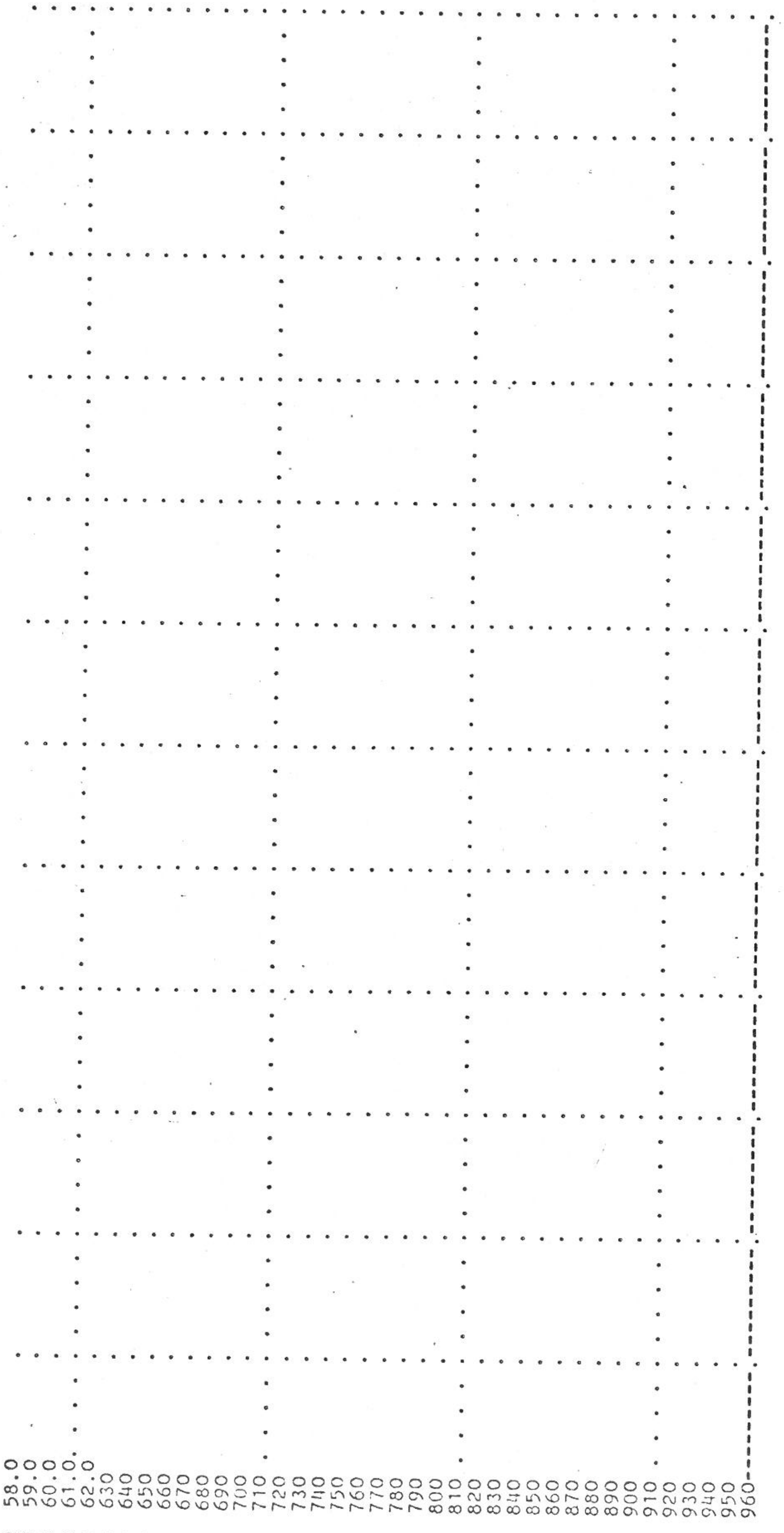
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20100 650
20200 660
20300 670
20400 680
20500 690
20600 700
20700 710
20800 720
20900 730
21000 740
21100 750
21200 760
21300 770
21400 780
21500 790
21600 800
21700 810
21800 820
21900 830
22000 840
22100 850
22200 860
22300 870
30000 880
30100 890
30200 900
30300 910
30400 920
30500 930
30600 940
30700 950
30800 960

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

          *************
          *           *
 76 KK    *   SUB1C   *
          *           *
          *************
                        COMBINE RUNOFF FROM SUB1A AND SUB1B

 78 HC         HYDROGRAPH COMBINATION
                    ICOMP          2  NUMBER OF HYDROGRAPHS TO COMBINE

                                              ***

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

                                    HYDROGRAPH AT STATION    SUB1C
                                       SUM OF  2 HYDROGRAPHS

*****************************************************************************************************************************
                                  *                                  *                                  *
  DA MON HRMN  ORD        FLOW    *  DA MON HRMN  ORD        FLOW    *  DA MON HRMN  ORD        FLOW    *  DA MON HRMN  ORD        FLOW
                                  *                                  *                                  *
  30 AUG 0900    1          0.    *  31 AUG 0900   25        140.    *   1 SEP 0900   49         99.    *   2 SEP 0900   73          5.
  30 AUG 1000    2          0.    *  31 AUG 1000   26        215.    *   1 SEP 1000   50         76.    *   2 SEP 1000   74          4.
  30 AUG 1100    3          0.    *  31 AUG 1100   27        269.    *   1 SEP 1100   51         64.    *   2 SEP 1100   75          4.
  30 AUG 1200    4          0.    *  31 AUG 1200   28        324.    *   1 SEP 1200   52         57.    *   2 SEP 1200   76          3.
  30 AUG 1300    5          0.    *  31 AUG 1300   29        508.    *   1 SEP 1300   53         68.    *   2 SEP 1300   77          3.
  30 AUG 1400    6          0.    *  31 AUG 1400   30        797.    *   1 SEP 1400   54         80.    *   2 SEP 1400   78          3.
  30 AUG 1500    7          0.    *  31 AUG 1500   31        867.    *   1 SEP 1500   55         80.    *   2 SEP 1500   79          3.
  30 AUG 1600    8          0.    *  31 AUG 1600   32       1023.    *   1 SEP 1600   56         69.    *   2 SEP 1600   80          2.
  30 AUG 1700    9          0.    *  31 AUG 1700   33       1150.    *   1 SEP 1700   57         56.    *   2 SEP 1700   81          2.
  30 AUG 1800   10          0.    *  31 AUG 1800   34       1267.    *   1 SEP 1800   58         53.    *   2 SEP 1800   82          2.
  30 AUG 1900   11          0.    *  31 AUG 1900   35       1648.    *   1 SEP 1900   59         47.    *   2 SEP 1900   83          2.
  30 AUG 2000   12          0.    *  31 AUG 2000   36       2093.    *   1 SEP 2000   60         39.    *   2 SEP 2000   84          2.
  30 AUG 2100   13          0.    *  31 AUG 2100   37       1940.    *   1 SEP 2100   61         31.    *   2 SEP 2100   85          2.
  30 AUG 2200   14          0.    *  31 AUG 2200   38       1321.    *   1 SEP 2200   62         24.    *   2 SEP 2200   86          2.
  30 AUG 2300   15          0.    *  31 AUG 2300   39        844.    *   1 SEP 2300   63         19.    *   2 SEP 2300   87          1.
  31 AUG 0000   16          0.    *   1 SEP 0000   40        740.    *   2 SEP 0000   64         16.    *   3 SEP 0000   88          1.
  31 AUG 0100   17          0.    *   1 SEP 0100   41        625.    *   2 SEP 0100   65         13.    *   3 SEP 0100   89          1.
  31 AUG 0200   18          0.    *   1 SEP 0200   42        391.    *   2 SEP 0200   66         11.    *   3 SEP 0200   90          1.
  31 AUG 0300   19          0.    *   1 SEP 0300   43        414.    *   2 SEP 0300   67         10.    *   3 SEP 0300   91          1.
  31 AUG 0400   20          1.    *   1 SEP 0400   44        692.    *   2 SEP 0400   68          8.    *   3 SEP 0400   92          1.
  31 AUG 0500   21          2.    *   1 SEP 0500   45        798.    *   2 SEP 0500   69          7.    *   3 SEP 0500   93          1.
  31 AUG 0600   22          6.    *   1 SEP 0600   46        398.    *   2 SEP 0600   70          6.    *   3 SEP 0600   94          1.
  31 AUG 0700   23         23.    *   1 SEP 0700   47        221.    *   2 SEP 0700   71          6.    *   3 SEP 0700   95          1.
  31 AUG 0800   24         71.    *   1 SEP 0800   48        139.    *   2 SEP 0800   72          5.    *   3 SEP 0800   96          1.
                                  *                                  *                                  *
*****************************************************************************************************************************

 PEAK FLOW      TIME                           MAXIMUM AVERAGE FLOW
                                     6-HR         24-HR         72-HR       95.00-HR
 (CU M/S)       (HR)
                         (CU M/S)
   2093.        35.00                1545.         784.          277.         210.
                             (MM)  238.392      483.539       512.160      512.280
                       (1000 CU M)  33375.       67696.        71702.       71719.

                         CUMULATIVE AREA =   140.00 SQ KM
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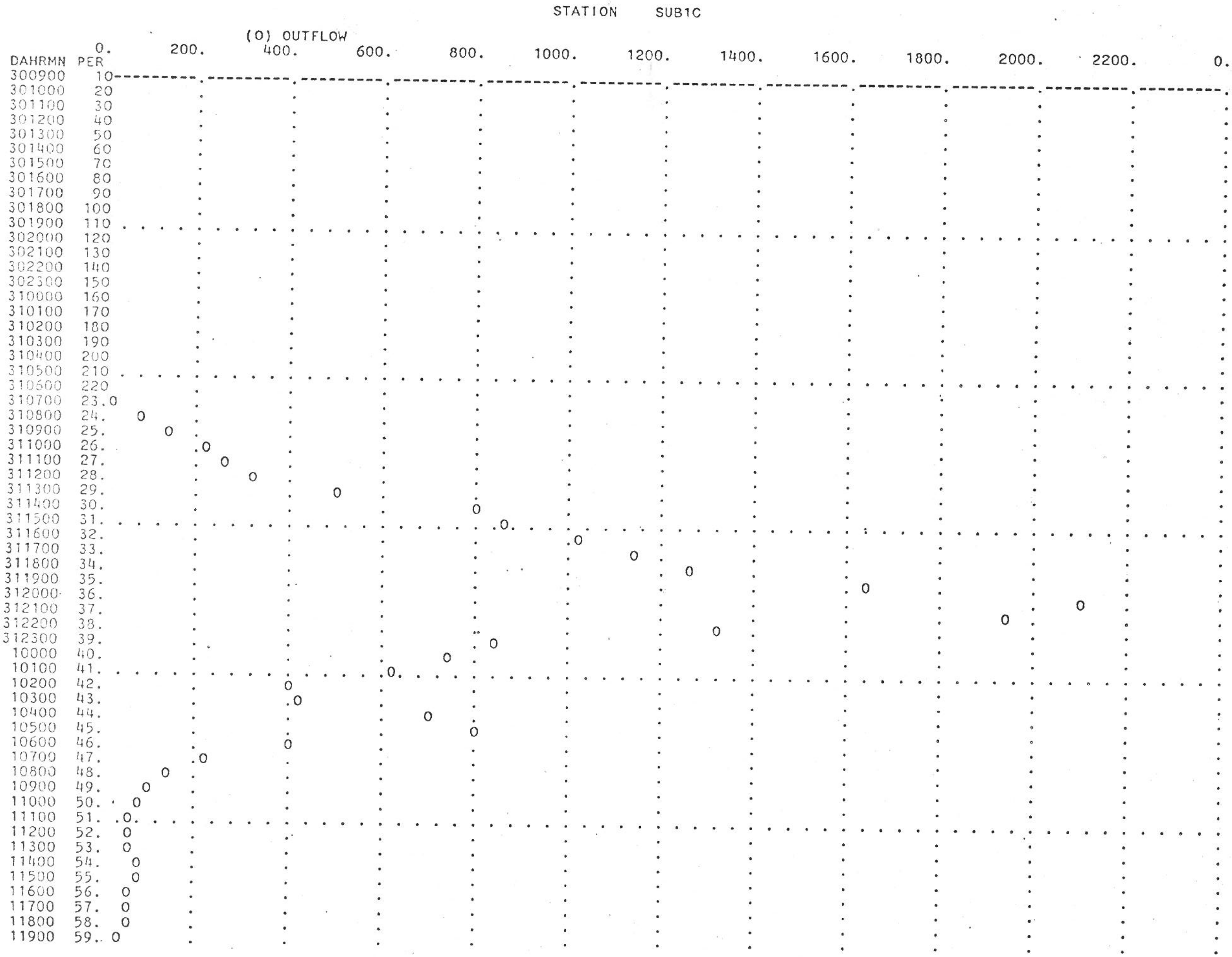
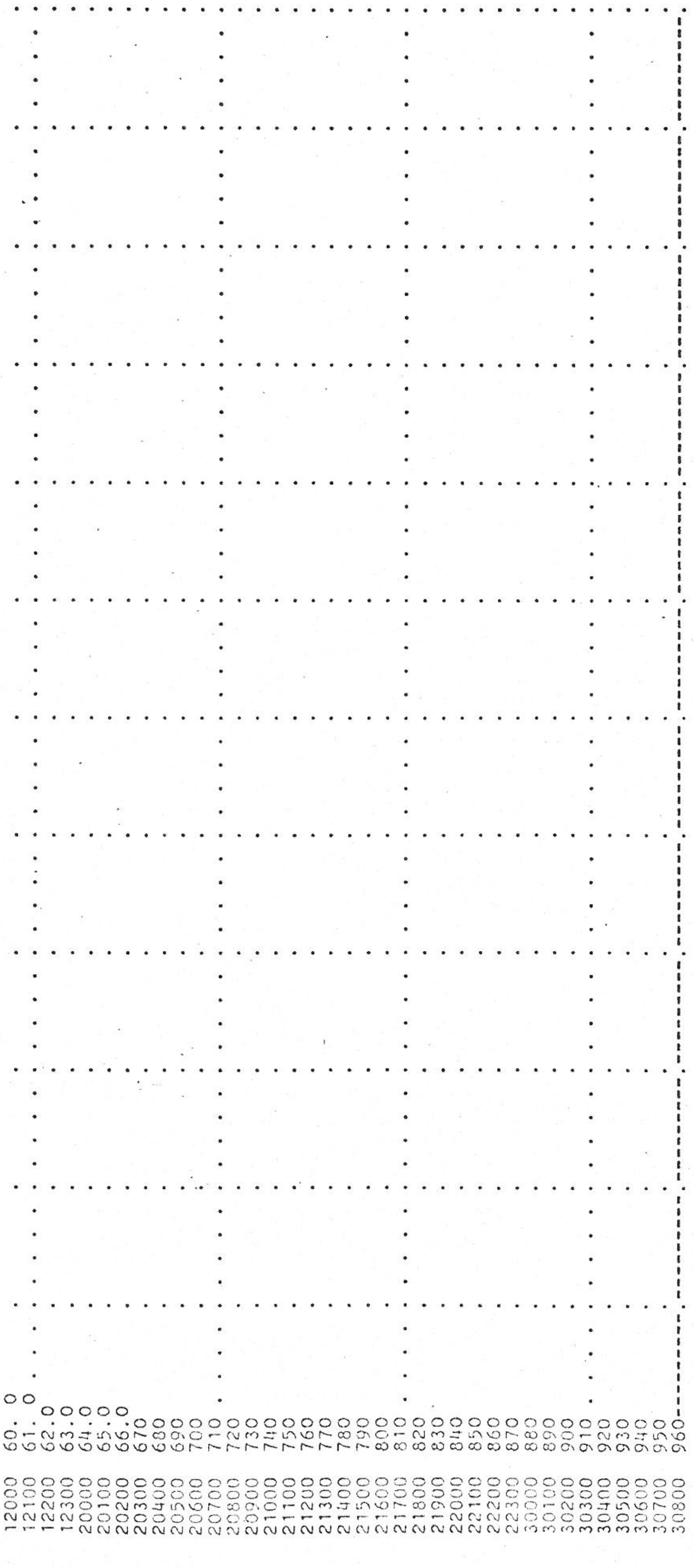

STATION SUBIC
(O) OUTFLOW
0.
200.
400.
600.
800.
1000.
1200.
1400.
1600.
1800.
2000.
2200.
0.
DAHRMN PER
300900 10
301000 20
301100 30
301200 40
301300 50
301400 60
301500 70
301600 80
301700 90
301800 100
301900 110
302000 120
302100 130
302200 140
302300 150
310000 160
310100 170
310200 180
310300 190
310400 200
310500 210
310600 220
310700 23.
310800 24.
310900 25.
311000 26.
311100 27.
311200 28.
311300 29.
311400 30.
311500 31.
311600 32.
311700 33.
311800 34.
311900 35.
312000 36.
312100 37.
312200 38.
312300 39.
10000 40.
10100 41.
10200 42.
10300 43.
10400 44.
10500 45.
10600 46.
10700 47.
10800 48.
10900 49.
11000 50.
11100 51.
11200 52.
11300 53.
11400 54.
11500 55.
11600 56.
11700 57.
11800 58.
11900 59.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20000 64.0
20100 65.0
20200 66.0
20300 670
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20600 700
20700 710
20800 720
20900 730
21000 740
21100 750
21200 760
21300 770
21400 780
21500 790
21600 800
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21800 820
21900 830
22000 840
22100 850
22200 860
22300 870
30000 880
30100 890
30200 900
30300 910
30400 920
30500 930
30600 940
30700 950
30800 960

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

           *************
           *           *
 79 KK     *   SUB1C   *
           *           *
           *************
                         RUNOFF FROM SUBBASIN 1C

                SUBBASIN RUNOFF DATA

 85 BA            SUBBASIN CHARACTERISTICS
                        TAREA       45.00  SUBBASIN AREA

                  PRECIPITATION DATA

 83 PT             TOTAL STORM STATIONS         20         40         50
 84 PW                          WEIGHTS        .20        .40        .40

 81 PR               RECORDING STATIONS          3          4          7
 82 PW                          WEIGHTS        .40        .40        .20

 86 LS            SCS LOSS RATE
                        STRTL       12.70  INITIAL ABSTRACTION
                       CRVNBR       80.00  CURVE NUMBER
                        RTIMP         .00  PERCENT IMPERVIOUS AREA

                  KINEMATIC WAVE
 87 UK              OVERLAND-FLOW ELEMENT NO. 1
                            L       4500.  OVERLAND FLOW LENGTH
                            S       .5000  SLOPE
                            N        .300  ROUGHNESS COEFFICIENT
                           PA       100.0  PERCENT OF SUBBASIN
 88 RK              MAIN CHANNEL
                            L       7500.  CHANNEL LENGTH
                            S       .0133  SLOPE
                            N        .026  CHANNEL ROUGHNESS COEFFICIENT
                           CA       45.00  CONTRIBUTING AREA
                        SHAPE        TRAP  CHANNEL SHAPE
                           WD       85.00  BOTTOM WIDTH OR DIAMETER
                            Z       10.00  SIDE SLOPE
                       RUPSTQ         YES  ROUTE UPSTREAM HYDROGRAPH

                                                        ***

                PRECIPITATION STATION DATA

                         STATION    TOTAL    AVG. ANNUAL    WEIGHT
                              20   300.00            .00       .20
                              40   450.10            .00       .40
                              50   611.90            .00       .40

                  TEMPORAL DISTRIBUTIONS

                  STATION       3,  WEIGHT =      .40
                       .00       .00       .00       .30      1.70      1.00       .30       .30       .30      1.00
                      1.00       .00       .00       .00       .00       .00       .00       .00      1.00      1.00
                      1.00     12.00      3.00      5.00      6.00      6.00     16.00     20.00     14.00     16.00
                     20.00     18.00     24.00     38.00     44.00     16.00       .00       .00       .00       .00
                       .00       .00       .00       .00       .00       .00       .00       .00       .00       .00
```

```
         .00        .00        .00        .00        .00        .00        .00        .00

   STATION        4,  WEIGHT =     .40
         .00        .00        .00        .00        .10        .10        .10       4.20       4.40       2.00
        1.20       1.30        .80       5.40       1.60        .30       1.90       1.90       3.00       6.50
        8.50      11.60      10.20      12.40      10.70      13.40      25.00      25.00      25.00      34.40
       31.20      38.60      52.10      60.50      42.70      23.40      19.30      23.90      11.50       9.40
       15.60      30.60      16.60       5.00       2.60        .50       1.50        .90       1.30       1.30
        4.40       2.70       2.00        .50        .70       1.90        .40        .10

   STATION        7,  WEIGHT =     .20
         .00        .00        .00        .00        .00        .00        .00        .00        .00        .00
         .00        .00        .00        .00        .00        .00        .00       4.00       1.00       1.00
        8.00       3.00       3.50       3.50       5.00       5.00      10.00       9.00      13.00      12.00
       12.00      12.00      16.00      12.00      64.00      56.00      10.00      10.00       8.00      12.00
       10.00        .00        .00        .00        .00        .00        .00        .00        .00        .00
         .00        .00        .00        .00        .00        .00        .00        .00

 COMPUTED KINEMATIC PARAMETERS
     ELEMENT      ALPHA         M          DT (MIN)    DX (FT)
           1     3.5120      1.667          60.00      7381.89
           3      .2183      1.593          60.00     12303.15

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

                                                  HYDROGRAPH AT STATION     SUB1C

***************************************************************************************************************
                                                            *
 DA MON HRMN  ORD     RAIN     LOSS   EXCESS      COMP Q    *    DA MON HRMN  ORD     RAIN     LOSS   EXCESS      COMP Q
                                                            *
 30 AUG 0900    1      .00      .00      .00          0.    *     1 SEP 0900   49      .42      .01      .42        151.
 30 AUG 1000    2      .00      .00      .00          0.    *     1 SEP 1000   50      .61      .01      .60        113.
 30 AUG 1100    3      .00      .00      .00          0.    *     1 SEP 1100   51      .61      .01      .60         91.
 30 AUG 1200    4      .00      .00      .00          0.    *     1 SEP 1200   52     2.07      .03     2.04         78.
 30 AUG 1300    5      .14      .14      .00          0.    *     1 SEP 1300   53     1.27      .02     1.25         80.
 30 AUG 1400    6      .85      .85      .00          0.    *     1 SEP 1400   54      .94      .01      .93         90.
 30 AUG 1500    7      .52      .52      .00          0.    *     1 SEP 1500   55      .24      .00      .23         95.
 30 AUG 1600    8      .19      .19      .00          0.    *     1 SEP 1600   56      .33      .00      .33         88.
 30 AUG 1700    9     2.12     2.12      .00          0.    *     1 SEP 1700   57      .90      .01      .88         76.
 30 AUG 1800   10     2.21     2.21      .00          0.    *     1 SEP 1800   58      .19      .00      .19         67.
 30 AUG 1900   11     1.41     1.41      .00          0.    *     1 SEP 1900   59      .05      .00      .05         61.
 30 AUG 2000   12     1.04     1.04      .00          0.    *     1 SEP 2000   60      .00      .00      .00         53.
 30 AUG 2100   13      .61      .61      .00          0.    *     1 SEP 2100   61      .00      .00      .00         44.
 30 AUG 2200   14      .38      .38      .00          0.    *     1 SEP 2200   62      .00      .00      .00         36.
 30 AUG 2300   15     2.54     2.54      .00          0.    *     1 SEP 2300   63      .00      .00      .00         29.
 31 AUG 0000   16      .75      .75      .00          0.    *     2 SEP 0000   64      .00      .00      .00         24.
 31 AUG 0100   17      .14      .14      .00          0.    *     2 SEP 0100   65      .00      .00      .00         20.
 31 AUG 0200   18      .90      .88      .02          0.    *     2 SEP 0200   66      .00      .00      .00         17.
 31 AUG 0300   19     1.84     1.73      .11          0.    *     2 SEP 0300   67      .00      .00      .00         15.
 31 AUG 0400   20     2.12     1.88      .24          0.    *     2 SEP 0400   68      .00      .00      .00         13.
 31 AUG 0500   21     3.77     3.06      .70          0.    *     2 SEP 0500   69      .00      .00      .00         11.
 31 AUG 0600   22     6.36     4.51     1.85          1.    *     2 SEP 0600   70      .00      .00      .00         10.
 31 AUG 0700   23    11.82     6.69     5.13         10.    *     2 SEP 0700   71      .00      .00      .00          9.
 31 AUG 0800   24     7.04     3.22     3.83         44.    *     2 SEP 0800   72      .00      .00      .00          8.
 31 AUG 0900   25     9.02     3.50     5.52        116.    *     2 SEP 0900   73      .00      .00      .00          7.
 31 AUG 1000   26     9.04     2.96     6.09        207.    *     2 SEP 1000   74      .00      .00      .00          6.
 31 AUG 1100   27    10.32     2.86     7.46        286.    *     2 SEP 1100   75      .00      .00      .00          6.
 31 AUG 1200   28    21.67     4.70    16.97        360.    *     2 SEP 1200   76      .00      .00      .00          5.
 31 AUG 1300   29    23.32     3.73    19.59        561.    *     2 SEP 1300   77      .00      .00      .00          5.
 31 AUG 1400   30    21.43     2.63    18.81        898.    *     2 SEP 1400   78      .00      .00      .00          4.
 31 AUG 1500   31    26.57     2.54    24.03       1062.    *     2 SEP 1500   79      .00      .00      .00          4.
 31 AUG 1600   32    26.95     2.02    24.93       1246.    *     2 SEP 1600   80      .00      .00      .00          4.
 31 AUG 1700   33    29.49     1.76    27.73       1414.    *     2 SEP 1700   81      .00      .00      .00          3.
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  31 AUG 1800   34   39.62    1.84   37.78      1557.       *       2 SEP 1800   82     .00     .00     .00       3.
  31 AUG 1900   35   49.23    1.73   47.50      1978.       *       2 SEP 1900   83     .00     .00     .00       3.
  31 AUG 2000   36   55.92    1.47   54.44      2545.       *       2 SEP 2000   84     .00     .00     .00       3.
  31 AUG 2100   37   31.75     .67   31.08      2599.       *       2 SEP 2100   85     .00     .00     .00       2.
  31 AUG 2200   38   11.45     .22   11.23      1964.       *       2 SEP 2200   86     .00     .00     .00       2.
  31 AUG 2300   39   13.61     .25   13.37      1258.       *       2 SEP 2300   87     .00     .00     .00       2.
   1 SEP 0000   40    7.30     .13    7.17       934.       *       3 SEP 0000   88     .00     .00     .00       2.
   1 SEP 0100   41    7.25     .12    7.13       784.       *       3 SEP 0100   89     .00     .00     .00       2.
   1 SEP 0200   42    9.70     .16    9.55       563.       *       3 SEP 0200   90     .00     .00     .00       2.
   1 SEP 0300   43   14.42     .22   14.19       520.       *       3 SEP 0300   91     .00     .00     .00       2.
   1 SEP 0400   44    7.82     .12    7.70       751.       *       3 SEP 0400   92     .00     .00     .00       2.
   1 SEP 0500   45    2.36     .03    2.32       892.       *       3 SEP 0500   93     .00     .00     .00       1.
   1 SEP 0600   46    1.22     .02    1.21       585.       *       3 SEP 0600   94     .00     .00     .00       1.
   1 SEP 0700   47     .24     .00     .23       345.       *       3 SEP 0700   95     .00     .00     .00       1.
   1 SEP 0800   48     .71     .01     .70       217.       *       3 SEP 0800   96     .00     .00     .00       1.
                                                            *
*****************************************************************************************************************************

     TOTAL RAINFALL =  484.80, TOTAL LOSS =   68.67, TOTAL EXCESS =  416.13

   PEAK FLOW      TIME                        MAXIMUM AVERAGE FLOW
                                   6-HR        24-HR       72-HR      95.00-HR
   (CU M/S)       (HR)
                         (CU M/S)
     2599.       36.00              1996.        986.        348.        264.
                             (MM)  233.103     460.377     487.398     487.459
                       (1000 CU M)  43124.      85170.      90169.      90180.

                      CUMULATIVE AREA =  185.00 SQ KM
```

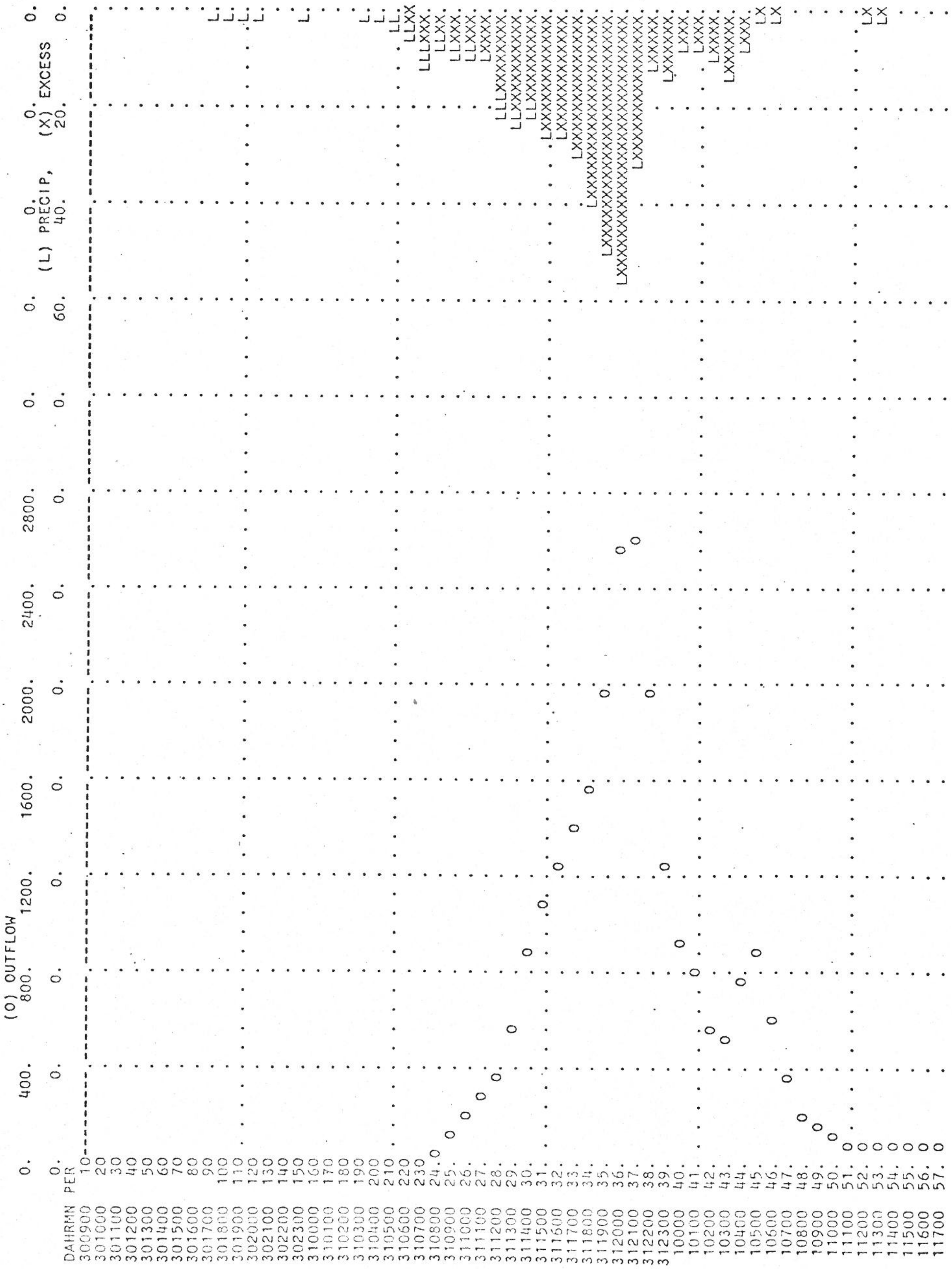
STATION SUBIC
(O) OUTFLOW
0.
400.
800.
1200.
1600.
2000.
2400.
2800.
(L) PRECIP,
(X) EXCESS
0.
20.
40.
60.
DAHRMN PER
300900 1
301000 2
301100 3
301200 4
301300 5
301400 6
301500 7
301600 8
301700 9
301800 10
301900 11
302000 12
302100 13
302200 14
302300 15
310000 16
310100 17
310200 18
310300 19
310400 20
310500 21
310600 22
310700 23
310800 24.
310900 25.
311000 26.
311100 27.
311200 28.
311300 29.
311400 30.
311500 31.
311600 32.
311700 33.
311800 34.
311900 35.
312000 36.
312100 37.
312200 38.
312300 39.
10000 40.
10100 41.
10200 42.
10300 43.
10400 44.
10500 45.
10600 46.
10700 47.
10800 48.
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11000 50.
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11200 52.
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11400 54.
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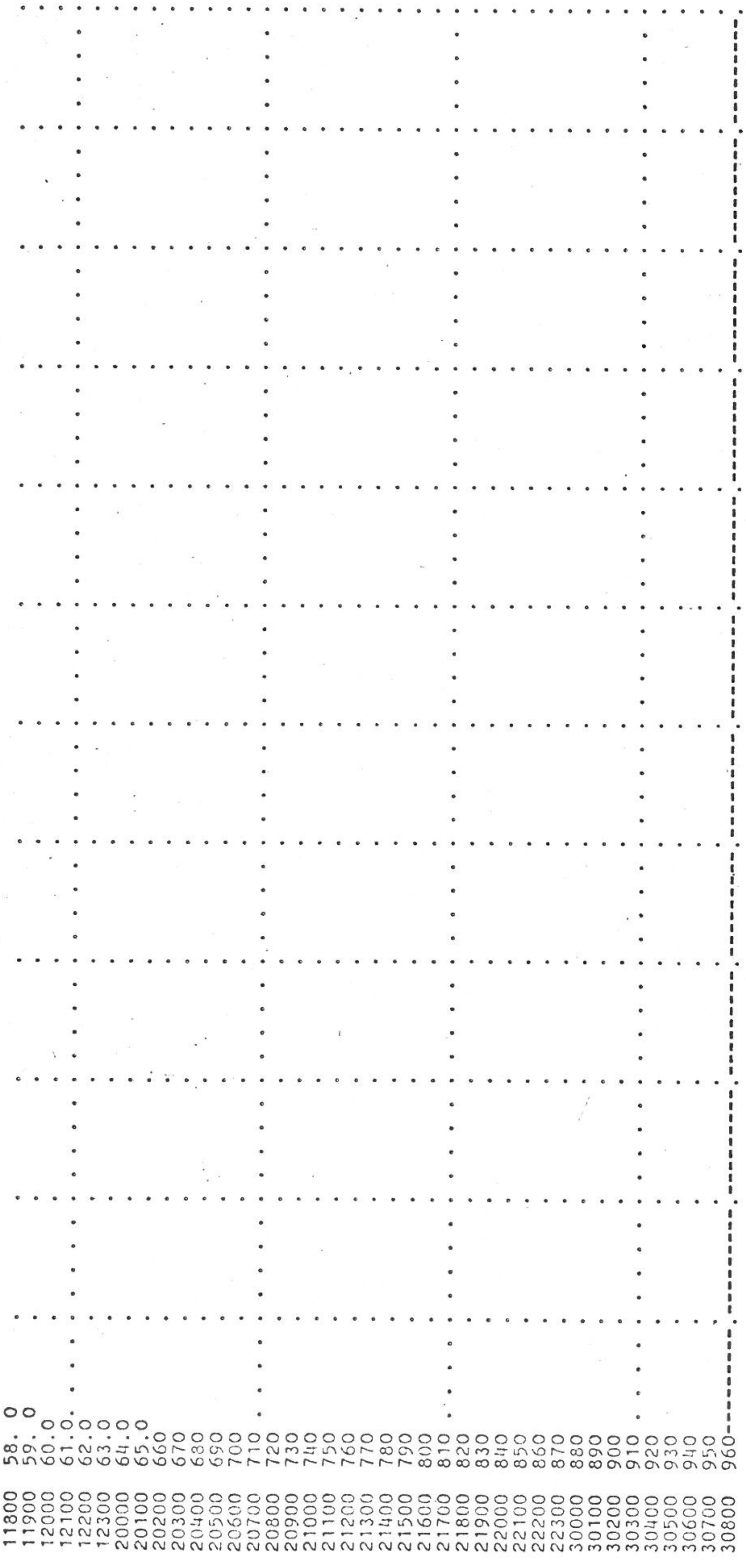
11700 57.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21100 750
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30000 880
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30200 900
30300 910
30400 920
30500 930
30600 940
30700 950
30800 960

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

            **************
 89 KK      *            *
            *     SUB2A  *
            *            *
            **************
                               RUNOFF FROM SUBBASIN 2A

              SUBBASIN RUNOFF DATA

 95 BA          SUBBASIN CHARACTERISTICS
                      TAREA       24.00  SUBBASIN AREA

                PRECIPITATION DATA

 93 PT           TOTAL STORM STATIONS         20         40
 94 PW                        WEIGHTS        .20        .80

 91 PR             RECORDING STATIONS          3          7
 92 PW                        WEIGHTS        .80        .20

 96 LS          SCS LOSS RATE
                      STRTL       12.70  INITIAL ABSTRACTION
                     CRVNBR       80.00  CURVE NUMBER
                      RTIMP         .00  PERCENT IMPERVIOUS AREA

                KINEMATIC WAVE
 97 UK            OVERLAND-FLOW ELEMENT NO. 1
                          L       2000.  OVERLAND FLOW LENGTH
                          S       .4000  SLOPE
                          N        .300  ROUGHNESS COEFFICIENT
                         PA       100.0  PERCENT OF SUBBASIN
 98 RK            MAIN CHANNEL
                          L       6500.  CHANNEL LENGTH
                          S       .0108  SLOPE
                          N        .022  CHANNEL ROUGHNESS COEFFICIENT
                         CA       24.00  CONTRIBUTING AREA
                      SHAPE        TRAP  CHANNEL SHAPE
                         WD       85.00  BOTTOM WIDTH OR DIAMETER
                          Z       10.00  SIDE SLOPE
                     RUPSTQ         YES  ROUTE UPSTREAM HYDROGRAPH

                                                           ***

              PRECIPITATION STATION DATA

                        STATION     TOTAL     AVG. ANNUAL     WEIGHT
                             20    300.00             .00        .20
                             40    450.10             .00        .80

                TEMPORAL DISTRIBUTIONS

                STATION        3,  WEIGHT =      .80
                      .00        .00        .00        .30       1.70       1.00        .30        .30        .30       1.00
                     1.00        .00        .00        .00        .00        .00        .00        .00       1.00       1.00
                     1.00      12.00       3.00       5.00       6.00       6.00      16.00      20.00      14.00      16.00
                    20.00      18.00      24.00      38.00      44.00      16.00        .00        .00        .00        .00
                      .00        .00        .00        .00        .00        .00        .00        .00        .00        .00
                      .00        .00        .00        .00        .00        .00        .00        .00
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          STATION        7,  WEIGHT =     .20
                .00         .00         .00         .00         .00         .00         .00         .00         .00         .00
                .00         .00         .00         .00         .00         .00         .00        4.00        1.00        1.00
               8.00        3.00        3.50        3.50        5.00        5.00       10.00        9.00       13.00       12.00
              12.00       12.00       16.00       12.00       64.00       56.00       10.00       10.00        8.00       12.00
              10.00         .00         .00         .00         .00         .00         .00         .00         .00         .00
                .00         .00         .00         .00         .00         .00         .00         .00

      COMPUTED KINEMATIC PARAMETERS
         ELEMENT      ALPHA          M        DT (MIN)     DX (FT)
               1     3.1412      1.667         60.00      3280.84
               3      .2325      1.593         60.00     10662.73

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

                                            HYDROGRAPH AT STATION     SUB2A

***************************************************************************************************************************
                                                          *
    DA MON HRMN  ORD     RAIN     LOSS  EXCESS      COMP Q  *        DA MON HRMN  ORD     RAIN     LOSS  EXCESS      COMP Q
                                                          *
    30 AUG 0900    1      .00      .00     .00          0.  *         1 SEP 0900   49      .00      .00     .00        178.
    30 AUG 1000    2      .00      .00     .00          0.  *         1 SEP 1000   50      .00      .00     .00        131.
    30 AUG 1100    3      .00      .00     .00          0.  *         1 SEP 1100   51      .00      .00     .00        103.
    30 AUG 1200    4      .00      .00     .00          0.  *         1 SEP 1200   52      .00      .00     .00         86.
    30 AUG 1300    5      .37      .37     .00          0.  *         1 SEP 1300   53      .00      .00     .00         81.
    30 AUG 1400    6     2.09     2.09     .00          0.  *         1 SEP 1400   54      .00      .00     .00         86.
    30 AUG 1500    7     1.23     1.23     .00          0.  *         1 SEP 1500   55      .00      .00     .00         93.
    30 AUG 1600    8      .37      .37     .00          0.  *         1 SEP 1600   56      .00      .00     .00         91.
    30 AUG 1700    9      .37      .37     .00          0.  *         1 SEP 1700   57      .00      .00     .00         82.
    30 AUG 1800   10      .37      .37     .00          0.  *         1 SEP 1800   58      .00      .00     .00         72.
    30 AUG 1900   11     1.23     1.23     .00          0.  *         1 SEP 1900   59      .00      .00     .00         65.
    30 AUG 2000   12     1.23     1.23     .00          0.  *         1 SEP 2000   60      .00      .00     .00         57.
    30 AUG 2100   13      .00      .00     .00          0.  *         1 SEP 2100   61      .00      .00     .00         49.
    30 AUG 2200   14      .00      .00     .00          0.  *         1 SEP 2200   62      .00      .00     .00         41.
    30 AUG 2300   15      .00      .00     .00          0.  *         1 SEP 2300   63      .00      .00     .00         34.
    31 AUG 0000   16      .00      .00     .00          0.  *         2 SEP 0000   64      .00      .00     .00         28.
    31 AUG 0100   17      .00      .00     .00          0.  *         2 SEP 0100   65      .00      .00     .00         24.
    31 AUG 0200   18      .00      .00     .00          0.  *         2 SEP 0200   66      .00      .00     .00         20.
    31 AUG 0300   19     1.23     1.23     .00          0.  *         2 SEP 0300   67      .00      .00     .00         17.
    31 AUG 0400   20     1.54     1.54     .00          0.  *         2 SEP 0400   68      .00      .00     .00         15.
    31 AUG 0500   21     1.54     1.54     .00          0.  *         2 SEP 0500   69      .00      .00     .00         13.
    31 AUG 0600   22     3.69     3.59     .10          0.  *         2 SEP 0600   70      .00      .00     .00         11.
    31 AUG 0700   23    15.67    11.71    3.96          0.  *         2 SEP 0700   71      .00      .00     .00         10.
    31 AUG 0800   24     4.76     2.72    2.04         28.  *         2 SEP 0800   72      .00      .00     .00          9.
    31 AUG 0900   25     7.22     3.59    3.62         85.  *         2 SEP 0900   73      .00      .00     .00          8.
    31 AUG 1000   26     8.91     3.74    5.17        182.  *         2 SEP 1000   74      .00      .00     .00          7.
    31 AUG 1100   27     8.91     3.14    5.77        279.  *         2 SEP 1100   75      .00      .00     .00          7.
    31 AUG 1200   28    22.73     6.12   16.61        367.  *         2 SEP 1200   76      .00      .00     .00          6.
    31 AUG 1300   29    27.34     5.08   22.25        577.  *         2 SEP 1300   77      .00      .00     .00          6.
    31 AUG 1400   30    21.19     2.89   18.30        956.  *         2 SEP 1400   78      .00      .00     .00          5.
    31 AUG 1500   31    23.34     2.50   20.85       1162.  *         2 SEP 1500   79      .00      .00     .00          5.
    31 AUG 1600   32    28.26     2.36   25.90       1345.  *         2 SEP 1600   80      .00      .00     .00          4.
    31 AUG 1700   33    25.80     1.71   24.10       1544.  *         2 SEP 1700   81      .00      .00     .00          4.
    31 AUG 1800   34    34.40     1.81   32.59       1699.  *         2 SEP 1800   82      .00      .00     .00          4.
    31 AUG 1900   35    50.38     2.00   48.38       2111.  *         2 SEP 1900   83      .00      .00     .00          3.
    31 AUG 2000   36    73.72     2.06   71.66       2752.  *         2 SEP 2000   84      .00      .00     .00          3.
    31 AUG 2100   37    36.86      .78   36.08       3020.  *         2 SEP 2100   85      .00      .00     .00          3.
    31 AUG 2200   38     3.07      .06    3.01       2360.  *         2 SEP 2200   86      .00      .00     .00          3.
    31 AUG 2300   39     3.07      .06    3.01       1498.  *         2 SEP 2300   87      .00      .00     .00          2.
     1 SEP 0000   40     2.46      .05    2.41       1010.  *         3 SEP 0000   88      .00      .00     .00          2.
     1 SEP 0100   41     3.69      .07    3.62        829.  *         3 SEP 0100   89      .00      .00     .00          2.
     1 SEP 0200   42     3.07      .06    3.02        628.  *         3 SEP 0200   90      .00      .00     .00          2.
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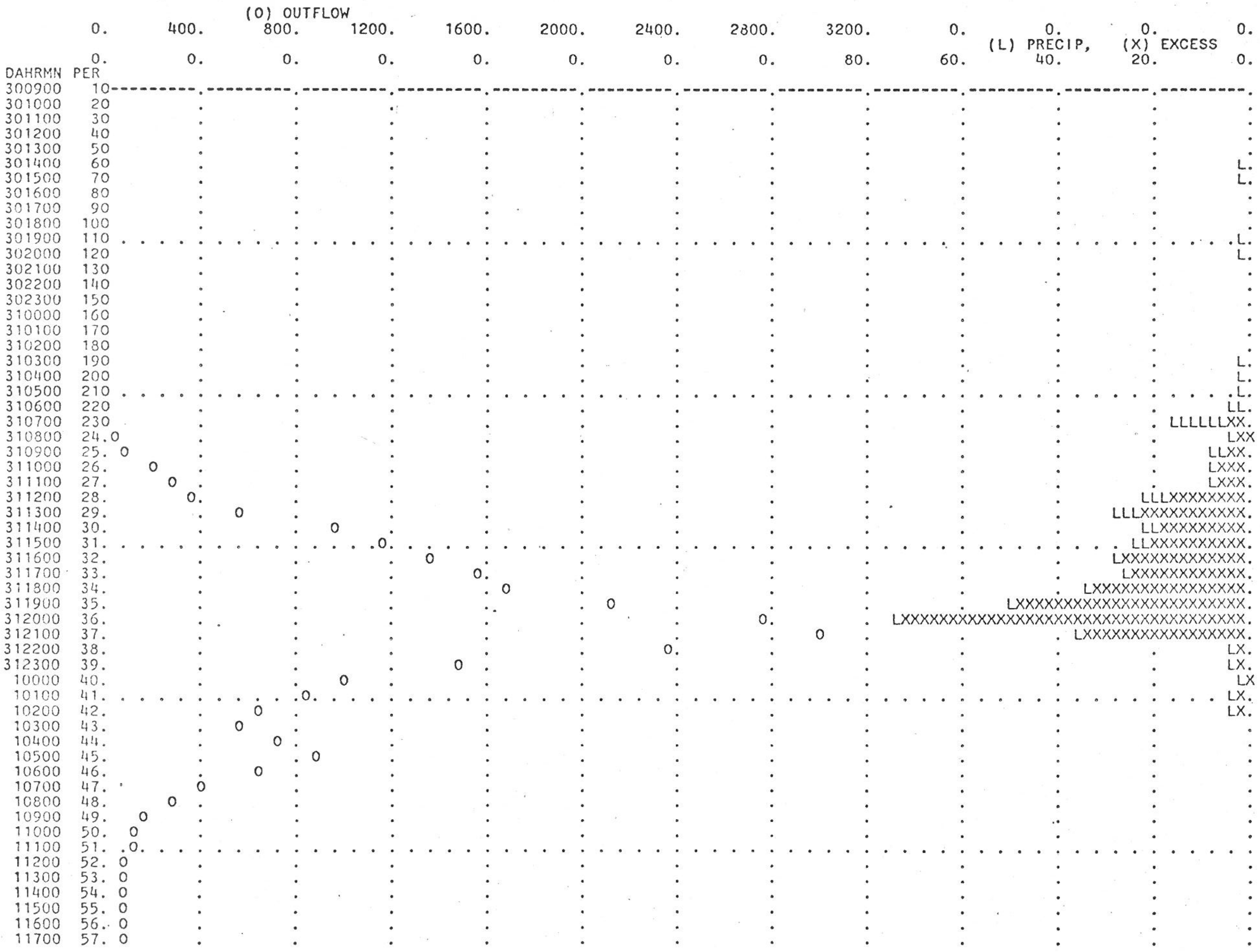
   1 SEP 0300   43    .00     .00     .00       552.      *    3 SEP 0300  91    .00     .00     .00       2.
   1 SEP 0400   44    .00     .00     .00       716.      *    3 SEP 0400  92    .00     .00     .00       2.
   1 SEP 0500   45    .00     .00     .00       871.      *    3 SEP 0500  93    .00     .00     .00       2.
   1 SEP 0600   46    .00     .00     .00       651.      *    3 SEP 0600  94    .00     .00     .00       2.
   1 SEP 0700   47    .00     .00     .00       409.      *    3 SEP 0700  95    .00     .00     .00       1.
   1 SEP 0800   48    .00     .00     .00       260.      *    3 SEP 0800  96    .00     .00     .00       1.
                                                          *
************************************************************************************************************************************

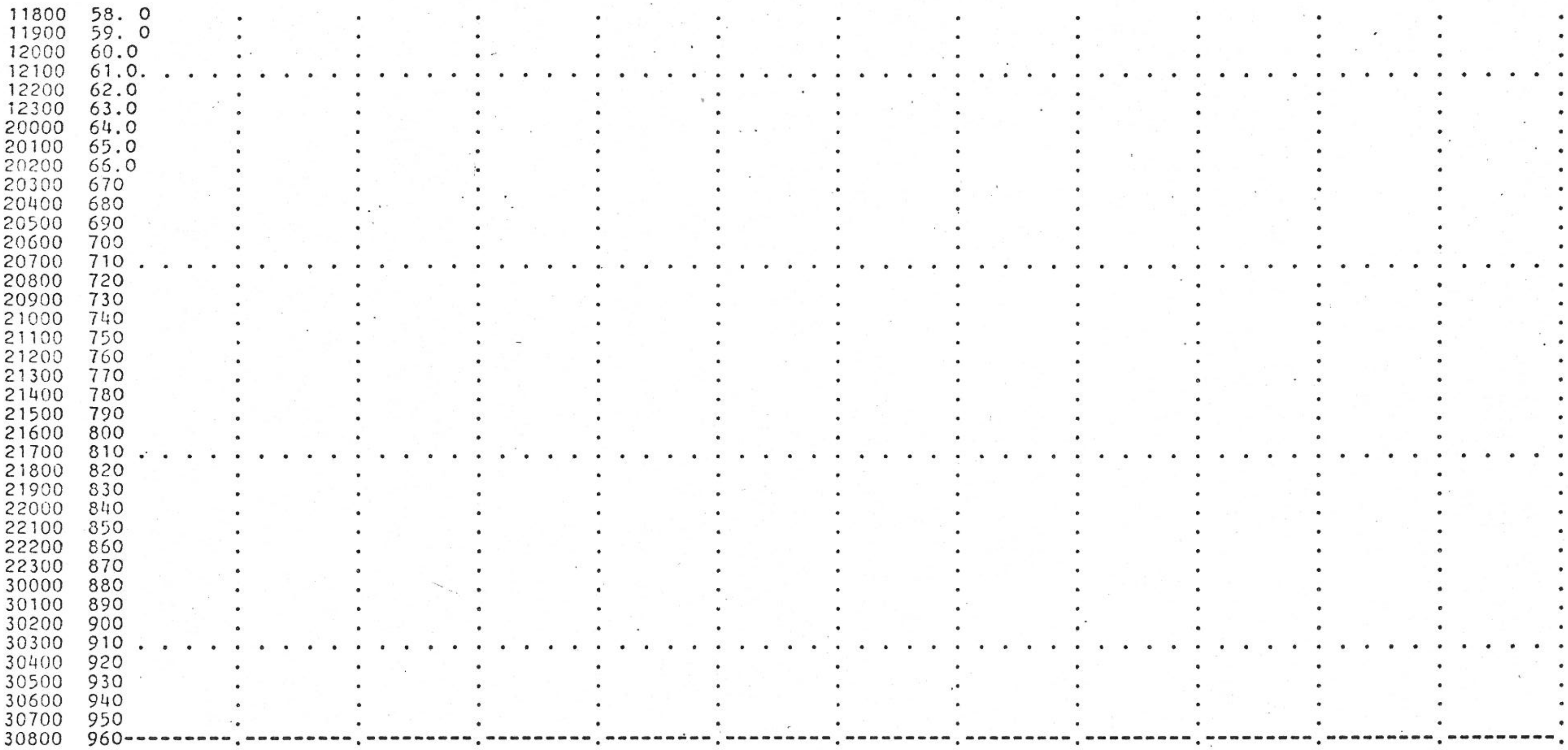
  TOTAL RAINFALL =  420.08, TOTAL LOSS =   67.64, TOTAL EXCESS =  352.44

PEAK FLOW     TIME                         MAXIMUM AVERAGE FLOW
                               6-HR       24-HR        72-HR      95.00-HR
(CU M/S)      (HR)
                    (CU M/S)
  3020.       36.00            2244.       1080.        380.          288.
                        (MM)  231.887     446.642      471.527       471.552
                   (1000 CU M)  48464.      93348.       98549.        98554.

                     CUMULATIVE AREA =  209.00 SQ KM
```

STATION SUB2A





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30700 950
30800 960

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

          **************
          *            *
 99 KK    *    SUB2B   *
          *            *
          **************
                        RUNOFF FROM SUBBASIN 2B

           SUBBASIN RUNOFF DATA

105 BA       SUBBASIN CHARACTERISTICS
                   TAREA       56.00  SUBBASIN AREA

             PRECIPITATION DATA

103 PT        TOTAL STORM STATIONS          20         30         40
104 PW                     WEIGHTS         .35        .10        .55

101 PR          RECORDING STATIONS           3          7
102 PW                     WEIGHTS         .65        .35

106 LS       SCS LOSS RATE
                   STRTL       12.70  INITIAL ABSTRACTION
                  CRVNBR       80.00  CURVE NUMBER
                   RTIMP         .00  PERCENT IMPERVIOUS AREA

             KINEMATIC WAVE
107 UK         OVERLAND-FLOW ELEMENT NO. 1
                       L       3500.  OVERLAND FLOW LENGTH
                       S       .2000  SLOPE
                       N        .300  ROUGHNESS COEFFICIENT
                      PA       100.0  PERCENT OF SUBBASIN
108 RK         MAIN CHANNEL
                       L      11500.  CHANNEL LENGTH
                       S       .0452  SLOPE
                       N        .030  CHANNEL ROUGHNESS COEFFICIENT
                      CA       56.00  CONTRIBUTING AREA
                   SHAPE        TRAP  CHANNEL SHAPE
                      WD       45.00  BOTTOM WIDTH OR DIAMETER
                       Z       10.00  SIDE SLOPE
                  RUPSTQ          NO  ROUTE UPSTREAM HYDROGRAPH

                                                          ***

           PRECIPITATION STATION DATA

                  STATION     TOTAL    AVG. ANNUAL    WEIGHT
                       20    300.00          .00         .35
                       30    251.30          .00         .10
                       40    450.10          .00         .55

             TEMPORAL DISTRIBUTIONS

             STATION        3,  WEIGHT =     .65
                   .00        .00        .00        .30       1.70       1.00        .30        .30        .30       1.00
                  1.00        .00        .00        .00        .00        .00        .00        .00       1.00       1.00
                  1.00      12.00       3.00       5.00       6.00       6.00      16.00      20.00      14.00      16.00
                 20.00      18.00      24.00      38.00      44.00      16.00        .00        .00        .00        .00
                   .00
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        STATION          7,  WEIGHT =     .35
              .00        .00        .00        .00        .00        .00        .00        .00        .00        .00
              .00        .00        .00        .00        .00        .00        .00       4.00       1.00       1.00
             8.00       3.00       3.50       3.50       5.00       5.00      10.00       9.00      13.00      12.00
            12.00      12.00      16.00      12.00      64.00      56.00      10.00      10.00       8.00      12.00
            10.00

     COMPUTED KINEMATIC PARAMETERS
         ELEMENT     ALPHA         M        DT (MIN)   DX (FT)
               1    2.2212     1.667        60.00     5741.47
               3     .6034     1.549        60.00    18864.83

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

                                                  HYDROGRAPH AT STATION     SUB2B

***************************************************************************************************************************
                                                                 *
  DA MON HRMN  ORD     RAIN     LOSS   EXCESS      COMP Q        *       DA MON HRMN  ORD     RAIN     LOSS   EXCESS      COMP Q
                                                                 *
  30 AUG 0900    1      .00      .00      .00          0.        *        1 SEP 0900   49      .00      .00      .00         18.
  30 AUG 1000    2      .00      .00      .00          0.        *        1 SEP 1000   50      .00      .00      .00         15.
  30 AUG 1100    3      .00      .00      .00          0.        *        1 SEP 1100   51      .00      .00      .00         12.
  30 AUG 1200    4      .00      .00      .00          0.        *        1 SEP 1200   52      .00      .00      .00         10.
  30 AUG 1300    5      .26      .26      .00          0.        *        1 SEP 1300   53      .00      .00      .00          9.
  30 AUG 1400    6     1.50     1.50      .00          0.        *        1 SEP 1400   54      .00      .00      .00          8.
  30 AUG 1500    7      .88      .88      .00          0.        *        1 SEP 1500   55      .00      .00      .00          7.
  30 AUG 1600    8      .26      .26      .00          0.        *        1 SEP 1600   56      .00      .00      .00          6.
  30 AUG 1700    9      .26      .26      .00          0.        *        1 SEP 1700   57      .00      .00      .00          5.
  30 AUG 1800   10      .26      .26      .00          0.        *        1 SEP 1800   58      .00      .00      .00          5.
  30 AUG 1900   11      .88      .88      .00          0.        *        1 SEP 1900   59      .00      .00      .00          4.
  30 AUG 2000   12      .88      .88      .00          0.        *        1 SEP 2000   60      .00      .00      .00          4.
  30 AUG 2100   13      .00      .00      .00          0.        *        1 SEP 2100   61      .00      .00      .00          3.
  30 AUG 2200   14      .00      .00      .00          0.        *        1 SEP 2200   62      .00      .00      .00          3.
  30 AUG 2300   15      .00      .00      .00          0.        *        1 SEP 2300   63      .00      .00      .00          3.
  31 AUG 0000   16      .00      .00      .00          0.        *        2 SEP 0000   64      .00      .00      .00          2.
  31 AUG 0100   17      .00      .00      .00          0.        *        2 SEP 0100   65      .00      .00      .00          2.
  31 AUG 0200   18      .00      .00      .00          0.        *        2 SEP 0200   66      .00      .00      .00          2.
  31 AUG 0300   19     1.90     1.90      .00          0.        *        2 SEP 0300   67      .00      .00      .00          2.
  31 AUG 0400   20     1.36     1.36      .00          0.        *        2 SEP 0400   68      .00      .00      .00          2.
  31 AUG 0500   21     1.36     1.36      .00          0.        *        2 SEP 0500   69      .00      .00      .00          2.
  31 AUG 0600   22     4.68     4.63      .05          0.        *        2 SEP 0600   70      .00      .00      .00          1.
  31 AUG 0700   23    12.00     9.59     2.41          0.        *        2 SEP 0700   71      .00      .00      .00          1.
  31 AUG 0800   24     4.31     2.75     1.55          0.        *        2 SEP 0800   72      .00      .00      .00          1.
  31 AUG 0900   25     6.07     3.42     2.65          1.        *        2 SEP 0900   73      .00      .00      .00          1.
  31 AUG 1000   26     7.66     3.70     3.97          3.        *        2 SEP 1000   74      .00      .00      .00          1.
  31 AUG 1100   27     7.66     3.15     4.52         10.        *        2 SEP 1100   75      .00      .00      .00          1.
  31 AUG 1200   28    18.85     6.06    12.79         18.        *        2 SEP 1200   76      .00      .00      .00          1.
  31 AUG 1300   29    21.90     5.04    16.86         49.        *        2 SEP 1300   77      .00      .00      .00          1.
  31 AUG 1400   30    18.51     3.20    15.31        111.        *        2 SEP 1400   78      .00      .00      .00          1.
  31 AUG 1500   31    19.80     2.70    17.10        169.        *        2 SEP 1500   79      .00      .00      .00          1.
  31 AUG 1600   32    23.33     2.52    20.81        215.        *        2 SEP 1600   80      .00      .00      .00          1.
  31 AUG 1700   33    21.56     1.87    19.70        263.        *        2 SEP 1700   81      .00      .00      .00          1.
  31 AUG 1800   34    28.75     2.00    26.75        289.        *        2 SEP 1800   82      .00      .00      .00          1.
  31 AUG 1900   35    39.19     2.10    37.10        341.        *        2 SEP 1900   83      .00      .00      .00          1.
  31 AUG 2000   36    69.17     2.60    66.57        460.        *        2 SEP 2000   84      .00      .00      .00          1.
  31 AUG 2100   37    40.69     1.11    39.57        744.        *        2 SEP 2100   85      .00      .00      .00          1.
  31 AUG 2200   38     4.75      .12     4.63        820.        *        2 SEP 2200   86      .00      .00      .00          1.
  31 AUG 2300   39     4.75      .11     4.63        338.        *        2 SEP 2300   87      .00      .00      .00          1.
   1 SEP 0000   40     3.80      .09     3.71        180.        *        3 SEP 0000   88      .00      .00      .00          1.
   1 SEP 0100   41     5.70      .13     5.57        123.        *        3 SEP 0100   89      .00      .00      .00          1.
   1 SEP 0200   42     4.75      .11     4.64        103.        *        3 SEP 0200   90      .00      .00      .00          0.
   1 SEP 0300   43      .00      .00      .00         91.        *        3 SEP 0300   91      .00      .00      .00          0.
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  1 SEP 0400   44    .00     .00     .00       68.      *      3 SEP 0400   92     .00     .00     .00       0.
  1 SEP 0500   45    .00     .00     .00       50.      *      3 SEP 0500   93     .00     .00     .00       0.
  1 SEP 0600   46    .00     .00     .00       37.      *      3 SEP 0600   94     .00     .00     .00       0.
  1 SEP 0700   47    .00     .00     .00       28.      *      3 SEP 0700   95     .00     .00     .00       0.
  1 SEP 0800   48    .00     .00     .00       22.      *      3 SEP 0800   96     .00     .00     .00       0.
                                                        *
*****************************************************************************************************************

    TOTAL RAINFALL =  377.68, TOTAL LOSS =    66.79, TOTAL EXCESS =  310.89

 PEAK FLOW     TIME                           MAXIMUM AVERAGE FLOW
                                     6-HR        24-HR        72-HR       95.00-HR
 (CU M/S)      (HR)
                         (CU M/S)
   820.       37.00                  492.         190.          65.          49.
                             (MM)  189.936      293.428      300.679      300.683
                       (1000 CU M)  10636.       16432.       16838.       16838.

                       CUMULATIVE AREA =    56.00 SQ KM
```
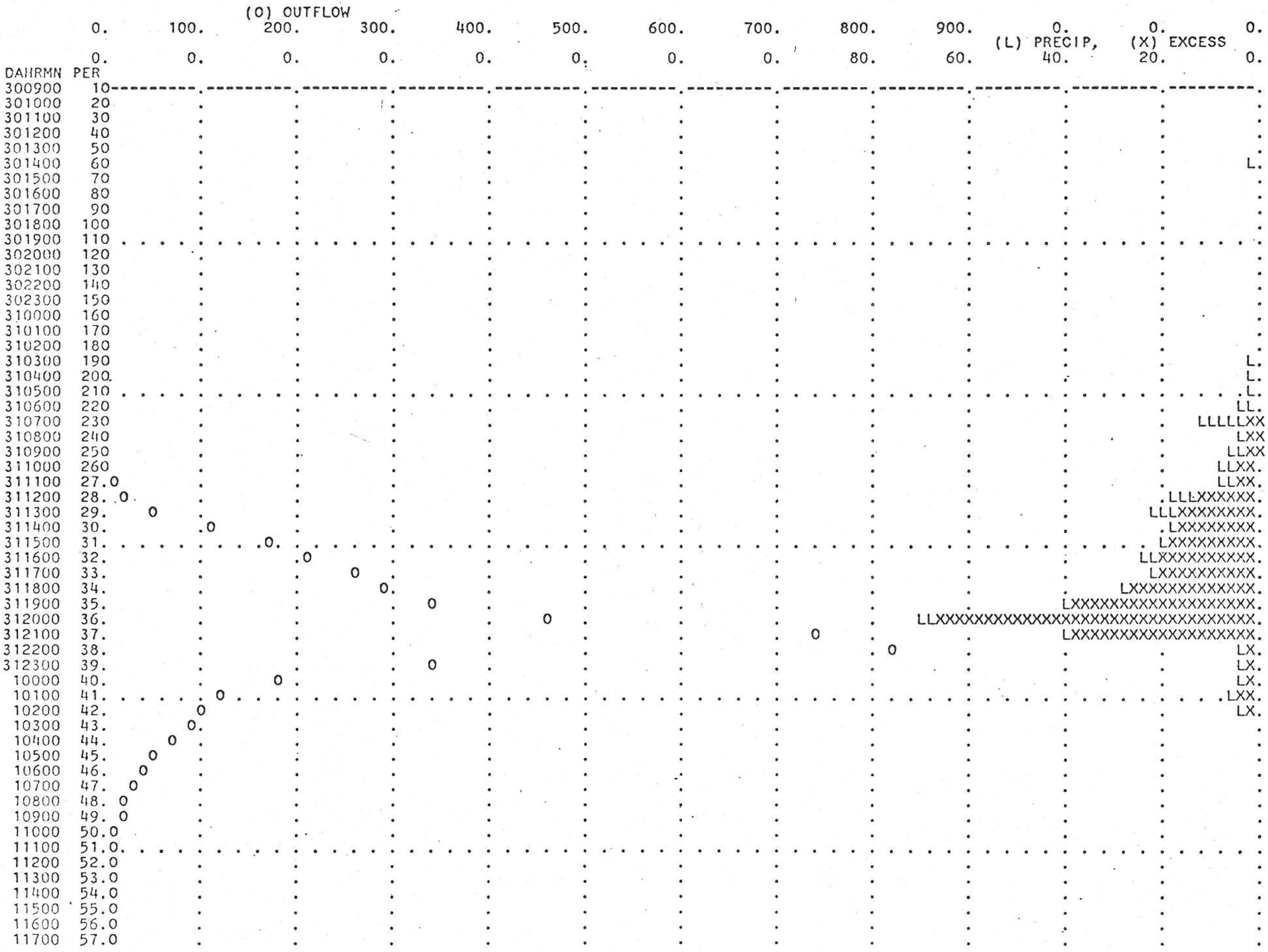
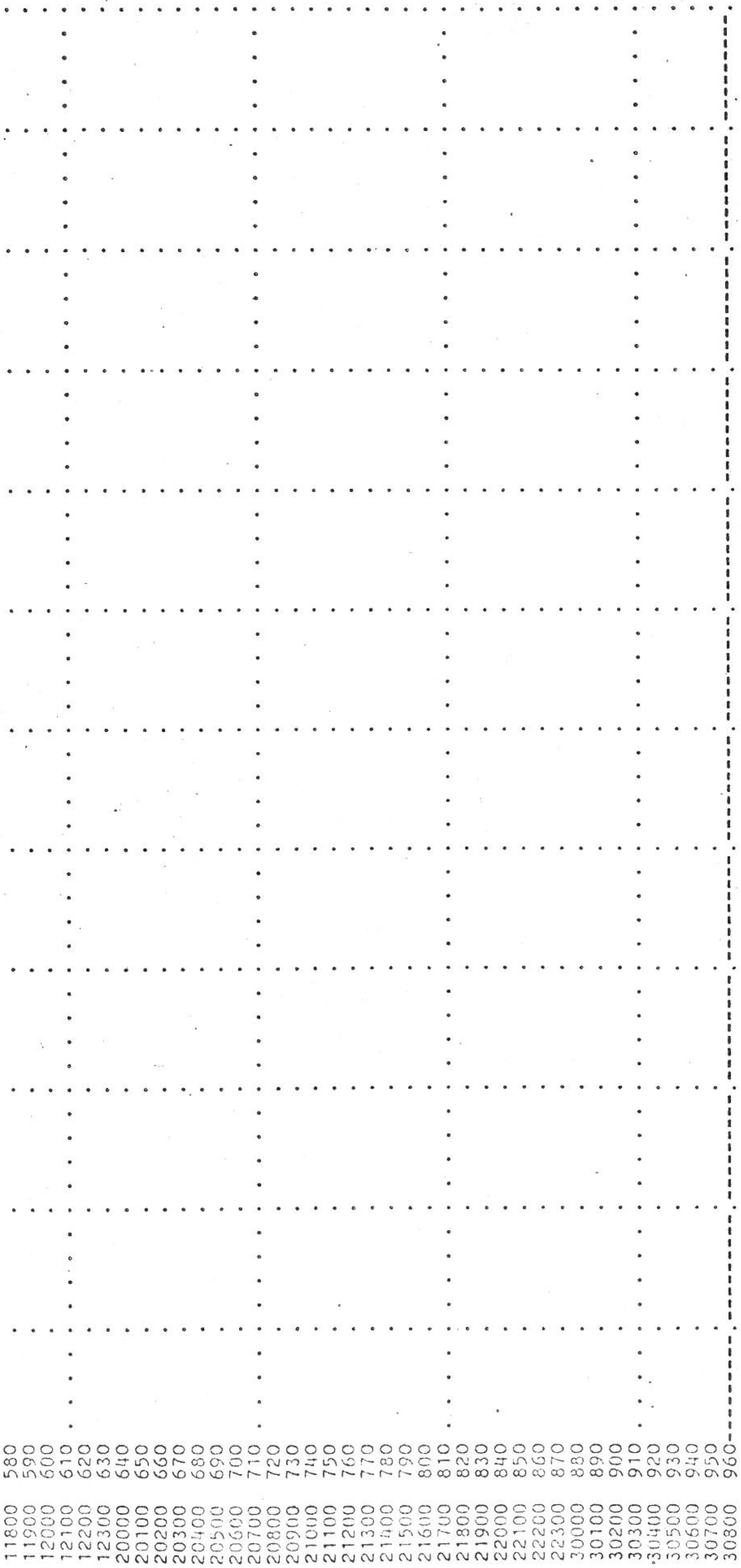
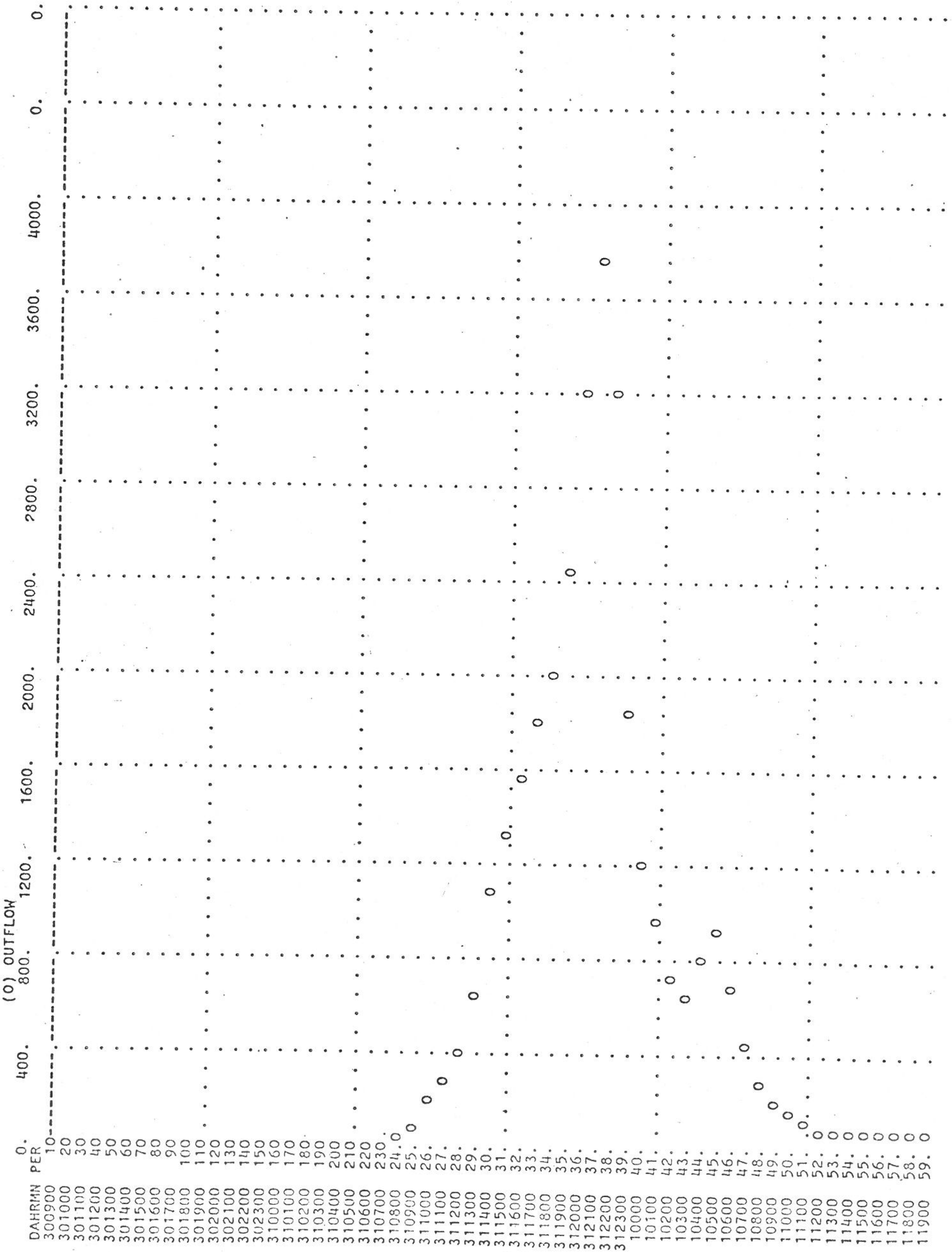
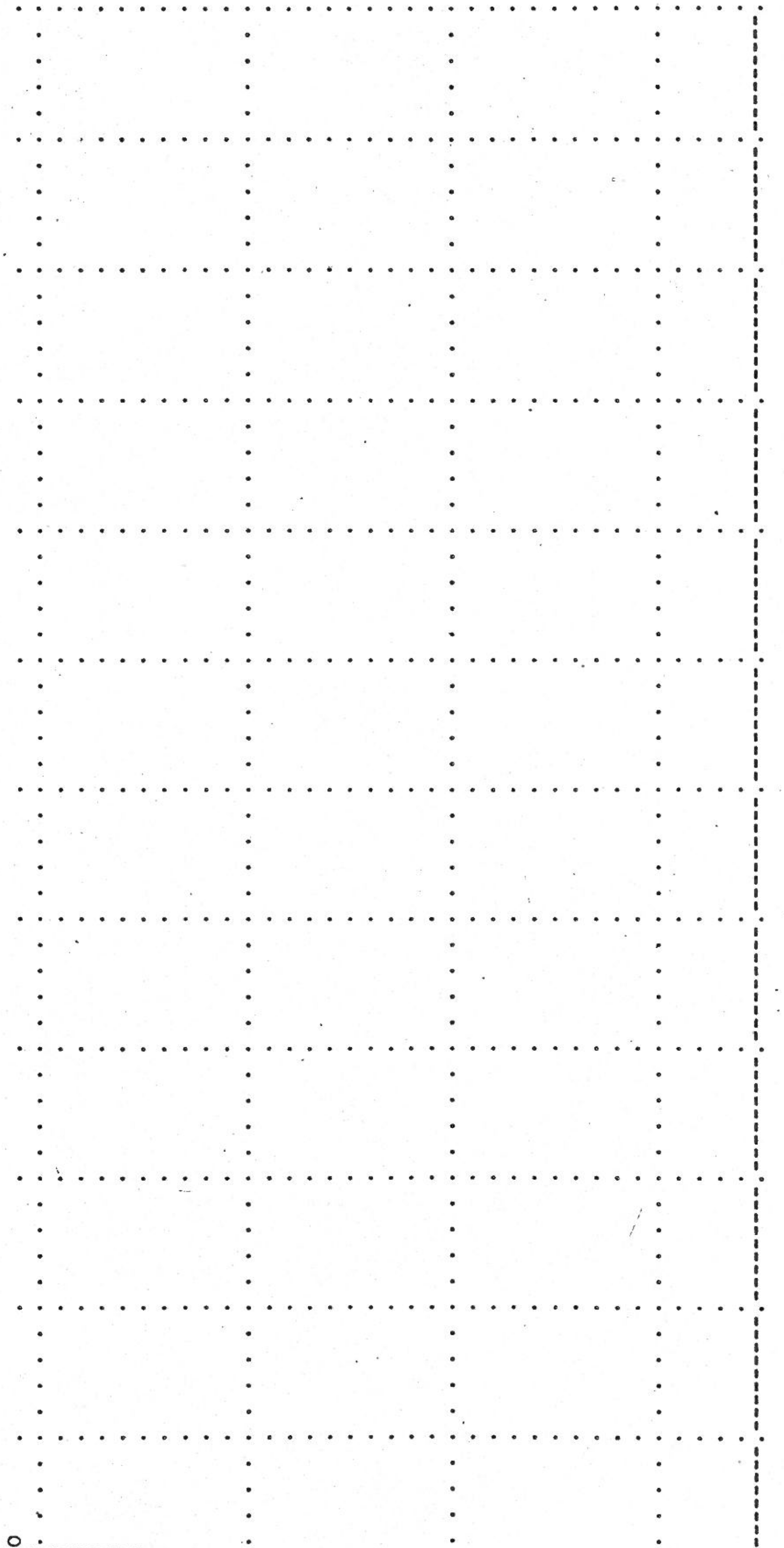

STATION SUB2B




11800 580
11900 590
12000 600
12100 610
12200 620
12300 630
20000 640
20100 650
20200 660
20300 670
20400 680
20500 690
20600 700
20700 710
20800 720
20900 730
21000 740
21100 750
21200 760
21300 770
21400 780
21500 790
21600 800
21700 810
21800 820
21900 830
22000 840
22100 850
22200 860
22300 870
30000 880
30100 890
30200 900
30300 910
30400 920
30500 930
30600 940
30700 950
30800 960

```
*** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** ***

           *************
           *           *
 109 KK    *   SUB2C   *
           *           *
           *************
                          COMBINE RUNOFF FROM SUB2A AND SUB2B

 111 HC         HYDROGRAPH COMBINATION
                      ICOMP          2  NUMBER OF HYDROGRAPHS TO COMBINE

                                                ***

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

                                          HYDROGRAPH AT STATION    SUB2C
                                             SUM OF  2 HYDROGRAPHS

*************************************************************************************************************************************
                                 *                                *                                *
  DA MON HRMN  ORD       FLOW    *  DA MON HRMN  ORD       FLOW   *  DA MON HRMN  ORD       FLOW   *  DA MON HRMN  ORD       FLOW
                                 *                                *                                *
  30 AUG 0900    1         0.    *  31 AUG 0900   25        86.   *   1 SEP 0900   49       196.   *   2 SEP 0900   73         9.
  30 AUG 1000    2         0.    *  31 AUG 1000   26       185.   *   1 SEP 1000   50       146.   *   2 SEP 1000   74         8.
  30 AUG 1100    3         0.    *  31 AUG 1100   27       288.   *   1 SEP 1100   51       115.   *   2 SEP 1100   75         8.
  30 AUG 1200    4         0.    *  31 AUG 1200   28       386.   *   1 SEP 1200   52        96.   *   2 SEP 1200   76         7.
  30 AUG 1300    5         0.    *  31 AUG 1300   29       626.   *   1 SEP 1300   53        90.   *   2 SEP 1300   77         6.
  30 AUG 1400    6         0.    *  31 AUG 1400   30      1067.   *   1 SEP 1400   54        94.   *   2 SEP 1400   78         6.
  30 AUG 1500    7         0.    *  31 AUG 1500   31      1332.   *   1 SEP 1500   55       100.   *   2 SEP 1500   79         5.
  30 AUG 1600    8         0.    *  31 AUG 1600   32      1560.   *   1 SEP 1600   56        97.   *   2 SEP 1600   80         5.
  30 AUG 1700    9         0.    *  31 AUG 1700   33      1806.   *   1 SEP 1700   57        87.   *   2 SEP 1700   81         5.
  30 AUG 1800   10         0.    *  31 AUG 1800   34      1987.   *   1 SEP 1800   58        77.   *   2 SEP 1800   82         4.
  30 AUG 1900   11         0.    *  31 AUG 1900   35      2452.   *   1 SEP 1900   59        69.   *   2 SEP 1900   83         4.
  30 AUG 2000   12         0.    *  31 AUG 2000   36      3212.   *   1 SEP 2000   60        61.   *   2 SEP 2000   84         4.
  30 AUG 2100   13         0.    *  31 AUG 2100   37      3764.   *   1 SEP 2100   61        53.   *   2 SEP 2100   85         4.
  30 AUG 2200   14         0.    *  31 AUG 2200   38      3181.   *   1 SEP 2200   62        44.   *   2 SEP 2200   86         3.
  30 AUG 2300   15         0.    *  31 AUG 2300   39      1836.   *   1 SEP 2300   63        37.   *   2 SEP 2300   87         3.
  31 AUG 0000   16         0.    *   1 SEP 0000   40      1190.   *   2 SEP 0000   64        31.   *   3 SEP 0000   88         3.
  31 AUG 0100   17         0.    *   1 SEP 0100   41       953.   *   2 SEP 0100   65        26.   *   3 SEP 0100   89         3.
  31 AUG 0200   18         0.    *   1 SEP 0200   42       731.   *   2 SEP 0200   66        22.   *   3 SEP 0200   90         3.
  31 AUG 0300   19         0.    *   1 SEP 0300   43       643.   *   2 SEP 0300   67        19.   *   3 SEP 0300   91         2.
  31 AUG 0400   20         0.    *   1 SEP 0400   44       784.   *   2 SEP 0400   68        17.   *   3 SEP 0400   92         2.
  31 AUG 0500   21         0.    *   1 SEP 0500   45       920.   *   2 SEP 0500   69        15.   *   3 SEP 0500   93         2.
  31 AUG 0600   22         0.    *   1 SEP 0600   46       688.   *   2 SEP 0600   70        13.   *   3 SEP 0600   94         2.
  31 AUG 0700   23         0.    *   1 SEP 0700   47       438.   *   2 SEP 0700   71        12.   *   3 SEP 0700   95         2.
  31 AUG 0800   24        28.    *   1 SEP 0800   48       282.   *   2 SEP 0800   72        10.   *   3 SEP 0800   96         2.
                                 *                                *                                *
*************************************************************************************************************************************

 PEAK FLOW      TIME                          MAXIMUM AVERAGE FLOW
                                      6-HR          24-HR          72-HR        95.00-HR
 (CU M/S)       (HR)
                         (CU M/S)
   3764.        36.00                2736.          1270.           445.           337.
                             (MM)  223.022        414.168        435.419        435.444
                      (1000 CU M)   59101.        109754.        115386.        115393.

                   CUMULATIVE AREA =   265.00 SQ KM
```


STATION SUB2C
(O) OUTFLOW
0.
400.
800.
1200.
1600.
2000.
2400.
2800.
3200.
3600.
4000.
0.
0.
DAHRMN PER
300900 10
301000 20
301100 30
301200 40
301300 50
301400 60
301500 70
301600 80
301700 90
301800 100
301900 110
302000 120
302100 130
302200 140
302300 150
310000 160
310100 170
310200 180
310300 190
310400 200
310500 210
310600 220
310700 230
310800 24.
310900 25.
311000 26.
311100 27.
311200 28.
311300 29.
311400 30.
311500 31.
311600 32.
311700 33.
311800 34.
311900 35.
312000 36.
312100 37.
312200 38.
312300 39.
10000 40.
10100 41.
10200 42.
10300 43.
10400 44.
10500 45.
10600 46.
10700 47.
10800 48.
10900 49.
11000 50.
11100 51.
11200 52.
11300 53.
11400 54.
11500 55.
11600 56.
11700 57.
11800 58.
11900 59.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12100 61.0
12200 62.0
12300 63.0
20000 64.0
20100 65.0
20200 66.0
20300 670
20400 680
20500 690
20600 700
20700 710
20800 720
20900 730
21000 740
21100 750
21200 760
21300 770
21400 780
21500 790
21600 800
21700 810
21800 820
21900 830
22000 840
22100 850
22200 860
22300 870
30000 880
30100 890
30200 900
30300 910
30400 920
30500 930
30600 940
30700 950
30800 960

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

              **************
              *            *
112 KK        *    RESER   *
              *            *
              **************
                             ROUTE FLOW THROUGH RESERVOIR

                HYDROGRAPH ROUTING DATA

114 RS            STORAGE ROUTING
                       NSTPS           1  NUMBER OF SUBREACHES
                        ITYP         0.0  TYPE OF INITIAL CONDITION
                      RSVRIC         .00  INITIAL CONDITION
                           X         .00  WORKING R AND D COEFFICIENT

115 SV            STORAGE          .0       3.5      27.8      93.8     222.2     434.0     750.0    1191.0    1777.8    2531.3
                               3472.2    4621.5    6000.0

117 SE            ELEVATION       .00       .50      1.00      1.50      2.00      2.50      3.00      3.50      4.00      4.50
                                 5.00      5.50      6.00

119 SQ            DISCHARGE        0.       49.      156.      305.      490.      707.      953.     1227.     1525.     1847.
                                2192.     2557.     2943.

                                                            ***

*** WARNING *** MODIFIED PULS ROUTING MAY BE NUMERICALLY UNSTABLE FOR OUTFLOWS BETWEEN          0. TO      1227.
                THE ROUTED HYDROGRAPH SHOULD BE EXAMINED FOR OSCILLATIONS OR OUTFLOWS GREATER THAN PEAK INFLOWS.
                THIS CAN BE CORRECTED BY DECREASING THE TIME INTERVAL OR INCREASING STORAGE (USE A LONGER REACH.)
*******************************************************************************************************************************

                                          HYDROGRAPH AT STATION    RESER

*******************************************************************************************************************************
                                                 *                                                   *
DA MON HRMN ORD   OUTFLOW   STORAGE      STAGE   * DA MON HRMN ORD   OUTFLOW   STORAGE      STAGE    * DA MON HRMN ORD   OUTFLOW   STORAGE      STAGE
                                                 *                                                   *
30 AUG 0900   1        0.        .0         .0   * 31 AUG 1700  33     1659.    2091.1        4.2    *  2 SEP 0100  65       26.       1.8         .3
30 AUG 1000   2        0.        .0         .0   * 31 AUG 1800  34     1864.    2577.9        4.5    *  2 SEP 0200  66       22.       1.6         .2
30 AUG 1100   3        0.        .0         .0   * 31 AUG 1900  35     2147.    3348.3        4.9    *  2 SEP 0300  67       19.       1.4         .2
30 AUG 1200   4        0.        .0         .0   * 31 AUG 2000  36     2641.    4923.2        5.6    *  2 SEP 0400  68       17.       1.2         .2
30 AUG 1300   5        0.        .0         .0   * 31 AUG 2100  37     3209.    6948.3        6.3    *  2 SEP 0500  69       15.       1.0         .1
30 AUG 1400   6        0.        .0         .0   * 31 AUG 2200  38     3385.    7579.4        6.6    *  2 SEP 0600  70       13.        .9         .1
30 AUG 1500   7        0.        .0         .0   * 31 AUG 2300  39     2798.    5481.7        5.8    *  2 SEP 0700  71       12.        .8         .1
30 AUG 1600   8        0.        .0         .0   *  1 SEP 0000  40     1856.    2554.5        4.5    *  2 SEP 0800  72       10.        .7         .1
30 AUG 1700   9        0.        .0         .0   *  1 SEP 0100  41     1131.    1036.6        3.3    *  2 SEP 0900  73        9.        .7         .1
30 AUG 1800  10        0.        .0         .0   *  1 SEP 0200  42      812.     569.5        2.7    *  2 SEP 1000  74        9.        .6         .1
30 AUG 1900  11        0.        .0         .0   *  1 SEP 0300  43      661.     389.4        2.4    *  2 SEP 1100  75        8.        .5         .1
30 AUG 2000  12        0.        .0         .0   *  1 SEP 0400  44      727.     459.2        2.5    *  2 SEP 1200  76        7.        .5         .1
30 AUG 2100  13        0.        .0         .0   *  1 SEP 0500  45      873.     647.5        2.8    *  2 SEP 1300  77        6.        .5         .1
30 AUG 2200  14        0.        .0         .0   *  1 SEP 0600  46      793.     544.0        2.7    *  2 SEP 1400  78        6.        .4         .1
30 AUG 2300  15        0.        .0         .0   *  1 SEP 0700  47      504.     236.2        2.0    *  2 SEP 1500  79        5.        .4         .1
31 AUG 0000  16        0.        .0         .0   *  1 SEP 0800  48      297.      90.3        1.5    *  2 SEP 1600  80        5.        .4         .1
31 AUG 0100  17        0.        .0         .0   *  1 SEP 0900  49      204.      49.1        1.2    *  2 SEP 1700  81        5.        .3         .0
31 AUG 0200  18        0.        .0         .0   *  1 SEP 1000  50      150.      26.5        1.0    *  2 SEP 1800  82        4.        .3         .0
31 AUG 0300  19        0.        .0         .0   *  1 SEP 1100  51      115.      18.6         .8    *  2 SEP 1900  83        4.        .3         .0
31 AUG 0400  20        0.        .0         .0   *  1 SEP 1200  52       98.      14.7         .7    *  2 SEP 2000  84        4.        .3         .0
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 31 AUG 0500  21      0.       .0       .0 *  1 SEP 1300  53      89.     12.5      .7 *  2 SEP 2100  85       4.      .3      .0
 31 AUG 0600  22      0.       .0       .0 *  1 SEP 1400  54      94.     13.7      .7 *  2 SEP 2200  86       3.      .2      .0
 31 AUG 0700  23      0.       .0       .0 *  1 SEP 1500  55      99.     14.8      .7 *  2 SEP 2300  87       3.      .2      .0
 31 AUG 0800  24     27.      1.9       .3 *  1 SEP 1600  56      98.     14.6      .7 *  3 SEP 0000  88       3.      .2      .0
 31 AUG 0900  25     82.     11.0       .7 *  1 SEP 1700  57      87.     12.2      .7 *  3 SEP 0100  89       3.      .2      .0
 31 AUG 1000  26    175.     36.3      1.1 *  1 SEP 1800  58      78.      9.9      .6 *  3 SEP 0200  90       3.      .2      .0
 31 AUG 1100  27    274.     80.1      1.4 *  1 SEP 1900  59      69.      8.0      .6 *  3 SEP 0300  91       2.      .2      .0
 31 AUG 1200  28    368.    137.5      1.7 *  1 SEP 2000  60      62.      6.3      .6 *  3 SEP 0400  92       2.      .2      .0
 31 AUG 1300  29    559.    289.7      2.2 *  1 SEP 2100  61      53.      4.3      .5 *  3 SEP 0500  93       2.      .2      .0
 31 AUG 1400  30    909.    693.7      2.9 *  1 SEP 2200  62      45.      3.2      .5 *  3 SEP 0600  94       2.      .1      .0
 31 AUG 1500  31   1220.   1179.1      3.5 *  1 SEP 2300  63      37.      2.6      .4 *  3 SEP 0700  95       2.      .1      .0
 31 AUG 1600  32   1436.   1603.4      3.9 *  2 SEP 0000  64      31.      2.2      .3 *  3 SEP 0800  96       2.      .1      .0
                                           *                                           *
*************************************************************************************************************************************

  PEAK FLOW      TIME                           MAXIMUM AVERAGE FLOW
                                       6-HR          24-HR         72-HR        95.00-HR
  (CU M/S)       (HR)
                          (CU M/S)
    3385.       37.00                 2673.          1270.          445.           337.
                              (MM)  217.895        414.205       435.419        435.444
                       (1000 CU M)   57742.        109764.       115386.        115393.

 PEAK STORAGE    TIME                          MAXIMUM AVERAGE STORAGE
                                       6-HR          24-HR         72-HR        95.00-HR
 (1000 CU M)     (HR)
      7579.     37.00                 5141.          1814.          607.           460.

  PEAK STAGE     TIME                           MAXIMUM AVERAGE STAGE
                                       6-HR          24-HR         72-HR        95.00-HR
  (METERS)       (HR)
       6.57     37.00                  5.63           3.34          1.29            .98

                      CUMULATIVE AREA =   265.00 SQ KM
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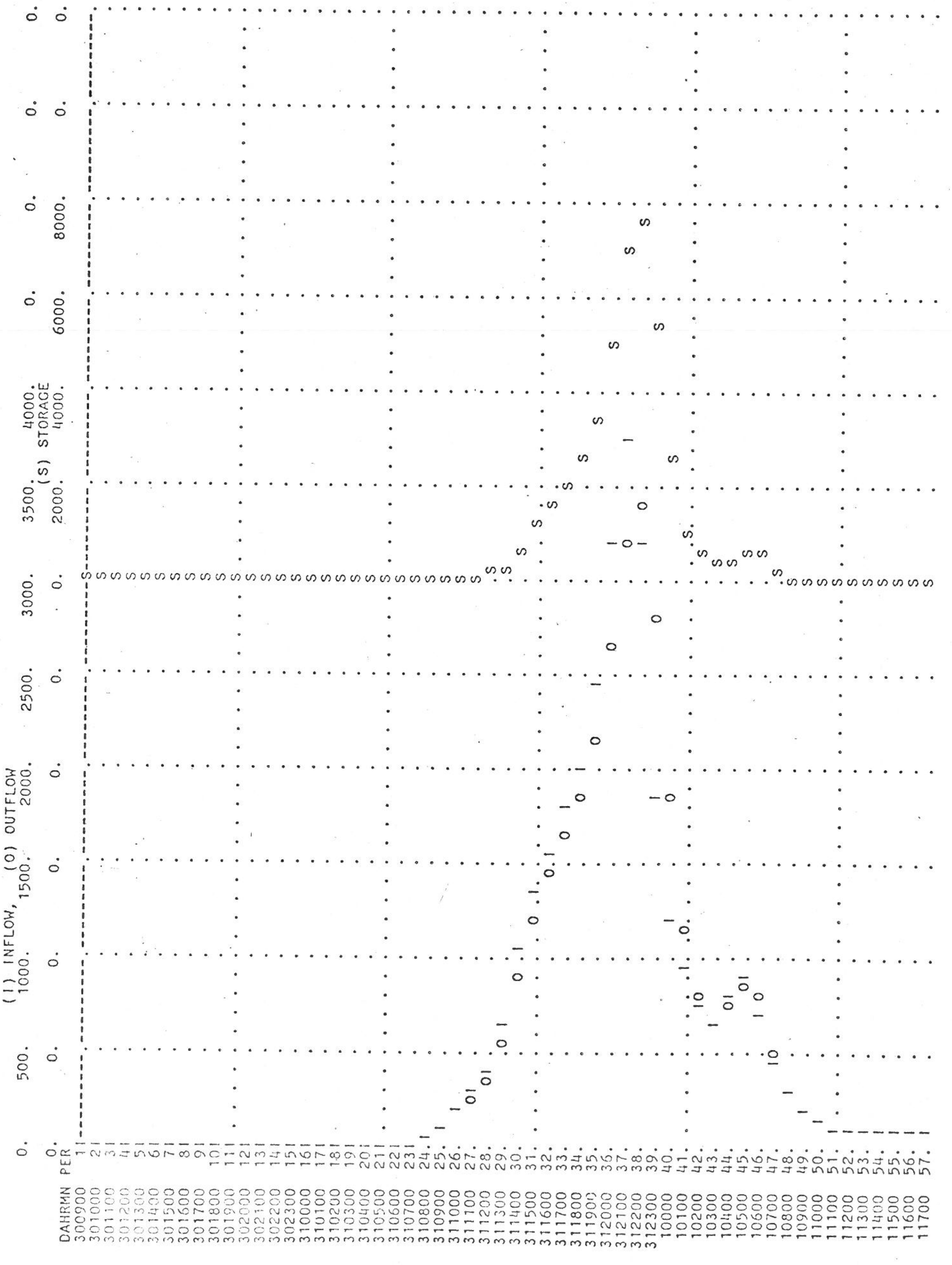
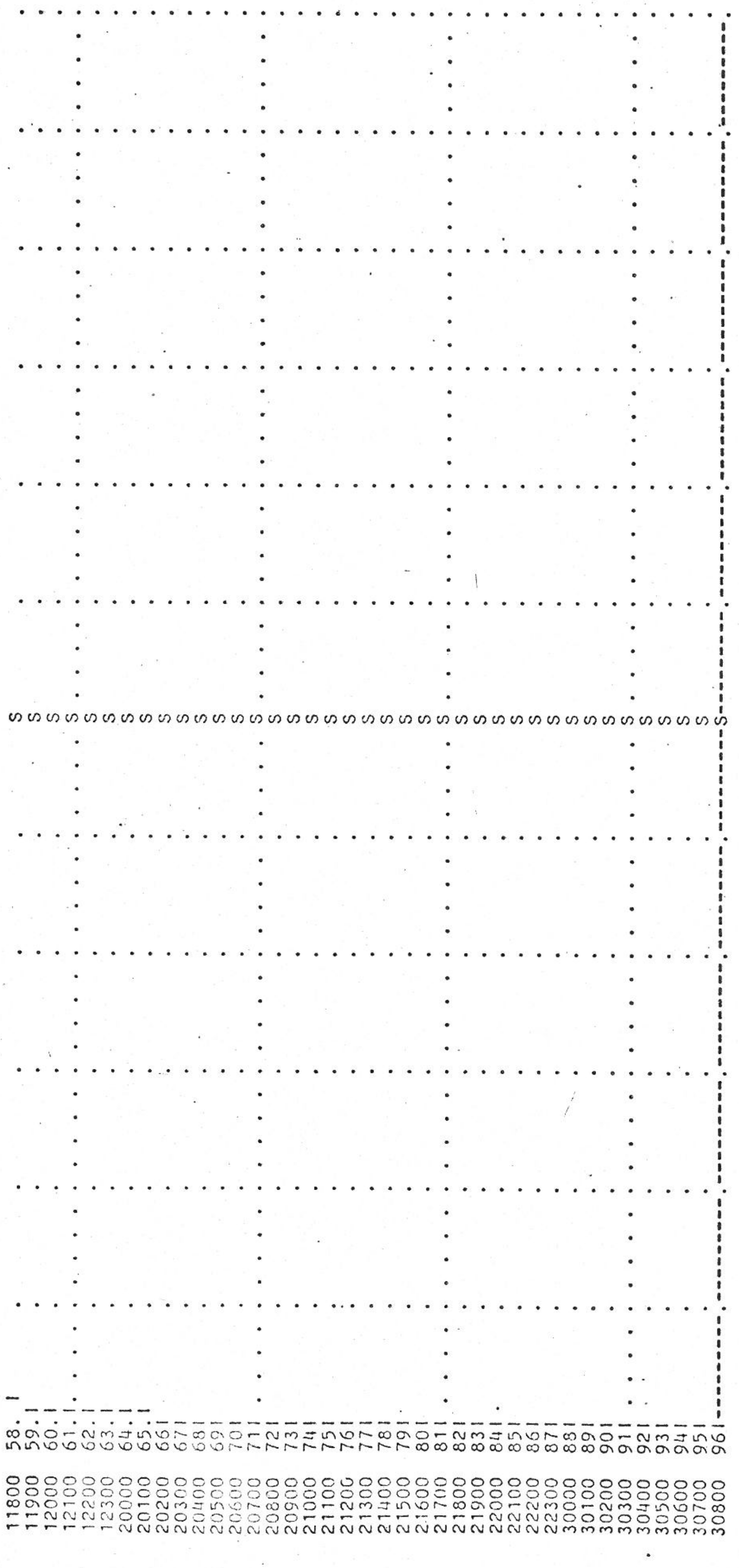

STATION RESER
(I) INFLOW, (O) OUTFLOW
(S) STORAGE
0.
500.
1000.
1500.
2000.
2500.
3000.
3500.
4000.
0.
2000.
4000.
6000.
8000.
DAHRMN
PER
300900 1
301000 2
301100 3
301200 4
301300 5
301400 6
301500 7
301600 8
301700 9
301800 10
301900 11
302000 12
302100 13
302200 14
302300 15
310000 16
310100 17
310200 18
310300 19
310400 20
310500 21
310600 22
310700 23
310800 24.
310900 25.
311000 26.
311100 27.
311200 28.
311300 29.
311400 30.
311500 31.
311600 32.
311700 33.
311800 34.
311900 35.
312000 36.
312100 37.
312200 38.
312300 39.
10000 40.
10100 41.
10200 42.
10300 43.
10400 44.
10500 45.
10600 46.
10700 47.
10800 48.
10900 49.
11000 50.
11100 51.
11200 52.
11300 53.
11400 54.
11500 55.
11600 56.
11700 57.



11800 58.
11900 59.
12000 60.
12100 61.
12200 62.
12300 63.
20000 64.
20100 65.
20200 66
20300 67
20400 68
20500 69
20600 70
20700 71
20800 72
20900 73
21000 74
21100 75
21200 76
21300 77
21400 78
21500 79
21600 80
21700 81
21800 82
21900 83
22000 84
22100 85
22200 86
22300 87
30000 88
30100 89
30200 90
30300 91
30400 92
30500 93
30600 94
30700 95
30800 96
S

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

              *************
              *           *
121 KK        *   SUB2C   *
              *           *
              *************
                            RUNOFF FROM SUBBASIN 2C

               SUBBASIN RUNOFF DATA

127 BA          SUBBASIN CHARACTERISTICS
                      TAREA       164.00  SUBBASIN AREA

                PRECIPITATION DATA

125 PT           TOTAL STORM STATIONS        20
126 PW                       WEIGHTS       1.00

123 PR            RECORDING STATIONS          7
124 PW                       WEIGHTS       1.00

128 LS          SCS LOSS RATE
                      STRTL        12.70  INITIAL ABSTRACTION
                     CRVNBR        80.00  CURVE NUMBER
                     RTIMP          .00  PERCENT IMPERVIOUS AREA

                KINEMATIC WAVE
129 UK            OVERLAND-FLOW ELEMENT NO. 1
                          L        4500.  OVERLAND FLOW LENGTH
                          S        .4000  SLOPE
                          N         .300  ROUGHNESS COEFFICIENT
                         PA        100.0  PERCENT OF SUBBASIN
130 RK            MAIN CHANNEL
                          L       21000.  CHANNEL LENGTH
                          S        .0086  SLOPE
                          N         .022  CHANNEL ROUGHNESS COEFFICIENT
                         CA       164.00  CONTRIBUTING AREA
                      SHAPE         TRAP  CHANNEL SHAPE
                         WD        70.00  BOTTOM WIDTH OR DIAMETER
                          Z        10.00  SIDE SLOPE
                     RUPSTQ          YES  ROUTE UPSTREAM HYDROGRAPH

                                                       ***

              PRECIPITATION STATION DATA

                    STATION    TOTAL     AVG. ANNUAL    WEIGHT
                         20   300.00          .00         1.00

               TEMPORAL DISTRIBUTIONS

               STATION       7,  WEIGHT =   1.00
                    .00      .00      .00      .00      .00      .00      .00      .00      .00      .00
                    .00      .00      .00      .00      .00      .00      .00     4.00     1.00     1.00
                   8.00     3.00     3.50     3.50     5.00     5.00    10.00     9.00    13.00    12.00
                  12.00    12.00    16.00    12.00    64.00    56.00    10.00    10.00     8.00    12.00
                  10.00

           COMPUTED KINEMATIC PARAMETERS
```

```
        ELEMENT     ALPHA         M      DT (MIN)    DX (FT)
              1    3.1412     1.667       60.00      7381.89
              3     .2454     1.581       60.00     34448.82

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

                                       HYDROGRAPH AT STATION     SUB2C

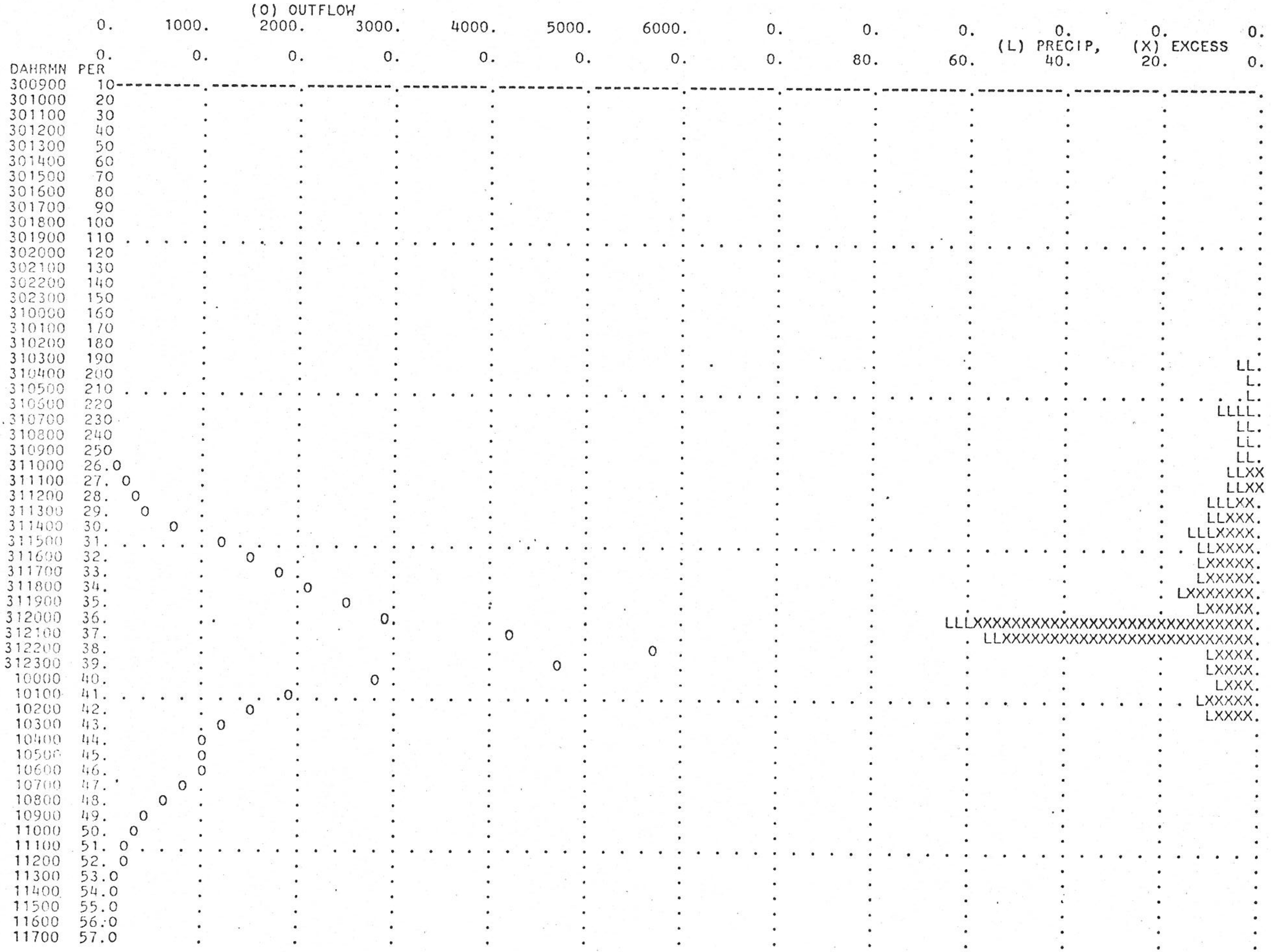
*************************************************************************************************************************
                                                              *
  DA MON HRMN  ORD     RAIN    LOSS  EXCESS     COMP Q        *   DA MON HRMN  ORD    RAIN    LOSS  EXCESS     COMP Q
                                                              *
  30 AUG 0900    1      .00     .00     .00         0.        *    1 SEP 0900   49     .00     .00     .00       375.
  30 AUG 1000    2      .00     .00     .00         0.        *    1 SEP 1000   50     .00     .00     .00       267.
  30 AUG 1100    3      .00     .00     .00         0.        *    1 SEP 1100   51     .00     .00     .00       203.
  30 AUG 1200    4      .00     .00     .00         0.        *    1 SEP 1200   52     .00     .00     .00       161.
  30 AUG 1300    5      .00     .00     .00         0.        *    1 SEP 1300   53     .00     .00     .00       133.
  30 AUG 1400    6      .00     .00     .00         0.        *    1 SEP 1400   54     .00     .00     .00       117.
  30 AUG 1500    7      .00     .00     .00         0.        *    1 SEP 1500   55     .00     .00     .00       111.
  30 AUG 1600    8      .00     .00     .00         0.        *    1 SEP 1600   56     .00     .00     .00       113.
  30 AUG 1700    9      .00     .00     .00         0.        *    1 SEP 1700   57     .00     .00     .00       113.
  30 AUG 1800   10      .00     .00     .00         0.        *    1 SEP 1800   58     .00     .00     .00       106.
  30 AUG 1900   11      .00     .00     .00         0.        *    1 SEP 1900   59     .00     .00     .00        95.
  30 AUG 2000   12      .00     .00     .00         0.        *    1 SEP 2000   60     .00     .00     .00        85.
  30 AUG 2100   13      .00     .00     .00         0.        *    1 SEP 2100   61     .00     .00     .00        76.
  30 AUG 2200   14      .00     .00     .00         0.        *    1 SEP 2200   62     .00     .00     .00        68.
  30 AUG 2300   15      .00     .00     .00         0.        *    1 SEP 2300   63     .00     .00     .00        60.
  31 AUG 0000   16      .00     .00     .00         0.        *    2 SEP 0000   64     .00     .00     .00        51.
  31 AUG 0100   17      .00     .00     .00         0.        *    2 SEP 0100   65     .00     .00     .00        44.
  31 AUG 0200   18      .00     .00     .00         0.        *    2 SEP 0200   66     .00     .00     .00        38.
  31 AUG 0300   19     4.00    4.00     .00         0.        *    2 SEP 0300   67     .00     .00     .00        29.
  31 AUG 0400   20     1.00    1.00     .00         0.        *    2 SEP 0400   68     .00     .00     .00        26.
  31 AUG 0500   21     1.00    1.00     .00         0.        *    2 SEP 0500   69     .00     .00     .00        23.
  31 AUG 0600   22     8.00    7.97     .03         0.        *    2 SEP 0600   70     .00     .00     .00        20.
  31 AUG 0700   23     3.00    2.75     .25         0.        *    2 SEP 0700   71     .00     .00     .00        18.
  31 AUG 0800   24     3.50    2.92     .58         0.        *    2 SEP 0800   72     .00     .00     .00        17.
  31 AUG 0900   25     3.50    2.65     .85         3.        *    2 SEP 0900   73     .00     .00     .00        15.
  31 AUG 1000   26     5.00    3.38    1.62        90.        *    2 SEP 1000   74     .00     .00     .00        14.
  31 AUG 1100   27     5.00    2.98    2.02       159.        *    2 SEP 1100   75     .00     .00     .00        13.
  31 AUG 1200   28    10.00    5.02    4.98       282.        *    2 SEP 1200   76     .00     .00     .00        12.
  31 AUG 1300   29     9.00    3.69    5.31       443.        *    2 SEP 1300   77     .00     .00     .00        11.
  31 AUG 1400   30    13.00    4.32    8.68       739.        *    2 SEP 1400   78     .00     .00     .00        10.
  31 AUG 1500   31    12.00    3.22    8.78      1153.        *    2 SEP 1500   79     .00     .00     .00         9.
  31 AUG 1600   32    12.00    2.67    9.33      1520.        *    2 SEP 1600   80     .00     .00     .00         9.
  31 AUG 1700   33    12.00    2.25    9.75      1833.        *    2 SEP 1700   81     .00     .00     .00         8.
  31 AUG 1800   34    16.00    2.50   13.50      2113.        *    2 SEP 1800   82     .00     .00     .00         8.
  31 AUG 1900   35    12.00    1.59   10.41      2461.        *    2 SEP 1900   83     .00     .00     .00         7.
  31 AUG 2000   36    64.00    5.83   58.17      2904.        *    2 SEP 2000   84     .00     .00     .00         7.
  31 AUG 2100   37    56.00    3.07   52.93      4250.        *    2 SEP 2100   85     .00     .00     .00         6.
  31 AUG 2200   38    10.00     .43    9.57      5714.        *    2 SEP 2200   86     .00     .00     .00         6.
  31 AUG 2300   39    10.00     .40    9.60      4724.        *    2 SEP 2300   87     .00     .00     .00         6.
   1 SEP 0000   40     8.00     .31    7.69      2827.        *    3 SEP 0000   88     .00     .00     .00         5.
   1 SEP 0100   41    12.00     .43   11.57      1925.        *    3 SEP 0100   89     .00     .00     .00         5.
   1 SEP 0200   42    10.00     .34    9.66      1464.        *    3 SEP 0200   90     .00     .00     .00         5.
   1 SEP 0300   43      .00     .00     .00      1217.        *    3 SEP 0300   91     .00     .00     .00         4.
   1 SEP 0400   44      .00     .00     .00      1023.        *    3 SEP 0400   92     .00     .00     .00         4.
   1 SEP 0500   45      .00     .00     .00       989.        *    3 SEP 0500   93     .00     .00     .00         4.
   1 SEP 0600   46      .00     .00     .00       961.        *    3 SEP 0600   94     .00     .00     .00         4.
   1 SEP 0700   47      .00     .00     .00       784.        *    3 SEP 0700   95     .00     .00     .00         4.
   1 SEP 0800   48      .00     .00     .00       553.        *    3 SEP 0800   96     .00     .00     .00         3.
                                                              *
*************************************************************************************************************************

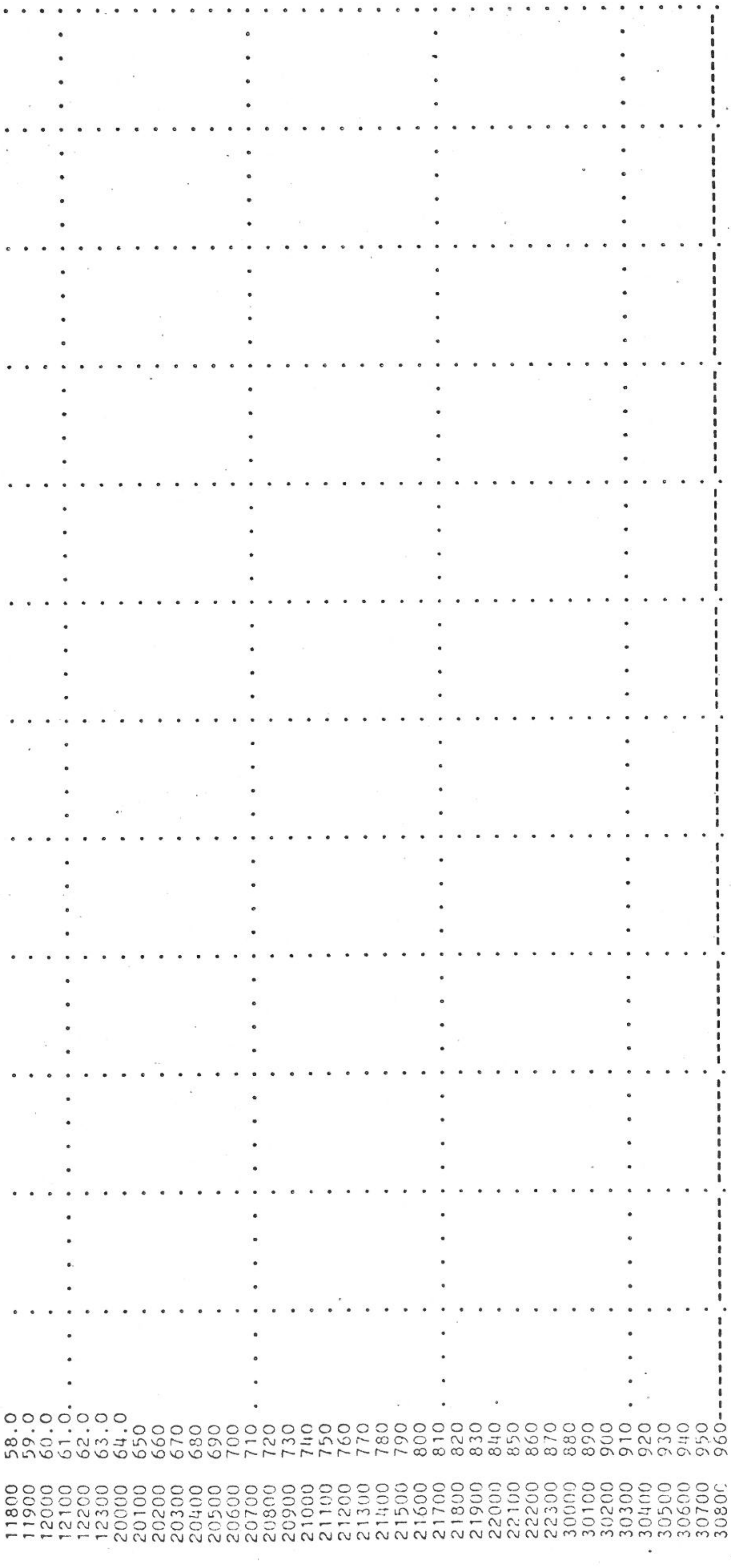
   TOTAL RAINFALL =   300.00, TOTAL LOSS =    64.71, TOTAL EXCESS =   235.29
```

```
                                                   MAXIMUM AVERAGE FLOW
PEAK FLOW      TIME                       6-HR         24-HR      72-HR       95.00-HR

(CU M/S)       (HR)                                                               449.
                          (CU M/S)       3769.         1696.        592.        357.951
  5714.        37.00                   189.753       341.562     357.951       153561.
                              (MM)       81404.       146530.     153561.
                         (1000 CU M)
                            CUMULATIVE AREA =     429.00 SQ KM
```

STATION SUB2C

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12100 61.0
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20000 64.0
20100 650
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20300 670
20400 680
20500 690
20600 700
20700 710
20800 720
20900 730
21000 740
21100 750
21200 760
21300 770
21400 780
21500 790
21600 800
21700 810
21800 820
21900 830
22000 840
22100 850
22200 860
22300 870
30000 880
30100 890
30200 900
30300 910
30400 920
30500 930
30600 940
30700 950
30800 960

```
*** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** ***

                 *************
                 *           *
 131 KK          *    SUB3   *
                 *           *
                 *************
                                  RUNOFF FROM SUBBASIN 3

                    SUBBASIN RUNOFF DATA

 137 BA               SUBBASIN CHARACTERISTICS
                            TAREA      106.00  SUBBASIN AREA

                      PRECIPITATION DATA

 135 PT                TOTAL STORM STATIONS        20         30         60
 136 PW                              WEIGHTS      .75        .05        .20

 133 PR                  RECORDING STATIONS         3          7
 134 PW                              WEIGHTS      .05        .95

 138 LS               SCS LOSS RATE
                            STRTL       12.70  INITIAL ABSTRACTION
                           CRVNBR       80.00  CURVE NUMBER
                            RTIMP         .00  PERCENT IMPERVIOUS AREA

                      KINEMATIC WAVE
 139 UK                 OVERLAND-FLOW ELEMENT NO. 1
                                L       2000.  OVERLAND FLOW LENGTH
                                S       .4000  SLOPE
                                N        .300  ROUGHNESS COEFFICIENT
                               PA       100.0  PERCENT OF SUBBASIN
 140 RK                 MAIN CHANNEL
                                L      21500.  CHANNEL LENGTH
                                S       .0293  SLOPE
                                N        .030  CHANNEL ROUGHNESS COEFFICIENT
                               CA      106.00  CONTRIBUTING AREA
                            SHAPE        TRAP  CHANNEL SHAPE
                               WD       45.00  BOTTOM WIDTH OR DIAMETER
                                Z       10.00  SIDE SLOPE
                           RUPSTQ          NO  ROUTE UPSTREAM HYDROGRAPH

                                                                ***

                    PRECIPITATION STATION DATA

                             STATION     TOTAL     AVG. ANNUAL     WEIGHT
                                  20    300.00             .00        .75
                                  30    251.30             .00        .05
                                  60    359.50             .00        .20

                      TEMPORAL DISTRIBUTIONS

                      STATION          3,  WEIGHT =     .05
                            .00        .00        .00        .30       1.70       1.00        .30        .30        .30       1.00
                           1.00        .00        .00        .00        .00        .00        .00        .00       1.00       1.00
                           1.00      12.00       3.00       5.00       6.00       6.00      16.00      20.00      14.00      16.00
                          20.00      18.00      24.00      38.00      44.00      16.00        .00        .00        .00        .00
                            .00
```

```
      STATION          7,  WEIGHT =     .95
               .00       .00       .00       .00       .00       .00       .00       .00       .00       .00
               .00       .00       .00       .00       .00       .00       .00      4.00      1.00      1.00
              8.00      3.00      3.50      3.50      5.00      5.00     10.00      9.00     13.00     12.00
             12.00     12.00     16.00     12.00     64.00     56.00     10.00     10.00      8.00     12.00
             10.00

   COMPUTED KINEMATIC PARAMETERS
       ELEMENT      ALPHA          M        DT (MIN)     DX (FT)
             1     3.1412.     1.667         60.00      3280.84
             3      .4858      1.549         60.00     35269.03

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

                                         HYDROGRAPH AT STATION      SUB3

*************************************************************************************************************************
                                                                       *
    DA MON HRMN  ORD      RAIN     LOSS   EXCESS      COMP Q           *      DA MON HRMN  ORD      RAIN     LOSS   EXCESS       COMP Q
                                                                       *
    30 AUG 0900    1       .00      .00      .00          0.           *       1 SEP 0900   49       .00      .00      .00          16.
    30 AUG 1000    2       .00      .00      .00          0.           *       1 SEP 1000   50       .00      .00      .00          13.
    30 AUG 1100    3       .00      .00      .00          0.           *       1 SEP 1100   51       .00      .00      .00          10.
    30 AUG 1200    4       .00      .00      .00          0.           *       1 SEP 1200   52       .00      .00      .00           8.
    30 AUG 1300    5       .02      .02      .00          0.           *       1 SEP 1300   53       .00      .00      .00           7.
    30 AUG 1400    6       .09      .09      .00          0.           *       1 SEP 1400   54       .00      .00      .00           6.
    30 AUG 1500    7       .05      .05      .00          0.           *       1 SEP 1500   55       .00      .00      .00           5.
    30 AUG 1600    8       .02      .02      .00          0.           *       1 SEP 1600   56       .00      .00      .00           4.
    30 AUG 1700    9       .02      .02      .00          0.           *       1 SEP 1700   57       .00      .00      .00           4.
    30 AUG 1800   10       .02      .02      .00          0.           *       1 SEP 1800   58       .00      .00      .00           3.
    30 AUG 1900   11       .05      .05      .00          0.           *       1 SEP 1900   59       .00      .00      .00           3.
    30 AUG 2000   12       .05      .05      .00          0.           *       1 SEP 2000   60       .00      .00      .00           3.
    30 AUG 2100   13       .00      .00      .00          0.           *       1 SEP 2100   61       .00      .00      .00           2.
    30 AUG 2200   14       .00      .00      .00          0.           *       1 SEP 2200   62       .00      .00      .00           2.
    30 AUG 2300   15       .00      .00      .00          0.           *       1 SEP 2300   63       .00      .00      .00           2.
    31 AUG 0000   16       .00      .00      .00          0.           *       2 SEP 0000   64       .00      .00      .00           2.
    31 AUG 0100   17       .00      .00      .00          0.           *       2 SEP 0100   65       .00      .00      .00           2.
    31 AUG 0200   18       .00      .00      .00          0.           *       2 SEP 0200   66       .00      .00      .00           1.
    31 AUG 0300   19      3.94     3.94      .00          0.           *       2 SEP 0300   67       .00      .00      .00           1.
    31 AUG 0400   20      1.04     1.04      .00          0.           *       2 SEP 0400   68       .00      .00      .00           1.
    31 AUG 0500   21      1.04     1.04      .00          0.           *       2 SEP 0500   69       .00      .00      .00           1.
    31 AUG 0600   22      7.94     7.90      .04          0.           *       2 SEP 0600   70       .00      .00      .00           1.
    31 AUG 0700   23      3.58     3.23      .35          0.           *       2 SEP 0700   71       .00      .00      .00           1.
    31 AUG 0800   24      3.60     2.93      .67          0.           *       2 SEP 0800   72       .00      .00      .00           1.
    31 AUG 0900   25      3.71     2.73      .98          0.           *       2 SEP 0900   73       .00      .00      .00           1.
    31 AUG 1000   26      5.24     3.43     1.81          0.           *       2 SEP 1000   74       .00      .00      .00           1.
    31 AUG 1100   27      5.24     3.01     2.23          2.           *       2 SEP 1100   75       .00      .00      .00           1.
    31 AUG 1200   28     10.68     5.13     5.55          9.           *       2 SEP 1200   76       .00      .00      .00           1.
    31 AUG 1300   29      9.91     3.84     6.06         38.           *       2 SEP 1300   77       .00      .00      .00           1.
    31 AUG 1400   30     13.54     4.23     9.31         96.           *       2 SEP 1400   78       .00      .00      .00           1.
    31 AUG 1500   31     12.65     3.18     9.48        175.           *       2 SEP 1500   79       .00      .00      .00           1.
    31 AUG 1600   32     12.86     2.67    10.20        239.           *       2 SEP 1600   80       .00      .00      .00           1.
    31 AUG 1700   33     12.76     2.22    10.54        279.           *       2 SEP 1700   81       .00      .00      .00           1.
    31 AUG 1800   34     17.01     2.46    14.56        301.           *       2 SEP 1800   82       .00      .00      .00           0.
    31 AUG 1900   35     13.80     1.67    12.13        353.           *       2 SEP 1900   83       .00      .00      .00           0.
    31 AUG 2000   36     65.35     5.45    59.90        387.           *       2 SEP 2000   84       .00      .00      .00           0.
    31 AUG 2100   37     56.01     2.85    53.16       1117.           *       2 SEP 2100   85       .00      .00      .00           0.
    31 AUG 2200   38      9.85      .40     9.46       1572.           *       2 SEP 2200   86       .00      .00      .00           0.
    31 AUG 2300   39      9.85      .37     9.48        890.           *       2 SEP 2300   87       .00      .00      .00           0.
     1 SEP 0000   40      7.88      .28     7.60        377.           *       3 SEP 0000   88       .00      .00      .00           0.
     1 SEP 0100   41     11.82      .40    11.42        262.           *       3 SEP 0100   89       .00      .00      .00           0.
     1 SEP 0200   42      9.85      .31     9.54        268.           *       3 SEP 0200   90       .00      .00      .00           0.
     1 SEP 0300   43       .00      .00      .00        302.           *       3 SEP 0300   91       .00      .00      .00           0.
```

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        1 SEP 0400   44     .00     .00     .00       182.       *        3 SEP 0400   92     .00     .00     .00         0.
        1 SEP 0500   45     .00     .00     .00        88.       *        3 SEP 0500   93     .00     .00     .00         0.
        1 SEP 0600   46     .00     .00     .00        48.       *        3 SEP 0600   94     .00     .00     .00         0.
        1 SEP 0700   47     .00     .00     .00        32.       *        3 SEP 0700   95     .00     .00     .00         0.
        1 SEP 0800   48     .00     .00     .00        22.       *        3 SEP 0800   96     .00     .00     .00         0.
                                                                  *
************************************************************************************************************************************

    TOTAL RAINFALL =  309.46, TOTAL LOSS =    65.01, TOTAL EXCESS =  244.46

 PEAK FLOW     TIME                          MAXIMUM AVERAGE FLOW
                                     6-HR       24-HR        72-HR     95.00-HR
 (CU M/S)     (HR)
                       (CU M/S)
   1572.     37.00                  776.        295.         99.          75.
                           (MM)  158.204      240.297      242.919      242.919
                    (1000 CU M)   16770.       25471.       25749.       25749.

                        CUMULATIVE AREA =   106.00 SQ KM
```
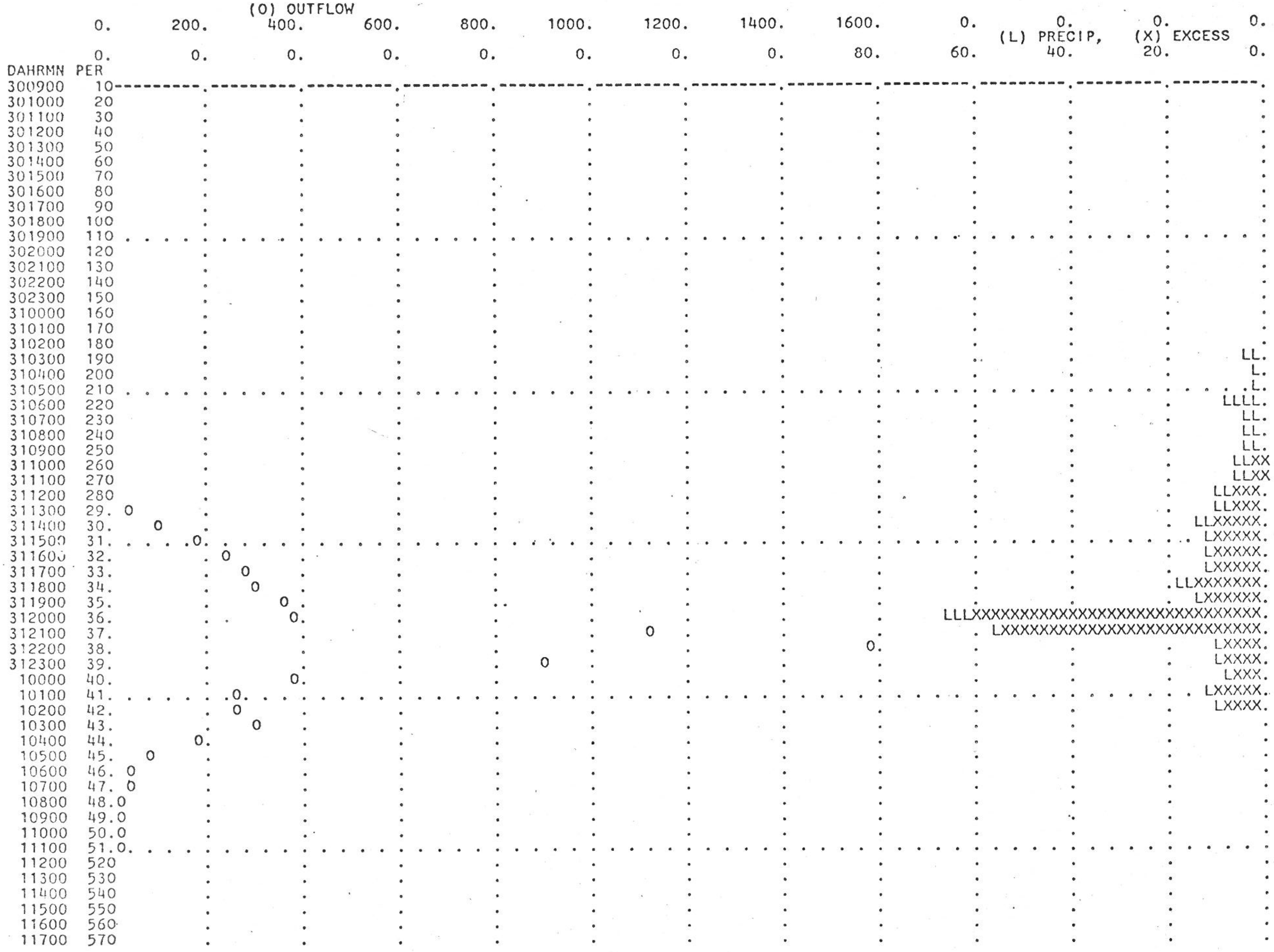
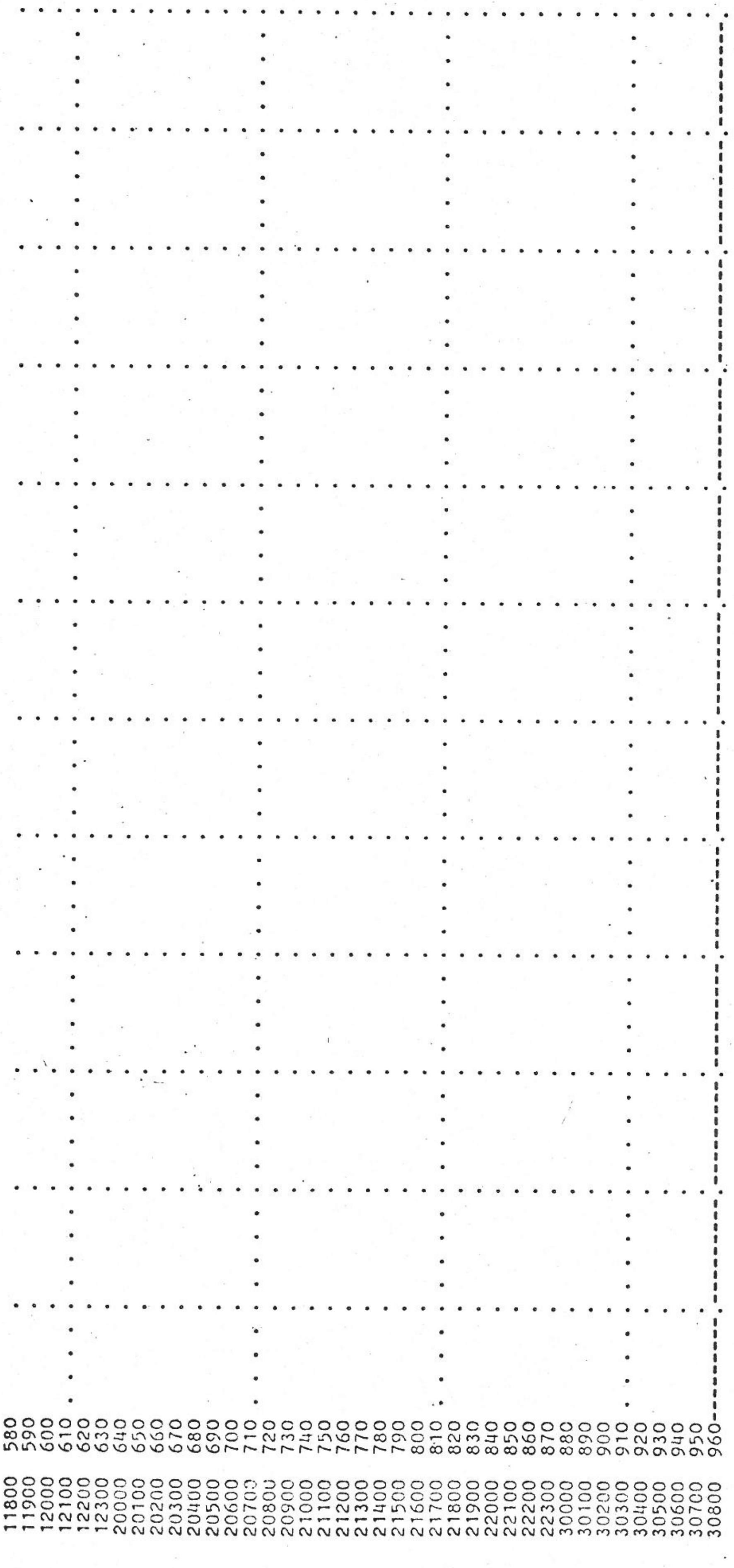

STATION SUB3

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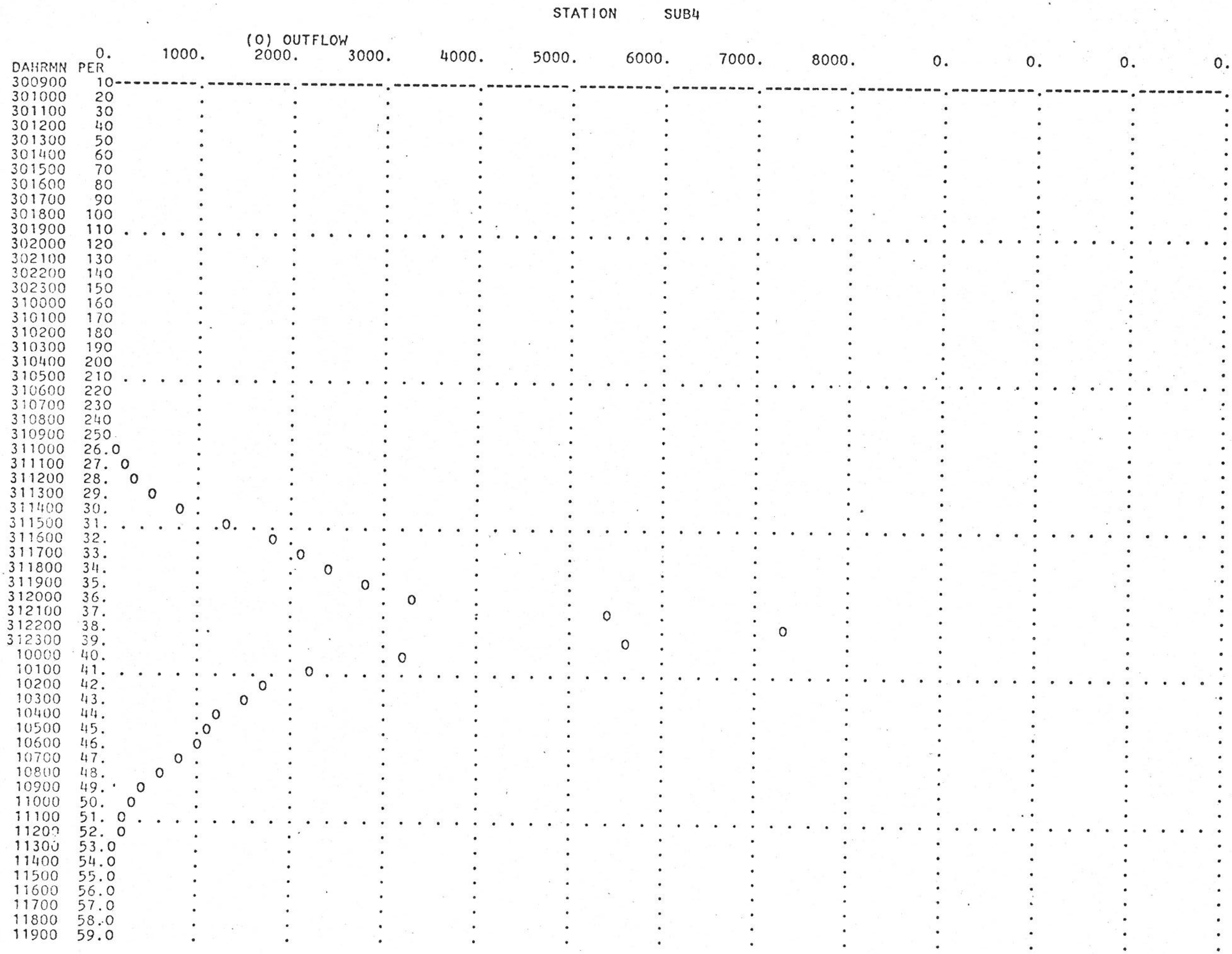
20700 710
20800 720
20900 730
21000 740
21100 750
21200 760
21300 770
21400 780
21500 790
21600 800
21700 810
21800 820
21900 830
22000 840
22100 850
22200 860
22300 870
30000 880
30100 890
30200 900
30300 910
30400 920
30500 930
30600 940
30700 950
30800 960

```
*** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** ***

              *************
              *           *
141 KK        *     SUB4  *
              *           *
              *************
                               COMBINE RUNOFF FROM SUB2C AND SUB3

143 HC             HYDROGRAPH COMBINATION
                        ICOMP            2  NUMBER OF HYDROGRAPHS TO COMBINE

                                                            ***

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

                                              HYDROGRAPH AT STATION      SUB4
                                                  SUM OF  2 HYDROGRAPHS

*****************************************************************************************************************************
                                   *                               *                               *
  DA MON HRMN  ORD        FLOW     *  DA MON HRMN  ORD       FLOW  *  DA MON HRMN  ORD       FLOW  *  DA MON HRMN  ORD        FLOW
                                   *                               *                               *
  30 AUG 0900    1          0.     *  31 AUG 0900   25         3.  *   1 SEP 0900   49       391.  *   2 SEP 0900   73         16.
  30 AUG 1000    2          0.     *  31 AUG 1000   26        90.  *   1 SEP 1000   50       280.  *   2 SEP 1000   74         15.
  30 AUG 1100    3          0.     *  31 AUG 1100   27       161.  *   1 SEP 1100   51       213.  *   2 SEP 1100   75         13.
  30 AUG 1200    4          0.     *  31 AUG 1200   28       291.  *   1 SEP 1200   52       169.  *   2 SEP 1200   76         12.
  30 AUG 1300    5          0.     *  31 AUG 1300   29       481.  *   1 SEP 1300   53       140.  *   2 SEP 1300   77         11.
  30 AUG 1400    6          0.     *  31 AUG 1400   30       835.  *   1 SEP 1400   54       123.  *   2 SEP 1400   78         11.
  30 AUG 1500    7          0.     *  31 AUG 1500   31      1328.  *   1 SEP 1500   55       117.  *   2 SEP 1500   79         10.
  30 AUG 1600    8          0.     *  31 AUG 1600   32      1759.  *   1 SEP 1600   56       118.  *   2 SEP 1600   80          9.
  30 AUG 1700    9          0.     *  31 AUG 1700   33      2113.  *   1 SEP 1700   57       117.  *   2 SEP 1700   81          9.
  30 AUG 1800   10          0.     *  31 AUG 1800   34      2414.  *   1 SEP 1800   58       109.  *   2 SEP 1800   82          8.
  30 AUG 1900   11          0.     *  31 AUG 1900   35      2815.  *   1 SEP 1900   59        98.  *   2 SEP 1900   83          8.
  30 AUG 2000   12          0.     *  31 AUG 2000   36      3292.  *   1 SEP 2000   60        88.  *   2 SEP 2000   84          7.
  30 AUG 2100   13          0.     *  31 AUG 2100   37      5366.  *   1 SEP 2100   61        79.  *   2 SEP 2100   85          7.
  30 AUG 2200   14          0.     *  31 AUG 2200   38      7286.  *   1 SEP 2200   62        70.  *   2 SEP 2200   86          6.
  30 AUG 2300   15          0.     *  31 AUG 2300   39      5614.  *   1 SEP 2300   63        62.  *   2 SEP 2300   87          6.
  31 AUG 0000   16          0.     *   1 SEP 0000   40      3204.  *   2 SEP 0000   64        53.  *   3 SEP 0000   88          6.
  31 AUG 0100   17          0.     *   1 SEP 0100   41      2187.  *   2 SEP 0100   65        46.  *   3 SEP 0100   89          5.
  31 AUG 0200   18          0.     *   1 SEP 0200   42      1732.  *   2 SEP 0200   66        39.  *   3 SEP 0200   90          5.
  31 AUG 0300   19          0.     *   1 SEP 0300   43      1518.  *   2 SEP 0300   67        31.  *   3 SEP 0300   91          5.
  31 AUG 0400   20          0.     *   1 SEP 0400   44      1205.  *   2 SEP 0400   68        27.  *   3 SEP 0400   92          4.
  31 AUG 0500   21          0.     *   1 SEP 0500   45      1077.  *   2 SEP 0500   69        24.  *   3 SEP 0500   93          4.
  31 AUG 0600   22          0.     *   1 SEP 0600   46      1009.  *   2 SEP 0600   70        21.  *   3 SEP 0600   94          4.
  31 AUG 0700   23          0.     *   1 SEP 0700   47       816.  *   2 SEP 0700   71        19.  *   3 SEP 0700   95          4.
  31 AUG 0800   24          0.     *   1 SEP 0800   48       575.  *   2 SEP 0800   72        17.  *   3 SEP 0800   96          4.
                                   *                               *                               *
*****************************************************************************************************************************

PEAK FLOW      TIME                          MAXIMUM AVERAGE FLOW
                                    6-HR          24-HR          72-HR        95.00-HR
(CU M/S)       (HR)
                         (CU M/S)
  7286.       37.00                 4544.         1991.          692.          524.
                             (MM)  183.451       321.474       335.160       335.160
                      (1000 CU M)   98146.       171989.       179310.       179310.

                      CUMULATIVE AREA =   535.00 SQ KM
```


STATION SUB4
(O) OUTFLOW
0.
1000.
2000.
3000.
4000.
5000.
6000.
7000.
8000.
0.
0.
0.
0.
DAHRMN PER
300900 10
301000 20
301100 30
301200 40
301300 50
301400 60
301500 70
301600 80
301700 90
301800 100
301900 110
302000 120
302100 130
302200 140
302300 150
310000 160
310100 170
310200 180
310300 190
310400 200
310500 210
310600 220
310700 230
310800 240
310900 250
311000 26.0
311100 27.
311200 28.
311300 29.
311400 30.
311500 31.
311600 32.
311700 33.
311800 34.
311900 35.
312000 36.
312100 37.
312200 38.
312300 39.
10000 40.
10100 41.
10200 42.
10300 43.
10400 44.
10500 45.
10600 46.
10700 47.
10800 48.
10900 49.
11000 50.
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11700 57.0
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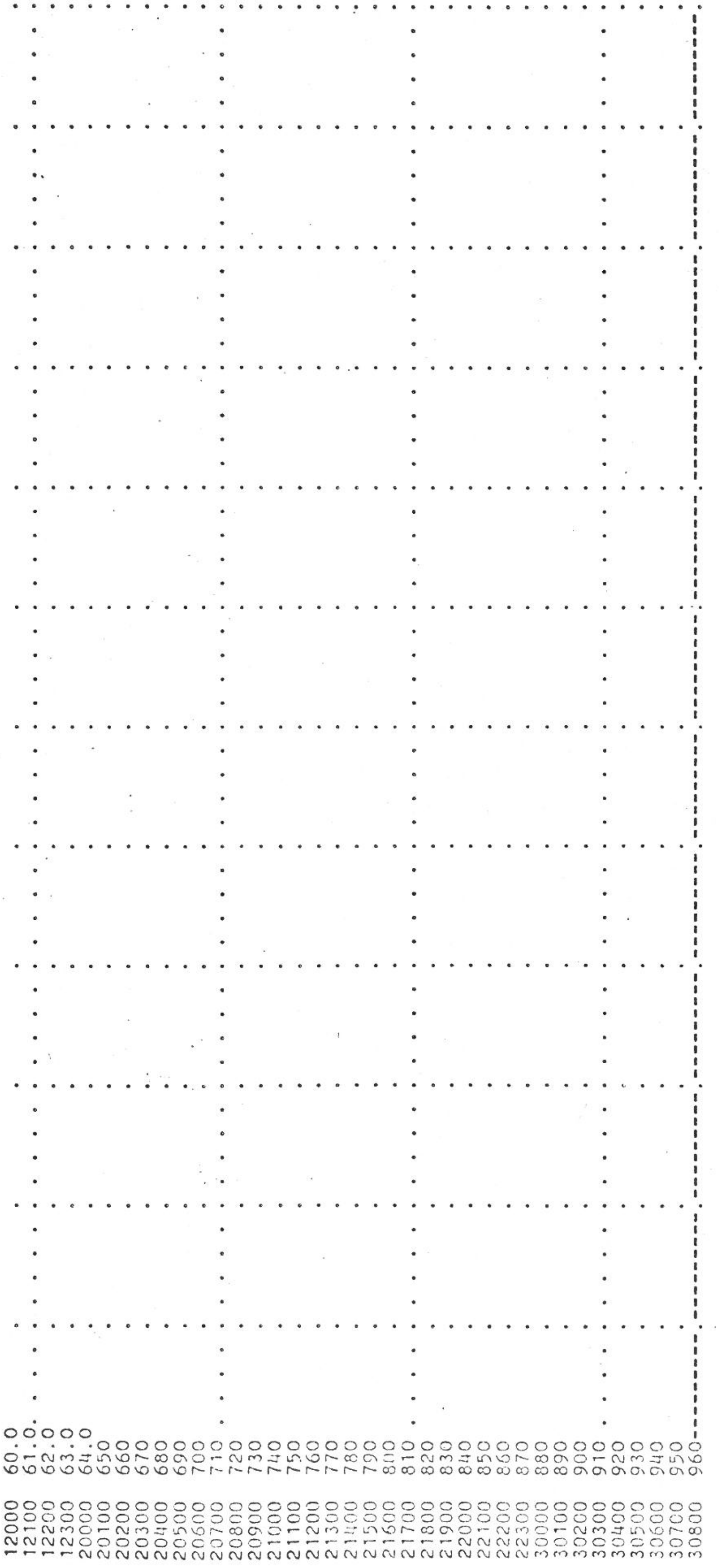
11900 59.0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12300 63.0
20000 64.0
20100 650
20200 660
20300 670
20400 680
20500 690
20600 700
20700 710
20800 720
20900 730
21000 740
21100 750
21200 760
21300 770
21400 780
21500 790
21600 800
21700 810
21800 820
21900 830
22000 840
22100 850
22200 860
22300 870
30000 880
30100 890
30200 900
30300 910
30400 920
30500 930
30600 940
30700 950
30800 960

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

            *************
            *           *
144 KK      *    SUB4   *
            *           *
            *************
                        RUNOFF FROM SUBBASIN 4

              SUBBASIN RUNOFF DATA

150 BA          SUBBASIN CHARACTERISTICS
                    TAREA        103.00  SUBBASIN AREA

                PRECIPITATION DATA

148 PT           TOTAL STORM STATIONS          10         20
149 PW                        WEIGHTS         .10        .90

146 PR             RECORDING STATIONS           7          9
147 PW                        WEIGHTS         .90        .10

151 LS          SCS LOSS RATE
                    STRTL         12.70  INITIAL ABSTRACTION
                   CRVNBR         80.00  CURVE NUMBER
                    RTIMP           .00  PERCENT IMPERVIOUS AREA

                KINEMATIC WAVE
152 UK            OVERLAND-FLOW ELEMENT NO. 1
                          L       5000.  OVERLAND FLOW LENGTH
                          S       .5000  SLOPE
                          N        .300  ROUGHNESS COEFFICIENT
                         PA       100.0  PERCENT OF SUBBASIN
153 RK            MAIN CHANNEL
                          L      11500.  CHANNEL LENGTH
                          S       .0148  SLOPE
                          N        .030  CHANNEL ROUGHNESS COEFFICIENT
                         CA      103.00  CONTRIBUTING AREA
                      SHAPE        TRAP  CHANNEL SHAPE
                         WD       80.00  BOTTOM WIDTH OR DIAMETER
                          Z       10.00  SIDE SLOPE
                     RUPSTQ         YES  ROUTE UPSTREAM HYDROGRAPH

                                                   ***

              PRECIPITATION STATION DATA

                    STATION     TOTAL    AVG. ANNUAL    WEIGHT
                         10    300.10           .00       .10
                         20    300.00           .00       .90

               TEMPORAL DISTRIBUTIONS

               STATION        7,  WEIGHT =    .90
                    .00       .00       .00       .00       .00       .00       .00       .00       .00       .00
                    .00       .00       .00       .00       .00       .00       .00      4.00      1.00      1.00
                   8.00      3.00      3.50      3.50      5.00      5.00     10.00      9.00     13.00     12.00
                  12.00     12.00     16.00     12.00     64.00     56.00     10.00     10.00      8.00     12.00
                  10.00
```

```
         STATION        9,  WEIGHT =     .10
                 .00      .00      .00      .00      .00      .00      .00      .00      .00      .00
                 .00      .00      .00      .00      .00      .00      .00      .00      .00      .00
                 .00      .00      .00      .50     5.50     6.00     4.00     6.00    16.90    11.10
               14.00    16.00    20.00    20.00    16.00    84.00    14.00    14.00     5.50     5.50
                1.70

      COMPUTED KINEMATIC PARAMETERS
         ELEMENT       ALPHA        M        DT (MIN)    DX (FT)
               1      3.5120     1.667        60.00      8202.10
               3       .2103     1.589        60.00     18864.83

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

                                        HYDROGRAPH AT STATION     SUB4

**************************************************************************************************************
                                                            *
      DA MON HRMN  ORD     RAIN    LOSS  EXCESS     COMP Q  *    DA MON HRMN  ORD     RAIN    LOSS  EXCESS     COMP Q
                                                            *
      30 AUG 0900    1      .00     .00     .00         0.  *     1 SEP 0900   49      .08     .00     .08       522.
      30 AUG 1000    2      .00     .00     .00         0.  *     1 SEP 1000   50      .10     .00     .10       378.
      30 AUG 1100    3      .00     .00     .00         0.  *     1 SEP 1100   51      .12     .00     .12       285.
      30 AUG 1200    4      .00     .00     .00         0.  *     1 SEP 1200   52      .12     .00     .12       224.
      30 AUG 1300    5      .00     .00     .00         0.  *     1 SEP 1300   53      .12     .00     .12       183.
      30 AUG 1400    6      .00     .00     .00         0.  *     1 SEP 1400   54      .12     .00     .12       156.
      30 AUG 1500    7      .00     .00     .00         0.  *     1 SEP 1500   55      .12     .00     .12       139.
      30 AUG 1600    8      .00     .00     .00         0.  *     1 SEP 1600   56      .10     .00     .10       132.
      30 AUG 1700    9      .00     .00     .00         0.  *     1 SEP 1700   57      .10     .00     .10       130.
      30 AUG 1800   10      .00     .00     .00         0.  *     1 SEP 1800   58      .10     .00     .10       125.
      30 AUG 1900   11      .00     .00     .00         0.  *     1 SEP 1900   59      .15     .00     .15       117.
      30 AUG 2000   12      .00     .00     .00         0.  *     1 SEP 2000   60      .15     .00     .15       106.
      30 AUG 2100   13      .00     .00     .00         0.  *     1 SEP 2100   61      .00     .00     .00        95.
      30 AUG 2200   14      .00     .00     .00         0.  *     1 SEP 2200   62      .00     .00     .00        86.
      30 AUG 2300   15      .00     .00     .00         0.  *     1 SEP 2300   63      .00     .00     .00        77.
      31 AUG 0000   16      .00     .00     .00         0.  *     2 SEP 0000   64      .00     .00     .00        68.
      31 AUG 0100   17      .00     .00     .00         0.  *     2 SEP 0100   65      .00     .00     .00        60.
      31 AUG 0200   18      .00     .00     .00         0.  *     2 SEP 0200   66      .00     .00     .00        52.
      31 AUG 0300   19     3.60    3.60     .00         0.  *     2 SEP 0300   67      .00     .00     .00        45.
      31 AUG 0400   20      .90     .90     .00         0.  *     2 SEP 0400   68      .00     .00     .00        38.
      31 AUG 0500   21      .90     .90     .00         0.  *     2 SEP 0500   69      .00     .00     .00        32.
      31 AUG 0600   22     7.20    7.20     .00         0.  *     2 SEP 0600   70      .00     .00     .00        29.
      31 AUG 0700   23     2.70    2.60     .10         0.  *     2 SEP 0700   71      .00     .00     .00        26.
      31 AUG 0800   24     3.15    2.77     .38         0.  *     2 SEP 0800   72      .00     .00     .00        23.
      31 AUG 0900   25     3.20    2.57     .63         0.  *     2 SEP 0900   73      .00     .00     .00        21.
      31 AUG 1000   26     5.05    3.63    1.42         0.  *     2 SEP 1000   74      .00     .00     .00        20.
      31 AUG 1100   27     5.10    3.21    1.89       151.  *     2 SEP 1100   75      .00     .00     .00        18.
      31 AUG 1200   28     9.40    4.99    4.41       216.  *     2 SEP 1200   76      .00     .00     .00        17.
      31 AUG 1300   29     8.70    3.79    4.91       399.  *     2 SEP 1300   77      .00     .00     .00        15.
      31 AUG 1400   30    13.39    4.70    8.69       723.  *     2 SEP 1400   78      .00     .00     .00        14.
      31 AUG 1500   31    11.91    3.34    8.57      1232.  *     2 SEP 1500   79      .00     .00     .00        13.
      31 AUG 1600   32    12.20    2.83    9.37      1751.  *     2 SEP 1600   80      .00     .00     .00        12.
      31 AUG 1700   33    12.40    2.40   10.00      2189.  *     2 SEP 1700   81      .00     .00     .00        11.
      31 AUG 1800   34    16.40    2.63   13.77      2555.  *     2 SEP 1800   82      .00     .00     .00        11.
      31 AUG 1900   35    12.80    1.72   11.08      3001.  *     2 SEP 1900   83      .00     .00     .00        10.
      31 AUG 2000   36    59.20    5.56   53.64      3488.  *     2 SEP 2000   84      .00     .00     .00         9.
      31 AUG 2100   37    58.80    3.33   55.47      5722.  *     2 SEP 2100   85      .00     .00     .00         8.
      31 AUG 2200   38    10.40     .46    9.94      8462.  *     2 SEP 2200   86      .00     .00     .00         8.
      31 AUG 2300   39    10.40     .43    9.97      6969.  *     2 SEP 2300   87      .00     .00     .00         7.
       1 SEP 0000   40     7.75     .30    7.45      4014.  *     3 SEP 0000   88      .00     .00     .00         7.
       1 SEP 0100   41    11.35     .42   10.93      2711.  *     3 SEP 0100   89      .00     .00     .00         7.
       1 SEP 0200   42     9.17     .32    8.85      2135.  *     3 SEP 0200   90      .00     .00     .00         6.
       1 SEP 0300   43      .17     .01     .16      1851.  *     3 SEP 0300   91      .00     .00     .00         6.
       1 SEP 0400   44      .17     .01     .16      1484.  *     3 SEP 0400   92      .00     .00     .00         6.
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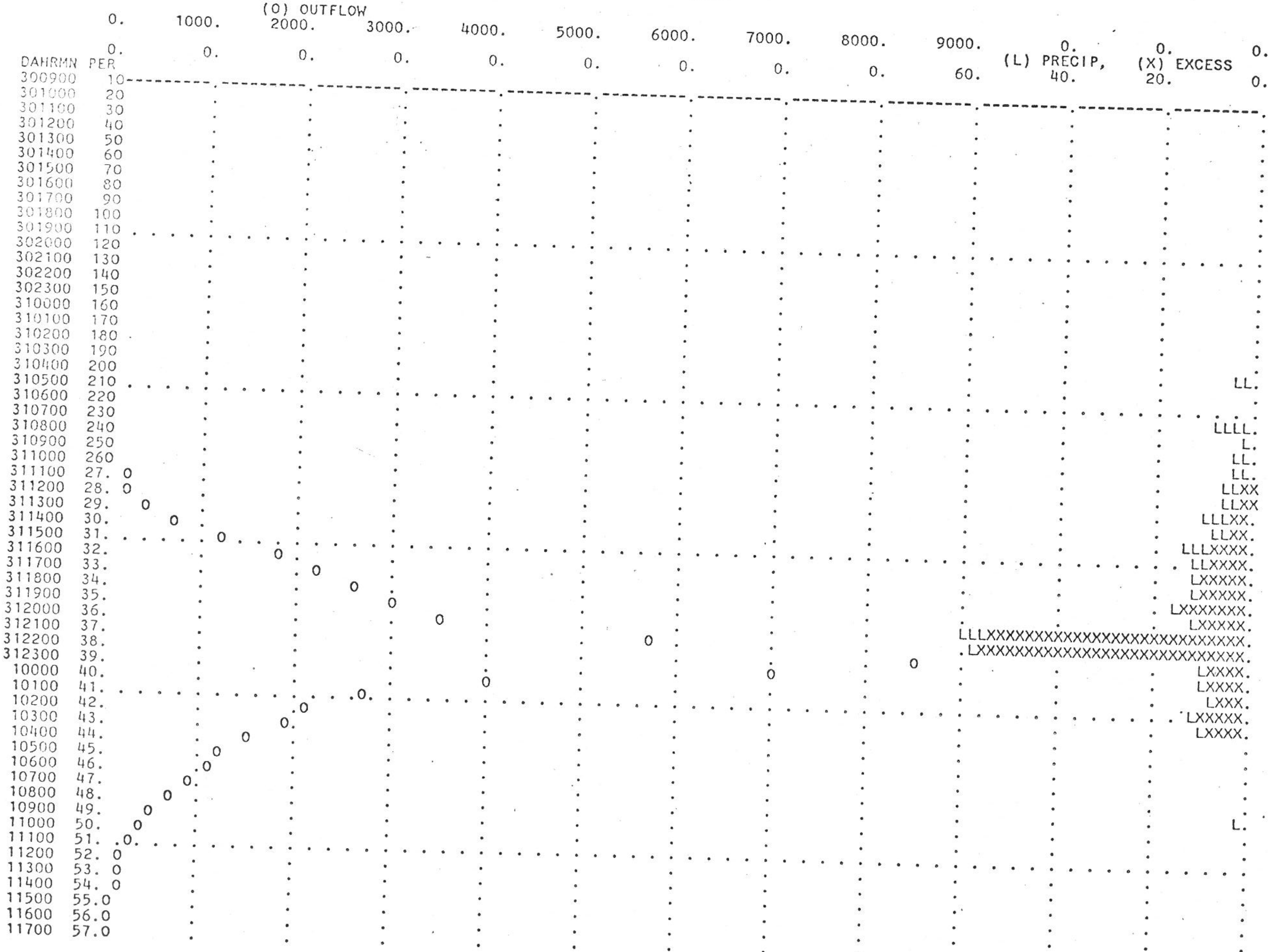
       1 SEP 0500   45      .80      .03      .77       1246.       *       3 SEP 0500   93     .00      .00      .00          5.
       1 SEP 0600   46      .29      .01      .28       1123.       *       3 SEP 0600   94     .00      .00      .00          5.
       1 SEP 0700   47      .11      .00      .11        949.       *       3 SEP 0700   95     .00      .00      .00          5.
       1 SEP 0800   48     1.02      .03      .99        721.       *       3 SEP 0800   96     .00      .00      .00          5.
                                                                    *
************************************************************************************************************************************

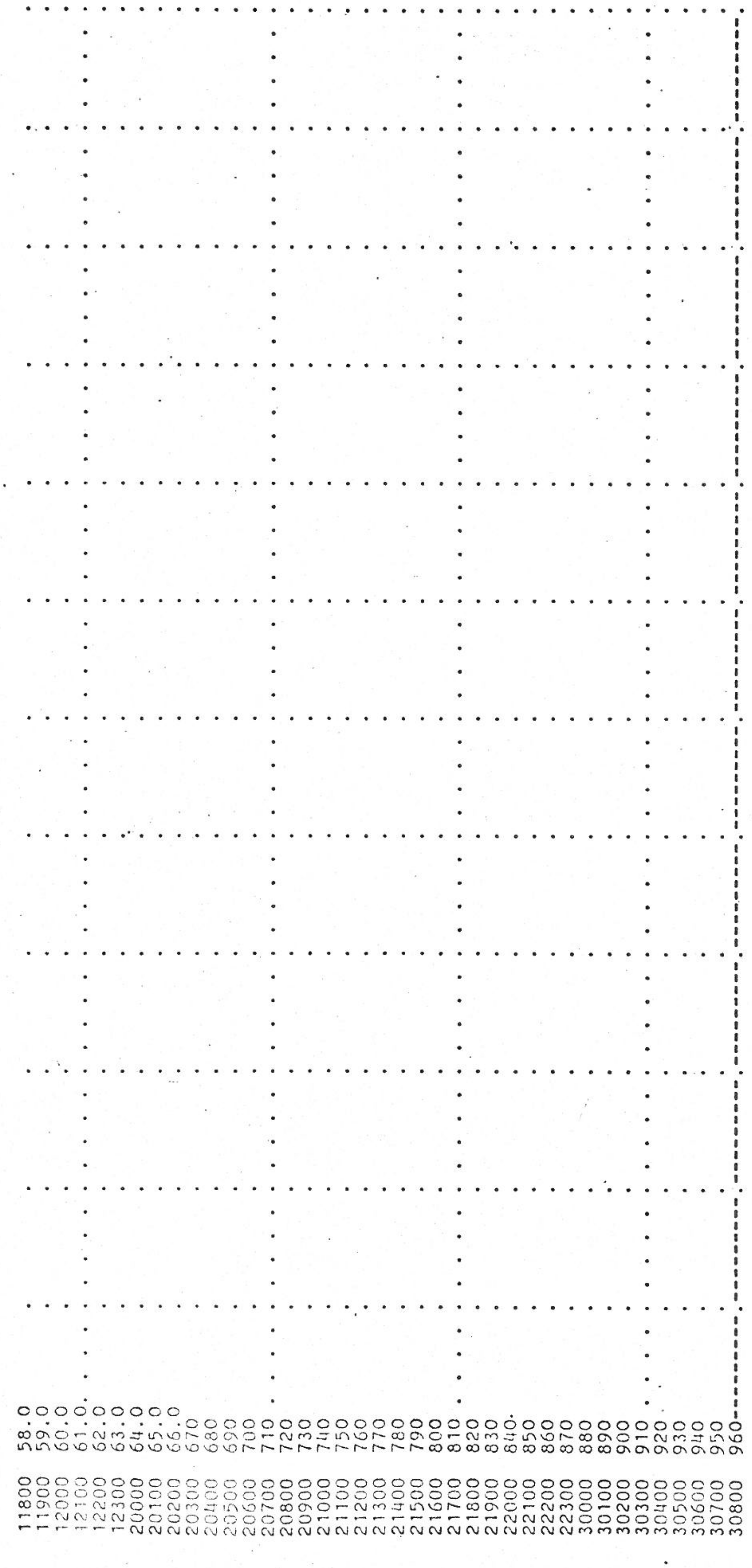
    TOTAL RAINFALL =   300.01, TOTAL LOSS =    64.71, TOTAL EXCESS =  235.30

  PEAK FLOW       TIME                              MAXIMUM AVERAGE FLOW
                                           6-HR         24-HR          72-HR        95.00-HR
  (CU M/S)        (HR)
                             (CU M/S)
    8462.        37.00                    5252.         2255.           784.           594.
                                  (MM)   177.801       305.423        318.590        318.590
                           (1000 CU M)   113437.       194860.        203260.        203260.

                              CUMULATIVE AREA =   638.00 SQ KM
```

STATION SUB4

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20100 65.0
20200 66.0
20300 670
20400 680
20500 690
20600 700
20700 710
20800 720
20900 730
21000 740
21100 750
21200 760
21300 770
21400 780
21500 790
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22200 860
22300 870
30000 880
30100 890
30200 900
30300 910
30400 920
30500 930
30600 940
30700 950
30800 960

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

              **************
              *            *
154 KK        *    SUB5    *
              *            *
              **************
                           RUNOFF FROM SUBBASIN 5

                SUBBASIN RUNOFF DATA

160 BA            SUBBASIN CHARACTERISTICS
                        TAREA       109.00  SUBBASIN AREA

                  PRECIPITATION DATA

158 PT             TOTAL STORM STATIONS          10        20        60
159 PW                          WEIGHTS         .10       .80       .10

156 PR               RECORDING STATIONS           7         9
157 PW                          WEIGHTS         .90       .10

161 LS            SCS LOSS RATE
                        STRTL        12.70  INITIAL ABSTRACTION
                       CRVNBR        80.00  CURVE NUMBER
                        RTIMP          .00  PERCENT IMPERVIOUS AREA

                  KINEMATIC WAVE
162 UK              OVERLAND-FLOW ELEMENT NO. 1
                            L        3000.  OVERLAND FLOW LENGTH
                            S        .4000  SLOPE
                            N         .300  ROUGHNESS COEFFICIENT
                           PA        100.0  PERCENT OF SUBBASIN
163 RK              MAIN CHANNEL
                            L       31000.  CHANNEL LENGTH
                            S        .0323  SLOPE
                            N         .040  CHANNEL ROUGHNESS COEFFICIENT
                           CA       109.00  CONTRIBUTING AREA
                        SHAPE         TRAP  CHANNEL SHAPE
                           WD        45.00  BOTTOM WIDTH OR DIAMETER
                            Z        10.00  SIDE SLOPE
                       RUPSTQ           NO  ROUTE UPSTREAM HYDROGRAPH

                                                             ***

                PRECIPITATION STATION DATA

                        STATION    TOTAL    AVG. ANNUAL    WEIGHT
                             10   300.10          .00         .10
                             20   300.00          .00         .80
                             60   359.50          .00         .10

                  TEMPORAL DISTRIBUTIONS

                  STATION        7,  WEIGHT =     .90
                       .00        .00        .00        .00        .00        .00        .00        .00        .00        .00
                       .00        .00        .00        .00        .00        .00        .00       4.00       1.00       1.00
                      8.00       3.00       3.50       3.50       5.00       5.00      10.00       9.00      13.00      12.00
                     12.00      12.00      16.00      12.00      64.00      56.00      10.00      10.00       8.00      12.00
                     10.00        .00        .00        .00        .00        .00        .00        .00        .00        .00
```

```
         .00        .00        .00        .00        .00        .00        .00        .00        .00

   STATION        9,  WEIGHT =     .10
         .00        .00        .00        .00        .00        .00        .00        .00        .00        .00
         .00        .00        .00        .00        .00        .00        .00        .00        .00        .00
         .00        .00        .00        .50       5.50       6.00       4.00       6.00      16.90      11.10
       14.00      16.00      20.00      20.00      16.00      84.00      14.00      14.00       5.50       5.50
        1.70       1.70       1.70       8.00       2.90       1.10      10.20        .80       1.00       1.20
        1.20       1.20       1.20       1.20       1.00       1.00       1.00       1.50       1.50

 COMPUTED KINEMATIC PARAMETERS
     ELEMENT      ALPHA         M        DT (MIN)    DX (FT)
           1     3.1412     1.667        60.00      4921.26
           3      .3826     1.549        60.00     50853.02

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

                                          HYDROGRAPH AT STATION      SUB5

*************************************************************************************************************
                                                             *
    DA MON HRMN  ORD     RAIN     LOSS   EXCESS      COMP Q  *      DA MON HRMN  ORD     RAIN     LOSS   EXCESS      COMP Q
                                                             *
    30 AUG 0900    1      .00      .00      .00          0.  *       1 SEP 0900   49      .08      .00      .08         39.
    30 AUG 1000    2      .00      .00      .00          0.  *       1 SEP 1000   50      .10      .00      .10         33.
    30 AUG 1100    3      .00      .00      .00          0.  *       1 SEP 1100   51      .12      .00      .12         27.
    30 AUG 1200    4      .00      .00      .00          0.  *       1 SEP 1200   52      .12      .00      .12         23.
    30 AUG 1300    5      .00      .00      .00          0.  *       1 SEP 1300   53      .12      .00      .12         20.
    30 AUG 1400    6      .00      .00      .00          0.  *       1 SEP 1400   54      .12      .00      .12         17.
    30 AUG 1500    7      .00      .00      .00          0.  *       1 SEP 1500   55      .12      .00      .12         15.
    30 AUG 1600    8      .00      .00      .00          0.  *       1 SEP 1600   56      .10      .00      .10         13.
    30 AUG 1700    9      .00      .00      .00          0.  *       1 SEP 1700   57      .10      .00      .10         12.
    30 AUG 1800   10      .00      .00      .00          0.  *       1 SEP 1800   58      .10      .00      .10         10.
    30 AUG 1900   11      .00      .00      .00          0.  *       1 SEP 1900   59      .15      .00      .15          9.
    30 AUG 2000   12      .00      .00      .00          0.  *       1 SEP 2000   60      .15      .00      .15          9.
    30 AUG 2100   13      .00      .00      .00          0.  *       1 SEP 2100   61      .00      .00      .00          8.
    30 AUG 2200   14      .00      .00      .00          0.  *       1 SEP 2200   62      .00      .00      .00          7.
    30 AUG 2300   15      .00      .00      .00          0.  *       1 SEP 2300   63      .00      .00      .00          7.
    31 AUG 0000   16      .00      .00      .00          0.  *       2 SEP 0000   64      .00      .00      .00          6.
    31 AUG 0100   17      .00      .00      .00          0.  *       2 SEP 0100   65      .00      .00      .00          6.
    31 AUG 0200   18      .00      .00      .00          0.  *       2 SEP 0200   66      .00      .00      .00          5.
    31 AUG 0300   19     3.67     3.67      .00          0.  *       2 SEP 0300   67      .00      .00      .00          5.
    31 AUG 0400   20      .92      .92      .00          0.  *       2 SEP 0400   68      .00      .00      .00          4.
    31 AUG 0500   21      .92      .92      .00          0.  *       2 SEP 0500   69      .00      .00      .00          4.
    31 AUG 0600   22     7.34     7.34      .00          0.  *       2 SEP 0600   70      .00      .00      .00          4.
    31 AUG 0700   23     2.75     2.63      .13          0.  *       2 SEP 0700   71      .00      .00      .00          3.
    31 AUG 0800   24     3.21     2.80      .41          0.  *       2 SEP 0800   72      .00      .00      .00          3.
    31 AUG 0900   25     3.26     2.59      .67          0.  *       2 SEP 0900   73      .00      .00      .00          3.
    31 AUG 1000   26     5.15     3.65     1.50          0.  *       2 SEP 1000   74      .00      .00      .00          3.
    31 AUG 1100   27     5.20     3.23     1.97          0.  *       2 SEP 1100   75      .00      .00      .00          2.
    31 AUG 1200   28     9.59     5.00     4.58          1.  *       2 SEP 1200   76      .00      .00      .00          2.
    31 AUG 1300   29     8.87     3.79     5.08          6.  *       2 SEP 1300   77      .00      .00      .00          2.
    31 AUG 1400   30    13.66     4.69     8.96         21.  *       2 SEP 1400   78      .00      .00      .00          2.
    31 AUG 1500   31    12.15     3.33     8.82         70.  *       2 SEP 1500   79      .00      .00      .00          2.
    31 AUG 1600   32    12.44     2.81     9.63        147.  *       2 SEP 1600   80      .00      .00      .00          2.
    31 AUG 1700   33    12.65     2.39    10.26        225.  *       2 SEP 1700   81      .00      .00      .00          2.
    31 AUG 1800   34    16.73     2.61    14.11        267.  *       2 SEP 1800   82      .00      .00      .00          1.
    31 AUG 1900   35    13.05     1.70    11.35        323.  *       2 SEP 1900   83      .00      .00      .00          1.
    31 AUG 2000   36    60.37     5.50    54.87        357.  *       2 SEP 2000   84      .00      .00      .00          1.
    31 AUG 2100   37    59.97     3.29    56.68        835.  *       2 SEP 2100   85      .00      .00      .00          1.
    31 AUG 2200   38    10.61      .45    10.16       1541.  *       2 SEP 2200   86      .00      .00      .00          1.
    31 AUG 2300   39    10.61      .42    10.18       1141.  *       2 SEP 2300   87      .00      .00      .00          1.
     1 SEP 0000   40     7.90      .30     7.61        517.  *       3 SEP 0000   88      .00      .00      .00          1.
     1 SEP 0100   41    11.58      .41    11.17        287.  *       3 SEP 0100   89      .00      .00      .00          1.
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       1 SEP 0200   42    9.35    .31    9.04      282.      *      3 SEP 0200   90    .00    .00    .00      1.
       1 SEP 0300   43     .17    .01     .17      288.      *      3 SEP 0300   91    .00    .00    .00      1.
       1 SEP 0400   44     .17    .01     .17      220.      *      3 SEP 0400   92    .00    .00    .00      1.
       1 SEP 0500   45     .82    .03     .79      134.      *      3 SEP 0500   93    .00    .00    .00      1.
       1 SEP 0600   46     .30    .01     .29       77.      *      3 SEP 0600   94    .00    .00    .00      1.
       1 SEP 0700   47     .11    .00     .11       60.      *      3 SEP 0700   95    .00    .00    .00      1.
       1 SEP 0800   48    1.04    .03    1.01       46.      *      3 SEP 0800   96    .00    .00    .00      1.
                                                             *
*****************************************************************************************************************************

    TOTAL RAINFALL =  305.96, TOTAL LOSS =   64.90, TOTAL EXCESS =  241.06

  PEAK FLOW     TIME                          MAXIMUM AVERAGE FLOW
                                    6-HR        24-HR        72-HR       95.00-HR
  (CU M/S)      (HR)
                         (CU M/S)
    1541.      37.00                 783.         291.         100.          75.
                             (MM)  155.128      230.461      236.756      236.756
                       (1000 CU M)  16909.       25120.       25806.       25806.

                        CUMULATIVE AREA =  109.00 SQ KM
```
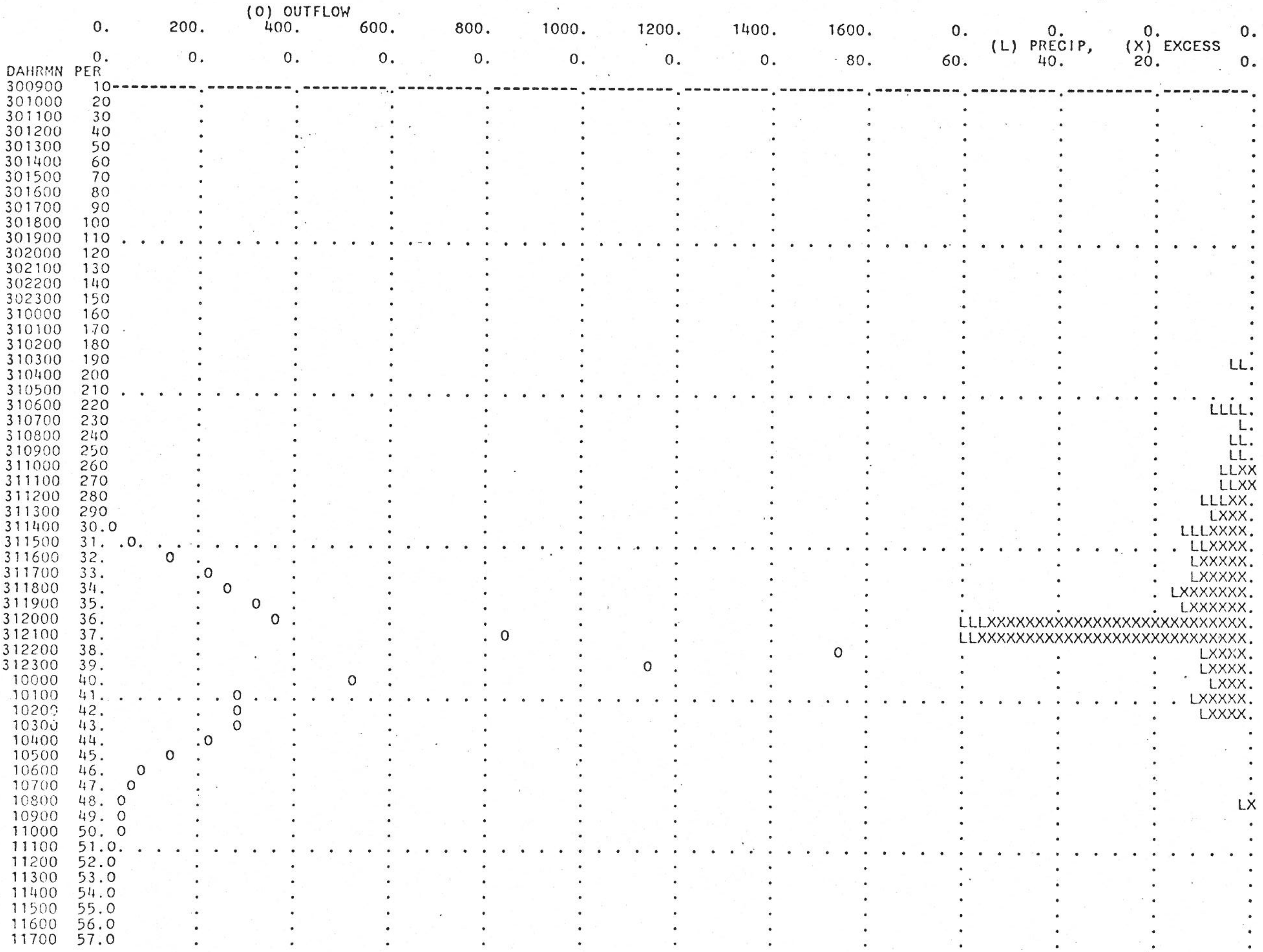
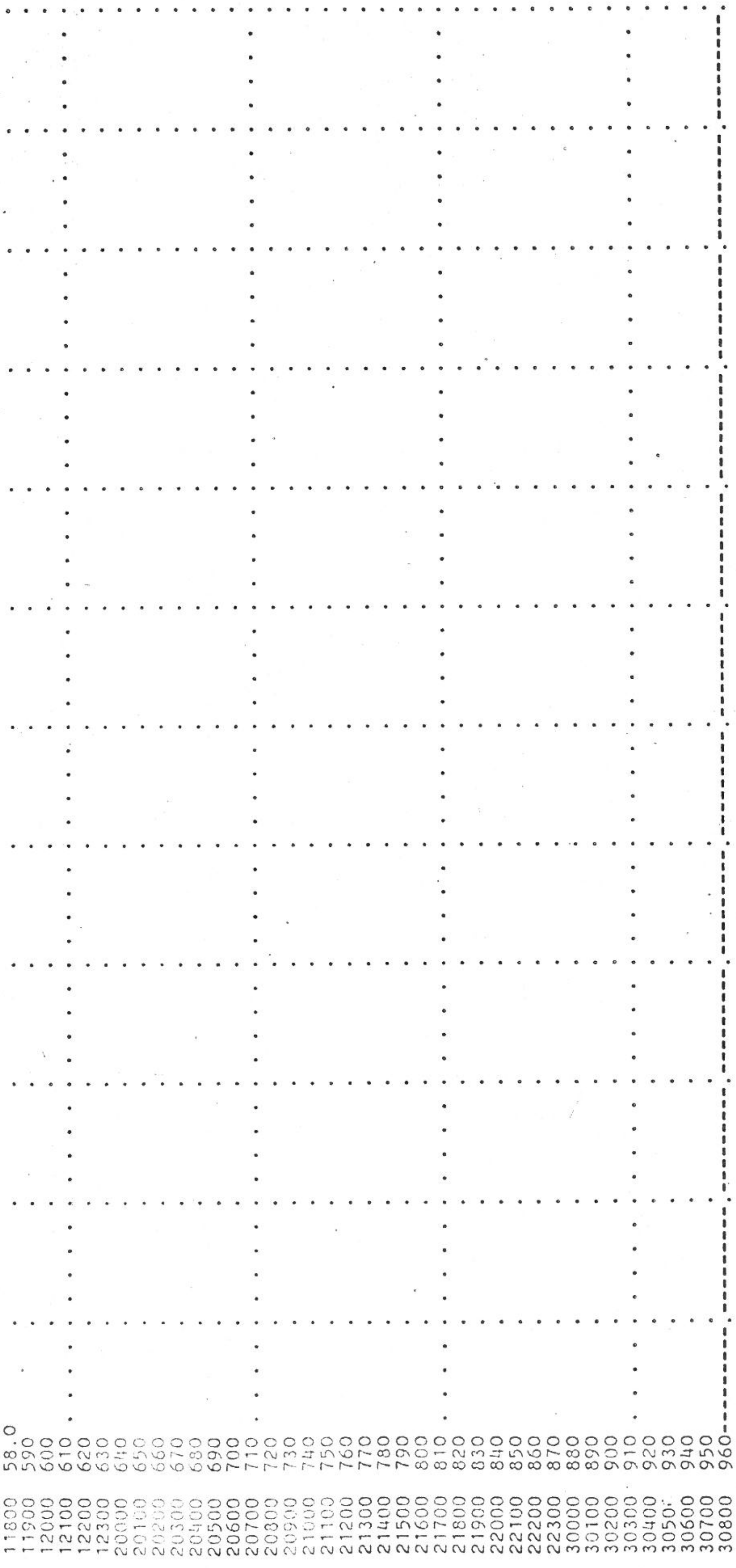

STATION SUB5

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20600 700
20700 710
20800 720
20900 730
21000 740
21100 750
21200 760
21300 770
21400 780
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30200 900
30300 910
30400 920
30500 930
30600 940
30700 950
30800 960

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

            *************
            *           *
 164 KK     *    SUB6   *
            *           *
            *************
                            COMBINE RUNOFF FROM SUB4 AND SUB5

 166 HC          HYDROGRAPH COMBINATION
                      ICOMP              2  NUMBER OF HYDROGRAPHS TO COMBINE

                                                                 ***

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

                                                    HYDROGRAPH AT STATION      SUB6
                                                         SUM OF  2 HYDROGRAPHS

*****************************************************************************************************************************
                                    *                               *                               *
  DA MON HRMN  ORD          FLOW    *  DA MON HRMN  ORD        FLOW *  DA MON HRMN  ORD        FLOW *  DA MON HRMN  ORD        FLOW
                                    *                               *                               *
  30 AUG 0900    1            0.    *  31 AUG 0900   25          0. *   1 SEP 0900   49        560. *   2 SEP 0900   73         24.
  30 AUG 1000    2            0.    *  31 AUG 1000   26          0. *   1 SEP 1000   50        410. *   2 SEP 1000   74         22.
  30 AUG 1100    3            0.    *  31 AUG 1100   27        151. *   1 SEP 1100   51        312. *   2 SEP 1100   75         20.
  30 AUG 1200    4            0.    *  31 AUG 1200   28        217. *   1 SEP 1200   52        248. *   2 SEP 1200   76         19.
  30 AUG 1300    5            0.    *  31 AUG 1300   29        404. *   1 SEP 1300   53        203. *   2 SEP 1300   77         17.
  30 AUG 1400    6            0.    *  31 AUG 1400   30        744. *   1 SEP 1400   54        173. *   2 SEP 1400   78         16.
  30 AUG 1500    7            0.    *  31 AUG 1500   31       1302. *   1 SEP 1500   55        154. *   2 SEP 1500   79         15.
  30 AUG 1600    8            0.    *  31 AUG 1600   32       1898. *   1 SEP 1600   56        145. *   2 SEP 1600   80         14.
  30 AUG 1700    9            0.    *  31 AUG 1700   33       2414. *   1 SEP 1700   57        141. *   2 SEP 1700   81         13.
  30 AUG 1800   10            0.    *  31 AUG 1800   34       2821. *   1 SEP 1800   58        136. *   2 SEP 1800   82         12.
  30 AUG 1900   11            0.    *  31 AUG 1900   35       3324. *   1 SEP 1900   59        126. *   2 SEP 1900   83         11.
  30 AUG 2000   12            0.    *  31 AUG 2000   36       3845. *   1 SEP 2000   60        114. *   2 SEP 2000   84         11.
  30 AUG 2100   13            0.    *  31 AUG 2100   37       6558. *   1 SEP 2100   61        103. *   2 SEP 2100   85         10.
  30 AUG 2200   14            0.    *  31 AUG 2200   38      10003. *   1 SEP 2200   62         93. *   2 SEP 2200   86          9.
  30 AUG 2300   15            0.    *  31 AUG 2300   39       8110. *   1 SEP 2300   63         84. *   2 SEP 2300   87          9.
  31 AUG 0000   16            0.    *   1 SEP 0000   40       4531. *   2 SEP 0000   64         74. *   3 SEP 0000   88          8.
  31 AUG 0100   17            0.    *   1 SEP 0100   41       2998. *   2 SEP 0100   65         65. *   3 SEP 0100   89          8.
  31 AUG 0200   18            0.    *   1 SEP 0200   42       2417. *   2 SEP 0200   66         57. *   3 SEP 0200   90          7.
  31 AUG 0300   19            0.    *   1 SEP 0300   43       2138. *   2 SEP 0300   67         49. *   3 SEP 0300   91          7.
  31 AUG 0400   20            0.    *   1 SEP 0400   44       1705. *   2 SEP 0400   68         42. *   3 SEP 0400   92          7.
  31 AUG 0500   21            0.    *   1 SEP 0500   45       1380. *   2 SEP 0500   69         36. *   3 SEP 0500   93          6.
  31 AUG 0600   22            0.    *   1 SEP 0600   46       1199. *   2 SEP 0600   70         32. *   3 SEP 0600   94          6.
  31 AUG 0700   23            0.    *   1 SEP 0700   47       1009. *   2 SEP 0700   71         29. *   3 SEP 0700   95          6.
  31 AUG 0800   24            0.    *   1 SEP 0800   48        768. *   2 SEP 0800   72         26. *   3 SEP 0800   96          5.
                                    *                               *                               *
*****************************************************************************************************************************

 PEAK FLOW      TIME                              MAXIMUM AVERAGE FLOW
                                        6-HR          24-HR          72-HR       95.00-HR
 (CU M/S)       (HR)
                           (CU M/S)
  10003.       37.00                   6035.          2545.           884.          670.
                               (MM)  174.493        294.374        306.649       306.649
                        (1000 CU M)  130346.        219897.        229067.       229067.

                              CUMULATIVE AREA =   747.00 SQ KM
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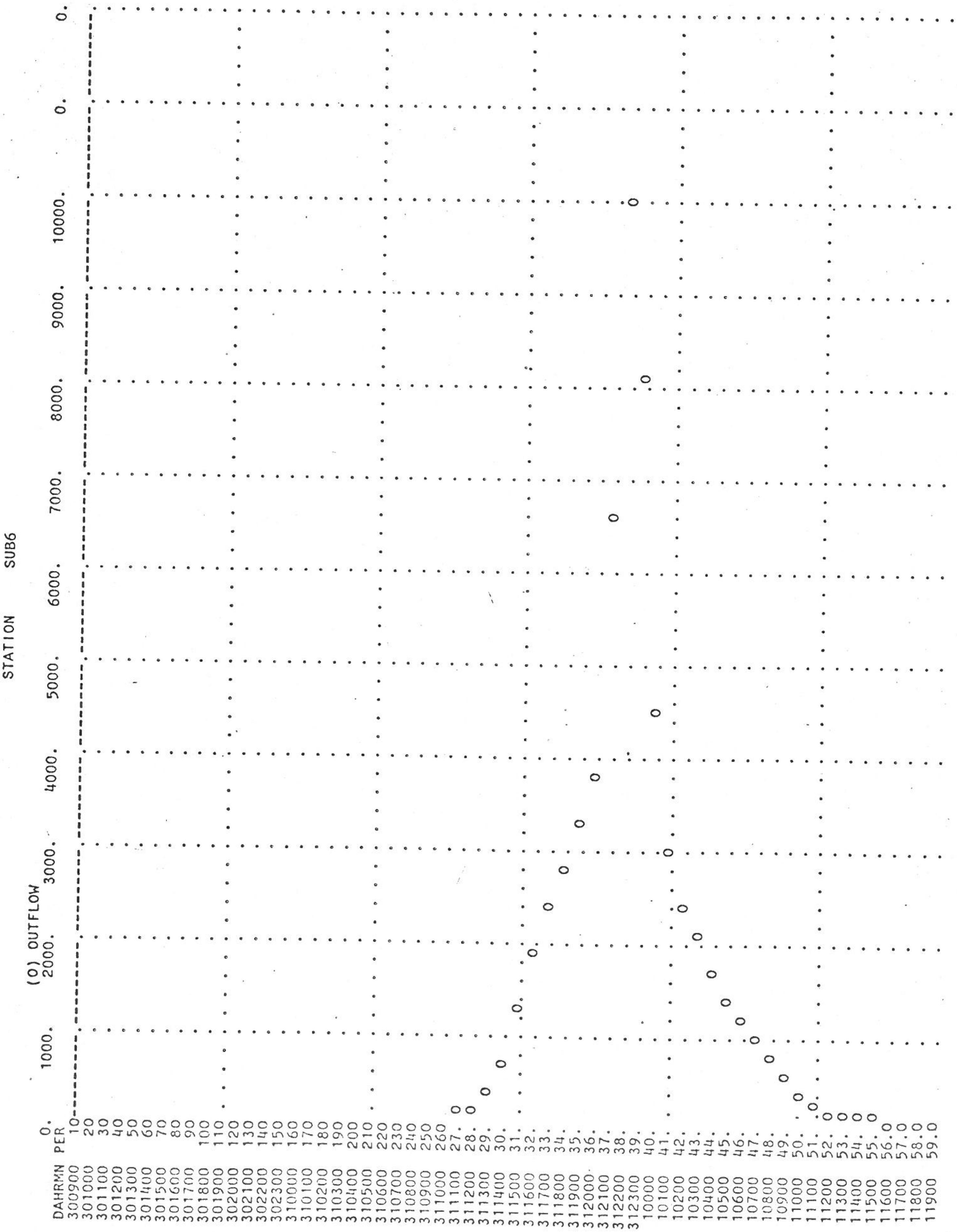
STATION SUB6
(O) OUTFLOW
0.
1000.
2000.
3000.
4000.
5000.
6000.
7000.
8000.
9000.
10000.
0.
0.
DAHRMN PER
300900 10
301000 20
301100 30
301200 40
301300 50
301400 60
301500 70
301600 80
301700 90
301800 100
301900 110
302000 120
302100 130
302200 140
302300 150
310000 160
310100 170
310200 180
310300 190
310400 200
310500 210
310600 220
310700 230
310800 240
310900 250
311000 260
311100 27.
311200 28.
311300 29.
311400 30.
311500 31.
311600 32.
311700 33.
311800 34.
311900 35.
312000 36.
312100 37.
312200 38.
312300 39.
10000 40.
10100 41.
10200 42.
10300 43.
10400 44.
10500 45.
10600 46.
10700 47.
10800 48.
10900 49.
11000 50.
11100 51.
11200 52.
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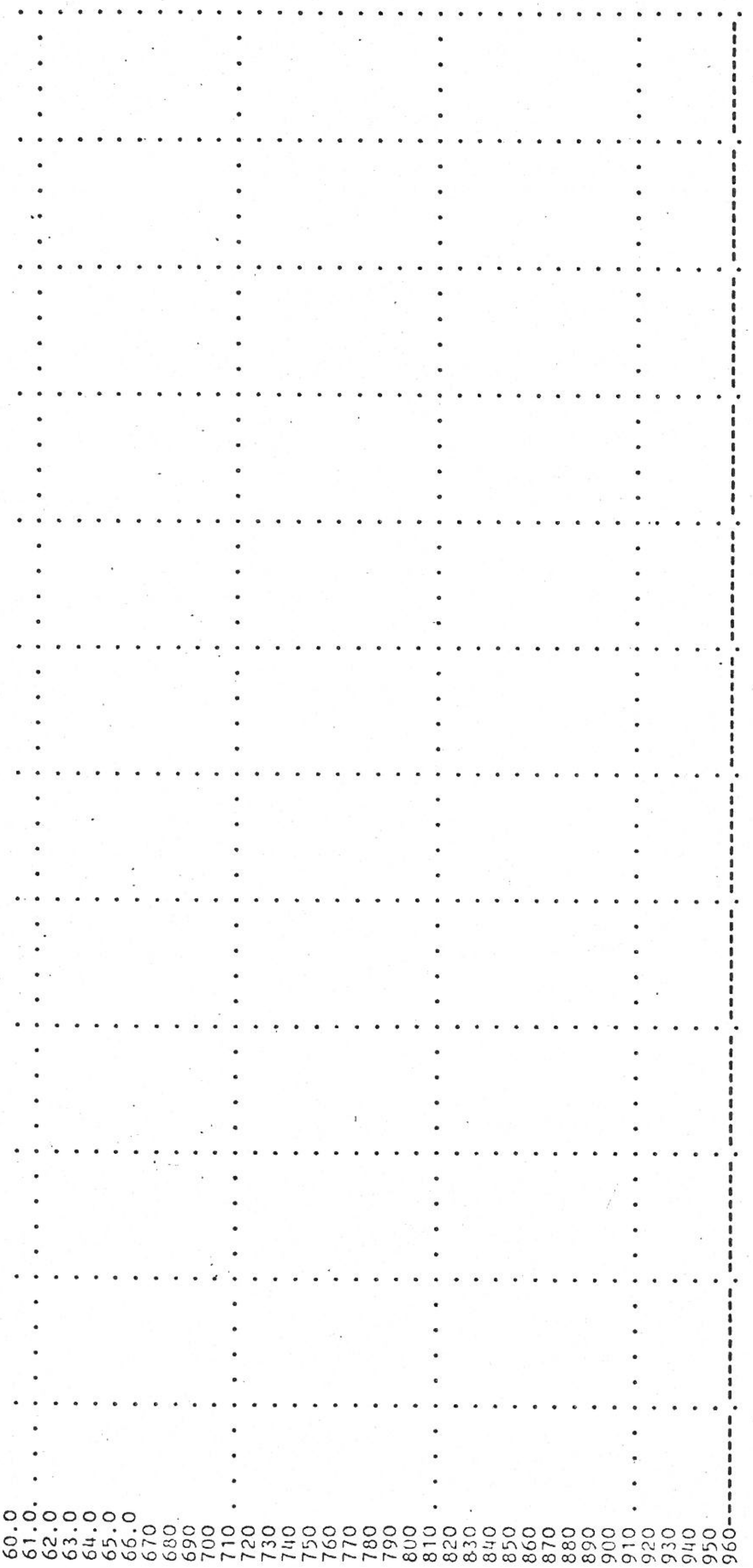
11400 54.
11500 55.
11600 56.0
11700 57.0
11800 58.0
11900 59.0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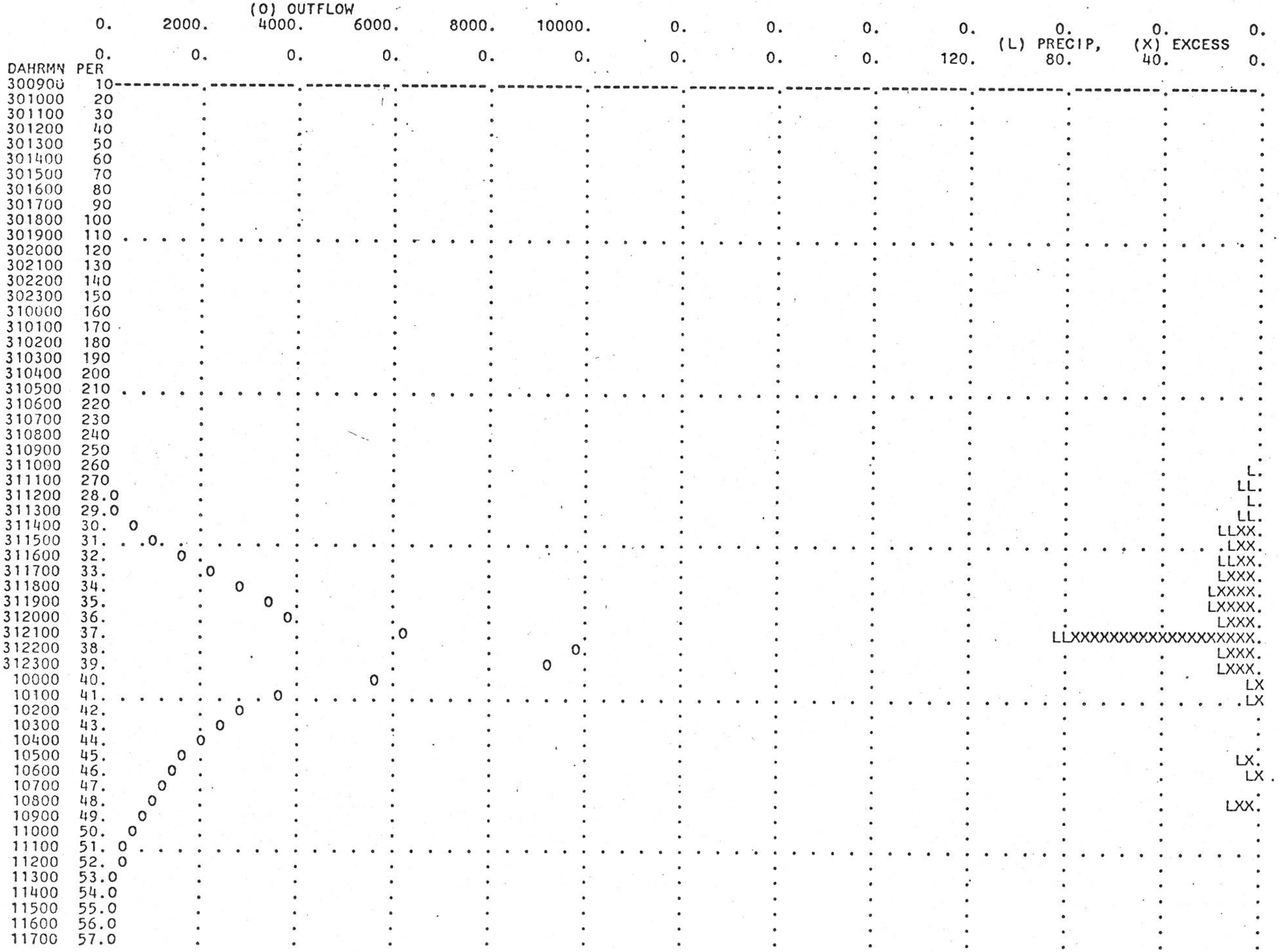
12200 62.0
12300 63.0
20000 64.0
20100 65.0
20200 66.0
20300 670
20400 680
20500 690
20600 700
20700 710
20800 720
20900 730
21000 740
21100 750
21200 760
21300 770
21400 780
21500 790
21600 800
21700 810
21800 820
21900 830
22000 840
22100 850
22200 860
22300 870
30000 880
30100 890
30200 900
30300 910
30400 920
30500 930
30600 940
30700 950
30800 960

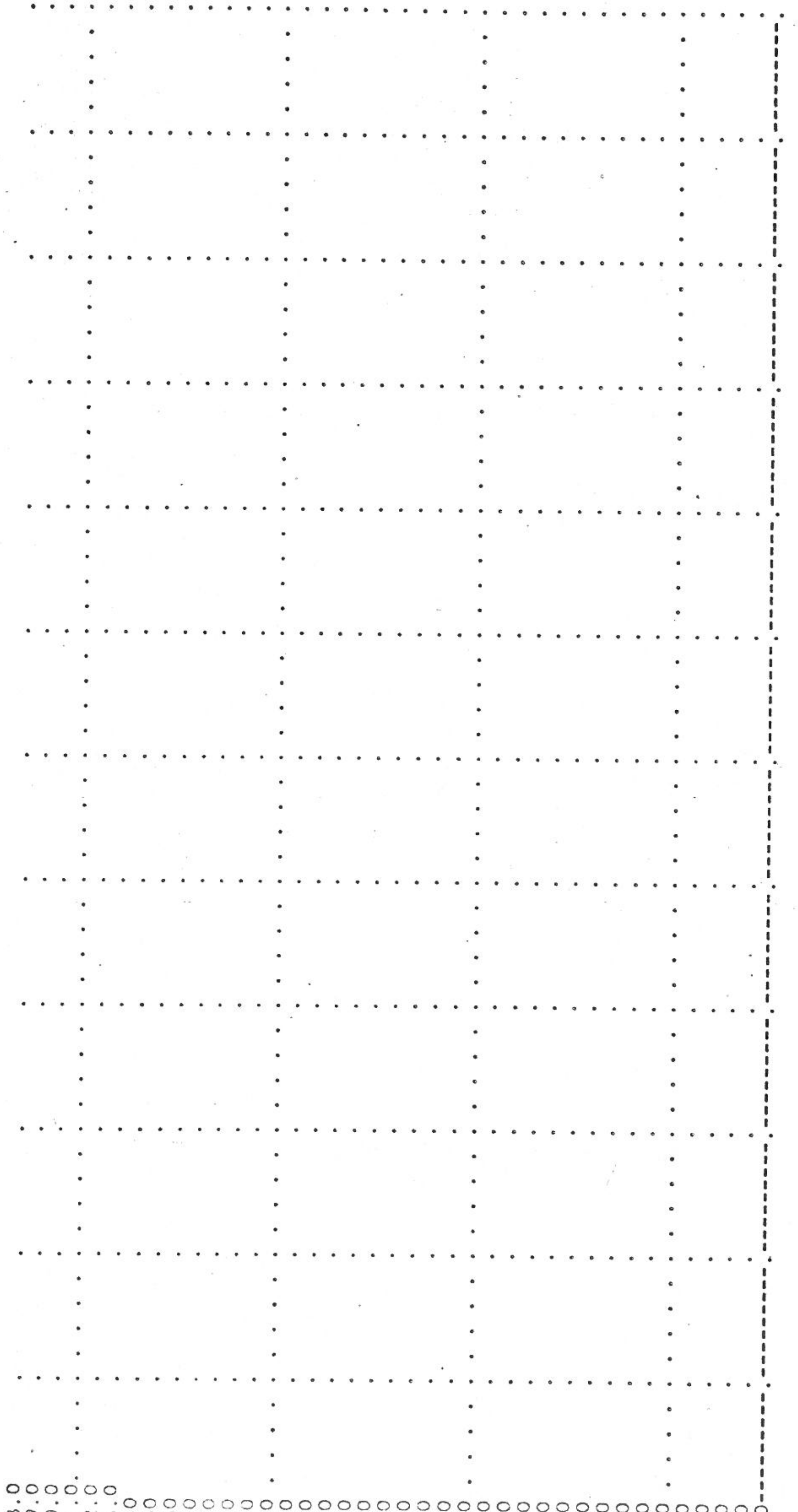
```
*** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** ***

              *************
              *           *
167 KK        *    SUB6   *
              *           *
              *************
                             RUNOFF FROM SUBBASIN 6

               SUBBASIN RUNOFF DATA

173 BA           SUBBASIN CHARACTERISTICS
                       TAREA        53.00  SUBBASIN AREA

                 PRECIPITATION DATA

171 PT            TOTAL STORM STATIONS        10
172 PW                         WEIGHTS      1.00

169 PR              RECORDING STATIONS         9
170 PW                         WEIGHTS      1.00

174 LS           SCS LOSS RATE
                       STRTL        12.70  INITIAL ABSTRACTION
                      CRVNBR        80.00  CURVE NUMBER
                       RTIMP          .00  PERCENT IMPERVIOUS AREA

                 KINEMATIC WAVE
175 UK             OVERLAND-FLOW ELEMENT NO. 1
                           L        5000.  OVERLAND FLOW LENGTH
                           S        .4000  SLOPE
                           N         .300  ROUGHNESS COEFFICIENT
                          PA        100.0  PERCENT OF SUBBASIN
176 RK             MAIN CHANNEL
                           L       13500.  CHANNEL LENGTH
                           S        .0119  SLOPE
                           N         .030  CHANNEL ROUGHNESS COEFFICIENT
                          CA        53.00  CONTRIBUTING AREA
                       SHAPE         TRAP  CHANNEL SHAPE
                          WD        80.00  BOTTOM WIDTH OR DIAMETER
                           Z        10.00  SIDE SLOPE
                      RUPSTQ          YES  ROUTE UPSTREAM HYDROGRAPH

                                                         ***

               PRECIPITATION STATION DATA

                      STATION     TOTAL     AVG. ANNUAL     WEIGHT
                           10    300.10             .00       1.00

                 TEMPORAL DISTRIBUTIONS

                 STATION        9,   WEIGHT =    1.00
                       .00        .00        .00        .00        .00        .00        .00        .00        .00        .00
                       .00        .00        .00        .00        .00        .00        .00        .00        .00        .00
                       .00        .00        .00        .50       5.50       6.00       4.00       6.00      16.90      11.10
                     14.00      16.00      20.00      20.00      16.00      84.00      14.00      14.00       5.50       5.50
                      1.70       1.70       1.70       8.00       2.90       1.10      10.20        .80       1.00       1.20
                      1.20       1.20       1.20       1.20       1.00       1.00       1.00       1.50       1.50
```

```
          COMPUTED KINEMATIC PARAMETERS
               ELEMENT      ALPHA          M        DT (MIN)    DX (FT)
                     1     3.1412      1.667          60.00     8202.10
                     3      .1886      1.589          60.00    22145.67

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

                                                     HYDROGRAPH AT STATION      SUB6

*********************************************************************************************************************************
                                                                  *
    DA MON HRMN  ORD      RAIN      LOSS  EXCESS      COMP Q      *      DA MON HRMN  ORD      RAIN      LOSS  EXCESS      COMP Q
                                                                  *
    30 AUG 0900    1       .00       .00     .00          0.      *       1 SEP 0900   49       .80       .03     .77        735.
    30 AUG 1000    2       .00       .00     .00          0.      *       1 SEP 1000   50      1.00       .04     .96        559.
    30 AUG 1100    3       .00       .00     .00          0.      *       1 SEP 1100   51      1.20       .04    1.16        427.
    30 AUG 1200    4       .00       .00     .00          0.      *       1 SEP 1200   52      1.20       .04    1.16        337.
    30 AUG 1300    5       .00       .00     .00          0.      *       1 SEP 1300   53      1.20       .04    1.16        274.
    30 AUG 1400    6       .00       .00     .00          0.      *       1 SEP 1400   54      1.20       .04    1.16        229.
    30 AUG 1500    7       .00       .00     .00          0.      *       1 SEP 1500   55      1.20       .04    1.16        199.
    30 AUG 1600    8       .00       .00     .00          0.      *       1 SEP 1600   56      1.00       .03     .97        179.
    30 AUG 1700    9       .00       .00     .00          0.      *       1 SEP 1700   57      1.00       .03     .97        168.
    30 AUG 1800   10       .00       .00     .00          0.      *       1 SEP 1800   58      1.00       .03     .97        161.
    30 AUG 1900   11       .00       .00     .00          0.      *       1 SEP 1900   59      1.50       .05    1.45        154.
    30 AUG 2000   12       .00       .00     .00          0.      *       1 SEP 2000   60      1.50       .05    1.45        144.
    30 AUG 2100   13       .00       .00     .00          0.      *       1 SEP 2100   61       .00       .00     .00        134.
    30 AUG 2200   14       .00       .00     .00          0.      *       1 SEP 2200   62       .00       .00     .00        121.
    30 AUG 2300   15       .00       .00     .00          0.      *       1 SEP 2300   63       .00       .00     .00        108.
    31 AUG 0000   16       .00       .00     .00          0.      *       2 SEP 0000   64       .00       .00     .00         97.
    31 AUG 0100   17       .00       .00     .00          0.      *       2 SEP 0100   65       .00       .00     .00         86.
    31 AUG 0200   18       .00       .00     .00          0.      *       2 SEP 0200   66       .00       .00     .00         76.
    31 AUG 0300   19       .00       .00     .00          0.      *       2 SEP 0300   67       .00       .00     .00         67.
    31 AUG 0400   20       .00       .00     .00          0.      *       2 SEP 0400   68       .00       .00     .00         59.
    31 AUG 0500   21       .00       .00     .00          0.      *       2 SEP 0500   69       .00       .00     .00         51.
    31 AUG 0600   22       .00       .00     .00          0.      *       2 SEP 0600   70       .00       .00     .00         45.
    31 AUG 0700   23       .00       .00     .00          0.      *       2 SEP 0700   71       .00       .00     .00         39.
    31 AUG 0800   24       .00       .00     .00          0.      *       2 SEP 0800   72       .00       .00     .00         35.
    31 AUG 0900   25       .50       .50     .00          0.      *       2 SEP 0900   73       .00       .00     .00         32.
    31 AUG 1000   26      5.50      5.50     .00          0.      *       2 SEP 1000   74       .00       .00     .00         29.
    31 AUG 1100   27      6.00      6.00     .00          0.      *       2 SEP 1100   75       .00       .00     .00         27.
    31 AUG 1200   28      4.00      3.84     .16        221.      *       2 SEP 1200   76       .00       .00     .00         25.
    31 AUG 1300   29      6.00      4.97    1.03        282.      *       2 SEP 1300   77       .00       .00     .00         23.
    31 AUG 1400   30     16.90     10.44    6.46        556.      *       2 SEP 1400   78       .00       .00     .00         21.
    31 AUG 1500   31     11.10      4.95    6.15       1055.      *       2 SEP 1500   79       .00       .00     .00         20.
    31 AUG 1600   32     14.00      4.88    9.12       1679.      *       2 SEP 1600   80       .00       .00     .00         18.
    31 AUG 1700   33     16.00      4.30   11.70       2269.      *       2 SEP 1700   81       .00       .00     .00         16.
    31 AUG 1800   34     20.00      4.09   15.91       2760.      *       2 SEP 1800   82       .00       .00     .00         15.
    31 AUG 1900   35     20.00      3.13   16.87       3302.      *       2 SEP 1900   83       .00       .00     .00         14.
    31 AUG 2000   36     16.00      2.02   13.98       3878.      *       2 SEP 2000   84       .00       .00     .00         13.
    31 AUG 2100   37     84.00      6.70   77.30       6113.      *       2 SEP 2100   85       .00       .00     .00         12.
    31 AUG 2200   38     14.00       .73   13.27       9872.      *       2 SEP 2200   86       .00       .00     .00         11.
    31 AUG 2300   39     14.00       .66   13.34       9153.      *       2 SEP 2300   87       .00       .00     .00         11.
     1 SEP 0000   40      5.50       .24    5.26       5530.      *       3 SEP 0000   88       .00       .00     .00         10.
     1 SEP 0100   41      5.50       .24    5.26       3595.      *       3 SEP 0100   89       .00       .00     .00          9.
     1 SEP 0200   42      1.70       .07    1.63       2736.      *       3 SEP 0200   90       .00       .00     .00          9.
     1 SEP 0300   43      1.70       .07    1.63       2326.      *       3 SEP 0300   91       .00       .00     .00          8.
     1 SEP 0400   44      1.70       .07    1.63       1919.      *       3 SEP 0400   92       .00       .00     .00          8.
     1 SEP 0500   45      8.00       .32    7.68       1560.      *       3 SEP 0500   93       .00       .00     .00          8.
     1 SEP 0600   46      2.90       .11    2.79       1341.      *       3 SEP 0600   94       .00       .00     .00          7.
     1 SEP 0700   47      1.10       .04    1.06       1150.      *       3 SEP 0700   95       .00       .00     .00          7.
     1 SEP 0800   48     10.20       .37    9.83        927.      *       3 SEP 0800   96       .00       .00     .00          7.
                                                                  *
*********************************************************************************************************************************
```

```
  TOTAL RAINFALL =  300.10, TOTAL LOSS =   64.71, TOTAL EXCESS =  235.39

PEAK FLOW      TIME                          MAXIMUM AVERAGE FLOW
                                    6-HR        24-HR      72-HR      95.00-HR
(CU M/S)       (HR)
                        (CU M/S)
  9872.        37.00                6332.       2669.       931.        706.
                             (MM)  170.976     288.257    301.803     301.803
                       (1000 CU M) 136781.     230606.    241442.     241442.

                     CUMULATIVE AREA =  800.00 SQ KM
```

STATION SUB6

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12000 60.0
12100 61.0
12200 62.0
12300 63.0
20000 640
20100 650
20200 660
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20400 680
20500 690
20600 700
20700 710
20800 720
20900 730
21000 740
21100 750
21200 760
21300 770
21400 780
21500 790
21600 800
21700 810
21800 820
21900 830
22000 840
22100 850
22200 860
22300 870
30000 880
30100 890
30200 900
30300 910
30400 920
30500 930
30600 940
30700 950
30800 960

```
                    RUNOFF SUMMARY, AVERAGE FLOW IN CUBIC METERS PER SECOND
                                  AREA IN SQUARE KILOMETERS

                                 PEAK    TIME OF      AVERAGE FLOW FOR MAXIMUM PERIOD         BASIN    MAXIMUM     TIME OF
OPERATION          STATION       FLOW      PEAK                                                AREA     STAGE     MAX STAGE
                                                      6-HOUR       24-HOUR      72-HOUR

HYDROGRAPH AT
                    SUB1A      1071.14    35.00       783.68       408.03       144.61        70.00

HYDROGRAPH AT
                    SUB1B      1022.03    35.00       764.95       375.54       132.03        70.00

2 COMBINED AT
                    SUB1C      2093.18    35.00      1545.13       783.51       276.63       140.00

HYDROGRAPH AT
                    SUB1C      2599.15    36.00      1996.48       985.76       347.87       185.00

HYDROGRAPH AT
                    SUB2A      3019.69    36.00      2243.72      1080.42       380.21       209.00

HYDROGRAPH AT
                    SUB2B       820.34    37.00       492.43       190.18        64.96        56.00

2 COMBINED AT
                    SUB2C      3763.89    36.00      2736.15      1270.31       445.16       265.00

ROUTED TO
                    RESER      3385.25    37.00      2673.25      1270.42       445.16       265.00
                                                                                                       6.57       37.00

HYDROGRAPH AT
                    SUB2C      5713.95    37.00      3768.70      1695.95       592.44       429.00

HYDROGRAPH AT
                     SUB3      1571.98    37.00       776.37       294.81        99.34       106.00

2 COMBINED AT
                     SUB4      7285.94    37.00      4543.80      1990.61       691.78       535.00

HYDROGRAPH AT
                     SUB4      8461.53    37.00      5251.71      2255.32       784.18       638.00

HYDROGRAPH AT
                     SUB5      1541.23    37.00       782.82       290.74        99.56       109.00

2 COMBINED AT
                     SUB6     10002.77    37.00      6034.53      2545.11       883.74       747.00

HYDROGRAPH AT
                     SUB6      9871.84    37.00      6332.44      2669.05       931.49       800.00

*** NORMAL END OF HEC-1 ***
```

1.8 STREAMFLOW FORECASTING MODEL

1.8.1 Selection of Models

Several existing simulation models were considered and reviewed to constitute the flood forecasting model for this project. The selection process is basically in the light of the state of the art of the model equations used, both requirement and their availability, the computer facility capabilities at INDHRI, and that the model provides suitable and acceptable results at reasonable cost within the forecast lead time frame. In view of these, two models were particularly examined namely the National Weather Service River Forecast System (National Weather Service, 1984) and the Flood Hydrograph Package (HEC-1) of the U.S. Army Corps of Engineers (1985). The NWSRFS is an operational model for continuous time streamflow simulation and real-time river forecasting. It is composed of several models developed independently including Sacramento soil moisture accounting model (SAC), snow accumulation and ablation model, routing models such as layered coefficient routing technique, Muskingum routing and unit hydrograph, precipitation and temperature models and extended streamflow prediction model. Also, this model contains procedures for data processing and analyses for calibration, testing and forecasting and auxiliary programs for data preprocessing and data file manipulation prior to and after model runs. On the other hand, the HEC-1 model simulates single event rainfall/snowmelt runoff processes. In this model, the surface runoff response of the river basin to precipitation is represented as a network system of hydrologic and hydraulic components such as overland flow plane, stream channel, pump station, diversion channel or a reservoir. For a given precipitation hydrograph the rainfall excess in derived using loss rate equations and routed via a unit hydrograph or kinematic wave method to obtain the surface runoff hydrograph. A baseflow component can also be added to the surface runoff at a basin or subbasin outlet using empirical methods. Sophisticated hydrologic analysis of basin wide flow-frequencies and analysis of expected annual flood damages may also be accomplished.

So far, the NWSRFS and HEC-1 models had found applications in several countries especially in the United States. Both models, however, have advantages and disadvantages which are unique but complementary to each other. On one hand, an attractive component of the NWSRFS model is the Sacramento soil moisture accounting model which has conceptually sound rainfall to channel inflow components transformation as compared to using precipitation loss equations in the HEC-1 model. On the other hand, the use of kinematic wave routing model of HEC-1 is more favored to the other routing techniques but is not available in the NWSRFS model. Thus combining the Sacramento soil moisture accounting model of the NWSRFS and the kinematic wave routing procedure of HEC-1 is believed to have more promising applications.

1.8.2 Development of SACKW Model

The latest version of the NWSRFS model obtained for this project is too large and requires a tremendous amount of core memory. Besides a PC-version of the NWSRFS model is not yet available and its use in definitely precluded in the IBM-34 computer at INDRHI. In view of this, steps were taken to develop a small version of NWSRFS model which specifically involved adapting the Sacramento soil-moisture accounting model (SAC) of the huge NWSRFS model. Similarly, the kinematic wave (KW) routing model of the HEC-1 model has been incorporated in the SAC model. In essence therefore, the streamflow forecasting model finally developed is the combination of Sacramento soil moisture accounting and kinematic wave routing referred to as SACKW model here.

For purposes of model calibration, the constrained Rosenbrock optimization routine presented by Kuester and Mize (1973) has also been adapted as an option to automatically calibrate the parameters of the SAC component of the model. This method is a sequential search technique which has been proven affective in finding the maximum or minimum of a multivariable, nonlinear objective function subject to nonlinear inequality constraints. This optimization technique is readily adaptable to SAC model since no derivatives are required.

1.8.3 Description of Model Components

Primarily, the SACKW model can be partitioned into two major components, namely: The Sacramento soil moisture accounting, and the kinematic wave routing. Given below are descriptions of each component. A subsection is also included to describe the watershed partitioning and timing considerations of the model.

1.8.3.1 Sacramento Soil Moisture Accounting Model

Referring to Figure 1.8.1, the Sacramento model computes various runoff components which are added together as total channel inflow and subsurface discharge through a soil moisture accounting procedure from a linkage of five basic soil moisture storages. Another function of the Sacramento model deals with the evapotranspiration process which has significant role in moisture movement in the hydrologic cycle.

The use of five basic storages and their linking mechanism is intended to provide a simple but effective representation of the vertical and horizontal movement of water through and over the soil. As

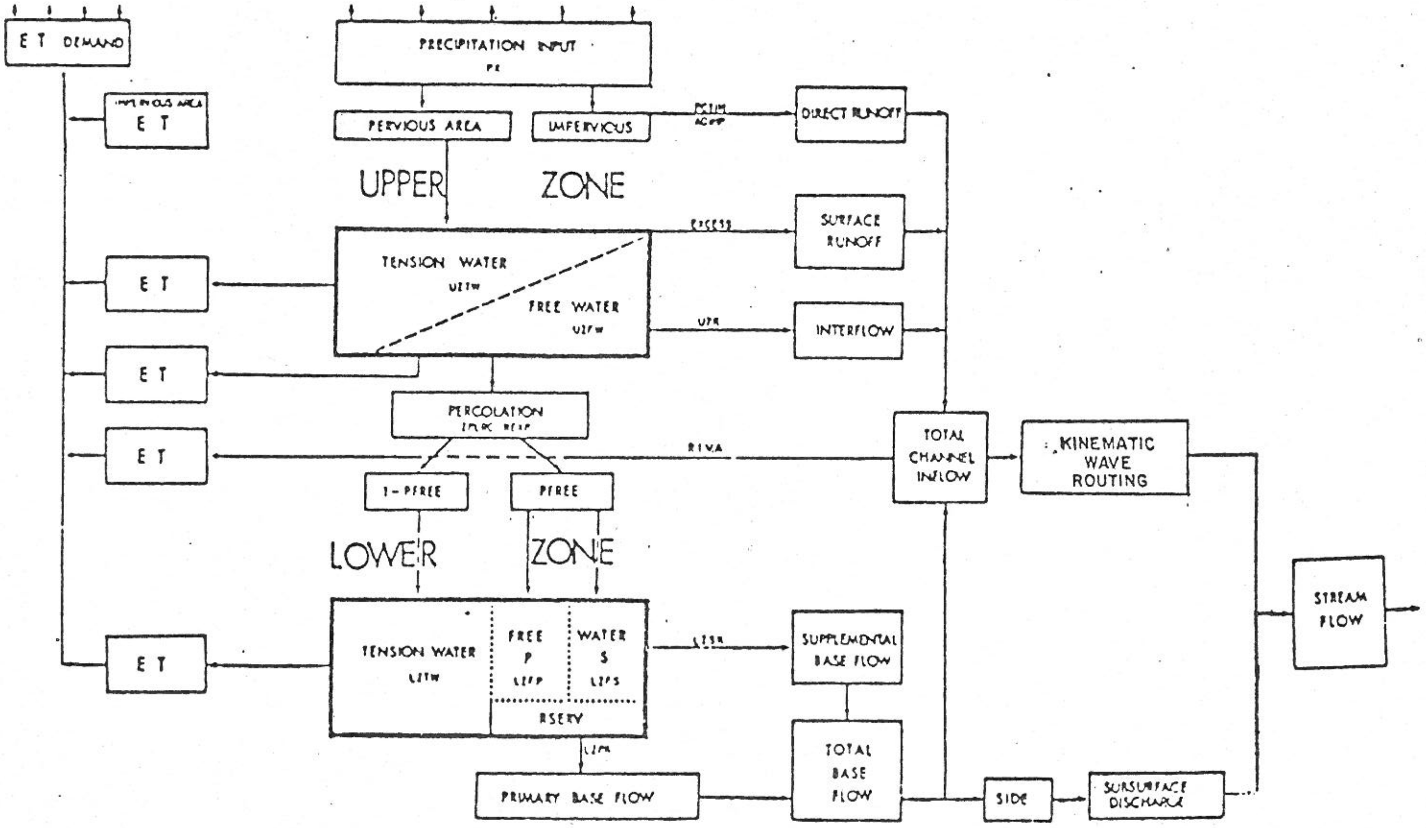


Figure 1.8.1. Flow chart of Sacramento soil-moisture accounting model.

shown in Figure 1.8.1, the five storages are: 1) the upper zone tension water which is the volume of water tightly bound to soil molecules but can be removed by evapotranspiration but occurs within such a shallow layer of soil that it is rapidly replaced by rainfall before sufficient moisture can accumulate to initiate the runoff process, 2) the upper zone free water is that water needed to produce fully effective wetting front which is a key factor to the percolation process and provides the source for rapid drainage in the form of interflow, 3) the lower zone tension water is that volume of water utilized by plants for evapotranspiration but not readily transferred from roots to leaf systems as in the shallower upper zone tension water, 4) the lower zone supplemental free water represents the source of rapidly draining component of subsurface runoff known as supplemental baseflow, and, 5) the lower zone primary water provides the source of slowly draining runoff component referred to as primary baseflow.

Three subprocesses in the Sacramento model worthwhile mentioning are the percolation process, evapotranspiration process and runoff process. The percolation process essentially centers on computing the water that percolates to deeper soil through vertical drainage prior to interflow calculation. The percolation rate is controlled by the amount of water available for percolation in the upper zone free water and the deficiency of lower zone moisture volume translated into the lower zone percolation demand as shown in Figure 1.8.2. The evapotranspiration process consists of evaporation from the area covered by surface water or phreatophyte vegetation and evapotranspiration from upper zone and lower zone water storages. Evaporation is computed at a potential rate while evapotranspiration from the soil moisture storages varies with the

PBASE = The continuing percolation rate under saturated conditions.

ZPERC = The number of PBASE units which must be added to the continuing saturated percolation rate to define the maximum percolation condition.

REXP = The exponent which defines the curvature in the percolation curve with changes in the lower zone soil moisture deficiency.

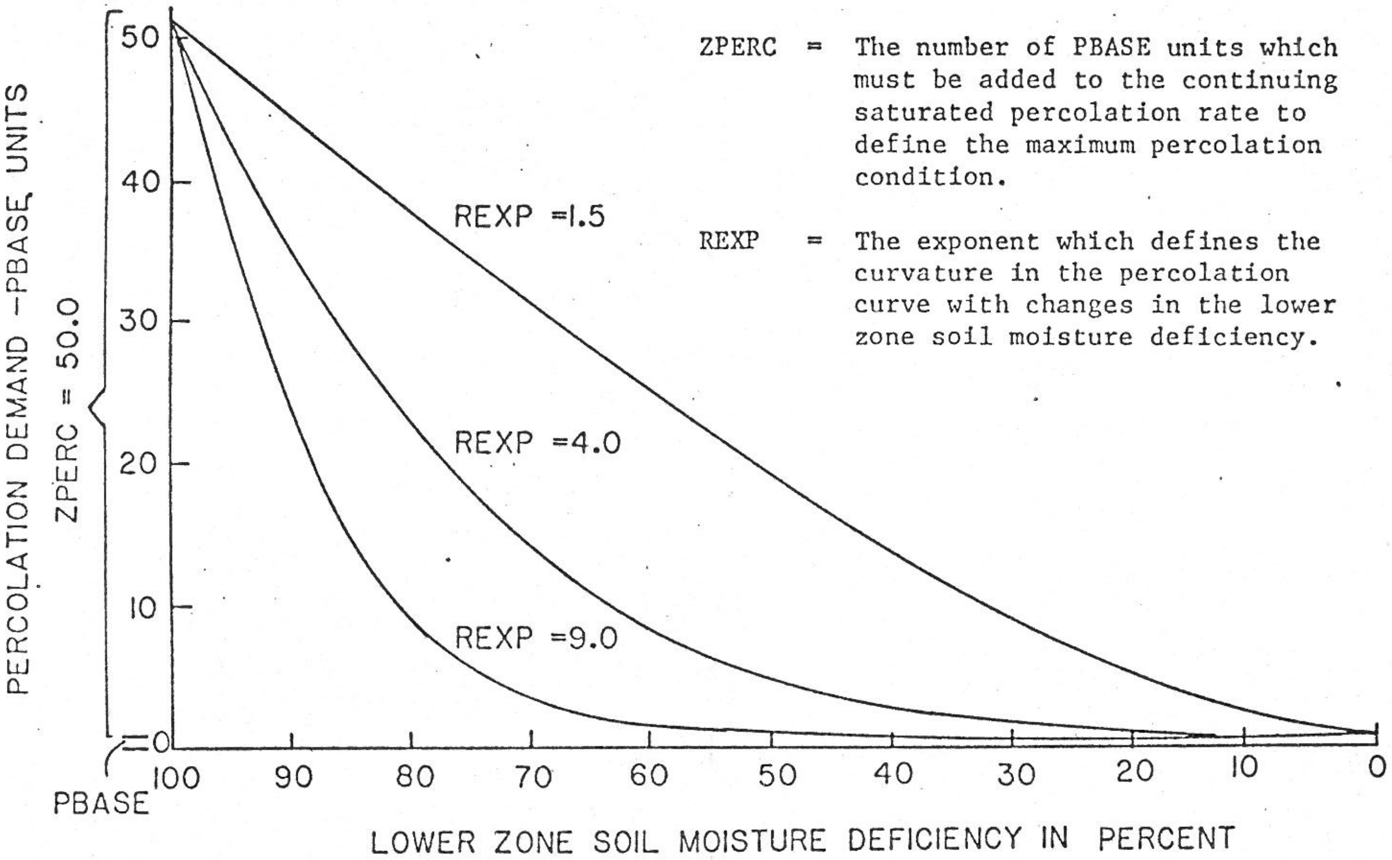


Figure 1.8.2. Relationship of percolation demand and lower zone moisture deficiency.

volume and distribution of tension water storage and evapotranspiration demand. Starting with a saturated soil, and exposing it to a constant evapotranspiration demand would produce an effective evapotranspiration use curve of the type illustrated in Figure 1.8.3.

The runoff resulting from soil-moisture accounting are given in five basic forms. These are: 1) the impervious runoff from impervious areas, and direct runoff from temporary impervious area, 2) surface runoff which occurs when the upper zone free water storage is full and the precipitation intensity exceeds the rate of percolation and interflow, 3) interflow resulting from lateral drainage of the upper zone free water storage, 4) supplemental baseflow, and 5) primary baseflow. The first three runoff components represents the total channel inflow while the latter two is the total baseflow. In the SACKW model, the so called total channel inflow constitute the surface runoff contribution to the stream flow hydrograph routed via the kinematic wave routing methodology and the total baseflow is the subsurface runoff contribution to streamflow. This baseflow component is added to the routed streamflow at the basin or subbasin outlet using a linear, decay weighting function of current and some specified previous time total baseflows.

1.8.3.2 Kinematic Wave Routing Model

The kinematic wave model provides the mechanism of water movement over the land surface and in stream channels towards the basin or subbasin outlet. The input to this model is the total channel inflow or hydrograph which is assumed to be uniform over the subbasin. In determining the subbasin runoff by the kinematic wave method, three conceptual elements are used: flow planes, collector channels and a

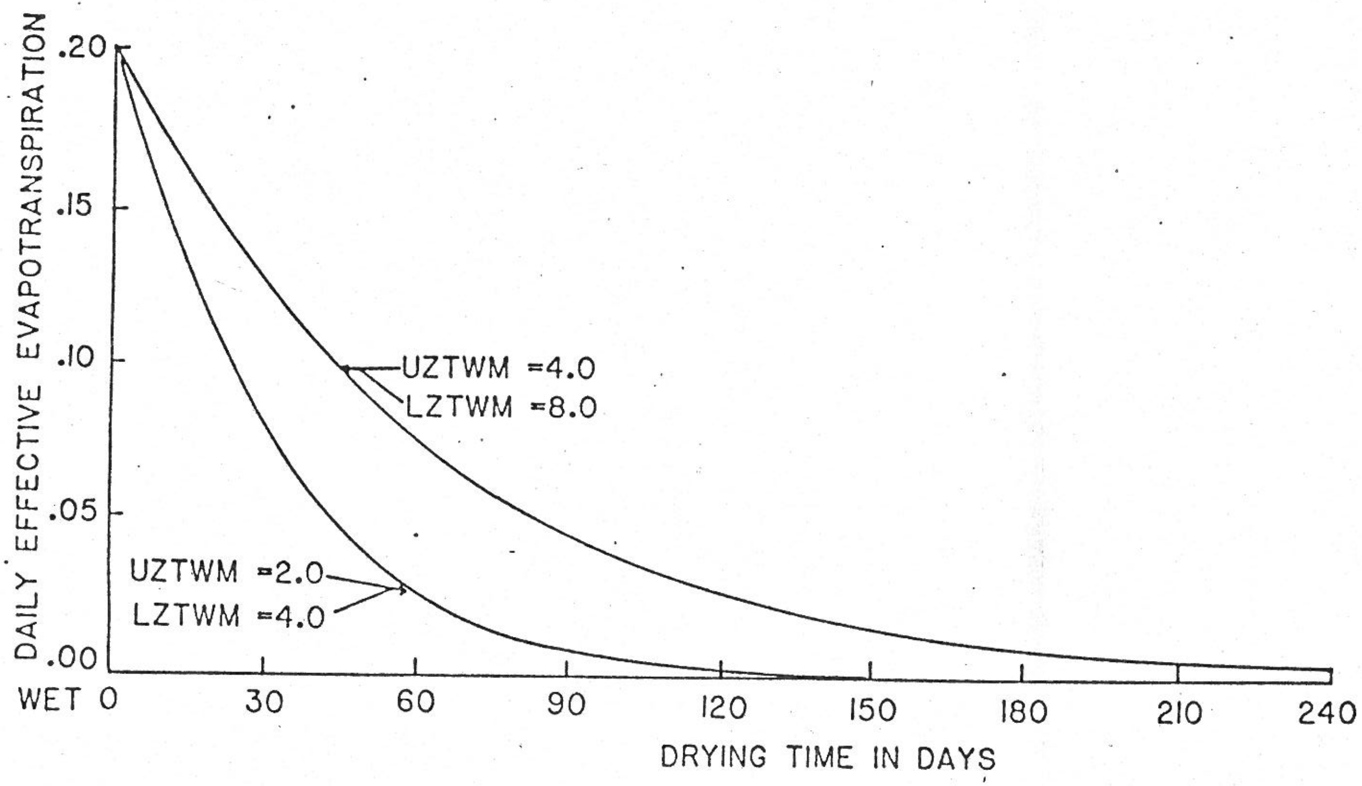


Figure 1.8.3. Daily effective evapotranspiration from initially wet soils exposed to a constant evapotranspiration demand.

main channel as shown in Figure 1.8.4. The kinematic wave method assumes that the bed slope and water surface slope are equal and acceleration effects are negligible. In this manner, the overland or channel flow can be represented as a power function of cross-sectional area with power coeficients related to flow geometry and surface roughners. The movement of flood wave is described solely by the continuity equation in partial differential form. Through combining the flow and continuity equations, a finite difference approximation can be developed and likewise solved by finite difference methods. For further details of the kinematic wave method and its solution, the HEC-1 User's Manual (U.S. Corps of Engineers, 1985) may be consulted.

1.8.3.3 Watershed Partitioning and Timing Considerations

Partitioning of the watershed provides the distributed parameter capability of the model. This is done to account for the spatial and temporal variabilities of the physical and hydrological characteristics of the basing, the climatic variables, and basin-wide response characteristics. In the SACKW model, the watershed can be partitioned into two levels. The first level, partitions the watershed into subwatersheds where each subwatershed is a homogeneous unit of the SAC model in terms of the SAC model parameters. Rainfall and evapotranspiration are assumed homogeneous or uniform over one subwatershed. The second level of partitioning divides further a subwatershed into smaller homogeneous units representing individual flow planes. Each flow plane is assumed to have homogeneous kinematic wave parameters.

The timing considerations for the model refers to the time basis of model operation. The model is set up to simulate basin hydrology on an

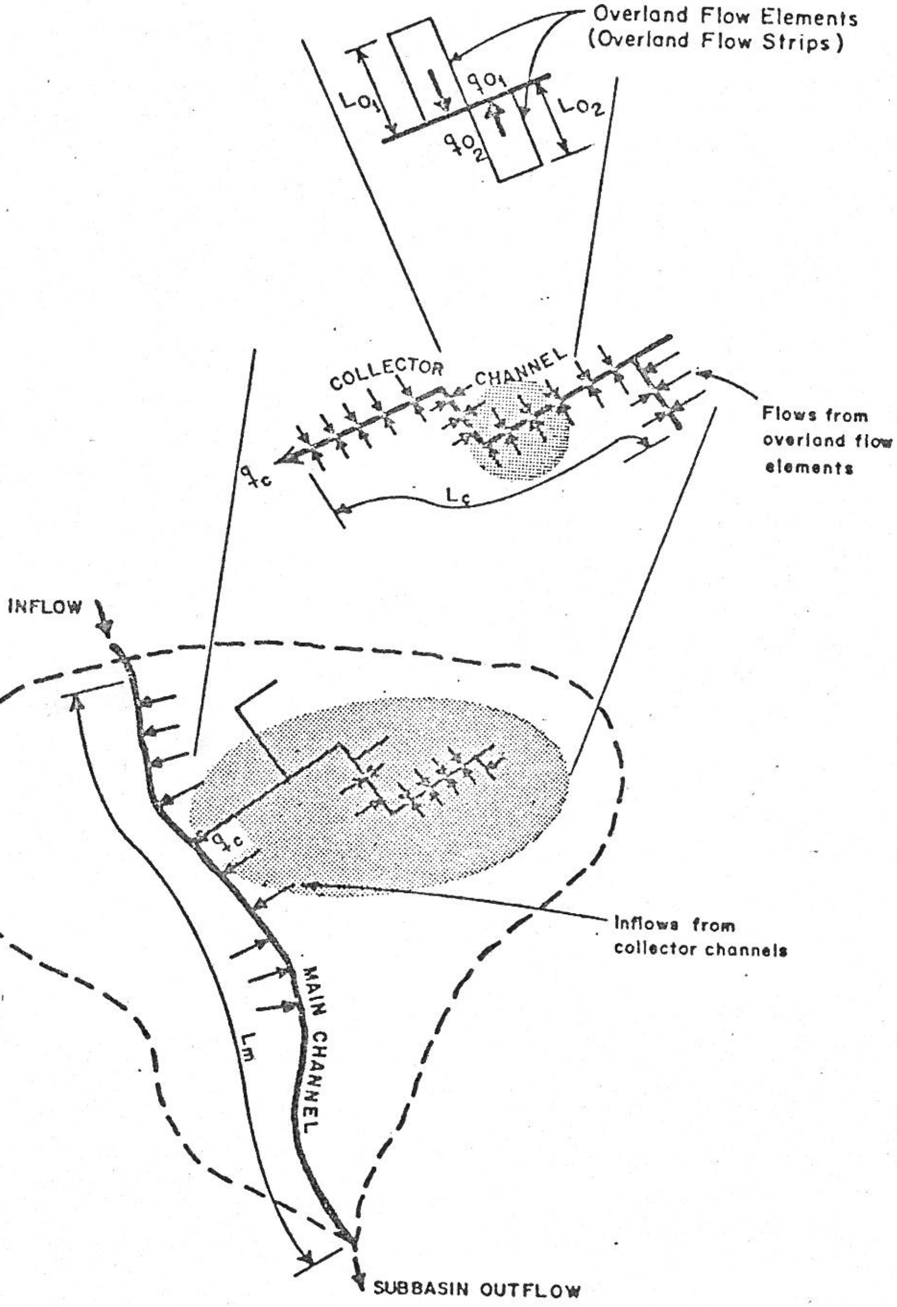


Figure 1.8.4. Relationship between flow elements in kinematic wave routing.

hourly basis and on longer time intervals which is a multiple integer of 1 hour. In the SAC model, the computational time interval is always done in an hourly basis so that rainfall, evapotranspiration and streamflow if given in longer time intervals are uniformly transformed into hourly data. Model outputs however are given on time intervals equal to those specified in the input data. In the kinematic wave routing computations, the time interval may vary depending on the stability criteria requirements of the finite-difference numerical sequence.

1.8.4 Model Calibration

This section reports the SACKW model calibration for the Nizao basin. In the ensuing text, the SACKW user's manual given in Appendix 1.8.A may be referred to which describes the model usage and capabilities, input requirements, program description, output information and some guidelines for model calibration.

Shown in Figure 1.8.5 is the Nizao basin and its watershed partitioning. It is decided that the basin be partitioned into three subwatersheds: La Estrechura, Palo de Caja and Paso del Ermitano, for purposes of the SAC model (first level partitioning). For each subwatershed, further partitioning is made to constitute the homogeneous flowplanes in the kinematic wave routing (second level partitioning).

A total of four years (1972-1975) of data is used for model calibration. The rainfall data used which are available hourly are areal averages from nine stations using optimal interpolation. Three sets of areal averaged time series were obtained corresponding to the three first level subwatersheds. Since not all of the nine rainfall stations are recording at one time or another, the areal averaging was

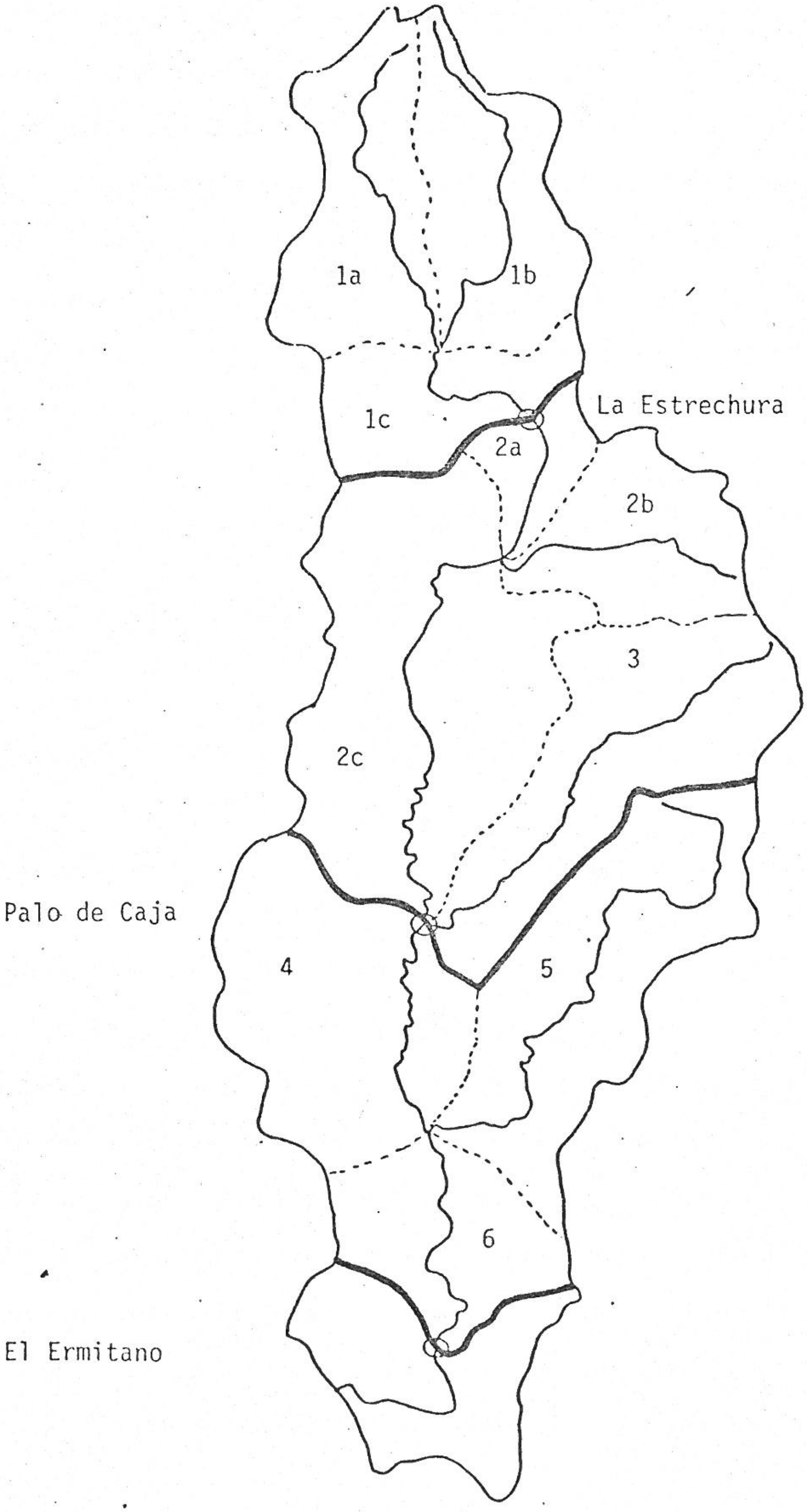


Figure 1.8.5. First and second level watershed partitions of Nizao basin for SACKW model.

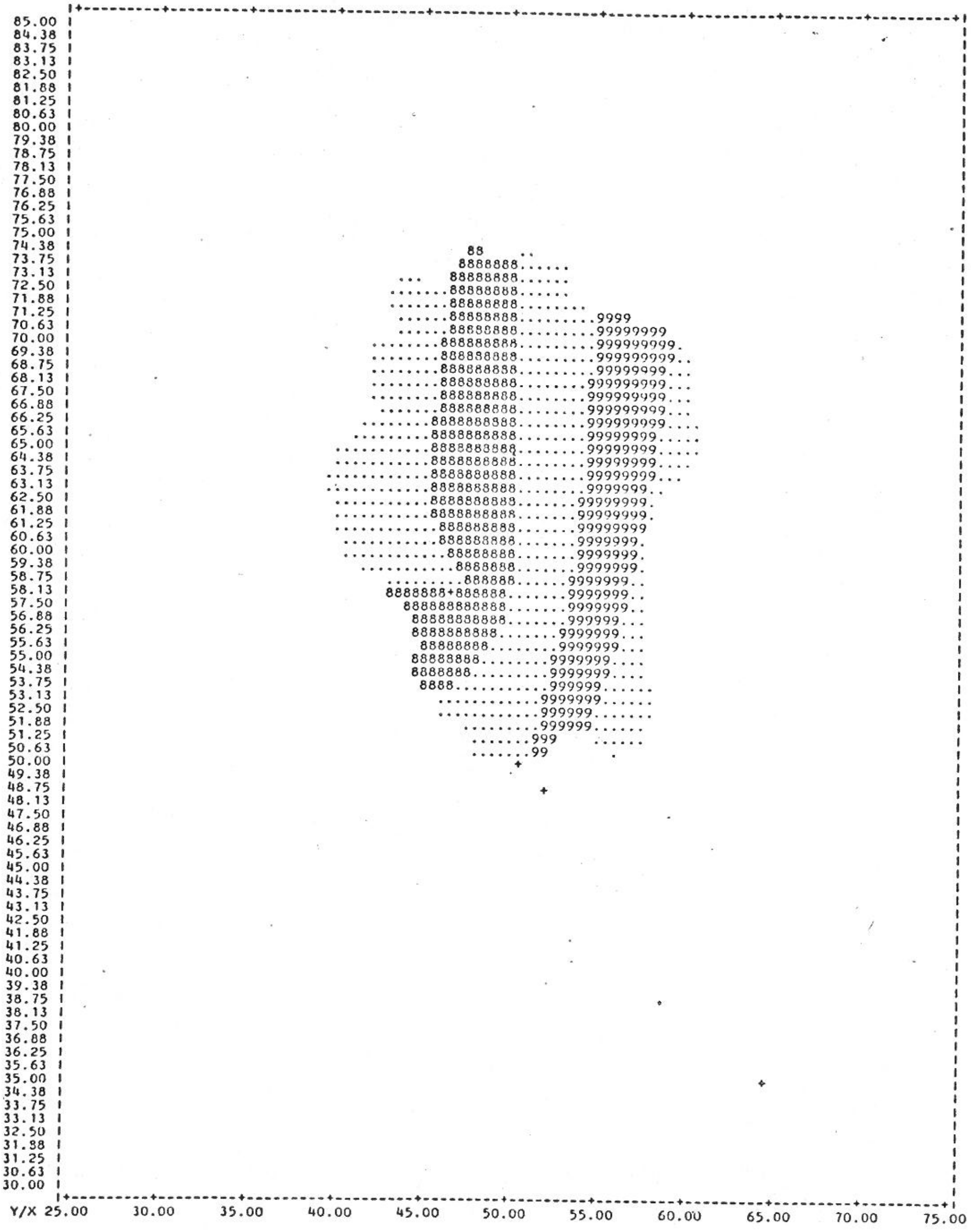
done on a case to case basis. As an example, in case of nine stations recording at the same time, Figure 1.8.6. to 1.8.8 show the optimal interpolation areal averages and the weights of each station using a hypothetical data. Nevertheless, Figures 1.8.9 through 1.8.20 show the areal averaged rainfall series plotted on a daily basis for each subwatershed and for each year. Daily streamflow at the outlet of each subwatershed were used for purposes of calibration. Figures 1.8.9 to 1.8.20 also show the daily streamflow for each subwatershed and for each year. The daily evapotranspiration demand data required in the model is obtained from the monthly pan evaporation of Valdesia station after converting them to daily values and multiplying by an adjustment coefficient of 0.7. This demand data is assumed to be uniform all over the basin.

Based on some guidelines suggested for model calibration in Appendix 1.8.A and references herein, the model input parameters were set up for the first year of data to be calibrated. The input file for this first year is given in Figure 1.8.21. The kinematic wave routing model parameters used were those obtained from the HEC-1 model calibration which is presented in Section 1.7.2 of the report. Beginning with year 1972, the best parameter estimates of the SAC model are obtained where some refinements were made using the optimization routine. The least squares objective function was used in the optimization runs between observed and computed daily stream flows at each subwatershed. Based on these 1972 model parameters, the calibration proceeds to 1973, then to 1974, and finally 1975. It is assumed that for four years, the kinematic wave parameters are the same such that only the SAC model parameters change. Given in Figure 1.8.22

```
               OPTIMAL INTERPOLATION BASED ON STRAIGHT DATA   LAESTRECHURA SUBBASIN

      I+---------+---------+---------+---------+---------+---------+---------+---------+---------+---------+I
85.00 I                                                                                                     I
84.38 I                                                                                                     I
83.75 I                                                                                                     I
83.13 I                                                                                                     I
82.50 I                                                                                                     I
81.88 I        44                                                                                           I
81.25 I        4....      ...6                                                                              I
80.63 I       44....555 .....6                                                                              I
80.00 I     444....55555.....66                                                                             I
79.38 I     444....5555.....66666                                                                           I
78.75 I     44....55555.....66666.....                                                                      I
78.13 I     4....55555.....666666.....                                                                      I
77.50 I     ....55555.....666666......7                                                                     I
76.88 I     ...55555......666666......77                                                                    I
76.25 I    ...55555......666666......7777                                                                   I
75.63 I    .555555......666666.......77777                                                                  I
75.00 I    555555......6666666......7777777                                                                 I
74.38 I     555.......6666666.......7777777.                                                                I
73.75 I         .....6666666.......77777777..                                                               I
73.13 I          ...6666666........7777777...                                                               I
72.50 I            6666666........77777777..                                                                I
71.88 I            666666........777777777..                                                                I
71.25 I            66666.........77777777...                                                                I
70.63 I            6666.........777777777....                                                               I
70.00 I            66..........777777777....                                                                I
69.38 I            6..........7777777777..                                                                  I
68.75 I             .........7777777777...                                                                  I
68.13 I              .......77777777777...                                                                  I
67.50 I              .....777777777777....                                                                  I
66.88 I               ...777777777777......                                                                 I
66.25 I                7     7777777......                                                                  I
65.63 I                       777777....                                                                    I
65.00 I                         777....                                                                     I
64.38 I                           ...                                                                       I
63.75 I                            ..                                                                       I
63.13 I                                                                                                     I
62.50 I                                                                                                     I
61.88 I                                                                                                     I
61.25 I                                                                                                     I
60.63 I                                                                                                     I
60.00 I                                                                                                     I
59.38 I                                                                                                     I
58.75 I                                                                                                     I
58.13 I                                           +                                                         I
57.50 I                                                                                                     I
56.88 I                                                                                                     I
56.25 I                                                                                                     I
55.63 I                                                                                                     I
55.00 I                                                                                                     I
54.38 I                                                                                                     I
53.75 I                                                                                                     I
53.13 I                                                                                                     I
52.50 I                                                                                                     I
51.88 I                                                                                                     I
51.25 I                                                                                                     I
50.63 I                                                                                                     I
50.00 I                                                   +                                                 I
49.38 I                                                                                                     I
48.75 I                                                     +                                               I
48.13 I                                                                                                     I
47.50 I                                                                                                     I
46.88 I                                                                                                     I
46.25 I                                                                                                     I
45.63 I                                                                                                     I
45.00 I                                                                                                     I
44.38 I                                                                                                     I
43.75 I                                                                                                     I
43.13 I                                                                                                     I
42.50 I                                                                                                     I
41.88 I                                                                                                     I
41.25 I                                                                                                     I
40.63 I                                                                                                     I
40.00 I                                                                                                     I
39.38 I                                                                                                     I
38.75 I                                                                                                     I
38.13 I                                                                                                     I
37.50 I                                                                                                     I
36.88 I                                                                                                     I
36.25 I                                                                                                     I
35.63 I                                                                                                     I
35.00 I                                                                              +                      I
34.38 I                                                                                                     I
33.75 I                                                                                                     I
33.13 I                                                                                                     I
32.50 I                                                                                                     I
31.88 I                                                                                                     I
31.25 I                                                                                                     I
30.63 I                                                                                                     I
30.00 I                                                                                                     I
      I+---------+---------+---------+---------+---------+---------+---------+---------+---------+---------+I
 Y/X 25.00     30.00     35.00     40.00     45.00     50.00     55.00     60.00     65.00     70.00     75.00


                               OPTIMAL AREAL AVERAGING

                 STA.NO.    STA. NAME     INPUT DATA     OPTIMAL WEIGHT

                    1        EL RIO         28.700           .0784
                    2        ENGOMBE        94.200           .0374
                    3        JUMA BON       54.000           .0664
                    4        LALAGUNA       50.800           .0334
                    5        QUEMADOS       46.400           .1696
                    6        NIZAO          46.900           .2404
                    7        PALOUECA       52.200           .0240
                    8        VALDESIA       64.800           .0364
                    9        VALLENUE       22.640           .3141

                      SUM OF OPTIMAL WEIGHT =    1.00000
                      OPTIMAL AREAL MEAN    =     40.917
                      STD. ERROR OF AREAL MEAN =   12.7183
```

Figure 1.8.6. Sample output of rainfall areal averaging for La Estrechura subbasin.

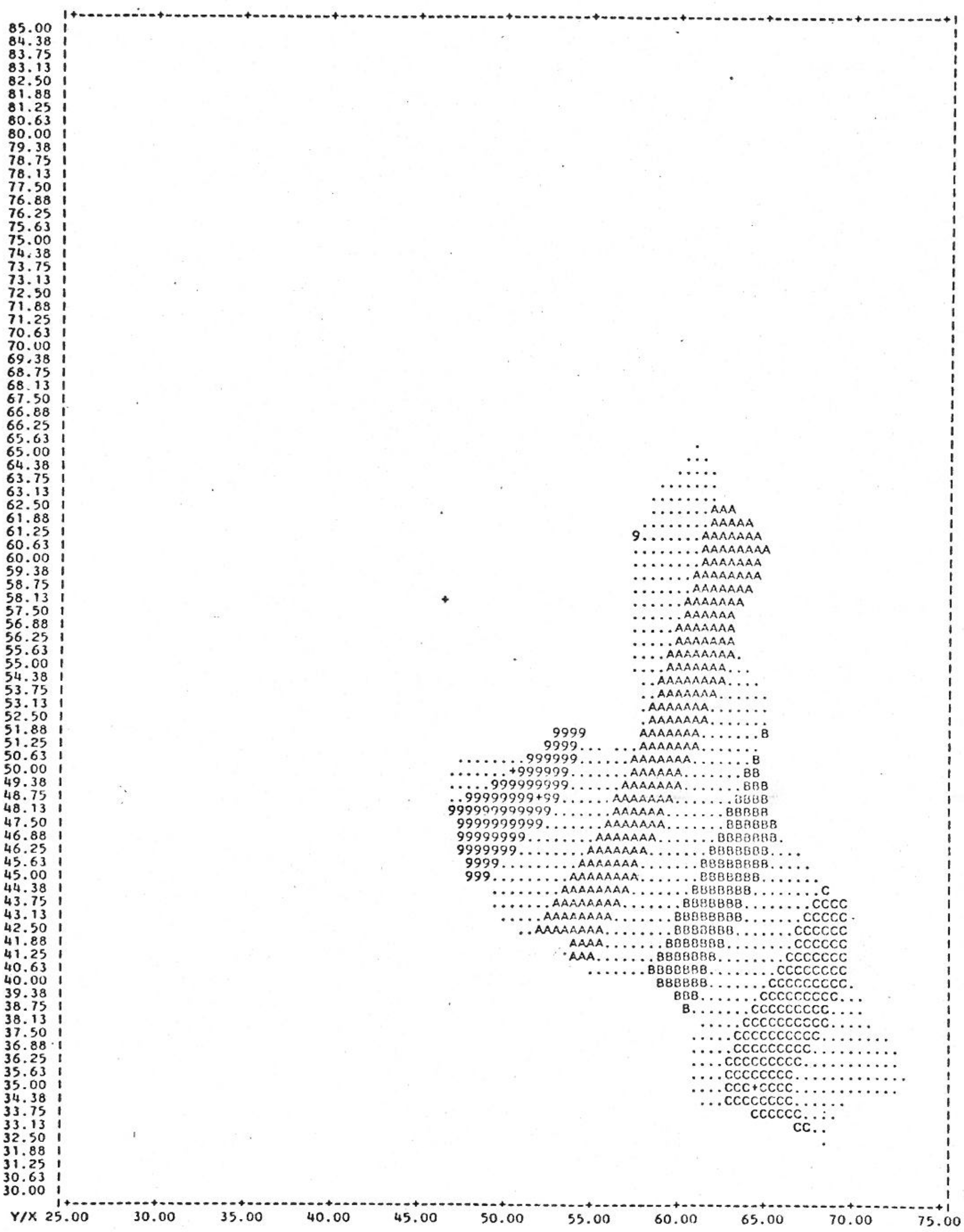
```
OPTIMAL INTERPOLATION BASED ON STRAIGHT DATA   PALO DE CAJA SUBBASIN
```



```
                        OPTIMAL AREAL AVERAGING

STA.NO.    STA. NAME     INPUT DATA      OPTIMAL WEIGHT

   1       EL RIO          28.700            .0269
   2       ENGOMBE         94.200            .0456
   3       JUMA BON        54.000            .0839
   4       LALAGUNA        50.800            .1298
   5       QUEMADOS        46.400            .0765
   6       NIZAO           46.900            .4423
   7       PALODECA        52.200            .0872
   8       VALDESIA        64.800            .0482
   9       VALLENUE        22.640            .0596

     SUM OF OPTIMAL WEIGHT =    1.00000
     OPTIMAL AREAL MEAN     =     49.510
     STD. ERROR OF AREAL MEAN =     9.9004
```

Figure 1.8.7. Sample output of rainfall areal averaging for Palo de Caja subbasin.

```
OPTIMAL INTERPOLATION BASED ON STRAIGHT DATA   PASO DEL ERMITANO SUBBASIN
```



```
                    OPTIMAL AREAL AVERAGING

STA.NO.   STA. NAME    INPUT DATA    OPTIMAL WEIGHT

   1       EL RIO        28.700          .0191
   2       ENGOMBE       94.200          .0807
   3       JUMA BON      54.000          .0404
   4       LALAGUNA      50.800          .0930
   5       QUEMADOS      46.400          .0204
   6       NIZAO         46.900          .0916
   7       PALODECA      52.200          .2892
   8       VALDESIA      64.800          .3430
   9       VALLENUE      22.640          .0226

       SUM OF OPTIMAL WEIGHT =   1.00000
       OPTIMAL AREAL MEAN    =    58.132
       STD. ERROR OF AREAL MEAN =  10.9390
```

Figure 1.8.8. Sample output of rainfall areal averaging for Paso del Ermitano subbasin.

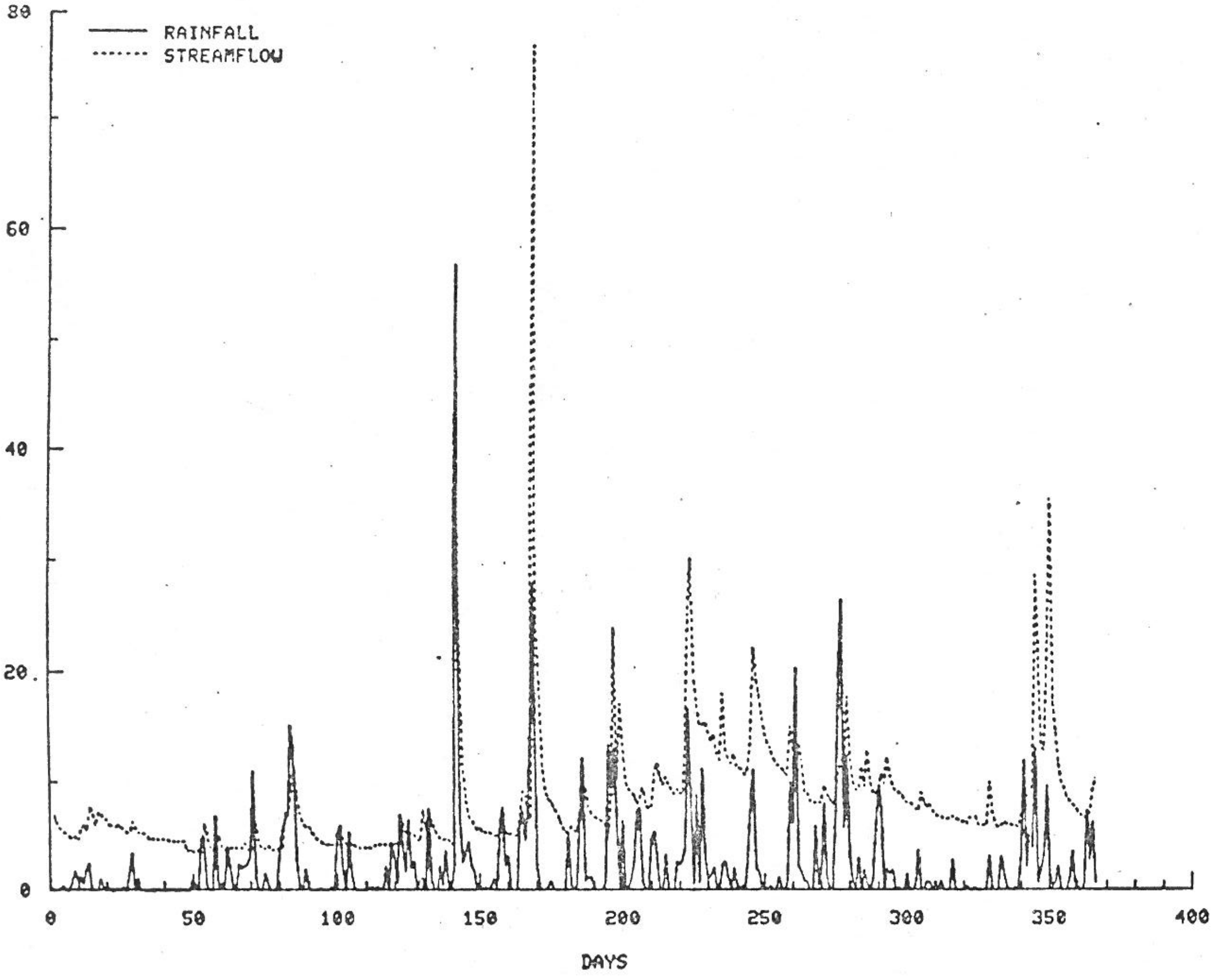


Figure 1.8.9. LA ESTRECHURA - 1972

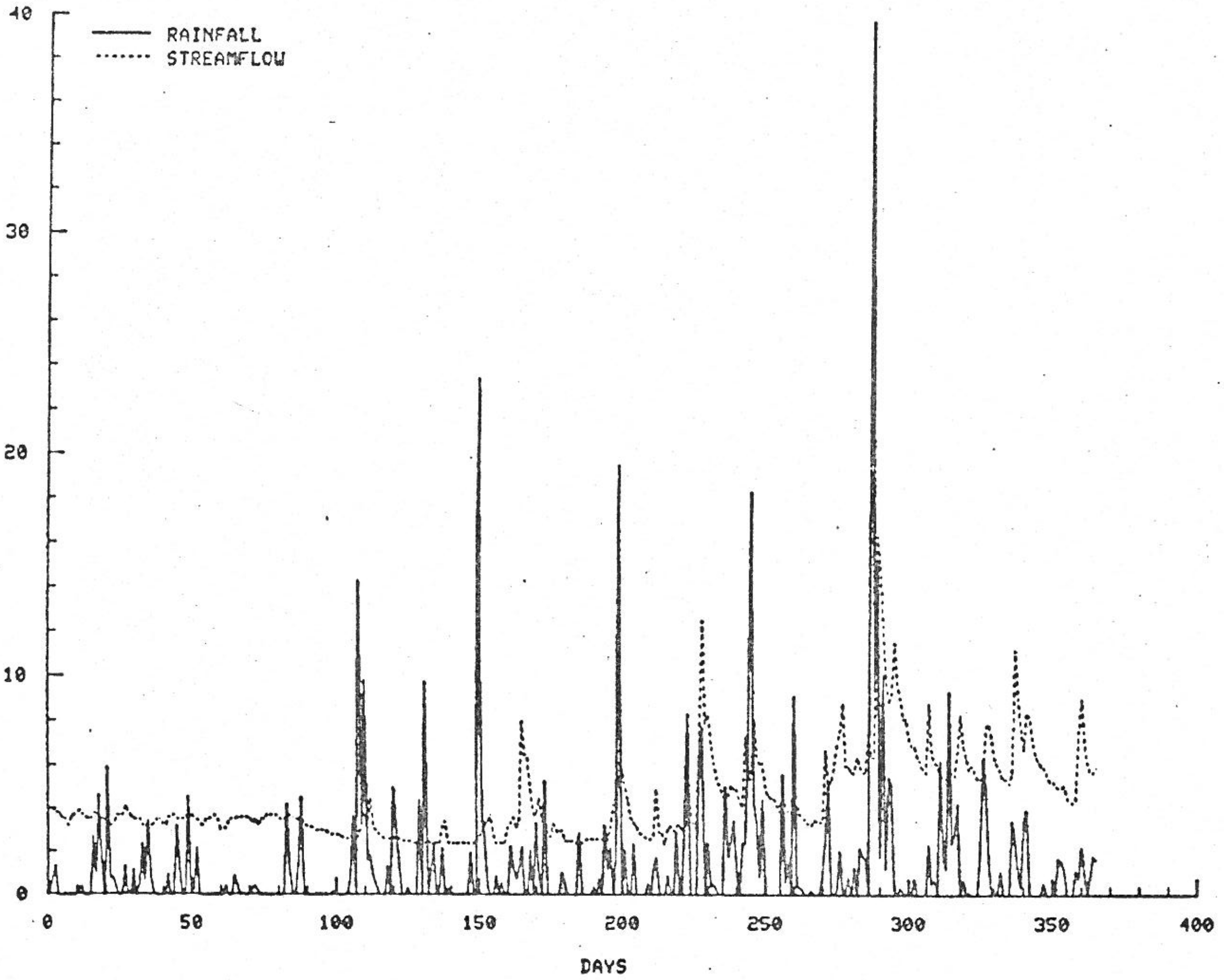


Figure 1.8.10. LA ESTRECHURA - 1973

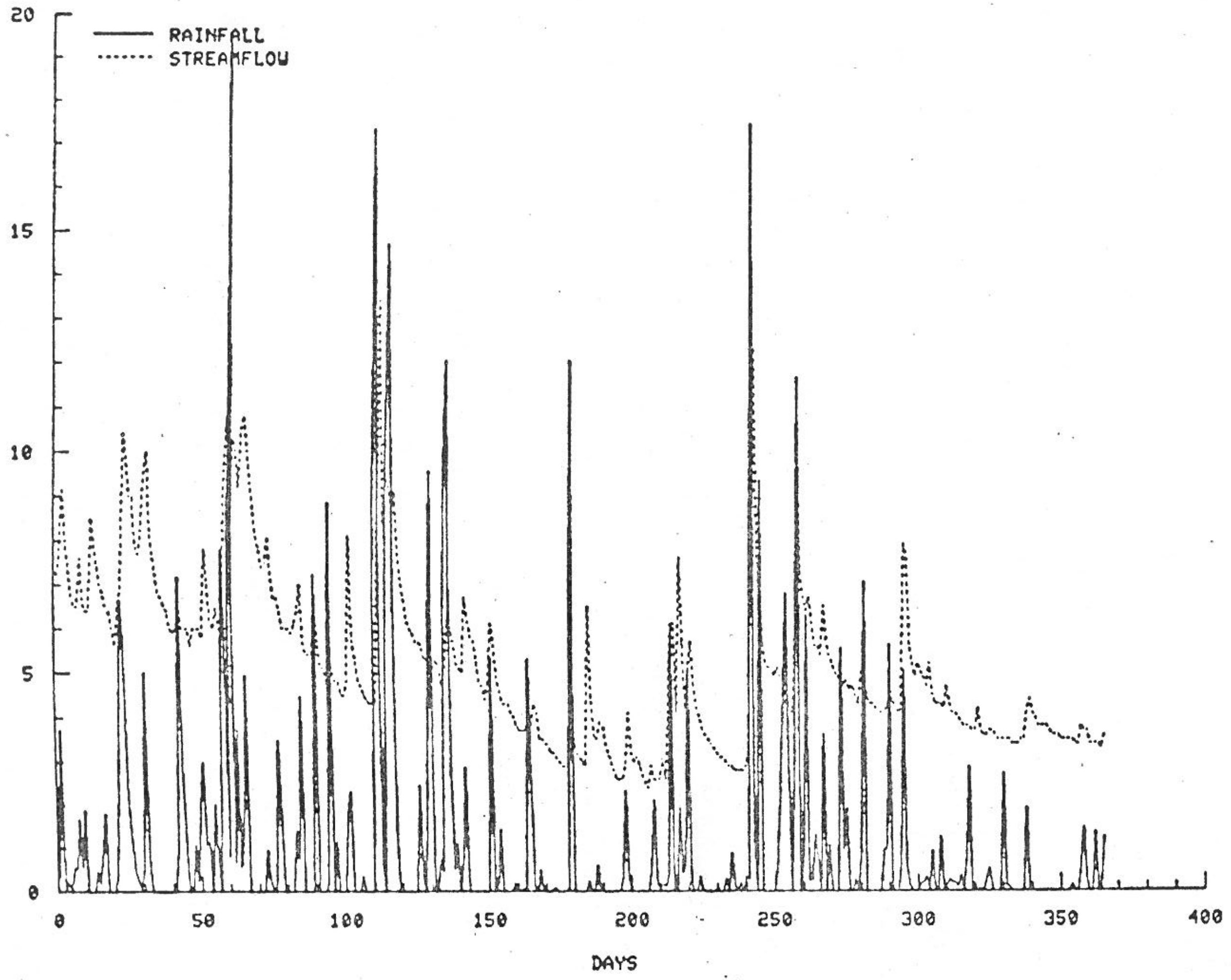


Figure 1.8.11. LA ESTRECHURA - 1974

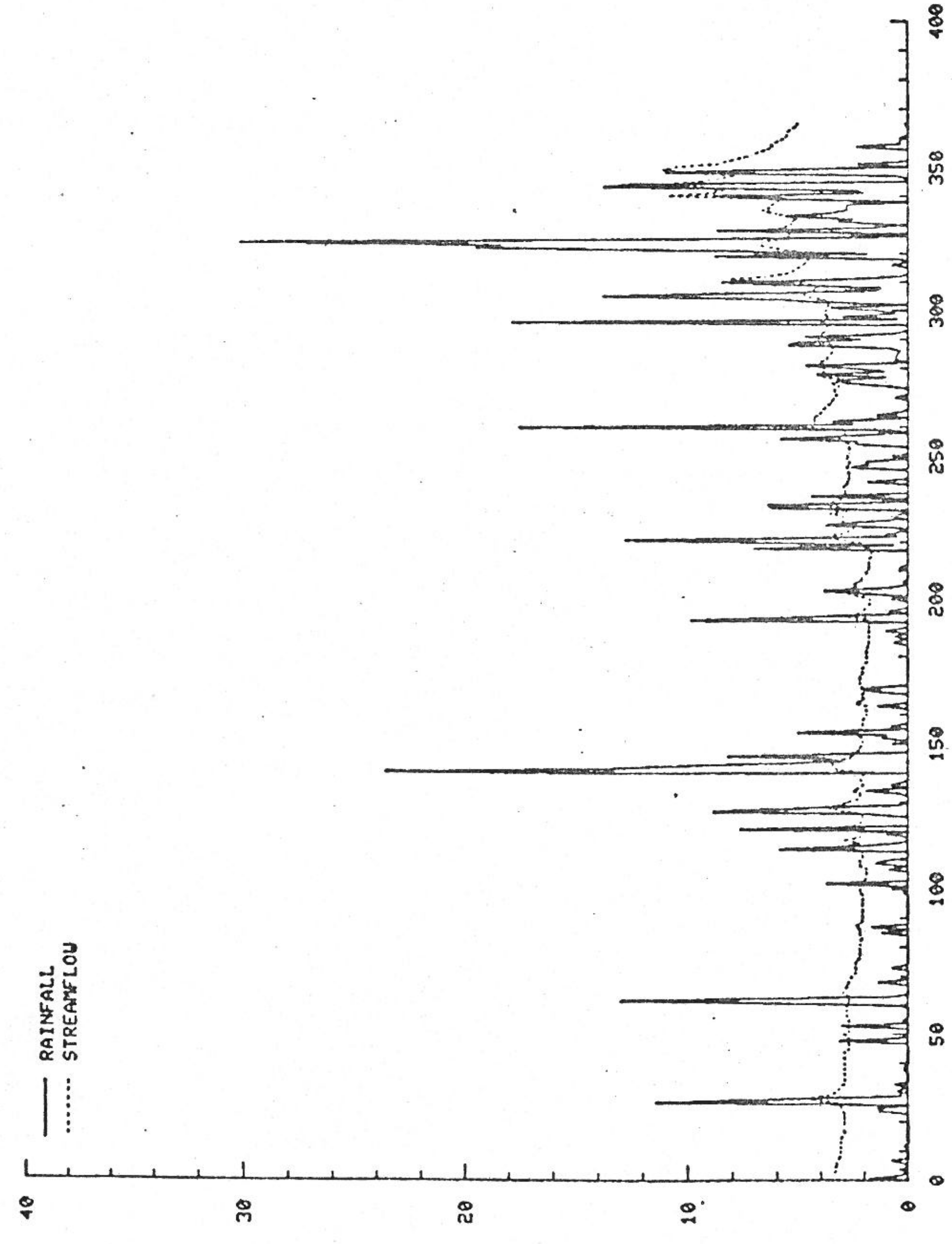


Figure 1.8.12. LA ESTRECHURA - 1975

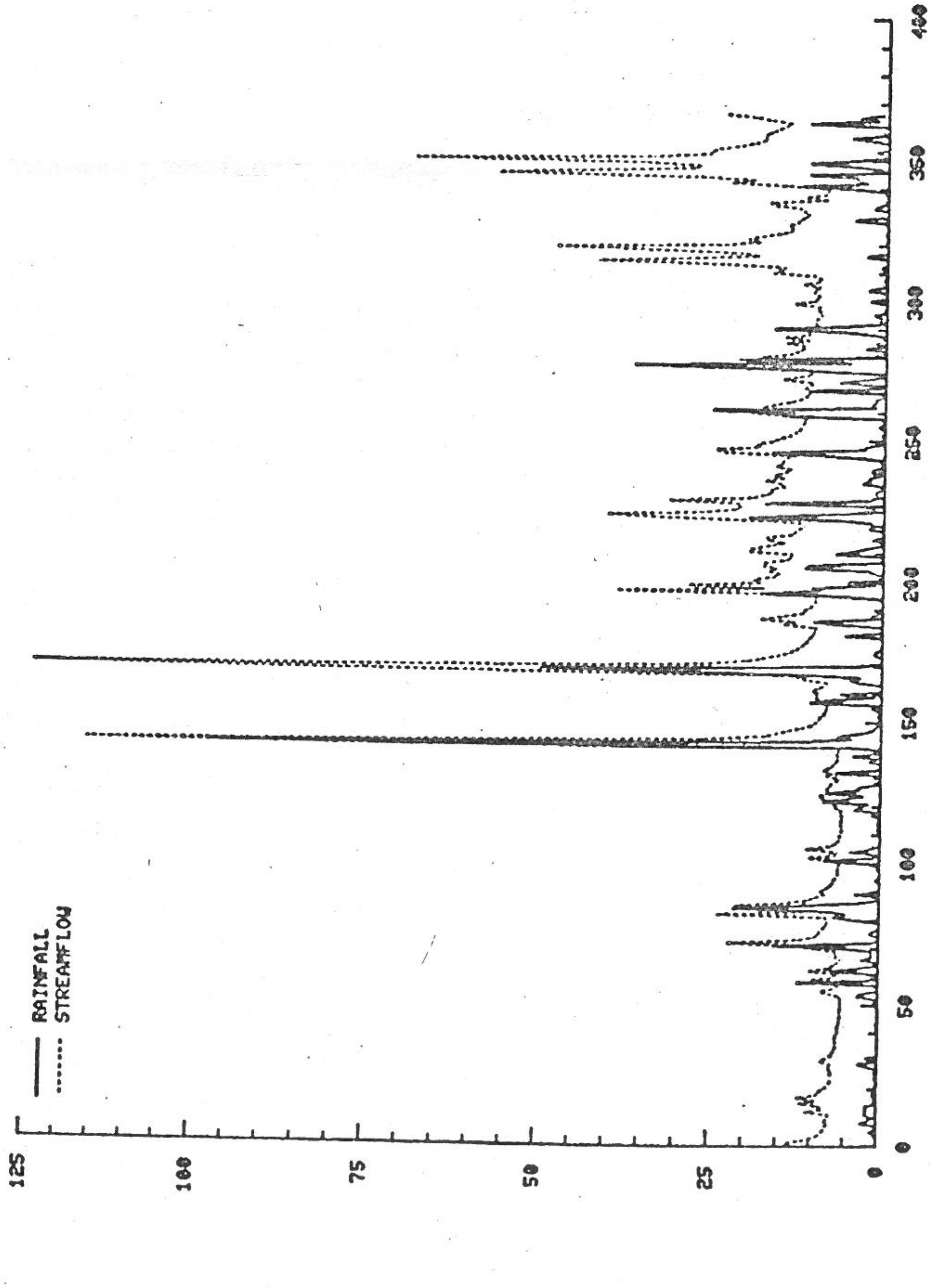


Figure 1.8.13. PALO DE CAJA - 1972

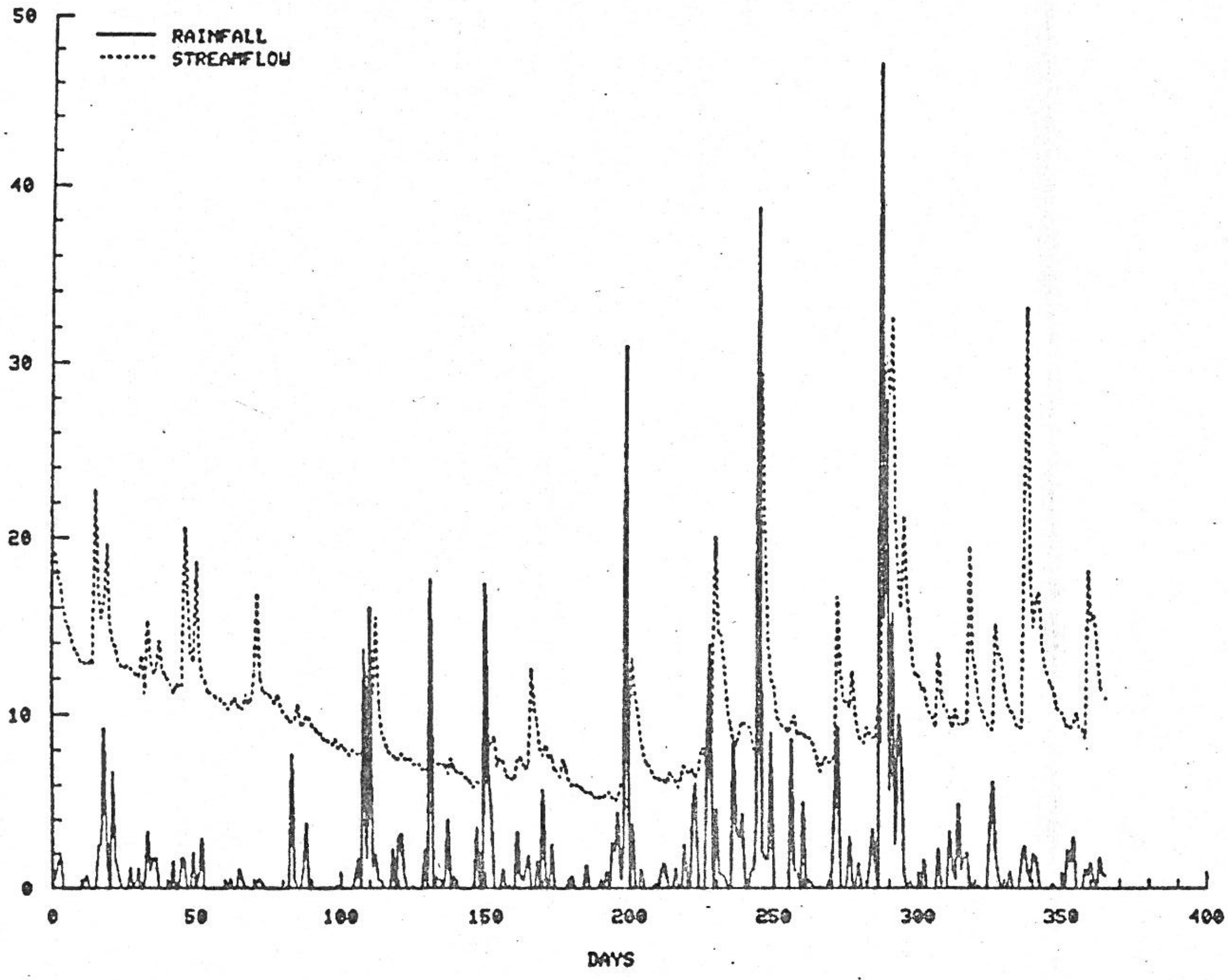


Figure 1.8.14. PALO DE CAJA - 1973

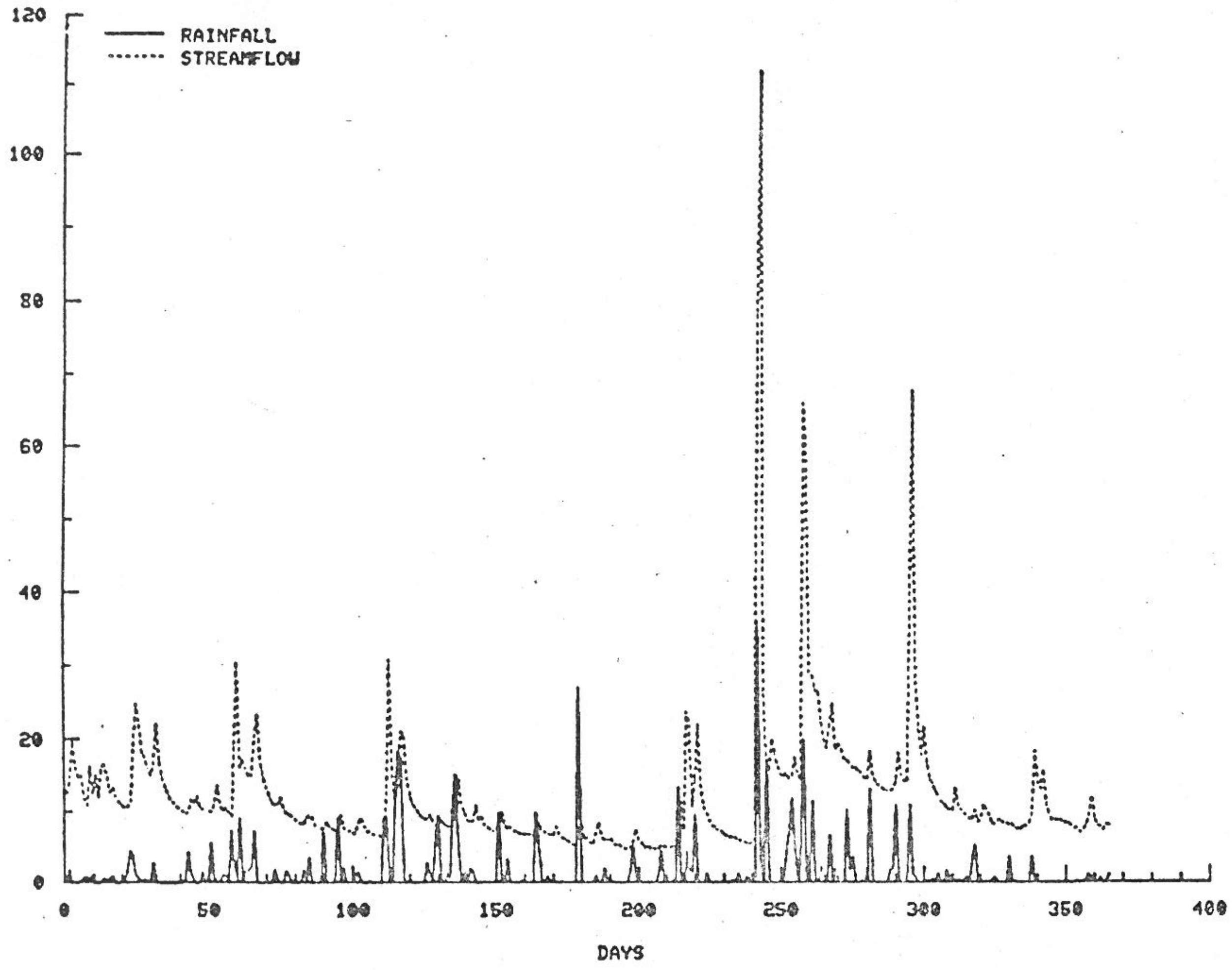


Figure 1.8.15. PALO DE CAJA - 1974

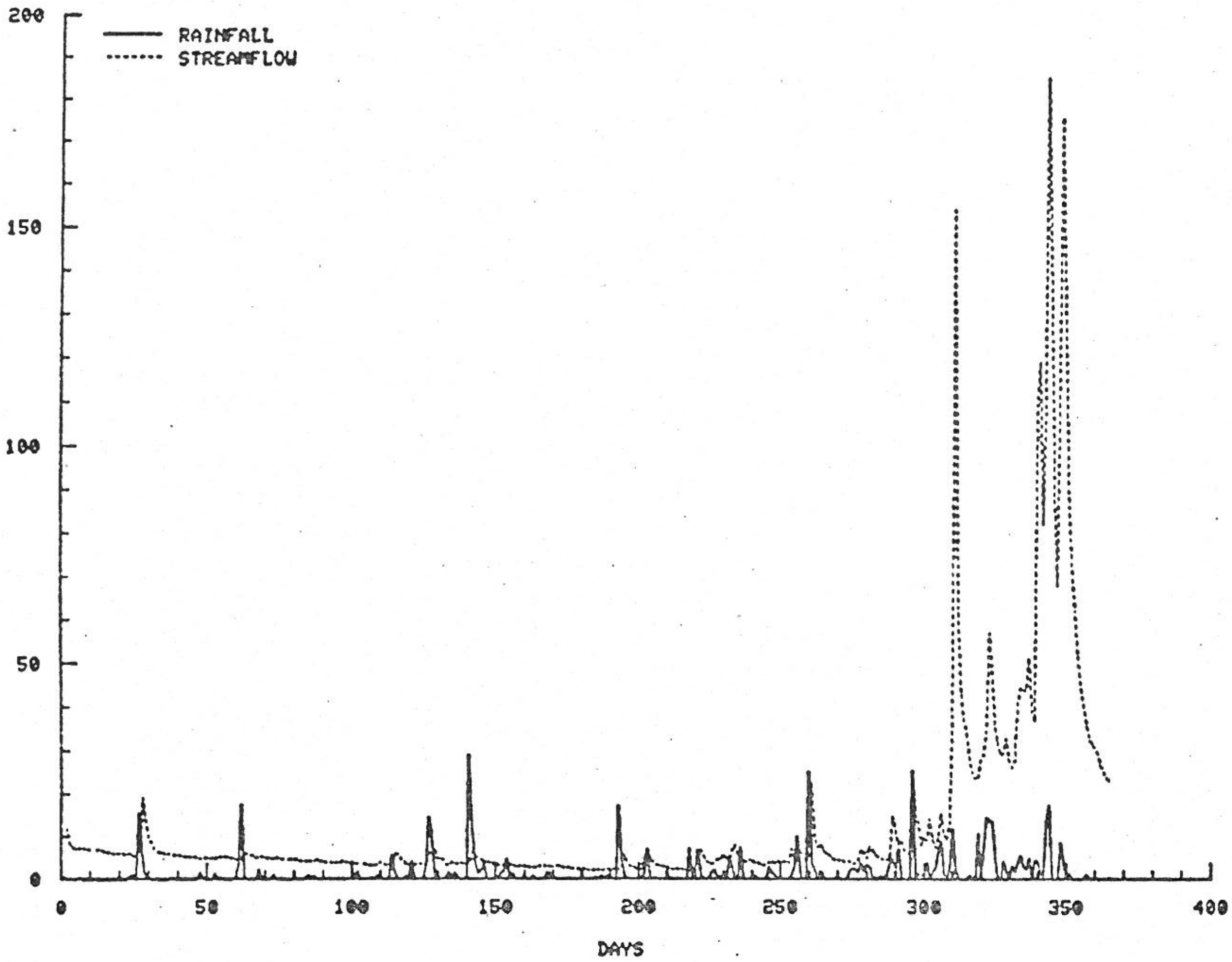


Figure 1.8.16. PALO DE CAJA - 1975

?

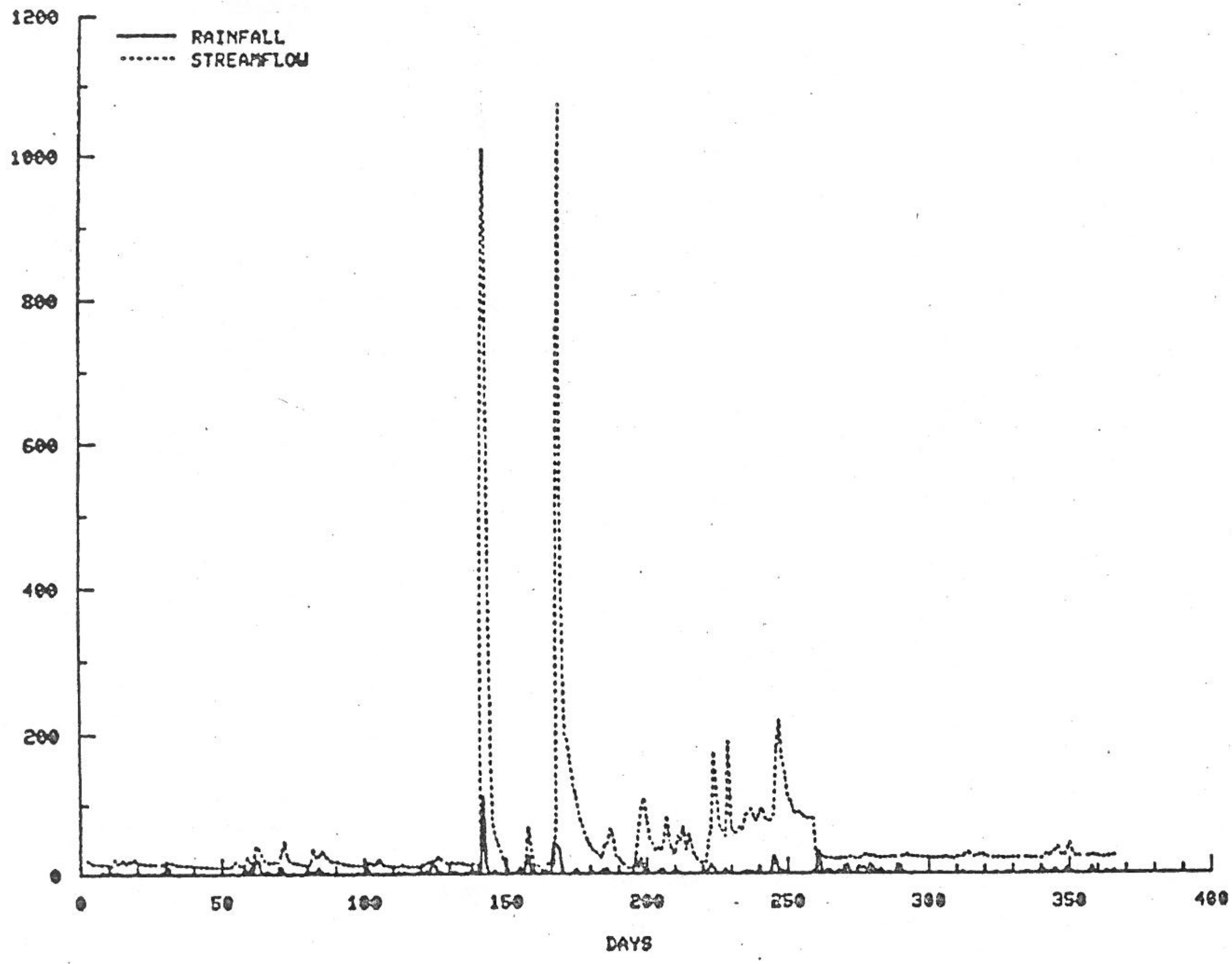


Figure 1.8.17. PASO DEL ERMITANO - 1972

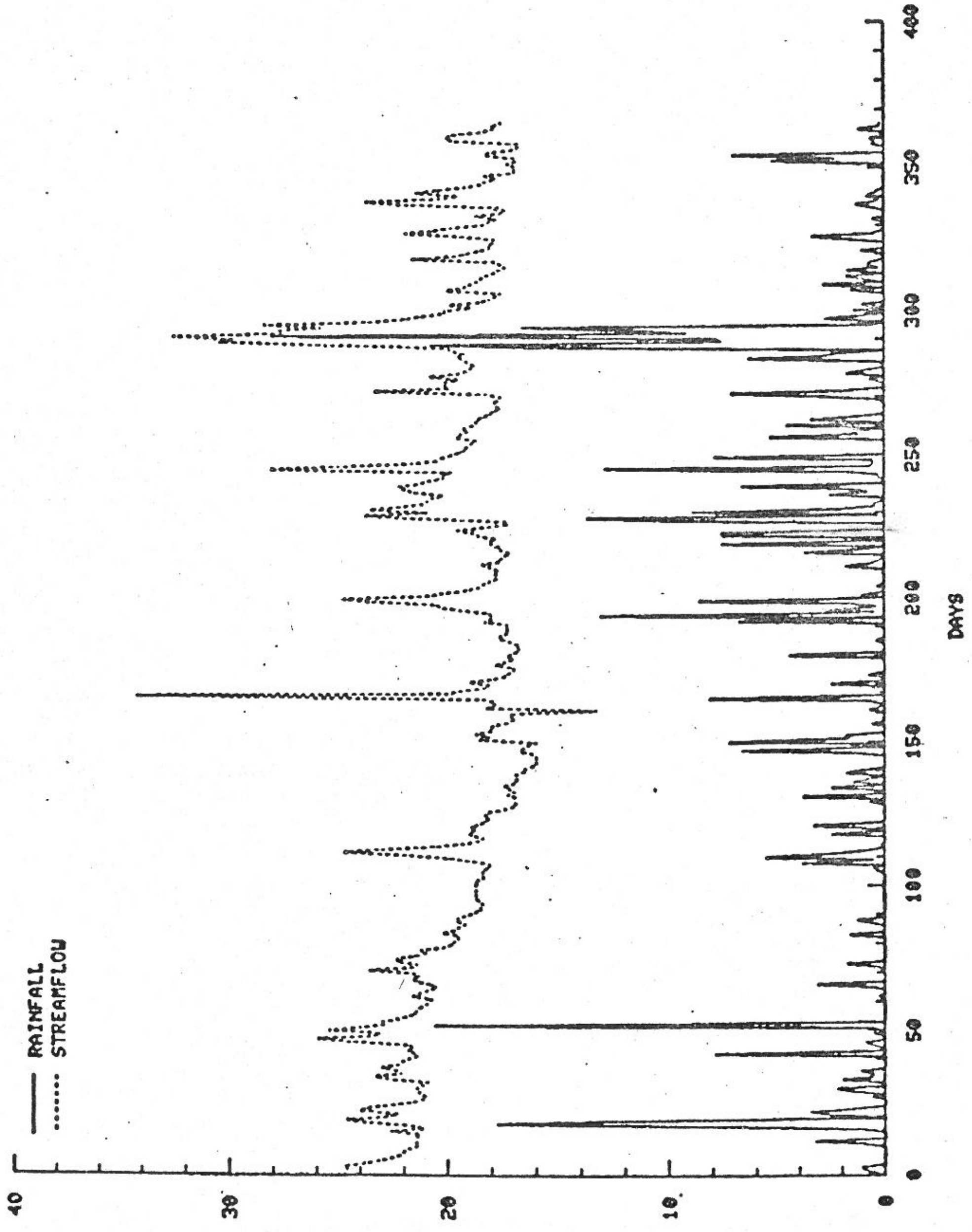


Figure 1.8.18. PASO DEL ERMITANO - 1973

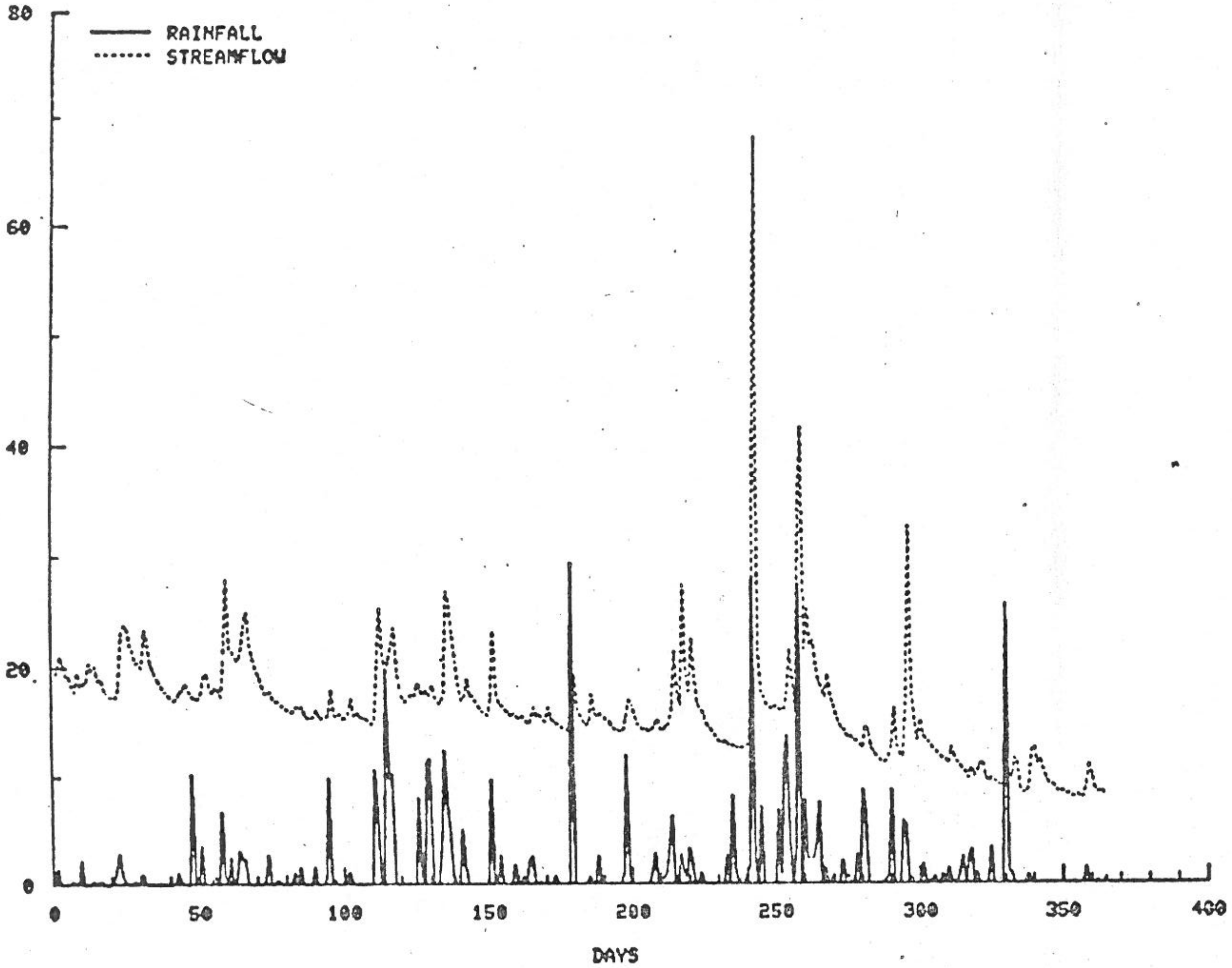


Figure 1.8.19. PASO DEL ERMITANO - 1974

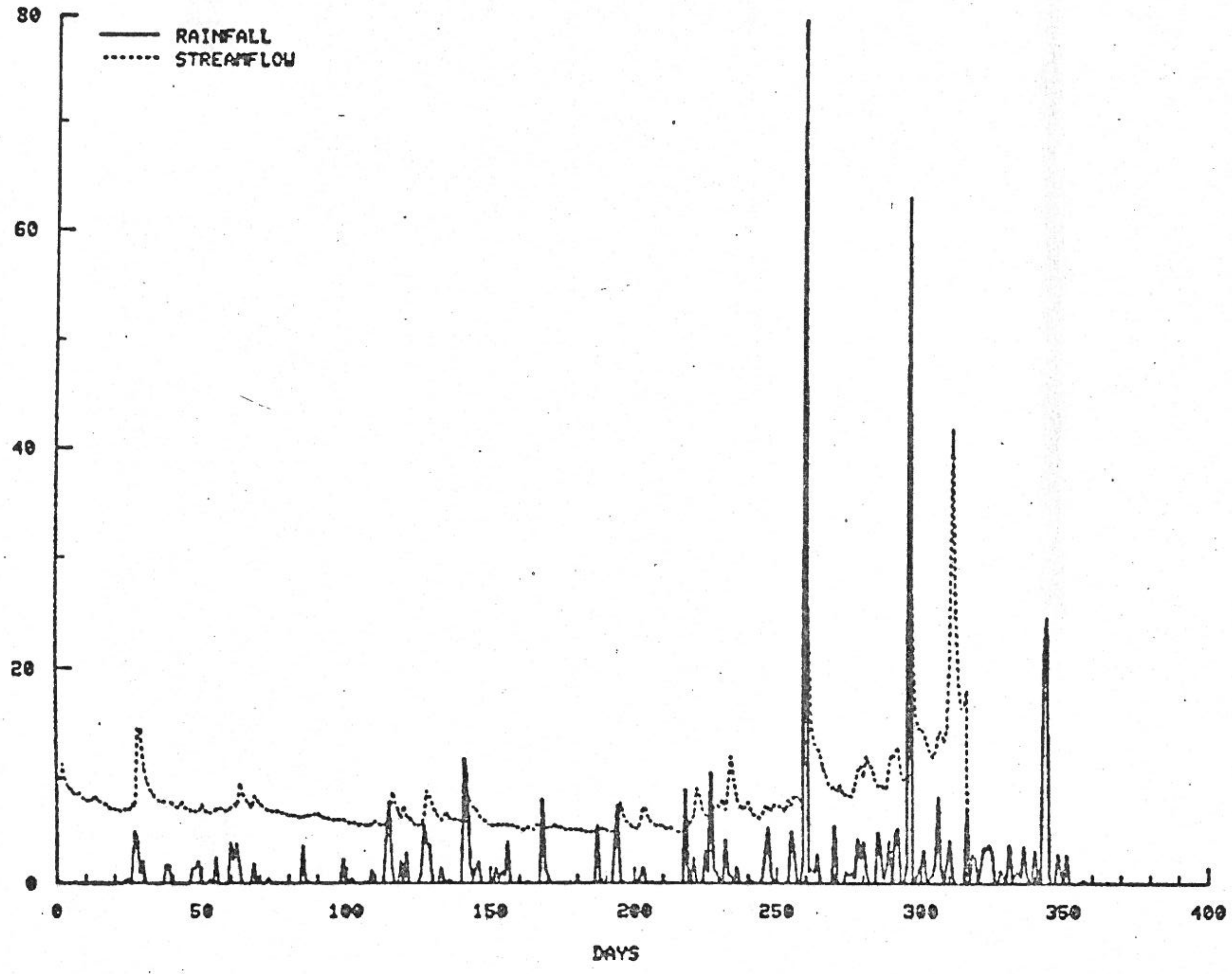


Figure 1.8.20. PASO DEL ERMITANO - 1975

```
0.3          0.5          0.2
ROUTE
103.0
2000.        0.4          0.3          100.
33000.       0.0293       0.05         00.0
5.0          10.0         1.0          14.0         0.0
BASEF       2
0.3          0.5          0.2
ADD         2
END
RAIN
    1 8784     7      1      1
(20X,F10.0)
ETDATA
   24      9      1      1
(10F8.0)
FLOW
   24  366     8      1      1
(20X,F10.0)
END
BASIN C - PASO DEL ERMITANO (1972)
   17       0  730 8784      1
1.0          25.0         0.0001       1.0          1.0
ZPERC        33.70        15.0         150.         5.0
REXP         4.83         0.5          5.0          0.1
SIDE         0.006        0.001        10.0         0.001
UZK          0.900        0.15         0.95          0.01
ADIMP        0.092        0.001        0.5          0.001
RSERV        0.440        0.01         .50          0.01
RIVA         0.829        0.25         0.90          0.01
PCTIM        0.908        0.10         .90          0.01
LZPK         0.012        0.01         .80          0.01
LZSK         0.476        0.01         .50          0.01
PFREE        0.994        0.001        .999         0.0001
UZTWC        98.0         50.0         150.0        2.0
UZFWC        57.0         40.0         80.0         2.0
LZTWC        195.0        40.0         200.0        .5.0
LZFSC        74.65        60.0         150.0        2.0
LZFPC        501.0        400.0        800.0        5.0
ADIMC        350.0        100.0        400.0        10.0
UZTWM        150.0
UZFWM        100.0
LZTWM        300.0
LZFSM        200.0
LZFPM        800.0
PXADJ        1.0
PEADJ        0.7
END
ROUTE
103.0
5000.0       0.5          0.3          100.0
18000.       0.0148       0.04         0.0
5.0          80.0         1.0          23.6         1.0
BASEF       2
0.3          0.5          0.2
```

Figure 1.8.21 (continuation)

```
ROUTE
109.0
3000.     0.4       0.3       100.
34000.    0.0323    0.05      00.0
5.0       10.0      1.0       23.6      0.0
BASEF     2
0.3       0.5       0.2
ADD       2
ROUTE
53.0
5000.0    0.4       0.3       100.0
18000.    0.0119    0.040     00.0
5.0       80.0      1.0       23.6      1.0
BASEF     2
0.3       0.5       0.2
END
RAIN
    1 8784    7    1    1
(30X,F10.0)
ETDATA
   24    9    1    1
(10F8.0)
FLOW
   24  366    8    1    1
(30X,F10.0)
```

Figure 1.8.21 (continuation)

LA ESTRECHURA

	1972	1973	1974	1975	AVE
ZPERC	87.000	97.000	17.000	147.000	87.000
REXP	.709	.659	1.909	1.819	1.274
SIDE	.176	.207	.175	.219	.194
UZK	.010	.006	.005	.005	.007
ADIMP	.115	.115	.085	.073	.097
RSERV	.350	.500	.593	.621	.516
RIVA	.570	.880	.880	.990	.830
PCTIM	.089	.014	.003	.001	.027
LZPK	.010	.009	.013	.025	.014
LZSK	.006	.005	.015	.029	.014
PFREE	.793	.793	.800	.801	.797
UZTWC	96.000	100.000	148.300	84.600	
UZFWC	34.000	2.320	.103	.010	
LZTWC	197.000	300.000	295.100	274.000	
LZFSC	34.000	99.000	84.680	19.790	
LZFPC	405.000	320.000	267.200	92.020	
ADIMC	115.000	390.000	439.800	349.000	
UZTWM	150.000	150.000	150.000	150.000	150.000
UZFWM	100.000	100.000	100.000	100.000	100.000
LZTWM	300.000	301.000	301.000	301.000	300.750
LZFSM	200.000	200.000	200.000	200.000	200.000
LZFPM	800.000	800.000	800.000	800.000	800.000
PXADJ	1.000	1.000	1.000	1.000	1.000
PEADJ	.700	.700	.700	.700	.700

PALO DE CAJA

	1972	1973	1974	1975	AVE
ZPERC	178.000	198.000	140.000	145.000	165.250
REXP	.400	.275	.440	.285	.350
SIDE	1.050	1.057	1.049	1.000	1.039
UZK	.030	.020	.050	.002	.026
ADIMP	.145	.141	.171	.121	.145
RSERV	.225	.365	.585	.585	.440
RIVA	.339	.439	.739	.939	.614
PCTIM	.015	.001	.031	.001	.012
LZPK	.003	.008	.011	.041	.016
LZSK	.002	.002	.004	.015	.006
PFREE	.987	.987	.989	.999	.991
UZTWC	43.000	100.000	148.300	85.400	
UZFWC	32.500	4.160	.008	.006	
LZTWC	42.500	278.000	214.800	160.800	
LZFSC	44.000	183.000	118.200	65.360	
LZFPC	324.500	721.700	322.900	137.200	
ADIMC	217.500	385.500	437.500	348.900	
UZTWM	150.000	150.000	150.000	150.000	150.000
UZFWM	100.000	100.000	100.000	100.000	100.000
LZTWM	300.000	300.000	300.000	300.000	300.000
LZFSM	200.000	200.000	200.000	200.000	200.000
LZFPM	800.000	800.000	800.000	800.000	800.000
PXADJ	1.000	1.000	1.000	1.000	1.000
PEADJ	.700	.700	.700	.700	.700

PASO DEL ERMITANO

	1972	1973	1974	1975	AVE
ZPERC	33.700	199.300	218.700	199.600	162.825

Figure 1.8.22 Summary of SAC model parameters calibrated for years 1972 to 1975.

REXP	4.830	.502	.130	.100	1.391
SIDE	.006	.372	.360	.236	.244
UZK	.900	.125	.135	.152	.328
ADIMP	.092	.004	.003	.002	.025
RSERV	.440	.470	.750	.190	.463
RIVA	.829	.879	.880	.320	.727
PCTIM	.908	.155	.040	.051	.289
LZPK	.012	.010	.010	.004	.009
LZSK	.476	.075	.016	.003	.143
PFREE	.994	.975	.948	.742	.915
UZTWC	98.000	100.000	148.300	84.800	
UZFWC	57.000	.000	.000	.010	
LZTWC	195.000	160.000	137.400	126.500	
LZFSC	74.650	4.600	3.824	20.230	
LZFPC	501.000	165.000	187.400	127.900	
ADIMC	350.000	386.000	438.800	348.400	
UZTWM	150.000	150.000	150.000	150.000	150.000
UZFWM	100.000	100.000	100.000	100.000	100.000
LZTWM	300.000	300.000	300.000	300.000	300.000
LZFSM	200.000	200.000	200.000	200.000	200.000
LZFPM	800.000	800.000	800.000	800.000	800.000
PXADJ	1.000	1.000	1.000	1.000	1.000
PEADJ	.700	.700	.700	.700	.700

Figure 1.8.22 (continuation)

is the summary SAC model parameters for each year and for each subwatershed. Figures 1.8.23 through 1.8.34 show the observed and computed streamflow for each year and for each subwatershed.

It is seen from these figures that some years in some subwatersheds are not fairly satisfactory. Generally, the fit between observed and computed streamflows worsens in going from La Estrechura to Paso del Ermitano (i.e. upstream to downstream). This can be expected since any calibration inadequacy at the upstream flow points are carried to the downstream flow points. It appears that the best fit is in year 1972.

One major problem encountered in the model calibration is the rainfall data where inconsistencies with respect to streamflow are found. For example, the worst fit between observed and computed streamflow experienced in La Estrechura in 1974 can well be attributed to the rainfall data as seen in the plots of rainfall with streamflow in Figure 1.8.12. Admittedly, this is difficult to resolve since the inconsistency can be caused by inadequacies in areal averaging, representativeness of rainfall stations recording at this time, or sampling errors. It may be noted that rainfall is the most critical input data in the model as shown in Figure 1.8.A. , Appendix 1.8.A.2.

1.8.5 Model Testing by Forecasting

This section exemplifies the application of the SACKW model in a forecasting mode. The interest here is to arrive at the streamflow estimate of Paso del Ermitano during the hurricanes David and Frederic that hit the Dominican Republic around late August, 1979 and early September, 1979, respectively. For purposes of this exercise, the model parameters calibrated for year 1972 are used since it is found to have the best fit as well as this year experienced a high flood flow regime

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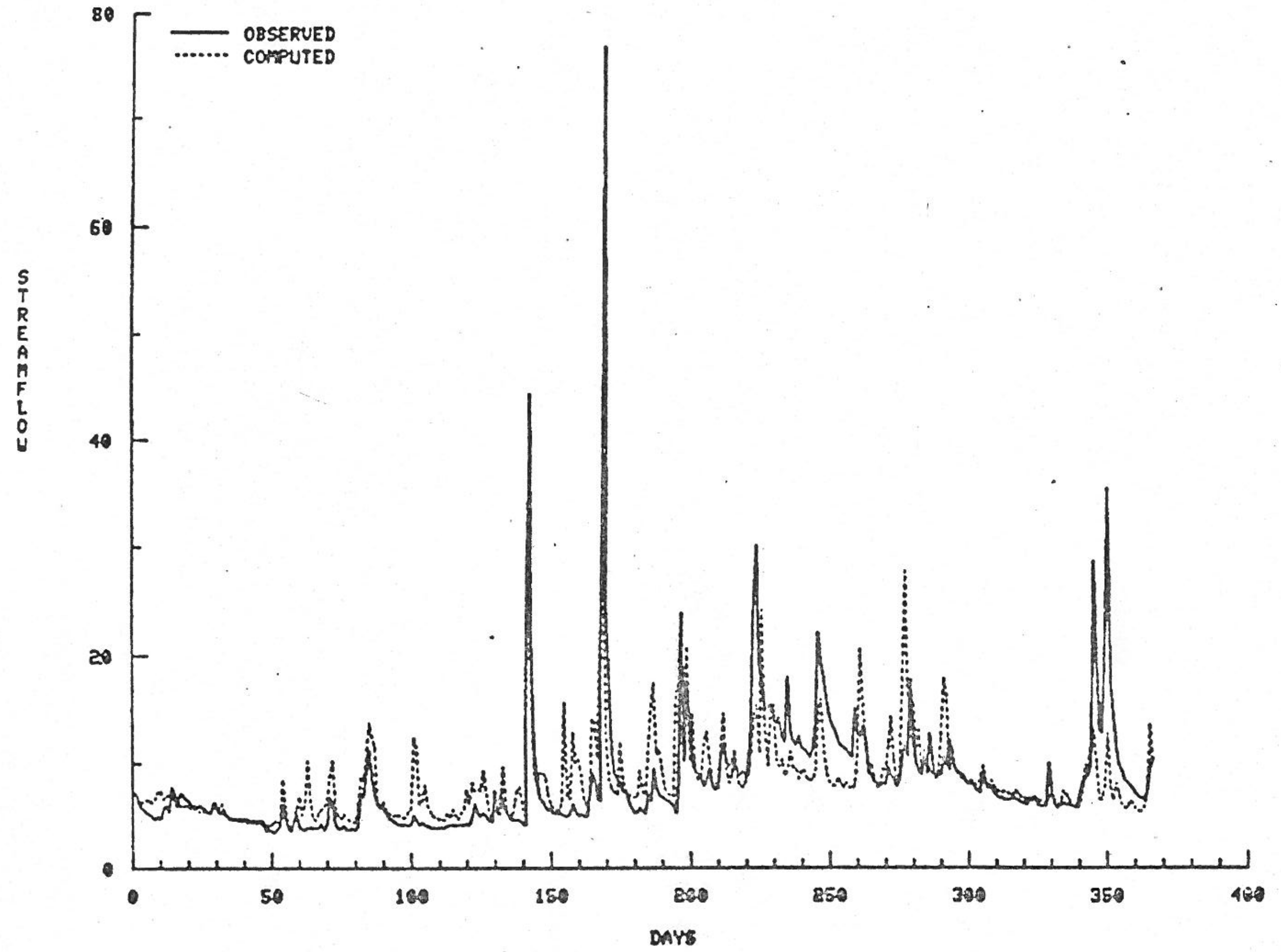

Figure 1.8.23. LA ESTRECHURA - 1972

?

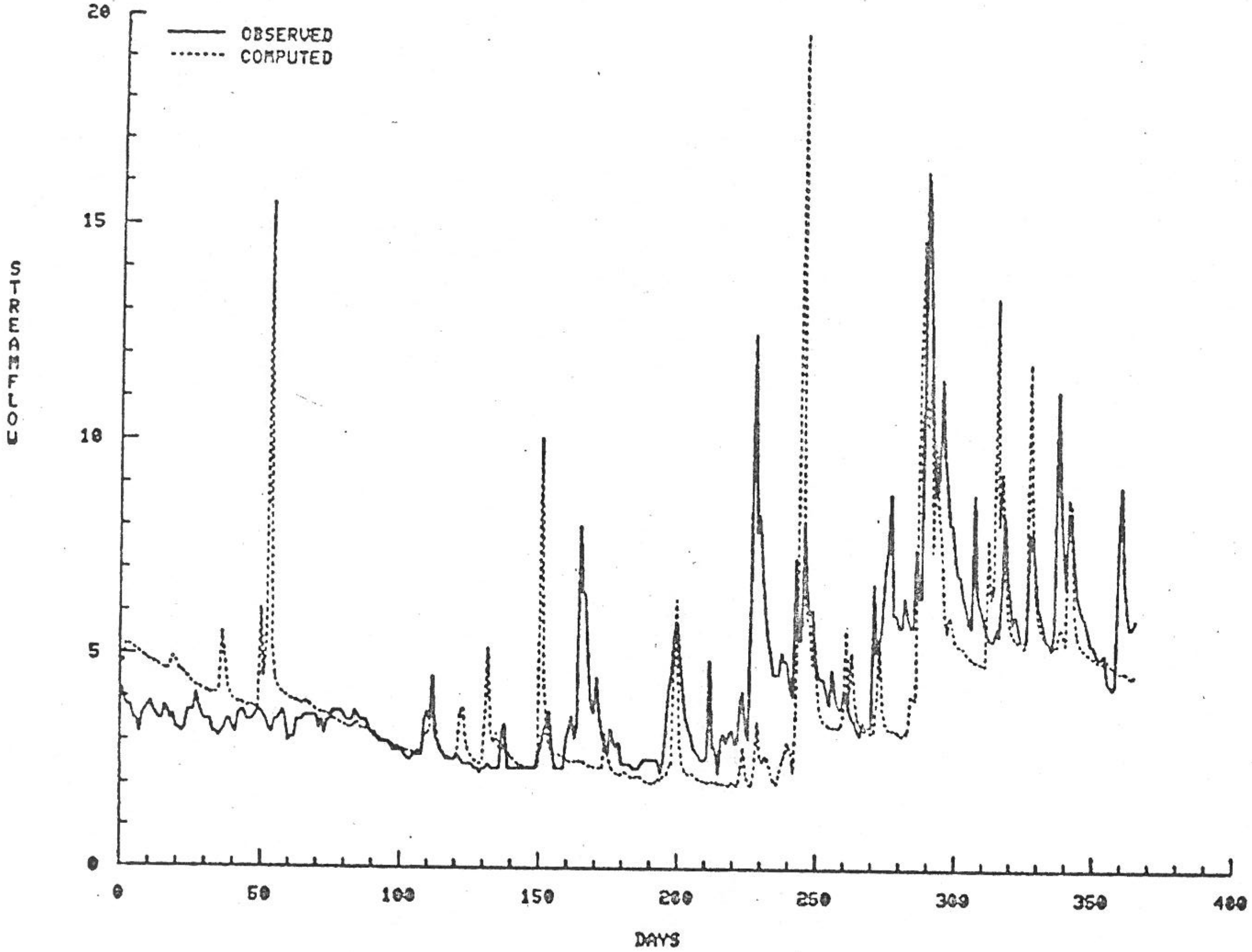

Figure 1.8.24. LA ESTRECHURA - 1973

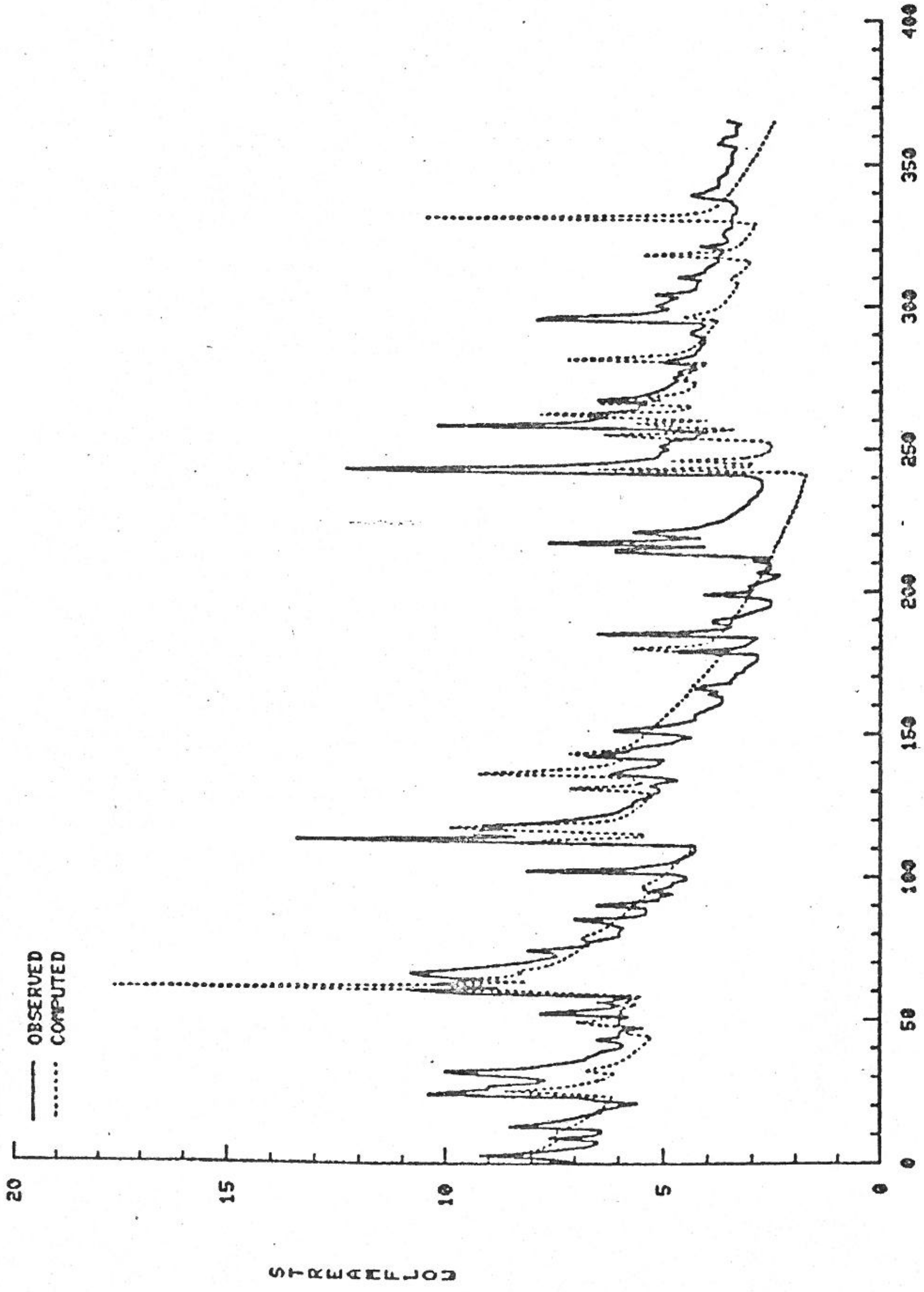

Figure 1.8.25. LA ESTRECHURA - 1974

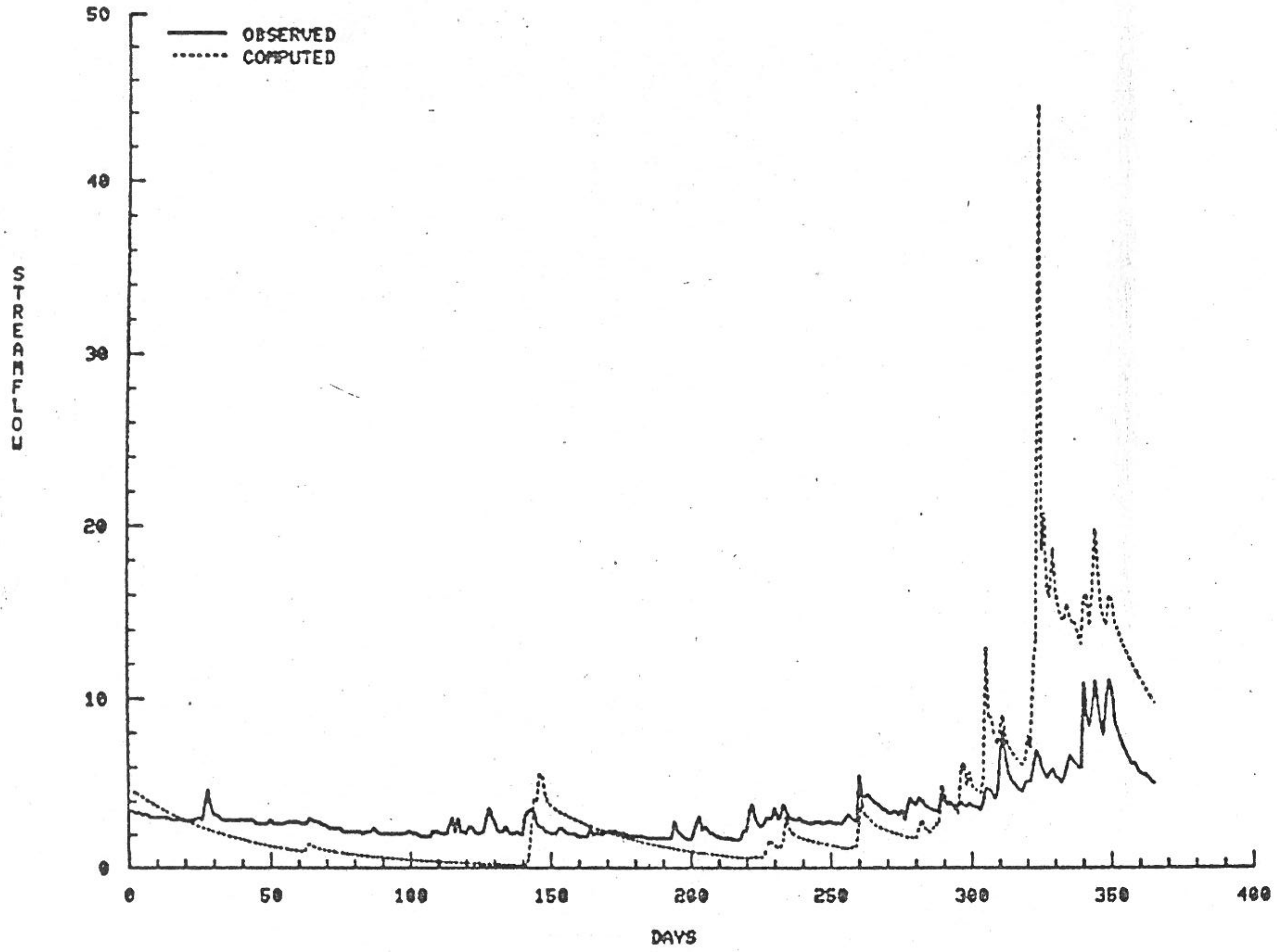

Figure 1.8.26. LA ESTRECHURA - 1975

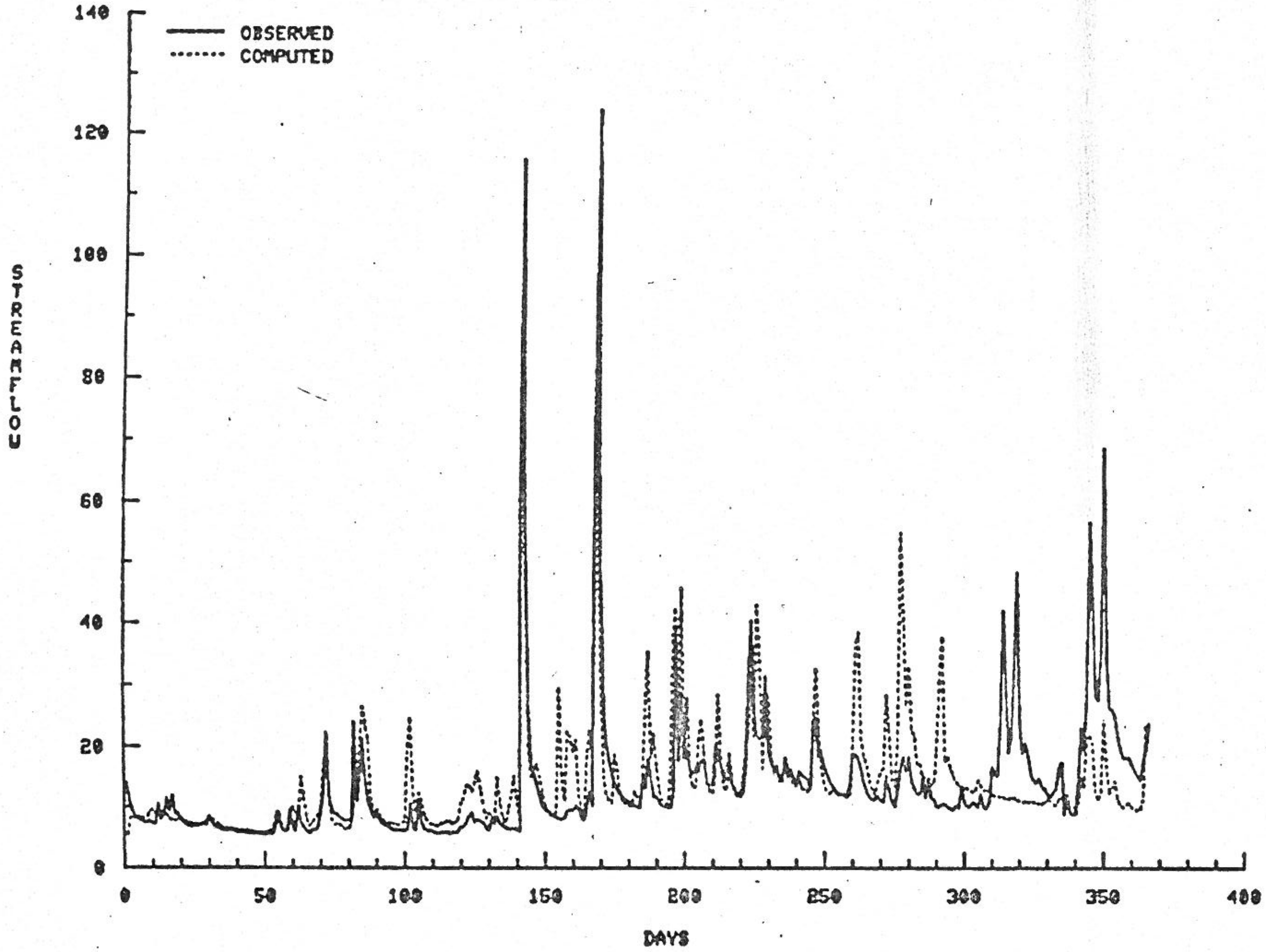

Figure 1.8.27. PALO DE CAJA - 1972

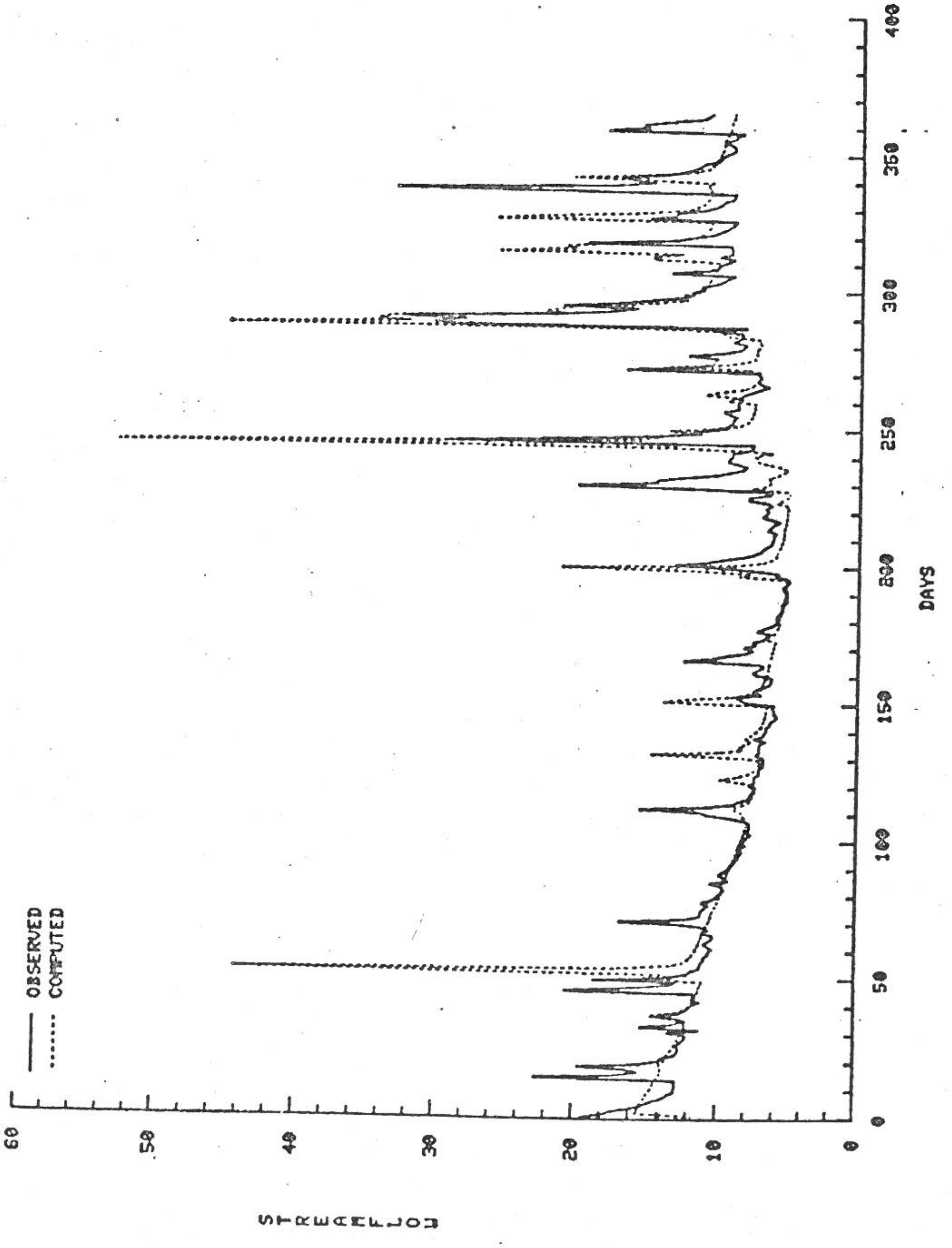

Figure 1.8.28. PALO DE CAJA - 1973

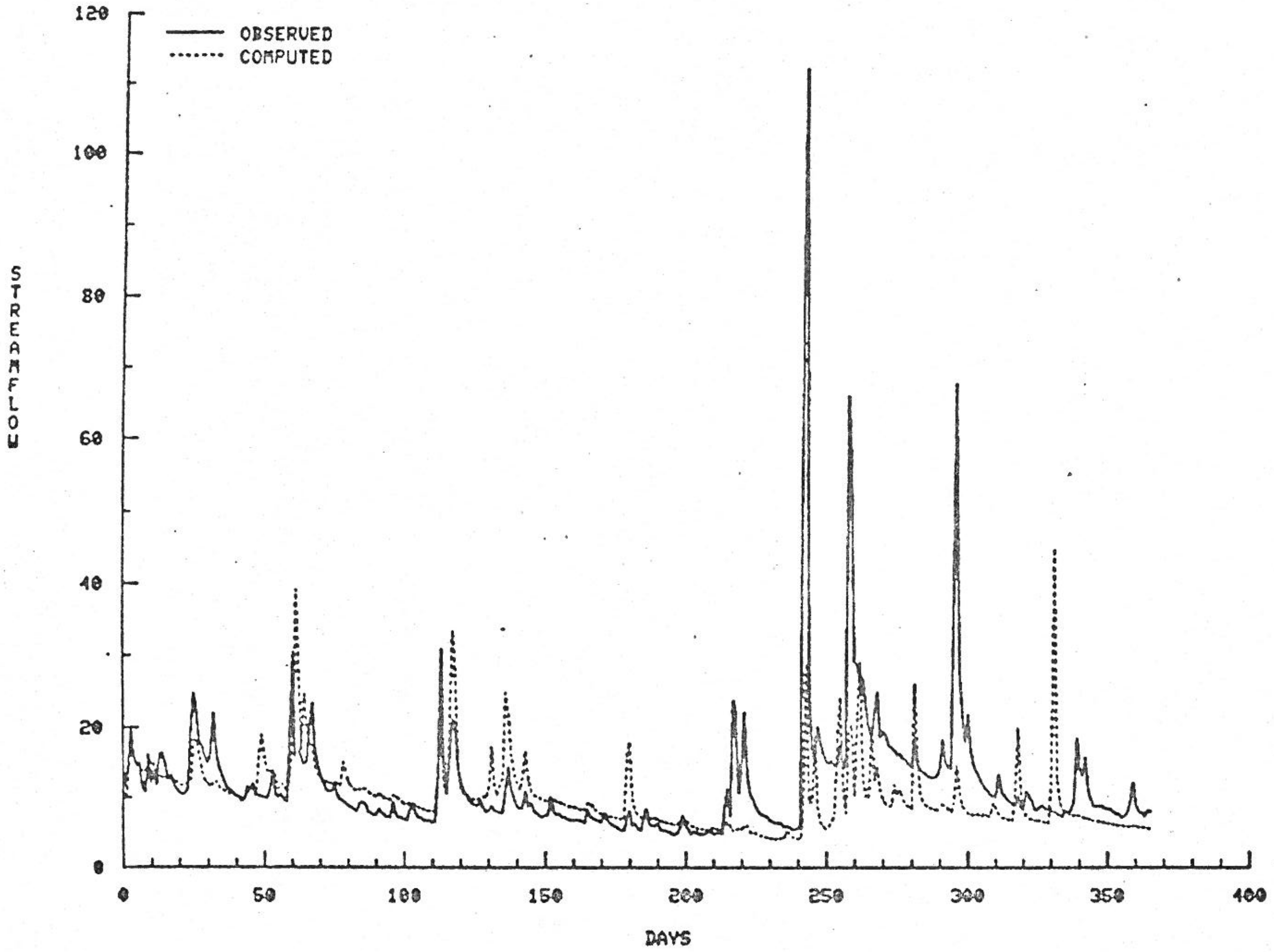

Figure 1.8.29. PALO DE CAJA - 1974

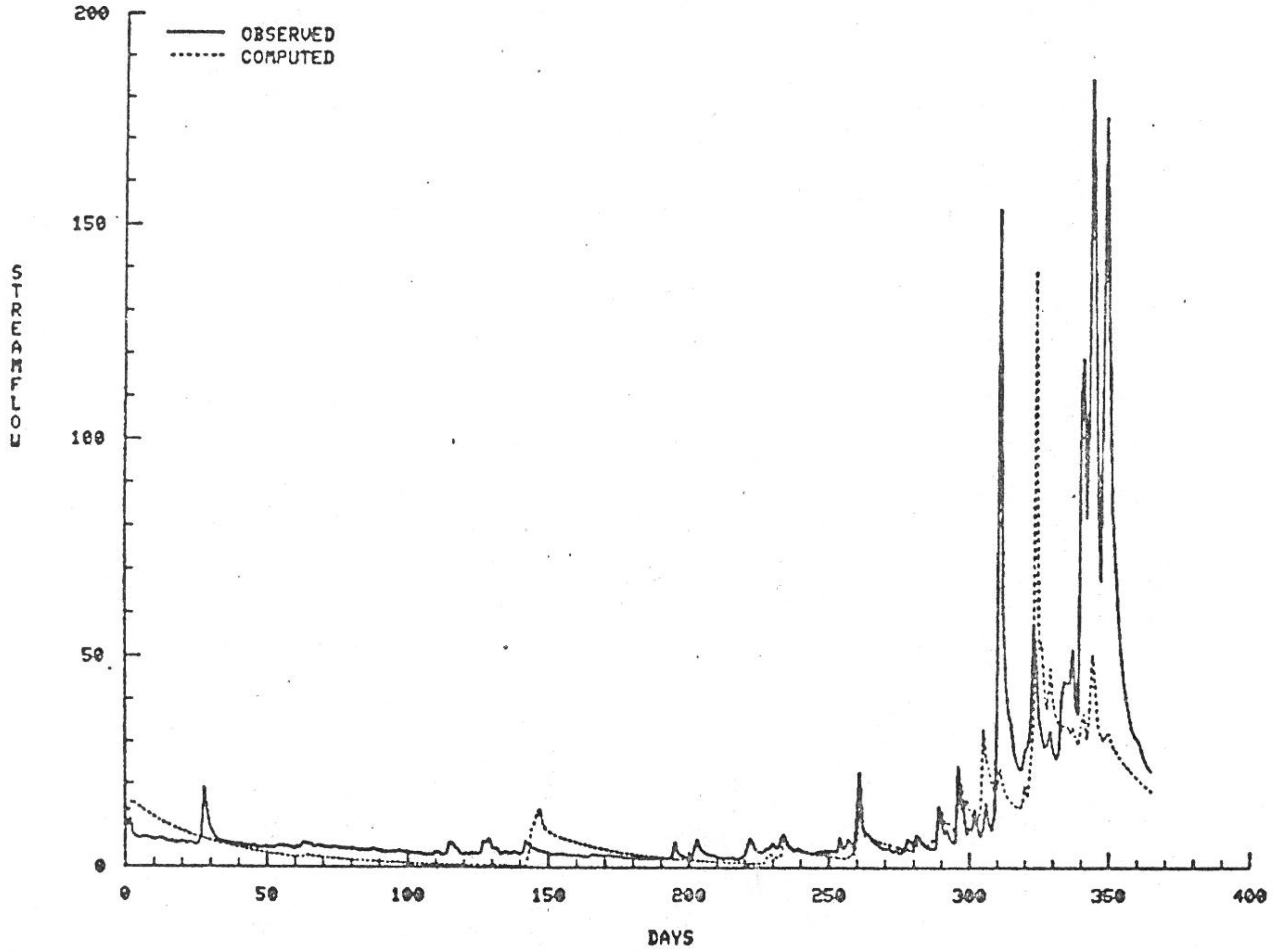

Figure 1.8.30. PALO DE CAJA - 1975

?

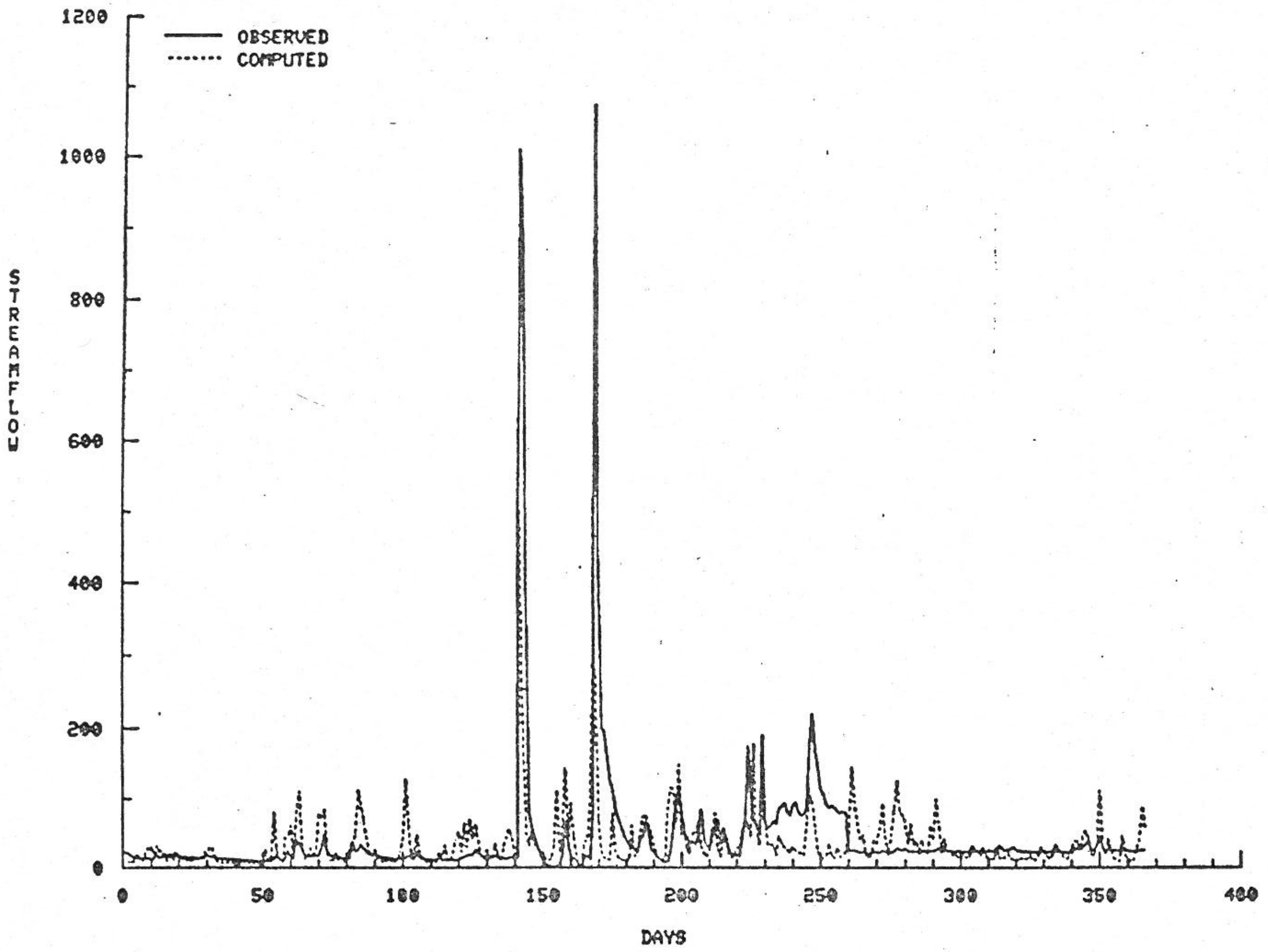

Figure 1.8.31. PASO DEL ERMITANO - 1972

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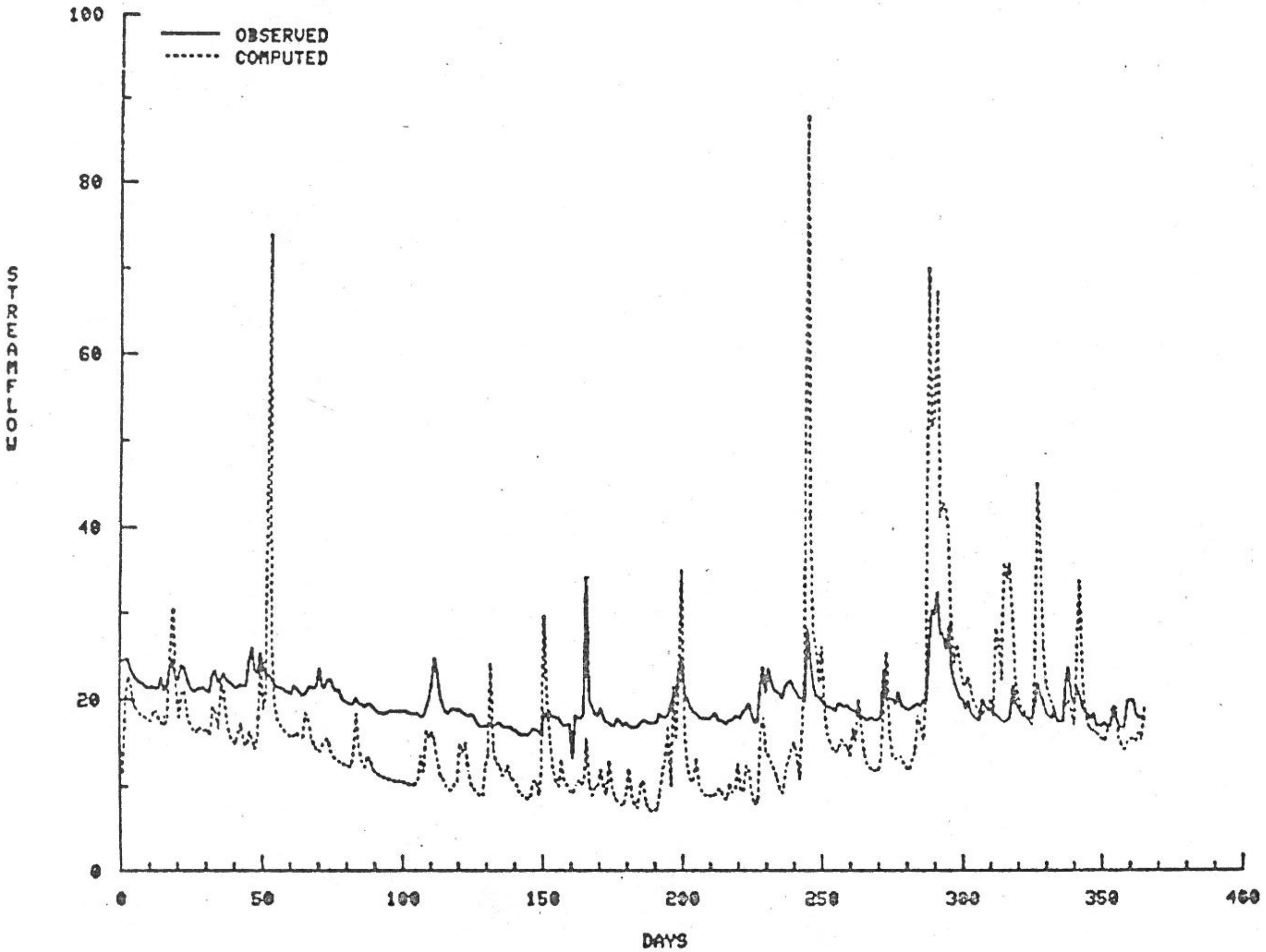

Figure 1.8.32. PASO DEL ERMITANO - 1973

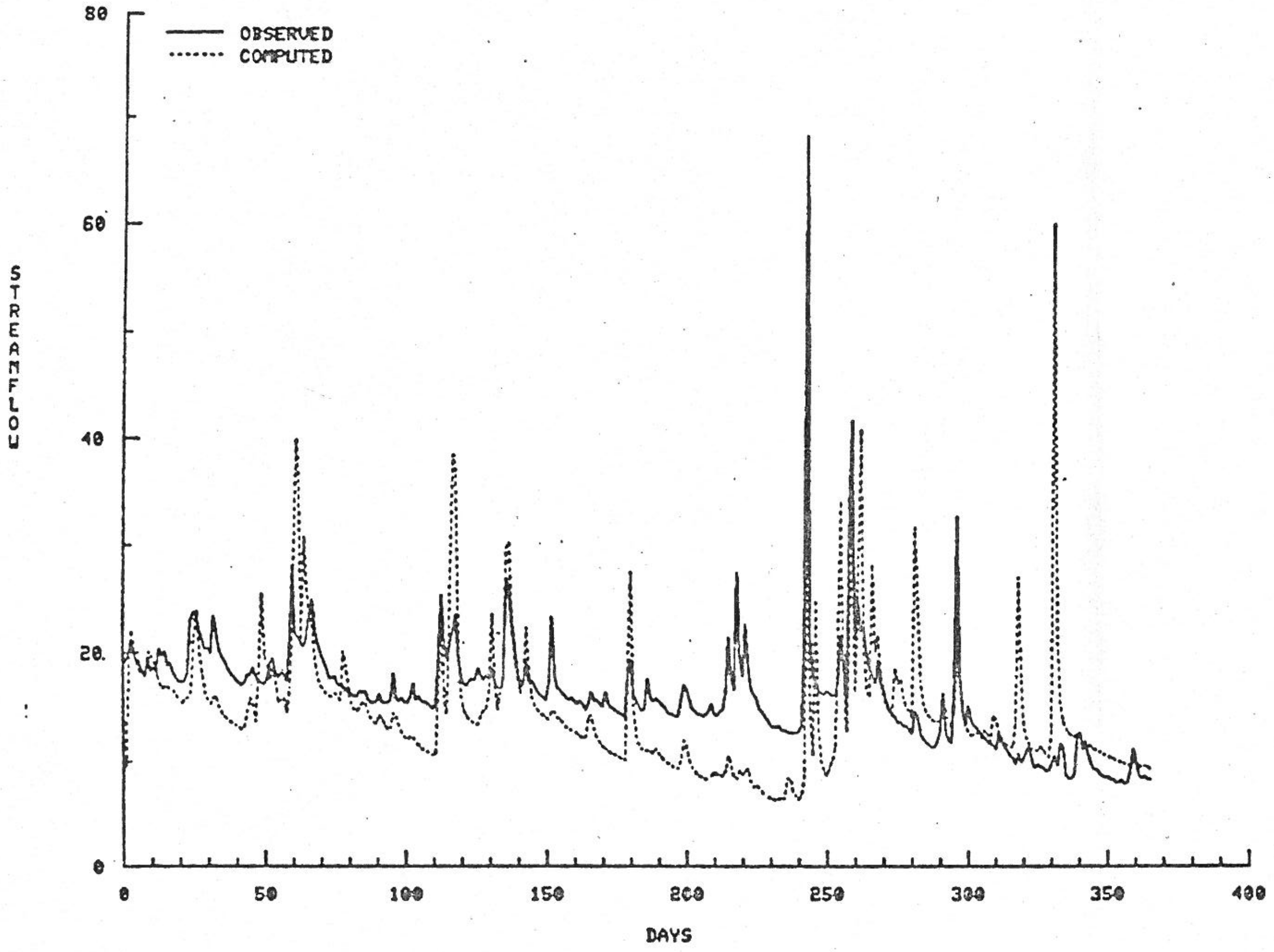

Figure 1.8.33. PASO DEL ERMITANO - 1974

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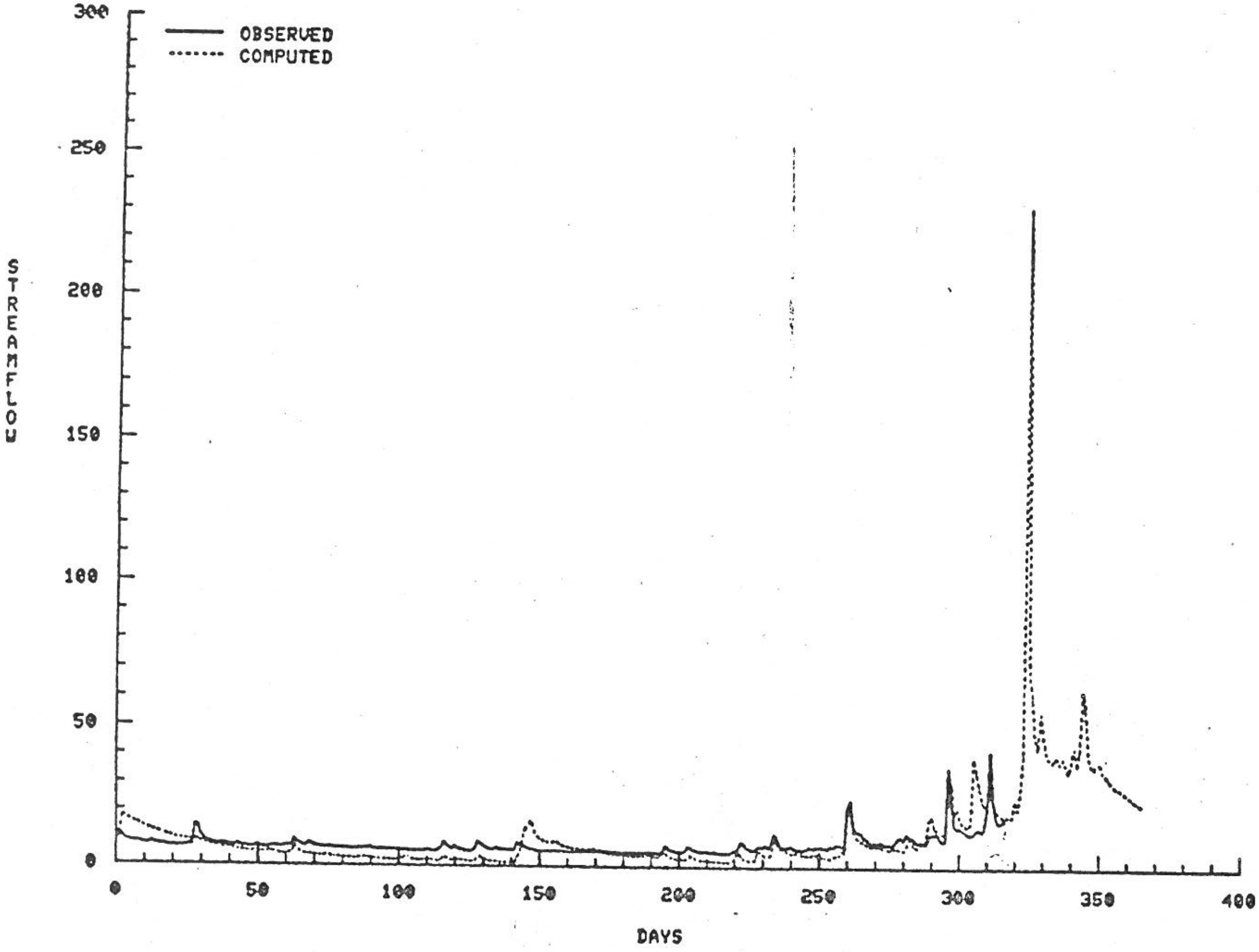

Figure 1.8.34. PASO DEL ERMITANO - 1975

which occurred around the month of June. Note that there is no streamflow record for the hurricane period of interest. However, hourly rainfall data is available.

The input data file for the model is shown in Figure 1.8.35. To obtain the forecast streamflow during the hurricane period of interest, the model has to be ran from year 1976 up to 1979. Results from this run are shown in Figures 1.8.36 and 1.8.37 assuming that there is an evapotranspiration (ET) demand and without ET demand, respectively. For hurricane David, the highest streamflows estimated are 6983 cms for the case where there is ET demand and 7074 cms for the case with no ET demand. Both highest flows occurred on the 21st hour of August 31, 1979. These flows are rather lower than those obtained using the HEC-1 model but they can be considered and admissibly within the streamflow regime in that hurricane David period.

1.8.6 References

Burnash, R.J.C., 1985. Real-time forecasting with the Sacramento watershed model. In Proc. 14th Annual Hydrology Day, Colorado State University, Ft. Collins, CO, pp. 103-113.

Burnash, R.J.C., R.L. Ferral and R.A. McGuire, 1979. A generalized streamflow simulation system conceptual modeling for digital computers. National Weather Service, California Dept. of Water Resources, March, 1979 (second printing).

Kuester, J.L. and J.H. Mize, 1973. Optimization techniques with FORTRAN. McGraw-Hill Book Co., New York.

National Weather Service, 1984. NWS-river forecast system manual calibration version 3.0. National Weather Service, Silver Spring, Md.

U.S. Army Corps of Engineers, 1985. HEC-1 flood hydrograph package user's manual. The Hydrologic Engineering Center, Dan's, CA, January, 1985 (revised edition).

```
BASIN A - LA ESTRECHURA (1976-1979)  1972 PARAMETERS
    0    0 8766 8766    1
ZPERC     87.00
REXP      0.709
SIDE      0.176
UZK       0.010
ADIMP     0.115
RSERV     0.35
RIVA      0.57
PCTIM     0.089
LZPK      0.010
LZSK      0.006
PFREE     0.793
UZTWM     150.0
UZFWM     100.0
LZTWM     300.0
LZFSM     200.0
LZFPM     800.0
UZTWC     120.4
UZFWC     0.005
LZTWC     297.27
LZFSC     41.06
LZFPC     185.43
ADIMC     416.5
PXADJ     1.0
PEADJ     0.7
END
ROUTE
70.0
2500.0    0.6       0.4       100.0
16000.    0.105     0.06      0.0
5.0       15.0      1.0       5.10      0.0
BASEF    2
0.3       0.5       0.2
ROUTE
70.0
2500.     0.6       0.4       100.
20000.    0.0837    0.06      70.0
5.0       15.0      1.0       5.10      0.0
BASEF    2
0.3       0.5       0.2
ADD      2
ROUTE
45.0
4500.0    0.5       0.3       100.0
8500.0    0.0133    0.040     45.0
5.0       85.0      1.0       5.10      1.0
BASEF    2
0.3       0.5       0.2
END
RAIN
    135064    7    1    1
(10X,F10.0)
ETDATA
   24    9    1    1
```

Figure 1.8.35 Model input file for model testing by forecasting hurricanes David and Frederic flood flow regime.

```
(10F8.0)
FLOW
    1    0
END
BASIN B - PALO DE CAJA (1976-1979)  1972 PARAMETERS
    0    0 8766 8766    1
ZPERC     178.0
REXP      0.400
SIDE      1.050
UZK       0.030
ADIMP     0.145
RSERV     0.225
RIVA      0.339
PCTIM     0.015
LZPK      0.003
LZSK      0.002
PFREE     0.987
UZTWM     150.0
UZFWM     100.0
LZTWM     300.0
LZFSM     200.0
LZFPM     800.0
UZTWC     120.4     40.0      150.0     2.0
UZFWC     .000      00.0      80.0      2.0
LZTWC     75.0      40.0      300.0     5.0
LZFSC     56.05     40.0      200.0     2.0
LZFPC     92.07     100.0     500.0     5.0
ADIMC     414.4     100.0     450.0     10.0
PXADJ     1.0
PEADJ     0.7
END
ROUTE
24.0
2000.0    0.4       0.3       100.0
7500.0    0.108     0.040     0.0
5.0       85.0      1.0       23.1      1.0
BASEF    2
0.3       0.5       0.2
ROUTE
56.0
3500.     0.2       0.3       100.
13500.    0.0452    0.05      0.0
5.0       10.0      1.0       23.1      0.0
BASEF    2
0.3       0.5       0.2
ADD      2
ROUTE
164.0
4500.0    0.4       0.3       100.0
33500.0   0.0086    0.040     00.0
5.0       70.0      1.0       23.1      1.0
BASEF    2
0.3       0.5       0.2
ROUTE
103.0
```

Figure 1.8.35 (continuation)

```
2000.     0.4       0.3       100.
33000.    0.0293    0.05      00.0
5.0       10.0      1.0       23.1      0.0
BASEF    2
0.3       0.5       0.2
ADD      2
END
RAIN
    135064    7    1    1
(20X,F10.0)
ETDATA
   24    9    1    1
(10F8.0)
FLOW
    1    0
END
BASIN C - PASO DEL ERMITANO (1976-1979)  1972 PARAMETERS
    0    0 8766 8766    1
ZPERC     33.70
REXP      4.83
SIDE      0.006
UZK       0.900
ADIMP     0.092
RSERV     0.440
RIVA      0.829
PCTIM     0.908
LZPK      0.012
LZSK      0.476
PFREE     0.994
UZTWM     150.0
UZFWM     100.0
LZTWM     300.0
LZFSM     200.0
LZFPM     800.0
UZTWC     84.8      50.0      150.0     2.0
UZFWC     0.01      00.0      80.0      2.0
LZTWC     126.5     40.0      200.0     5.0
LZFSC     20.23     60.0      150.0     2.0
LZFPC     127.9     0.0       800.0     5.0
ADIMC     348.4     100.0     400.0     10.0
PXADJ     1.0
PEADJ     0.7
END
ROUTE
103.0
5000.0    0.5       0.3       100.0
18000.    0.0148    0.04      0.0
5.0       80.0      1.0       29.18     1.0
BASEF    2
0.3       0.5       0.2
ROUTE
109.0
3000.     0.4       0.3       100.
34000.    0.0323    0.05      00.0
5.0       10.0      1.0       29.18     0.0
```

Figure 1.8.35 (continuation)

```
BASEF    2
0.3       0.5       0.2
ADD      2
ROUTE
53.0
5000.0    0.4       0.3       100.0
18000.    0.0119    0.040     00.0
5.0       80.0      1.0       29.18     1.0
BASEF    2
0.3       0.5       0.2
END
RAIN
    135064    7    1    1
(30X,F10.0)
ETDATA
   24    9    1    1
(10F8.0)
FLOW
    1    0
```

Figure 1.8.35 (continuation)

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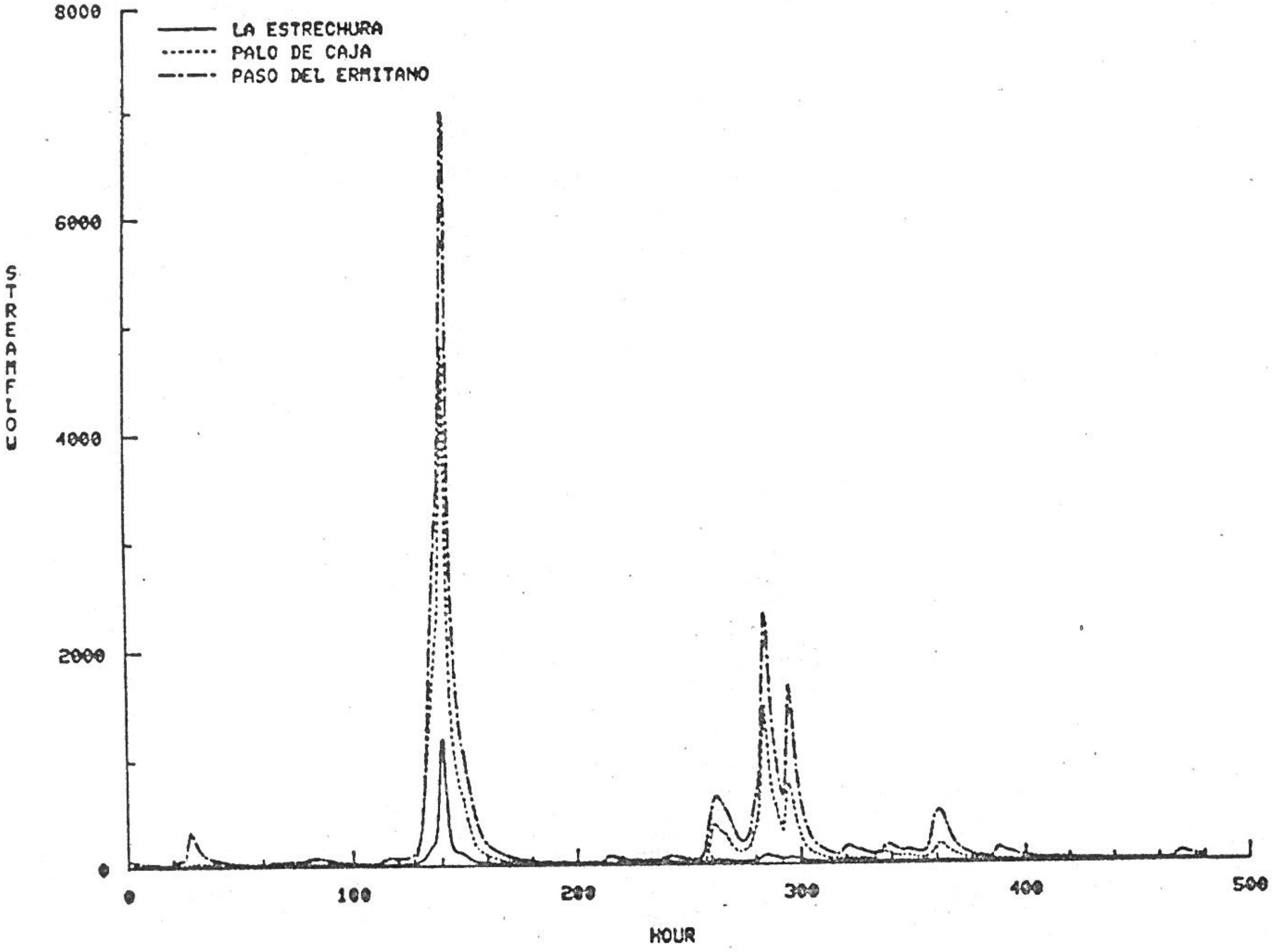

Figure 1.8.36. Results of model run with evapotranspiration demand for hurricanes David and Frederic (Aug 26-Sep 14, 1979).

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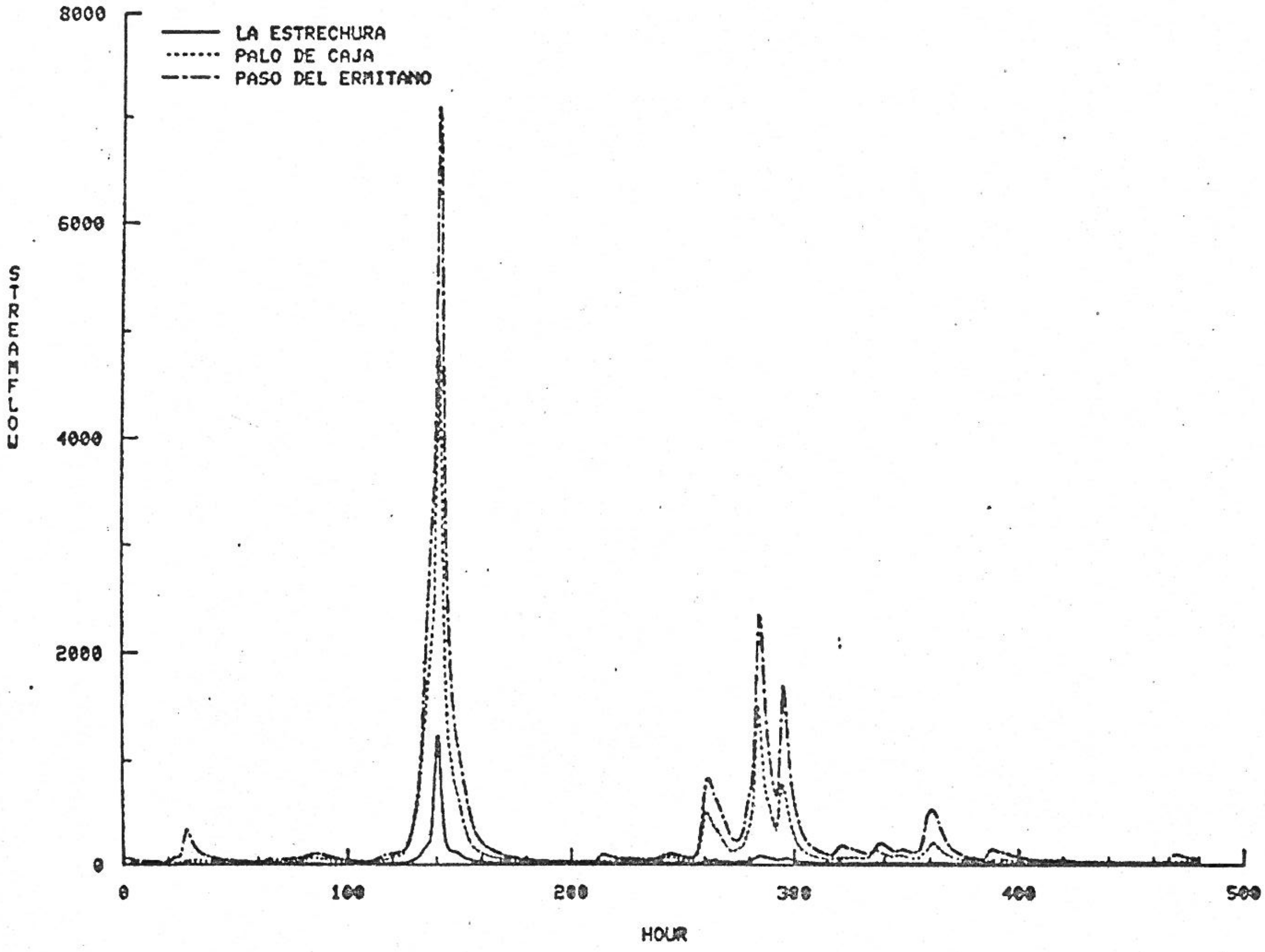


Figure 1.8.37. Results of model run without evapotranspiration demand for hurricanes David and Frederic (Aug 26-Sep 14, 1979).

APPENDIX 1.8.A

SACKW MODEL USER'S MANUAL

1.8.A.1 Introduction

The program SACKW is a conceptual-hydraulic model of watershed which simulates the various elements of the hydrologic cycle. Basically, the model starts with simulating the basin hydrology through the conceptual based Sacramento soil moisture accouting (SAC) model to derive the different runoff components in the basin accruiing from input precipitation. Then, the pertinent runoff components are hydraulically routed through overland-flow planes and channels to arrive at the streamflows at the basin outlet using the kinematic wave (KW) routing methodology. The model has two operational modes: the calibration mode for model parameter estimation, and the forecasting mode for simulating basin hydrology under some specified or known set of model parameters. In the calibration mode, the parameters of the SAC model may be calibrated manually or automatically using the constrained Rosenbrock optimization technique. The time scale of model simulation is at the least on an hourly basis and can be at longer time intervals but as multiples of one hour.

The ensuing sections present the description of Program SACKW, input requirements, output information, some guidelines for model usage and parameter calibration, and sample model application.

1.8.A.2 Program Description

Program SACKW is written in FORTRAN 77 which can be ran in mainframe computers or desktop computers. The program listing is given in Appendix 1.8.B. It is composed of 14 subprograms and a main program.

A descriptive flowchart of the program operation and sequence is given in Figure 1.8.A.1. Included in the flowchart are the pertinent program and subprograms used in the various operations. Given below are brief descriptions of the main program and subprograms.

<u>MAIN PROGRAM</u>

The MAIN program reads all input data and controls the overall sequence of program operations.

<u>Subroutine SETPAR</u>

This subprogram checks and sets up default values of model parameters for the Sacramento soil moisture accounting model.

<u>Subroutine SACROUT</u>

Subroutine SACROUT resets model parameters, sequences the soil moisture accounting and routing operations, and output some execution results.

<u>Subroutine SACSMA</u>

Subroutine SACSMA specifically controls the time loop of the Sacramento soil moisture accounting, performs water balance and prints results of soil moisture accounting.

<u>Subroutine SMAONE</u>

This subroutine performs all soil moisture accounting computations for one time step.

<u>Subroutine KINWAVE</u>

This subroutine controls the timing and sequencing of kinematic wave routing operations. Additionally, the routed streamflows and computed baseflows from different flow planes and subbasins are combined in this subroutine.

Subroutine KINOFF

This subroutine determines the runoff hydrograph for each flow plane using the kinematic wave method.

Subroutine FDKRUT

Subroutine FDKRUT generates overland flow runoff hydrograph or stream discharge hydrographs.

Subroutine ROFGRD

Subroutine ROFGRD computes the incremental length and time required in finite-difference grid computations for overland flow.

Subroutine FLOGRO

This subroutine computes the size and number incremental lengths required in finite-difference solution in the stream discharge routing computation.

Subroutine FRMMTC

Converts input data from metric units to English units in the kinematic wave routing computations.

Subroutine TOMTRC

Converts computed results in English units to metric system in the kinematic wave routing computation.

Subroutine OPTIM

Subroutine OPTIM performs the constrained Rosenrock optimization algorithm for the SAC model parameters.

Function FPOBS

This subprogram computes the value of the objective function for the optimization routine based on observed and computed streamflows.

Subroutine UPDATE

This subprogram generates an updated model input data file if derived to incorporate adjusted model parameters when optimized and sending volumes of soil-moisture contents for eventual use in the future.

1.8.A.3 Input and Output Information

Generally, the program input can be summarized in the following sequence:

1. Model run information
2. Control parameters for input, output and optimization options
3. Soil-moisture accounting model parameters
4. Kinematic wave model parameters
5. Hydrologic input data control parameters

A detailed description and sequence of the program input is given in Appendix 1.8.C. To facilitate in model inputting some data or parameter input (data sets) require a five-letter word identifier as a leading record or contained in the beginning of an input record. For further clarification on the input requirements, Section 1.8.A.5. presents a sample program application.

The program output is primarily in the form of tabular and graphical displays on a line printer. The tabular outputs include summaries of soil-moisture contents, runoff components, evapotranspiration and rainfall. Tabular and graphical outputs of observed and simulated streamflows at subbasin outlets are also given. There are printing frequency control options provided in the program. A sample program output is given in Section 1.8.A.5.

1.8.A.4. Some Guidelines For Model Usage and Parameter Calibration

For details of setting-up the parameter values of the SAC model and kinematic wave routing model, the manuals prepared by Burnash, et al., 1979 and the U.S. Corps of Engineers (1985), respectively can be consulted. The ensuing text presents only some guidelines on model parameter calibration with emphasis on the SAC model parameters.

For the SAC model, Burnash (1985) have shown that from several tests conducted on the sensitivity of the model, the rainfall input data practically accounts for all variations in the computed streamflows as opposed to the rest of the model parameters. This result is shown in Figure 1.8.A.2. in which a particular runoff hydrograph is ten times as sensitive to a shift in the rainfall input as it is to a similar change in the most sensitive parameters. In view of this, an important aspect in using the model is to resolve the question of handling the rainfall data. As done in the model calibration for Nizao basin, the rainfall input data has been defined for each subwatershed based on areally averaging point rainfall time series data from several stations. An areal averaging technique such as Thiessen method or optimal interpolation technique can be used for this purpose.

As mentioned earlier, the initial model parameters of SAC model may be obtained from guidelines given by Burnash, et al., (1979). Once this is set-up, some parameters may be refined by manual calibration or automatically through the optimization algorithm. Generally, the SAC model parameters to be calibrated are: UZK, REXP, ZPERC, SIDE, UZTWM, UZFWM, LZTWM, LZFSM and LZFPM. In the case of manually calibrating the model parameters, the following guidelines may be useful.

1. If surface runoff is excessive and baseflow is too low, the percolation could be inadequate. A possible action is to increase LZFSM and LZFPM which increases percolation and potential baseflow.

2. If initial runoff is inadequate, decreasing UZTWM allows runoff to take place sooner.

3. If surface runoff is generally excessive, the following action may be taken: i) raise ZPERC and thus increase percolation, ii) enlarge LZFSM and LZFPM which results in higher potential baseflow, and iii) lower REXP to increase continuing percolation and also alter shape of percolation curve.

4. If streamflow rising limbs are underforecast, too much water may be required to fill LZTWM. Action: reduce LZTWM by as much as water balance residual.

5. If streamflow rising limbs are overforecast but recession limbs underforecast, interflow could be inadequate which can be corrected by increasing UZFWM.

6. If the streamflow hydrograph baseflow time is too wide and rising peaks are flat the impervious area parameter ADIMP may be small. Decreasing ADIMP sharpens rising peaks and diminishes baseflow area.

7. To increase the general level of surface runoff and slightly decrease the trailing baseflow, ZPERC may be reduced.

For the kinematic wave model, most of the parameters can be obtained from basin topographic maps, such as basin areas and overland-flow and channel slopes, widths and lengths. The channel geometry may be obtained from actual photographs with scales or river cross-sectional data. The parameter that may require some calibration is the roughness

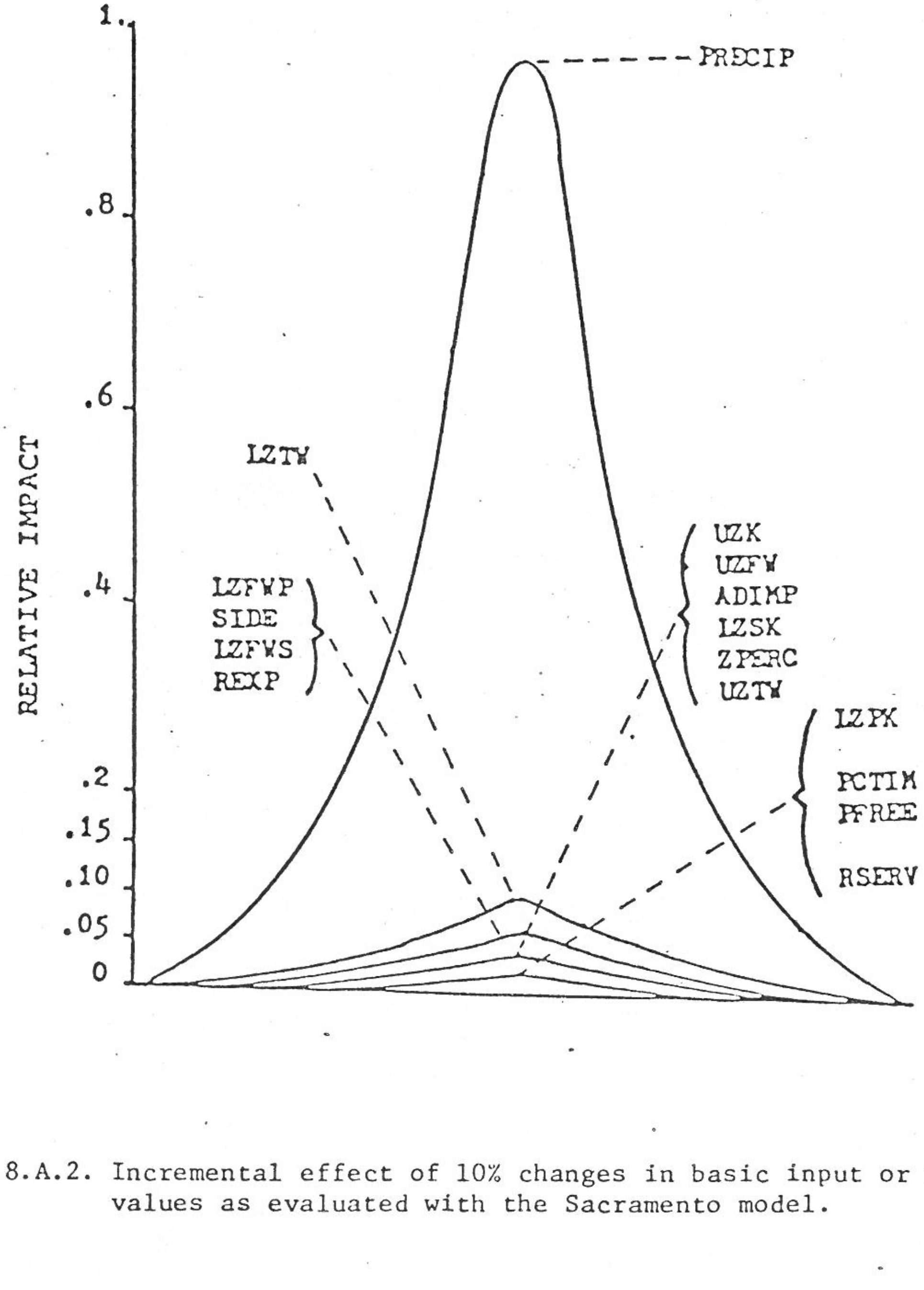
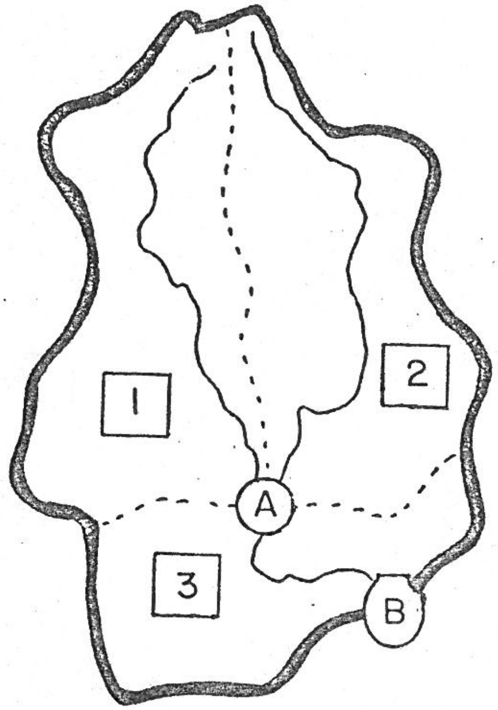
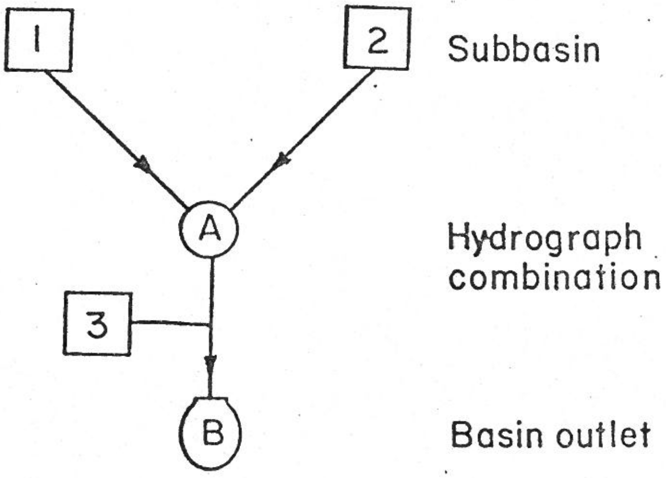


Figure 1.8.A.2. Incremental effect of 10% changes in basic input or parameter values as evaluated with the Sacramento model.



Example River Basin



Example River Basin Schematic

Figure 1.8.A.3. Sample river basin and schematic representation.

coefficient since flow-plane or channel heterogeneity effects may be difficult to fully parameterize into some lumped or average values.

1.8.A.5. Sample Model Application

This section presents a sample model application for illustration purposes. One watershed is used in the example with three overland-flow elements as shown in Figure 1.8.A.3. The input hydrologic data are rainfall, streamflow and evapotranspiration demand which are on an hourly basis. Given in Figure 1.8.A.4. is the input data file for the model. In this case, the hydrologic data are read as part of the overall model input file.

It is worthwhile to mention the manner in which the kinematic wave routing parameters are inputted with respect to the river basin configuration. Referring to Figures 1.8.A.3. and 1.8.A.4., the overland-flow element 1 runoff hydrograph is computed first which corresponds to the first "ROUTE" operation in the data file. Then the hydrograph of overland-flow element 2 is computed in the second "ROUTE" operation. In both cases, the "ROUTE" operation are followed by "BASEF" operations so that baseflow components are added at their outlet. At point A, the two hydrographs are combined using the "ADD" operation. The hydrograph for overland-flow element 3 is computed in the third "ROUTE" operation plus the contribution of baseflow upon issuing the last "BASEF" operation. Note that in this third "ROUTE" operation, the variable ARUPF(.) is set equal to 1.0 which indicates that the upstream hydrograph (at point A) is also routed together with the flows in subbasin 3.

The program output for this run is given in Figure 1.8.A.5. In this output all soil-moisture accouting results are printed on an hourly

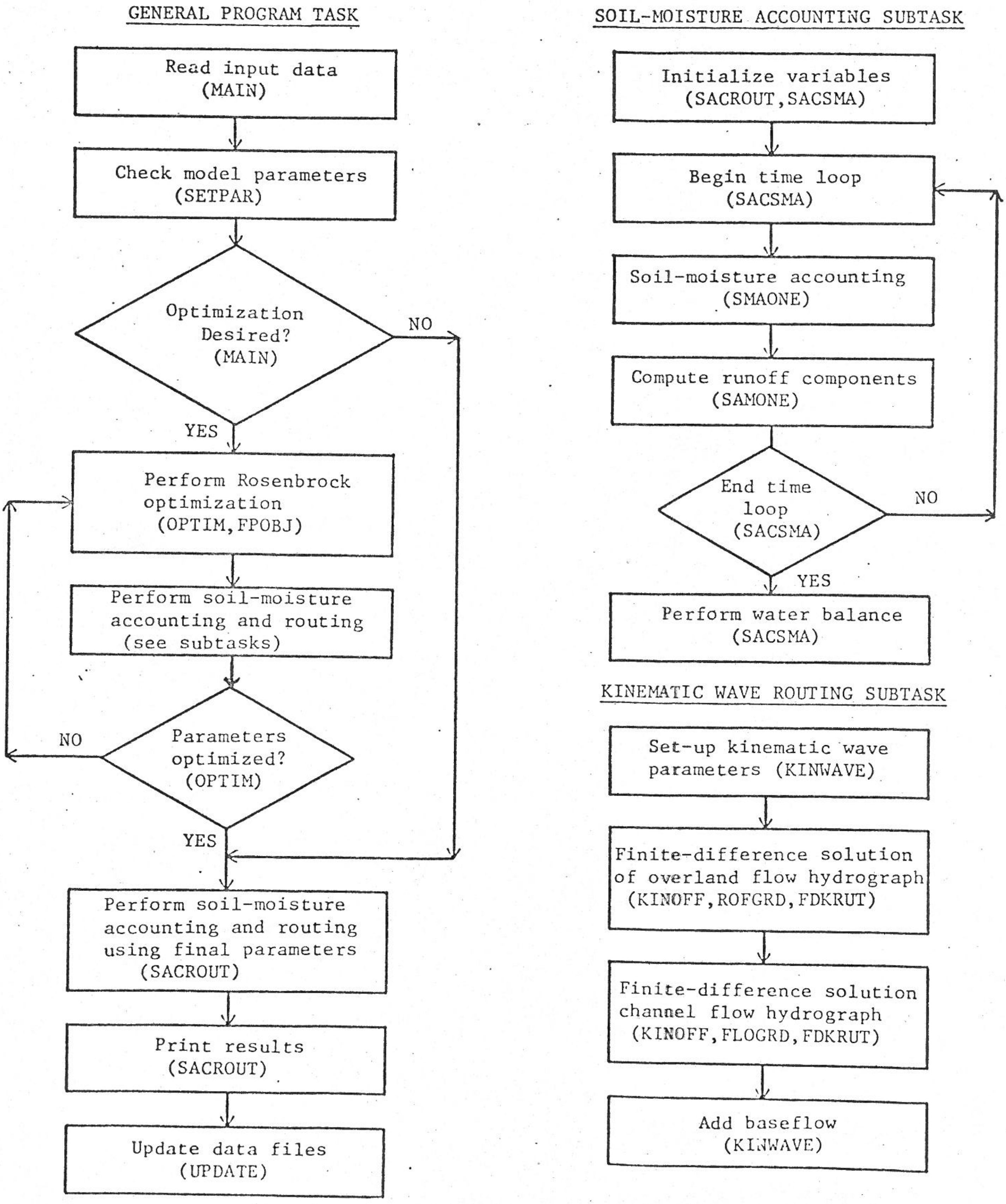


Figure 1.8.A.1. Descriptive flow chart of PROGRAM SACKW.

```
SAMPLE MODEL APPLICATION
    5    0   72    1    1
0.01        1   25    1    1
ZPERC     147.0     15.0      160.      5.0
REXP      0.507     0.4       5.0       0.1
SIDE      0.183     0.0001    10.0      0.001
UZK       0.0096    0.001     0.90       0.001
ADIMP     0.1175    0.001     0.5       0.001
RSERV     0.42      0.01      .50       0.01
RIVA      0.84      0.25      0.90       0.01
PCTIM     0.089     0.05      .80       0.01
LZPK      0.010     0.005     .80       0.001
LZSK      0.0055    0.003     .50       0.001
PFREE     0.790     0.01      .999      0.0001
UZTWC     89.0      50.0      150.0     2.0
UZFWC     33.0      30.0      80.0      2.0
LZTWC     120.0     40.0      250.0     5.0
LZFSC     33.00     30.0      150.0     2.0
LZFPC     405.0     400.0     800.0     5.0
ADIMC     102.0      90.0     400.0     10.0
UZTWM     150.0
UZFWM     100.0
LZTWM     300.0
LZFSM     200.0
LZFPM     800.0
PXADJ     1.0
PEADJ     0.7
END
ROUTE
70.0
2500.0    0.6       0.4       100.0
16000.    0.105     0.06      0.0
5.0       15.0      1.0       4.92      0.0
BASEF    2
ROUTE
70.0
2500.     0.6       0.4       100.
20000.    0.0837    0.06      70.0
5.0       15.0      1.0       4.92      0.0
BASEF    2
ADD      2
ROUTE
45.0
4500.0    0.5       0.3       100.0
8500.0    0.0133    0.040     45.0
5.0       85.0      1.0       4.92      1.0
BASEF    2
END
RAIN
    1   72     0    1    0
(8F10.0)
0.6       0.2       0.2       2.70      0.7       1.10      0.5       0.0
2.50      57.6      15.1      0.90      0.4       0.0       0.0       0.0
0.00      0.0       0.0       0.0       0.0       0.0       0.0       0.0
0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
```

Figure 1.8.A.4 Input data file for sample model application.

```
0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
ETDATA
    1    0    1    0
(8F10.0)
0.438     0.438     0.438     0.438     0.438     0.438     0.438     0.438
0.438     0.438     0.438     0.438     0.179     0.179     0.179     0.179
0.179     0.179     0.179     0.179     0.179     0.179     0.179     0.179
0.179     0.179     0.179     0.179     0.179     0.179     0.179     0.179
0.179     0.179     0.179     0.179     0.217     0.217     0.217     0.217
0.271     0.271     0.271     0.271     0.271     0.271     0.271     0.271
0.271     0.271     0.271     0.271     0.271     0.271     0.271     0.271
0.271     0.271     0.271     0.271     0.271     0.271     0.271     0.271
0.271     0.271     0.271     0.271     0.271     0.271     0.271     0.271
FLOW
    1    1    0    1    0
(8F10.0)
4.92      4.92      5.57      5.57      5.57      5.57      5.57      5.57
6.27      6.27      6.64      7.84      17.4      39.46     50.1      39.46
30.44     24.64     20.41     17.40     15.34     10.65     12.86     12.28
11.72     11.18     10.65     10.14     9.65      9.65      9.18      8.71
8.71      8.27      7.84      7.84      7.84      7.84      7.84      7.42
7.42      7.02      7.02      7.02      7.02      7.02      7.02      7.02
7.02      6.64      6.27      6.27      6.27      6.27      6.27      6.27
6.57      6.27      6.27      6.27      6.27      6.27      6.27      6.27
7.02      6.64      6.27      6.27      6.27      6.27      6.27      6.27
END
```

Figure 1.8.A.4 (continuation)

```
BASIN 1 RUN: SAMPLE MODEL APPLICATION

LIST OF PARAMETERS TO BE OPTIMIZED

  NAME           VALUE        MINIMUM     MAXIMUM  STEP SIZES

 ZPERC          147.00000    15.00000   160.00000     5.00000
 REXP             0.50700     0.40000     5.00000     0.10000
 SIDE             0.18300     0.00010    10.00000     0.00100
 UZK              0.00960     0.00100     0.90000     0.00100
 ADIMP            0.11750     0.00100     0.50000     0.00100
LIST OF PARAMETERS MANUALLY CALIBRATED

  NAME           VALUE

 RSERV            0.42000
 RIVA             0.84000
 PCTIM            0.08900
 LZPK             0.01000
 LZSK             0.00550
 PFREE            0.79000
 UZTWC           89.00000
 UZFWC           33.00000
 LZTWC          120.00000
 LZFSC           33.00000
 LZFPC          405.00000
 ADIMC          102.00000
 UZTWM          150.00000
 UZFWM          100.00000
 LZTWM          300.00000
 LZFSM          200.00000
 LZFPM          800.00000
 PXADJ            1.00000
 PEADJ            0.70000

OPTIMIZATION PARAMETERS :
  OBJECTIVE FUNCTION TYPE              1
  MAXIMUM NUMBER OF ITERATIONS        25
  CONVERGENCE CRITERION     0.10000E-01
  STEP SIZE UPDATE OPTION              1
  PRINTING FREQUENCY                   1

NUMBER OF PARAMETERS TO BE OPTIMIZED =   5
NUMBER OF PARAMETERS MANUALLY CALIBRATED = 19

PARAMETERS TO BE OPTIMIZED AFTER CHECKING

   ITEM NAME       VALUE        MINIMUM     MAXIMUM  STEP SIZES

   1  ZPERC       147.00000    15.00000   160.00000     5.00000
   2  REXP          0.50700     0.40000     5.00000     0.10000
   3  SIDE          0.18300     0.00010    10.00000     0.00100
   4  UZK           0.00960     0.00100     0.90000     0.00100
   5  ADIMP         0.11750     0.00100     0.50000     0.00100

PARAMETERS MANUALLY CALIBRATED AFTER CHECKING

  ITEM NAME       VALUE

   6  RSERV       0.42000
   7  RIVA        0.84000
   8  PCTIM       0.08900
```

Figure 1.8.A.5 Program output of sample model application.

```
  9  LZPK         0.01000
 10  LZSK         0.00550
 11  PFREE        0.79000
 12  UZTWC       89.00000
 13  UZFWC       33.00000
 14  LZTWC      120.00000
 15  LZFSC       33.00000
 16  LZFPC      405.00000
 17  ADIMC      102.00000
 18  UZTWM      150.00000
 19  UZFWM      100.00000
 20  LZTWM      300.00000
 21  LZFSM      200.00000
 22  LZFPM      800.00000
 23  PXADJ        1.00000
 24  PEADJ        0.70000
```

Figure 1.8.A.5 (continuation)

```
        OPTIMIZATION BY ROSENBROCK HILLCLIMB PROCEDURE


STAGE          FUNCTION              PROGRESS           LATERAL PROGRESS
  1       -0.90737742E+01       0.16250006E+02       0.24414062E-06

NUMBER OF FUNCTION EVALUATIONS =          70

VALUES OF X(.) AT THIS STAGE
  X( 1) =      0.158250E+03     X( 2) =      0.492937E+00     X( 3) =      0.183000E+00
  X( 4) =      0.959805E-02     X( 5) =      0.117500E+00     X(


STAGE          FUNCTION              PROGRESS           LATERAL PROGRESS
  1       -0.90737672E+01       0.16250006E+02       0.24414062E-06

NUMBER OF FUNCTION EVALUATIONS =          76

VALUES OF X(.) AT THIS STAGE
  X( 1) =      0.158260E+03     X( 2) =      0.492831E+00     X( 3) =      0.183000E+00
  X( 4) =      0.959803E-02     X( 5) =      0.117500E+00     X(

FINAL DIRECTION VECTOR MATRIX
  V( 1, 1) = 0.99999963     V( 1, 2) = -.00086538     V( 1, 3) = 0.00000002
  V( 1, 4) = -.00000012     V( 1, 5) = 0.00000002     V(
  V( 2, 1) = -.00086538     V( 2, 2) = -.99999962     V( 2, 3) = 0.00001736
  V( 2, 4) = -.00013889     V( 2, 5) = 0.00001736     V(
  V( 3, 1) = -.00000012     V( 3, 2) = 0.00000000     V( 3, 3) = 0.12309149
  V( 3, 4) = -.98473193     V( 3, 5) = 0.12309149     V(
  V( 4, 1) = -.00000012     V( 4, 2) = 0.00000000     V( 4, 3) = 0.00000000
  V( 4, 4) = -.99227788     V( 4, 5) = 0.12403473     V(
  V( 5, 1) = -.00000002     V( 5, 2) = 0.00000000     V( 5, 3) = 0.00000000
  V( 5, 4) = 0.00000000     V( 5, 5) = 1.00000000     V(

FINAL STEP SIZES
  S( 1) =      0.976563E-02     S( 2) =      0.195312E-03     S( 3) =      0.122070E-06
  S( 4) =      0.122070E-06     S( 5) =      0.122070E-06     S(
```

Figure 1.8.A.5 (continuation)

```
SACRAMENTO SOIL-MOISTURE ACCOUNTING OPERATION

PARAMETER VALUES - CAPACITIES ARE IN MM.

   PX-ADJ    PE-ADJ     UZTWM     UZFWM       UZK     PCTIM     ADIMP      RIVA
    1.000     0.700   150.000   100.000     0.010     0.089     0.118     0.840

DAILY ET DIST. ASSUMED UNIFORM

    PBASE     ZPERC      REXP     LZTWM     LZFSM     LZFPM      LZSK      LZPK     PFREE     RSERV      SIDE
    9.100   158.260     0.493   300.000   200.000   800.000     0.006     0.010     0.790     0.420     0.183


SOIL-MOISTURE CONTENTS (MM)

    UZTWC     UZFWC     LZTWC     LZFSC     LZFPC     ADIMC
   89.000    33.000   120.000    33.000   405.000   102.000


DETAILED SOIL-MOISTURE ACCOUNTING OUTPUT                   UNITS ARE IN MM.

   DAY HR  UZTWC  UZFWC  LZTWC  LZFSC  LZFPC  ADIMC    PERC     IMP     DIR     SUR     INT     SUP     PRI  TOT-RO  ET-DMD ACT-ET    RAIN

    1   1   89.4 20.511 122.59 36.974 410.71 102.41  12.479   0.053   0.000   0.000   0.008   0.005   0.115   0.105   0.307  0.269    0.60
    1   2   89.4 12.705 124.19 39.436 414.22 102.43   7.800   0.018   0.000   0.000   0.005   0.006   0.116   0.069   0.307  0.269    0.20
    1   3   89.5  7.758 125.20 40.985 416.40 102.44   4.943   0.018   0.000   0.000   0.003   0.006   0.117   0.068   0.307  0.269    0.20
    1   4   92.0  4.637 125.82 41.955 417.71 104.96   3.118   0.240   0.000   0.000   0.002   0.006   0.117   0.290   0.307  0.269    2.70
    1   5   92.5  2.537 126.22 42.604 418.53 105.46   2.099   0.062   0.000   0.000   0.001   0.006   0.117   0.115   0.307  0.270    0.70
    1   6   93.4  1.389 126.43 42.953 418.90 106.37   1.147   0.098   0.000   0.000   0.000   0.007   0.118   0.151   0.307  0.270    1.10
    1   7   93.7  0.761 126.53 43.140 419.03 106.68   0.628   0.045   0.000   0.000   0.000   0.007   0.118   0.099   0.307  0.270    0.50
    1   8   93.5  0.417 126.57 43.237 419.02 106.48   0.344   0.000   0.000   0.000   0.000   0.007   0.118   0.055   0.307  0.270    0.00
    1   9   95.8  0.229 126.58 43.286 418.93 108.79   0.188   0.223   0.000   0.000   0.000   0.007   0.118   0.277   0.307  0.270    2.50
    1  10  150.0  3.349 126.57 43.308 418.81 166.18   0.103   5.126   0.001   0.000   0.000   0.007   0.118   5.185   0.307  0.270   57.60
    1  11  150.0 14.545 127.32 44.418 420.35 180.90   3.595   1.344   0.009   0.000   0.002   0.007   0.118   1.480   0.307  0.279   15.10
    1  12  150.0  9.521 128.50 46.151 422.86 181.48   5.613   0.080   0.001   0.000   0.004   0.007   0.118   0.210   0.307  0.279    0.90
    1  13  150.0  5.970 129.30 47.323 424.52 181.75   3.823   0.036   0.000   0.000   0.002   0.007   0.119   0.164   0.125  0.114    0.40
    1  14  149.9  3.595 129.80 48.044 425.49 181.63   2.373   0.000   0.000   0.000   0.001   0.007   0.119   0.128   0.125  0.114    0.00
    1  15  149.7  1.987 130.14 48.528 426.09 181.50   1.608   0.000   0.000   0.000   0.001   0.007   0.119   0.127   0.125  0.114    0.00
    1  16  149.6  1.099 130.33 48.790 426.34 181.38   0.888   0.000   0.000   0.000   0.000   0.007   0.120   0.127   0.125  0.114    0.00
    1  17  149.5  0.608 130.43 48.930 426.39 181.25   0.491   0.000   0.000   0.000   0.000   0.008   0.120   0.127   0.125  0.114    0.00
    1  18  149.4  0.337 130.49 49.002 426.35 181.13   0.271   0.000   0.000   0.000   0.000   0.008   0.120   0.127   0.125  0.114    0.00
    1  19  149.2  0.186 130.52 49.037 426.24 181.00   0.150   0.000   0.000   0.000   0.000   0.008   0.120   0.127   0.125  0.114    0.00
    1  20  149.1  0.103 130.54 49.051 426.10 180.88   0.083   0.000   0.000   0.000   0.000   0.008   0.120   0.127   0.125  0.114    0.00
    1  21  149.0  0.057 130.54 49.054 425.95 180.76   0.046   0.000   0.000   0.000   0.000   0.008   0.120   0.127   0.125  0.114    0.00
    1  22  148.9  0.032 130.55 49.050 425.78 180.63   0.025   0.000   0.000   0.000   0.000   0.008   0.120   0.127   0.125  0.114    0.00
    1  23  148.8  0.017 130.55 49.043 425.61 180.51   0.014   0.000   0.000   0.000   0.000   0.008   0.120   0.127   0.125  0.114    0.00
    1  24  148.6  0.010 130.55 49.034 425.43 180.38   0.008   0.000   0.000   0.000   0.000   0.008   0.120   0.126   0.125  0.114    0.00
    2  25  148.5  0.010 130.55 49.023 425.26 180.26   0.000   0.000   0.000   0.000   0.000   0.008   0.119   0.126   0.125  0.114    0.00
    2  26  148.4  0.010 130.55 49.012 425.08 180.13   0.000   0.000   0.000   0.000   0.000   0.008   0.119   0.126   0.125  0.114    0.00
    2  27  148.3  0.010 130.55 49.001 424.90 180.01   0.000   0.000   0.000   0.000   0.000   0.008   0.119   0.126   0.125  0.114    0.00
    2  28  148.1  0.010 130.55 48.989 424.72 179.89   0.000   0.000   0.000   0.000   0.000   0.008   0.119   0.126   0.125  0.114    0.00
    2  29  148.0  0.010 130.55 48.978 424.54 179.76   0.000   0.000   0.000   0.000   0.000   0.008   0.119   0.126   0.125  0.114    0.00
    2  30  147.9  0.010 130.55 48.967 424.37 179.64   0.000   0.000   0.000   0.000   0.000   0.008   0.119   0.126   0.125  0.114    0.00
    2  31  147.8  0.010 130.55 48.956 424.19 179.51   0.000   0.000   0.000   0.000   0.000   0.008   0.119   0.126   0.125  0.114    0.00
    2  32  147.6  0.010 130.55 48.944 424.01 179.39   0.000   0.000   0.000   0.000   0.000   0.008   0.119   0.126   0.125  0.114    0.00
    2  33  147.5  0.010 130.55 48.933 423.83 179.27   0.000   0.000   0.000   0.000   0.000   0.008   0.119   0.125   0.125  0.114    0.00
    2  34  147.4  0.010 130.55 48.922 423.66 179.14   0.000   0.000   0.000   0.000   0.000   0.008   0.119   0.125   0.125  0.114    0.00
    2  35  147.3  0.010 130.55 48.911 423.48 179.02   0.000   0.000   0.000   0.000   0.000   0.008   0.119   0.125   0.125  0.114    0.00
    2  36  147.1  0.010 130.55 48.899 423.30 178.90   0.000   0.000   0.000   0.000   0.000   0.008   0.119   0.125   0.125  0.114    0.00
    2  37  147.0  0.010 130.55 48.888 423.12 178.75   0.000   0.000   0.000   0.000   0.000   0.008   0.119   0.125   0.152  0.138    0.00
    2  38  146.8  0.010 130.55 48.877 422.95 178.60   0.000   0.000   0.000   0.000   0.000   0.008   0.119   0.125   0.152  0.138    0.00
    2  39  146.7  0.010 130.55 48.866 422.77 178.45   0.000   0.000   0.000   0.000   0.000   0.008   0.119   0.124   0.152  0.138    0.00
    2  40  146.5  0.010 130.54 48.854 422.59 178.30   0.000   0.000   0.000   0.000   0.000   0.008   0.119   0.124   0.152  0.138    0.00
    2  41  146.4  0.010 130.54 48.843 422.42 178.12   0.000   0.000   0.000   0.000   0.000   0.008   0.119   0.124   0.190  0.172    0.00
```

Figure 1.8.A.5 (continuation)

```
 2    42 146.2  0.010 130.54 48.832 422.24 177.93  0.000  0.000  0.000  0.000  0.000  0.008  0.119  0.123  0.190  0.172  0.00
 2    43 146.0  0.010 130.54 48.821 422.06 177.75  0.000  0.000  0.000  0.000  0.000  0.008  0.119  0.123  0.190  0.172  0.00
 2    44 145.8  0.010 130.54 48.809 421.89 177.56  0.000  0.000  0.000  0.000  0.000  0.008  0.119  0.123  0.190  0.172  0.00
 2    45 145.6  0.010 130.54 48.798 421.71 177.38  0.000  0.000  0.000  0.000  0.000  0.008  0.118  0.123  0.190  0.172  0.00
 2    46 145.4  0.010 130.54 48.787 421.53 177.19  0.000  0.000  0.000  0.000  0.000  0.008  0.118  0.123  0.190  0.172  0.00
 2    47 145.3  0.010 130.53 48.776 421.36 177.01  0.000  0.000  0.000  0.000  0.000  0.008  0.118  0.123  0.190  0.172  0.00
 2    48 145.1  0.010 130.53 48.765 421.18 176.82  0.000  0.000  0.000  0.000  0.000  0.008  0.118  0.122  0.190  0.172  0.00
 3    49 144.9  0.010 130.53 48.753 421.00 176.64  0.000  0.000  0.000  0.000  0.000  0.008  0.118  0.122  0.190  0.172  0.00
 3    50 144.7  0.010 130.53 48.742 420.83 176.45  0.000  0.000  0.000  0.000  0.000  0.008  0.118  0.122  0.190  0.172  0.00
 3    51 144.5  0.010 130.53 48.731 420.65 176.27  0.000  0.000  0.000  0.000  0.000  0.008  0.118  0.122  0.190  0.172  0.00
 3    52 144.3  0.010 130.52 48.720 420.47 176.09  0.000  0.000  0.000  0.000  0.000  0.008  0.118  0.122  0.190  0.172  0.00
 3    53 144.2  0.010 130.52 48.709 420.30 175.90  0.000  0.000  0.000  0.000  0.000  0.008  0.118  0.122  0.190  0.172  0.00
 3    54 144.0  0.010 130.52 48.697 420.12 175.72  0.000  0.000  0.000  0.000  0.000  0.008  0.118  0.121  0.190  0.172  0.00
 3    55 143.8  0.010 130.52 48.686 419.95 175.54  0.000  0.000  0.000  0.000  0.000  0.008  0.118  0.121  0.190  0.172  0.00
 3    56 143.6  0.010 130.52 48.675 419.77 175.36  0.000  0.000  0.000  0.000  0.000  0.008  0.118  0.121  0.190  0.172  0.00
 3    57 143.4  0.010 130.51 48.664 419.60 175.17  0.000  0.000  0.000  0.000  0.000  0.008  0.118  0.121  0.190  0.172  0.00
 3    58 143.2  0.010 130.51 48.653 419.42 174.99  0.000  0.000  0.000  0.000  0.000  0.008  0.118  0.121  0.190  0.172  0.00
 3    59 143.1  0.010 130.51 48.642 419.24 174.81  0.000  0.000  0.000  0.000  0.000  0.008  0.118  0.120  0.190  0.172  0.00
 3    60 142.9  0.010 130.51 48.630 419.07 174.63  0.000  0.000  0.000  0.000  0.000  0.007  0.118  0.120  0.190  0.172  0.00
 3    61 142.7  0.010 130.50 48.619 418.89 174.45  0.000  0.000  0.000  0.000  0.000  0.007  0.118  0.120  0.190  0.172  0.00
 3    62 142.5  0.010 130.50 48.608 418.72 174.27  0.000  0.000  0.000  0.000  0.000  0.007  0.118  0.120  0.190  0.172  0.00
 3    63 142.3  0.010 130.50 48.597 418.54 174.09  0.000  0.000  0.000  0.000  0.000  0.007  0.118  0.120  0.190  0.172  0.00
 3    64 142.2  0.010 130.50 48.586 418.37 173.91  0.000  0.000  0.000  0.000  0.000  0.007  0.118  0.119  0.190  0.172  0.00
 3    65 142.0  0.010 130.49 48.575 418.19 173.72  0.000  0.000  0.000  0.000  0.000  0.007  0.118  0.119  0.190  0.172  0.00
 3    66 141.8  0.010 130.49 48.563 418.02 173.54  0.000  0.000  0.000  0.000  0.000  0.007  0.117  0.119  0.190  0.172  0.00
 3    67 141.6  0.010 130.49 48.552 417.84 173.36  0.000  0.000  0.000  0.000  0.000  0.007  0.117  0.119  0.190  0.172  0.00
 3    68 141.4  0.010 130.48 48.541 417.67 173.18  0.000  0.000  0.000  0.000  0.000  0.007  0.117  0.119  0.190  0.172  0.00
 3    69 141.3  0.010 130.48 48.530 417.49 173.01  0.000  0.000  0.000  0.000  0.000  0.007  0.117  0.119  0.190  0.172  0.00
 3    70 141.1  0.010 130.48 48.519 417.32 172.83  0.000  0.000  0.000  0.000  0.000  0.007  0.117  0.118  0.190  0.172  0.00
 3    71 140.9  0.010 130.47 48.508 417.14 172.65  0.000  0.000  0.000  0.000  0.000  0.007  0.117  0.118  0.190  0.172  0.00
 3    72 140.7  0.010 130.47 48.496 416.97 172.47  0.000  0.000  0.000  0.000  0.000  0.007  0.117  0.118  0.190  0.172  0.00
TOTAL CHANNEL INFLOW =      15.5338
COMPONENTS OF TOTAL CHANNEL INFLOWS
 RUNOFF FROM PERMANENT IMPERVIOUS AREA =        7.3425
 RUNOFF FROM TEMPORARY IMPERVIOUS AREA =        0.0112
 SURFACE RUNOFF WHEN UZFWS IS FULL =      0.0000
 INTERFLOW FROM LATERAL DRAINAGE OF UZFWS =        0.0300
 SUPPLEMENTARY BASEFLOW =      0.5277
 PRIMARY BASEFLOW =      8.5188
WATER BALANCE RESIDUAL (IDEALLY EQ 0.0) =    0.00000
```

Figure 1.8.A.5(continuation)

```
KINEMATIC WAVE ROUTING FOR SUBBASIN  1

 TOTAL AREA =      70.00

OVERLAND FLOW ELEMENT 1

 CHLNG =    2500.00
 SLOPE =    0.60000
 RCMAN =    0.40000
 PAREA =    100.000


MAIN CHANNEL

 CHLNG =   16000.00
 SLOPE =    0.10500
 RCMAN =    0.06000
 SAREA =     70.000

 ISHAPE=          5
 CHWDT =     15.000
 ZLNG  =      1.000

 FLOIC =      4.920

COMPUTED KINEMATIC PARAMETERS

 ELEMENT      ALPHA        M        DT (MIN)    DX (MT)
    1        2.8854     1.667       60.00      833.55
    2        0.7189     1.604       60.00     8002.05

ADD BASEFLOW TO SUBBASIN  1 USING A LINEAR DECAY FUNCTION OF THE FORM:

 ADDED BF AT TIME T = SUM OF W(L) * BF(T-L) FOR L = 0 TO  2 ; WHERE

 W(L):  0.3000      0.5000      0.2000


KINEMATIC WAVE ROUTING FOR SUBBASIN  2

 TOTAL AREA =      70.00

OVERLAND FLOW ELEMENT 1

 CHLNG =    2500.00
 SLOPE =    0.60000
 RCMAN =    0.40000
 PAREA =    100.000


MAIN CHANNEL

 CHLNG =   20000.00
 SLOPE =    0.08370
 RCMAN =    0.06000
 SAREA =     70.000

 ISHAPE=          5
 CHWDT =     15.000
 ZLNG  =      1.000

 FLOIC =      4.920
```

Figure 1.8.A.5 (continuation)

```
COMPUTED KINEMATIC PARAMETERS

 ELEMENT       ALPHA        M          DT (MIN)    DX (MT)
    1         2.8854      1.667         60.00       833.55
    2         0.6419      1.604         60.00     10002.56

ADD BASEFLOW TO SUBBASIN  2 USING A LINEAR DECAY FUNCTION OF THE FORM:

 ADDED BF AT TIME T = SUM OF W(L) * BF(T-L) FOR L = 0 TO  2 ; WHERE

 W(L):  0.3000      0.5000      0.2000

ADD FLOWS OF SUBBASINS   1,  2,


KINEMATIC WAVE ROUTING FOR SUBBASIN  3

 TOTAL AREA =      45.00

OVERLAND FLOW ELEMENT 1

 CHLNG =    4500.00
 SLOPE =    0.50000
 RCMAN =    0.30000
 PAREA =    100.000


MAIN CHANNEL

 CHLNG =    8500.00
 SLOPE =    0.01330
 RCMAN =    0.04000
 SAREA =     45.000

 ISHAPE=          5
 CHWDT =     85.000
 ZLNG  =      1.000

 FLOIC =      4.920

ROUTE UPSTREAM FLOW


COMPUTED KINEMATIC PARAMETERS

 ELEMENT       ALPHA        M          DT (MIN)    DX (MT)
    1         3.5120      1.667         60.00      1125.29
    2         0.1068      1.654         60.00      4251.09

ADD BASEFLOW TO SUBBASIN  3 USING A LINEAR DECAY FUNCTION OF THE FORM:

 ADDED BF AT TIME T = SUM OF W(L) * BF(T-L) FOR L = 0 TO  2 ; WHERE

W(L):  0.3000      0.5000      0.2000

   VALUE OF OBJECTIVE FUNCTION (1) =          9.07377

  DAY  HOUR  OBSERVED  COMPUTED  I-------------------------------------------------------------------------
   1     1     4.920     0.589   IC     O                                                                   I
   1     2     4.920     1.453   I C    O                                                                   I
   1     3     5.570     2.542   I   C    O                                                                 I
   1     4     5.570     4.419   I      C O                                                               I
   1     5     5.570     5.923   I        E                                                                 I
                                                                                                           I
```

Figure 1.8.A.5 (continuation)

```
1    6    5.570    6.478
1    7    5.570    6.635
1    8    5.570    6.709
1    9    6.270    6.761
1   10    6.270    6.833
1   11    6.640    9.047
1   12    7.840   15.515
1   13   17.400   31.163
1   14   39.460   40.797
1   15   50.100   41.219
1   16   39.460   37.902
1   17   30.440   33.717
1   18   24.640   29.636
1   19   20.410   26.058
1   20   17.400   23.007
1   21   15.340   20.485
1   22   10.650   18.537
1   23   12.860   16.932
1   24   12.280   15.578
2   25   11.720   14.404
2   26   11.180   13.478
2   27   10.650   12.707
2   28   10.140   12.048
2   29    9.650   11.482
2   30    9.650   10.992
2   31    9.180   10.566
2   32    8.710   10.193
2   33    8.710    9.865
2   34    8.270    9.576
2   35    7.840    9.319
2   36    7.840    9.091
2   37    7.840    8.883
2   38    7.840    8.583
2   39    7.840    8.427
2   40    7.420    8.290
2   41    7.420    8.166
2   42    7.020    8.053
2   43    7.020    7.950
2   44    7.020    7.856
2   45    7.020    7.769
2   46    7.020    7.690
2   47    7.020    7.616
2   48    7.020    7.549
3   49    7.020    7.486
3   50    6.640    7.428
3   51    6.270    7.374
3   52    6.270    7.324
3   53    6.270    7.277
3   54    6.270    7.233
3   55    6.270    7.192
3   56    6.270    7.154
3   57    6.570    7.118
3   58    6.270    7.084
3   59    6.270    7.053
3   60    6.270    7.023
3   61    6.270    6.994
3   62    6.270    6.968
3   63    6.270    6.942
3   64    6.270    6.918
3   65    7.020    6.896
3   66    6.640    6.874
3   67    6.270    6.854
3   68    6.270    6.834
3   69    6.270    6.815
```

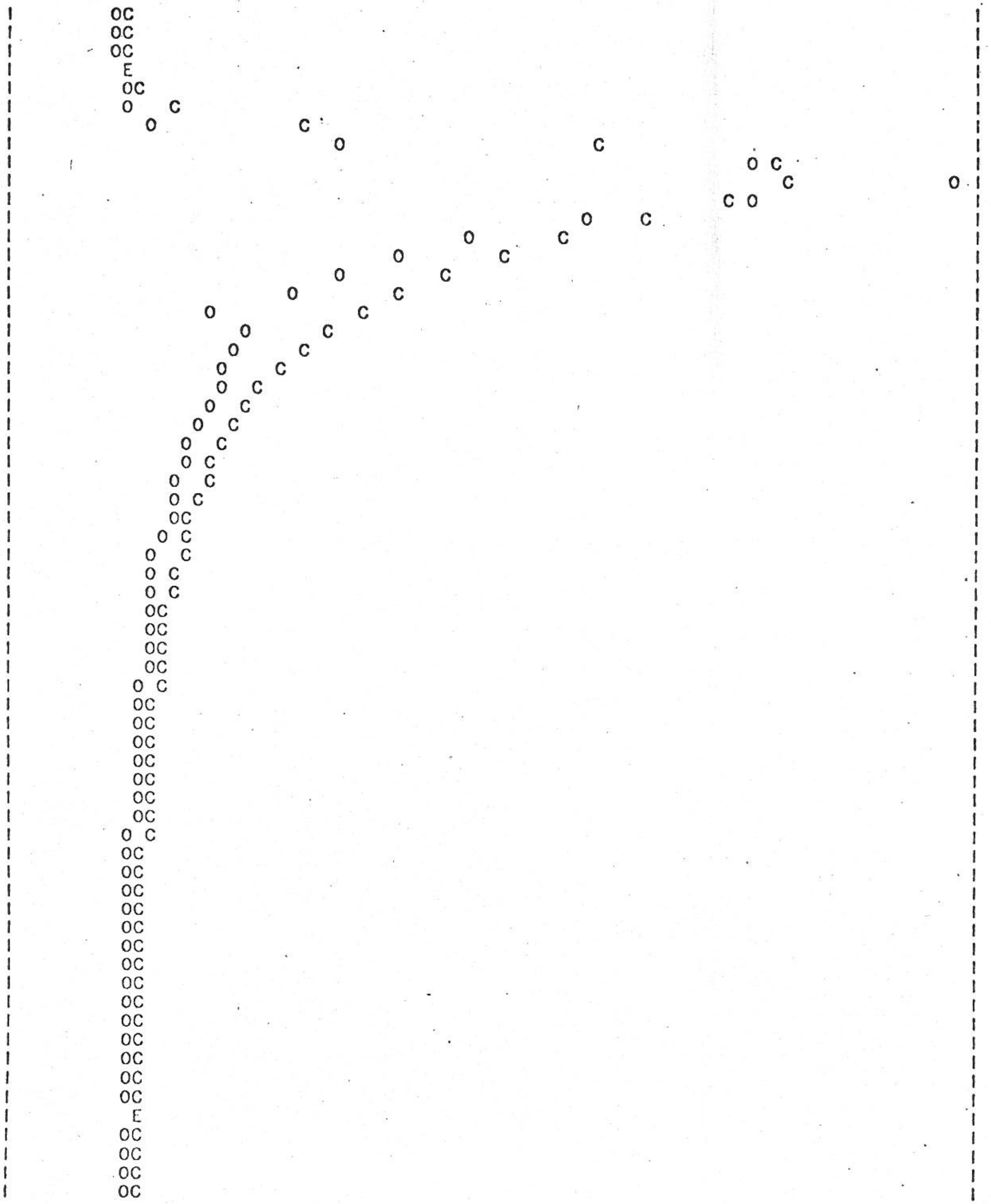


Figure 1.8.A.5 (continuation)

```
     3    70        6.270      6.798  I           OC                                                                      I
     3    71        6.270      6.781  I           OC                                                                      I
     3    72        6.270      6.765  I           E                                                                       I
                                      I---------------------------------------------------------------------------------- I

       MINIMUM ORDINATE =       0.59
       MAXIMUM ORDINATE =      50.10

       SYMBOLS USED:
        COMPUTED - C
        OBSERVED - O
        IF EQUAL - E

   NORMAL TERMINATION
```

Figure 1.8.A.5 (continuation)

basis. This sample run is made where 5 SAC model parameters are optimized. In the printout, for the optimization results, the X(.) variable correspond to the model parameters optimized in the order they are inputted.

APPENDIX 1.8.B

PROGRAM LISTING OF SACKW MODEL

```
      PROGRAM SACKW
     1 (TAPE5,OUTPUT,TAPE7,TAPE8,TAPE9,TAPE10,TAPE6=OUTPUT)
C
C     MAINLINE PROGRAM FOR CALIBRATION AND FORECASTING
C
      COMMON /CMIOP/         IOUA          , IOUB          ,
     1         NHOUR        ,NDATA         ,
     2        NTIME,NHRP,NHRQ,NDTQ,INPQ,NBASIN,IWBLNC,IPFRQR,IPFRQQ
      COMMON /CMPRM/         NPARM         , NPOP          , IOBF          ,
     1        MXITER       , NSTEP         , ERROR         , IPROP         ,
     2        INDX(50)     , XMP(50)       , XMIN(50)      , XMAX(50)      ,
     3    ESS(50),OBJFV
      COMMON /FDK00/ TAREA,TRMN,TRHR,METRC,IEL,NQ,MXNDX,MXNDT
      COMMON /FDK01/ CHLNG(5),SLOPE(5),RCMAN(5),PAREA(5),ISHAPE(5),
     1 CHWDT(5),ZLNG(5),ALPME(5),EMDEQ(5),DXROF(5),DXFLO(5),DTKWR(5),
     2 DXKWR(5),IRUPF(5),SAREA(5),FLOIC(5)
      COMMON /FDK02/ EXCSR(1224),Q(1224),
     1 QK(1224),QUB(1224),QBF(1224)
      COMMON /CMDAT/ RDT(1224),PDT(1224),QDT(1224)
      REAL                   LZTWM         , LZFSM         , LZFPM         ,
     1        LZSK         , LZPK          , LZTWC         , LZFSC         ,
     2        LZFPC
      COMMON /CMSMP/         PXADJ         , PEADJ         , UZTWM         ,
     1        UZFWM        , UZK           , PCTIM         , ADIMP         ,
     2        RIVA         , RSERV         , ZPERC         , REXP          ,
     3        LZTWM        , LZFSM         , LZFPM         , LZSK          ,
     4        LZPK         , PFREE         , SIDE          , SAVED         ,
     5        PCIAR
      COMMON /CMSMC/         UZTWC         , UZFWC         , LZTWC         ,
     1        LZFSC        , LZFPC         , ADIMC         , RSUM(7)
      COMMON /CMSMS/         SROT,   SRECHT,   SETT
      DIMENSION       ALIST(4),TITLE(10)    , FMT(10)       , PNAME(50)
      DATA ALIST/5HRAIN ,5HETDAT,5HFLOW ,5HEND  /
C
      IOUA = 5
      IOUB = 6
      NBASIN=0
      NHOUR=0
      NHRP=0
C
C     READ TITLE OF RUN
C
   90 READ (IOUA,200,END=91) TITLE
      NBASIN=NBASIN+1
      WRITE (IOUB,240) NBASIN, TITLE
      NHRQ=0
      INPQ=0
C
C     READ CONTROL PARAMETERS
C       NPOP = NUMBER OF PARAMETERS TO BE OPTIMIZED
C       IUPDF = 1 IF UPDATED DATA FILE TO BE GENERATED, 0 OTHERWISE
C       IWBLNC = WATER BALANCE COMPUTATION PERIOD
C       IPFRQR = PRINTING FREQUENCY FOR RAINFALL
C       IPFRQQ = PRINTING FREQUENCY FOR STREAMFLOW
C
      READ (IOUA,210) NPOP,IUPDF,IWBLNC,IPFRQR,IPFRQQ
```

```
      IF (NPOP.EQ.0) GO TO 100
C
C     READ OPTIMIZATION ROUTINE PARAMETERS IF NPOP .NE. 0
C
C       ERROR = CONVERGENCE CRITERION FOR RELATIVE OBJ FUNC IMPROVEMENT
C       IOBF = TYPE OF OBJECTIVE FUNCTION OPTION
C        NOTES ON TYPE OF OBJECTION FUNCTION OPTION FROM SEFE AND
C        BOUGHTON, JOUR. OF HYDROLOGY (NEW ZEALAND), VOL 21 NO 2, 1982.
C         IOBF = 1, SUM[(QOBS-QCOM)**2]. THIS FUNCTION GIVES MORE
C           WEIGHT TO LARGE DIFFERENCES THAN SMALL DIFFERENCES
C           LEADING TO BETTER ESTIMATE OF HIGH FLOWS.
C         IOBF = 2, SUM[ABS(QOBS-QCOM)]. THIS FUNCTION GIVES EQUAL
C           WEIGHT TO ALL RESIDUALS.
C         IOBF = 3, SUM[((QOBS-QCOM)/QOBS)**2]. THIS FUNCTION GIVES
C           EQUAL WEIGHT TO EQUAL PROPORTIONAL RESIDUALS AND ALSO
C           GREATER WEIGHT TO SMALLER ABSOLUTE RESIDUALS AT TIMES
C           OF LOW FLOW.
C         IOBF = 4, SUM[(QOBS**(1/3)-QCOM**(1/3))**2]. THIS FUNCTION
C           REDUCES THE EFFECT OF LARGE RESIDUALS THUS GIVING MORE
C           WEIGHT TO LOW FLOWS. THE CUBE-ROOT TRANSFORMATION OF THE
C           FUNCTION IS AIMED AT MAKING THE RESIDUALS MUTUALLY UNCOR-
C           RELATED, NORMALLY DISTRIBUTED AND THE LOG-LIKELIHOOD
C           FUNCTION OF THE RESIDUALS IS APPROXIMATELY QUADRATIC IN
C           THE PARAMETER VALUES IN THE NEIGHBORHOOD OF ITS MAXIMUM
C           SO THAT ITS CONTOURS ARE APPROXIMATELY ELLIPSOIDAL.
C         IOBF = 5, SUM[(QOBS**(1/2)-QCOM**(1/2))**2]. THIS  FUNCTION
C           IS SIMILAR TO OBJECTIVE FUNCTION OPTION IOBF = 4 BUT IT
C           USES A SQUARE-ROOT TRANSFORMATION INSTEAD.
C
C       MXITER = MAXIMUM NUMBER OF ITERATIONS
C       NSTEP = 0 IF STEP SIZES REMAIN THE SAME, 1 OTHERWISE
C       IPROP = PRINTING FREQUENCY FOR STAGE EVALUATION
C
      READ (IOUA,235) ERROR,IOBF,MXITER,NSTEP,IPROP
      IOBF = MAX0(IOBF,1)
      IOBF = MIN0(IOBF,5)
      MXITER = MAX0(MXITER,1)
      IPROP = MAX0(IPROP,1)
C
  100 IF (IUPDF.NE.0) WRITE (IOUB,250)
C
      IP = 0
      IF (NPOP.EQ.0) GO TO 120
C
C     READ PARAMETERS TO BE OPTIMIZED, ONE CARD EACH CONTAINING:
C       PNAME(.) = NAME OF VARIABLE (COLUMNS 1-5)
C       DUM = 5-CHARACTER LABEL FOR USER IDENTIFICATION (COLUMNS 6-10)
C       XMP(.) = INITIAL PARAMETER FLOATING-POINT VALUE (COLUMNS 11-20)
C       XMIN(.) = PARAMETER LOWER BOUND (COLUMNS 21-30)
C       XMAX(.) = PARAMETER UPPER BOUND (COLUMNS 31-40)
C       ESS(.) = PARAMETER STEP SIZE (COLUMNS 41-50)
C
      WRITE (IOUB,260)
      DO 110 I = 1,NPOP
         IP = IP + 1
         READ (IOUA,220) PNAME(IP),DUM,XMP(IP),XMIN(IP),XMAX(IP),ESS(IP)
```

```
      IF (PNAME(IP).EQ.ALIST(4)) GO TO 130
  110 WRITE (IOUB,280) PNAME(IP),DUM,XMP(IP),XMIN(IP),XMAX(IP),ESS(IP)
C
C     READ PARAMETERS MANUALLY CALIBRATED BY USER (INPUT VALUES),
C       ONE CARD CONTAINS SAME ITEMS AS ABOVE EXCLUDING XMIN(.),
C       XMAX(.) AND ESS(.)
C
  120 IP = IP + 1
      READ (IOUA,220) PNAME(IP),DUM,XMP(IP),XMIN(IP),XMAX(IP)
      IF (PNAME(IP).EQ.ALIST(4)) GO TO 130
      IF (IP.EQ.(NPOP + 1)) WRITE (IOUB,270)
      WRITE (IOUB,280) PNAME(IP),DUM,XMP(IP)
      GO TO 120
  130 IP = IP - 1
      NPARM = IP
      NPMC = NPARM - NPOP
      WRITE (IOUB,285) IOBF,MXITER,ERROR,NSTEP,IPROP
      WRITE (IOUB,290) NPOP,NPMC
C
C     CALL SETPAR FOR SETTING-UP AND CHECKING PARAMETERS
C
      CALL SETPAR (PNAME,NPMC)
C
C     READ KINEMATIC WAVE ROUTING PARAMETERS AND STORE IN TAPE10
C
      REWIND 10
  135 READ (IOUA,205) DUM,TITLE
      WRITE(10,200) TITLE
      IF(DUM.EQ.ALIST(4)) GO TO 136
      GO TO 135
C
C     READ HYDROLOGIC DATA
C
  136 READ(IOUA,205,END=170) RLIST
      DO 137 IL=1,4
      IF(RLIST.EQ.ALIST(IL)) GO TO 138
  137 CONTINUE
      WRITE(IOUB,295) RLIST
      STOP
  138 GO TO (141,142,160,170), IL
C
C     READ RAINFALL DATA
C
  141 READ (IOUA,210) NHOUR,NDATA,IOUC,KFMT,IREW
      IF(IOUC.EQ.0) IOUC=5
      IF(IREW.NE.0) REWIND IOUC
      IF (KFMT.NE.0) READ (IOUA,200) (FMT(I),I = 1,10)
      IF(KFMT.EQ.0) READ(IOUC,230) (RDT(I),I=1,NDATA)
      IF(KFMT.NE.0) READ(IOUC,FMT) (RDT(I),I=1,NDATA)
      GO TO 136
C
C     READ EVAPOTRANSPIRATION DEMAND DATA
C
  142 READ (IOUA,210) NHRP,IOUC,KFMT,IREW
      IF(IOUC.EQ.0) IOUC=5
      IF(IREW.NE.0) REWIND IOUC
```

```
      NHRP = MAX0(NHRP,1)
      NDTP=NDATA/NHRP
      IF (KFMT.NE.0) READ (IOUA,200)  (FMT(I),I = 1,10)
      IF (KFMT.EQ.0) READ (IOUC,230)  (PDT(I),I=1,NDTP)
      IF (KFMT.NE.0) READ (IOUC,FMT)  (PDT(I),I=1,NDTP)
      GO TO 136
C
C     READ STREAMFLOW DATA, REQUIRED IN MODEL CALIBRATION RUNS
C
  160 READ (IOUA,210) NHRQ,INPQ,IOUC,KFMT,IREW
      IF(IOUC.EQ.0) IOUC=5
      IF(IREW.NE.0) REWIND IOUC
      NHRQ = MAX0(NHRQ,1)
      NDTQ=NDATA/NHRQ
      IF(INPQ.EQ.0) GO TO 136
      IF (KFMT.NE.0) READ (IOUA,200)  (FMT(I),I = 1,10)
      IF (KFMT.EQ.0) READ (IOUC,230)  (QDT(I),I=1,NDTQ)
      IF (KFMT.NE.0) READ (IOUC,FMT)  (QDT(I),I=1,NDTQ)
      GO TO 136
  170 IF (NPOP.EQ.0) GO TO 180
      IF (INPQ.NE.0) GO TO 180
      WRITE (IOUB,300)
      STOP
  180 IF(NHOUR.NE.0) GO TO 183
      WRITE(IOUB,296)
      STOP
  183 IF(NHRP.NE.0) GO TO 181
      NHRP=NHOUR
      DO 140 I=1,NDATA
  140 PDT(I)=0.0
  181 IF (NHRQ.EQ.0) NHRQ = NHOUR
      NDTQ=NDATA/NHRQ
      IF (NPOP.EQ.0) GO TO 190
      IPRINT = 0
      CALL OPTIM (IPRINT)
  190 IPRINT = 1
      CALL SACROUT (IUPDF,IPRINT)
      IF(IUPDF.EQ.1) CALL UPDATE
      GO TO 90
   91 STOP
C
C
  200 FORMAT (10A8)
  205 FORMAT(A5,T1,10A8)
  210 FORMAT (16I5)
  220 FORMAT (2A5,7F10.0)
  230 FORMAT (8F10.0)
  235 FORMAT (F10.0,5I5)
  240 FORMAT('1'/5X,'BASIN',I2,' RUN: ',10A8/)
  250 FORMAT (/2X,'NOTE: UPDATED DATA FILE IS GENERATED'/)
  260 FORMAT (/2X,34HLIST OF PARAMETERS TO BE OPTIMIZED,//3X,5H NAME,10X
     1,5HVALUE,6X,7HMINIMUM,4X,19HMAXIMUM  STEP SIZES,/)
  270 FORMAT (/2X,38HLIST OF PARAMETERS MANUALLY CALIBRATED,//3X,5H NAME
     1,10X,5HVALUE,/)
  280 FORMAT (3X,2A5,2X,4F12.5)
  285 FORMAT (/2X,'OPTIMIZATION PARAMETERS :'/
```

```
     1 4X,'OBJECTIVE FUNCTION TYPE',T35,I5/
     2 4X,'MAXIMUM NUMBER OF ITERATIONS',T35,I5/
     3 4X,'CONVERGENCE CRITERION',T28,G12.5/
     4 4X,'STEP SIZE UPDATE OPTION',T35,I5/
     5 4X,'PRINTING FREQUENCY',T35,I5)
  290 FORMAT (/2X,38HNUMBER OF PARAMETERS TO BE OPTIMIZED =,I4/2X,42HNUM
     1BER OF PARAMETERS MANUALLY CALIBRATED =,I3)
  295 FORMAT(//3X,'***** EXECUTION TERMINATED - INPUT LIST ',A5,
     1 ' IS UNRECOGNIZED STATEMENT *****')
  300 FORMAT(//3X,'***** EXECUTION TERMINATED - OPTIMIZATION DESIRED BUT
     1 NO STREAMFLOW DATA *****')
  296 FORMAT(//3X,'***** EXECUTION TERMINATED - NO RAINFALL DATA *****')
      END
      SUBROUTINE SETPAR (PNAME,NPMC)
C
C     THIS ROUTINE CHECKS AND SETS-UP THE PARAMETERS
C
      COMMON /CMIOP/          IOUA          , IOUB          ,
     1          NHOUR       ,NDATA          ,
     2          NTIME,NHRP,NHRQ,NDTQ,INPQ,NBASIN,IWBLNC,IPFRQR,IPFRQQ
      COMMON /CMPRM/          NPARM         , NPOP          , IOBF          ,
     1          MXITER      , NSTEP         , ERROR         , IPROP         ,
     2          INDX(50)    , XMP(50)       , XMIN(50)      , XMAX(50)      ,
     3     ESS(50),OBJFV
      COMMON /FDK00/ TAREA,TRMN,TRHR,METRC,IEL,NQ,MXNDX,MXNDT
      COMMON /FDK01/ CHLNG(5),SLOPE(5),RCMAN(5),PAREA(5),ISHAPE(5),
     1 CHWDT(5),ZLNG(5),ALPME(5),EMDEQ(5),DXROF(5),DXFLO(5),DTKWR(5),
     2 DXKWR(5),IRUPF(5),SAREA(5),FLOIC(5)
      COMMON /FDK02/ EXCSR(1224),Q(1224),
     1 QK(1224),QUB(1224),QBF(1224)
      COMMON /CMDAT/ RDT(1224),PDT(1224),QDT(1224)
      REAL                    LZTWM         , LZFSM         , LZFPM         ,
     1          LZSK        , LZPK          , LZTWC         , LZFSC         ,
     2          LZFPC
      COMMON /CMSMP/          PXADJ         , PEADJ         , UZTWM         ,
     1          UZFWM       , UZK           , PCTIM         , ADIMP         ,
     2          RIVA        , RSERV         , ZPERC         , REXP          ,
     3          LZTWM       , LZFSM         , LZFPM         , LZSK          ,
     4          LZPK        , PFREE         , SIDE          , SAVED         ,
     5          PCIAR
      COMMON /CMSMC/          UZTWC         , UZFWC         , LZTWC         ,
     1          LZFSC       , LZFPC         , ADIMC         , RSUM(7)
      DIMENSION               PNAME(50)     , FNAME(24)
      DATA FNAME/5HPXADJ,5HPEADJ,5HPCTIM,5HADIMP,5HRIVA ,5HUZK  ,5HLZSK
     1,5HLZPK ,5HPFREE,5HRSERV,5HZPERC,5HREXP ,5HSIDE ,5HUZTWM,5HUZFWM,5
     2HLZTWM,5HLZFSM,5HLZFPM,5HUZTWC,5HLZTWC,5HUZFWC,5HLZFSC,5HLZFPC,5HA
     3DIMC/
      UZTWM = -99.0
      UZFWM = -99.0
      LZTWM = -99.0
      LZFSM = -99.0
      LZFPM = -99.0
      UZTWC = -99.0
      DO 460 IP = 1,NPARM
         DO 100 KP = 1,30
            IF (PNAME(IP).EQ.FNAME(KP)) GO TO 110
```

```
  100    CONTINUE
         WRITE (IOUB,500) PNAME(IP)
         STOP
  110    GO TO (120,130,140,150,160,170,180,190,200,210,220,230,240,250,
     1   260,270,280,290,300,310,320,330,340,350), KP
C
C     PARAMETER CHECKS
C
  120    PXADJ = XMP(IP)
         XLO = 0.0001
         XUP = 10.0
         PXADJ = AMAX1(PXADJ,XLO)
         PXADJ = AMIN1(PXADJ,XUP)
         XMP(IP) = PXADJ
         INDX(IP) = 1
         IF (IP.GT.NPOP) GO TO 460
         GO TO 430
  130    PEADJ = XMP(IP)
         XLO = 0.0001
         XUP = 10.0
         PEADJ = AMAX1(PEADJ,XLO)
         PEADJ = AMIN1(PEADJ,XUP)
         XMP(IP) = PEADJ
         INDX(IP) = 2
         IF (IP.GT.NPOP) GO TO 460
         GO TO 430
  140    PCTIM = XMP(IP)
         PCTIM = AMAX1(PCTIM,0.0001)
         PCTIM = AMIN1(PCTIM,1.0)
         XMP(IP) = PCTIM
         INDX(IP) = 3
         IF (IP.GT.NPOP) GO TO 460
         GO TO 420
  150    ADIMP = XMP(IP)
         ADIMP = AMAX1(ADIMP,0.0001)
         XUP = 1.0 - PCTIM
         ADIMP = AMIN1(ADIMP,XUP)
         XMP(IP) = ADIMP
         INDX(IP) = 4
         IF (IP.GT.NPOP) GO TO 460
         XLO = 0.0001
         GO TO 430
  160    RIVA = XMP(IP)
         RIVA = AMAX1(RIVA,0.0001)
         RIVA = AMIN1(RIVA,1.0)
         XMP(IP) = RIVA
         INDX(IP) = 5
         IF (IP.GT.NPOP) GO TO 460
         GO TO 420
  170    UZK = XMP(IP)
         UZK = AMAX1(UZK,0.0001)
         UZK = AMIN1(UZK,1.0)
         XMP(IP) = UZK
         INDX(IP) = 6
         IF (IP.GT.NPOP) GO TO 460
         GO TO 420
```

```
  180     LZSK = XMP(IP)
          LZSK = AMAX1(LZSK,0.0001)
          LZSK = AMIN1(LZSK,1.0)
          XMP(IP) = LZSK
          INDX(IP) = 7
          IF (IP.GT.NPOP) GO TO 460
          GO TO 420
  190     LZPK = XMP(IP)
          LZPK = AMAX1(LZPK,0.0001)
          LZPK = AMIN1(LZPK,1.0)
          XMP(IP) = LZPK
          INDX(IP) = 8
          IF (IP.GT.NPOP) GO TO 460
          GO TO 420
  200     PFREE = XMP(IP)
          PFREE = AMAX1(PFREE,0.0001)
          PFREE = AMIN1(PFREE,1.0)
          XMP(IP) = PFREE
          INDX(IP) = 9
          IF (IP.GT.NPOP) GO TO 460
          GO TO 420
  210     RSERV = XMP(IP)
          RSERV = AMAX1(RSERV,0.0001)
          RSERV = AMIN1(RSERV,1.0)
          XMP(IP) = RSERV
          INDX(IP) = 10
          IF (IP.GT.NPOP) GO TO 460
          GO TO 420
  220     ZPERC = XMP(IP)
          INDX(IP) = 11
          IF (IP.GT.NPOP) GO TO 460
          GO TO 440
  230     REXP = XMP(IP)
          INDX(IP) = 12
          IF (IP.GT.NPOP) GO TO 460
          GO TO 440
  240     SIDE = XMP(IP)
          INDX(IP) = 13
          IF (IP.GT.NPOP) GO TO 460
          GO TO 440
C
C     INSURE THAT CAPACITIES ARE NOT EQUAL TO ZERO
C
  250     UZTWM = XMP(IP)
          UZTWM = AMAX1(UZTWM,0.0001)
          XMP(IP) = UZTWM
          INDX(IP) = 14
          IF (IP.GT.NPOP) GO TO 460
          GO TO 440
  260     UZFWM = XMP(IP)
          UZFWM = AMAX1(UZFWM,0.0001)
          XMP(IP) = UZFWM
          INDX(IP) = 15
          IF (IP.GT.NPOP) GO TO 460
          GO TO 440
  270     LZTWM = XMP(IP)
```

```
      LZTWM = AMAX1(LZTWM,0.0001)
      XMP(IP) = LZTWM
      INDX(IP) = 16
      IF (IP.GT.NPOP) GO TO 460
      GO TO 440
280   LZFSM = XMP(IP)
      LZFSM = AMAX1(LZFSM,0.0001)
      XMP(IP) = LZFSM
      INDX(IP) = 17
      IF (IP.GT.NPOP) GO TO 460
      GO TO 440
290   LZFPM = XMP(IP)
      LZFPM = AMAX1(LZFPM,0.0001)
      XMP(IP) = LZFPM
      INDX(IP) = 18
      IF (IP.GT.NPOP) GO TO 460
      GO TO 440
300   UZTWC = XMP(IP)
      UZTWC = AMAX1(UZTWC,0.0)
      XUP = UZTWM
   IF(XUP.NE.-99.0) GO TO 305
   XUP=XMAX(IP)
   IF(XUP.NE.0.0.AND.XUP.GT.UZTWC) GO TO 305
   WRITE(IOUB,560) PNAME(IP),UZTWC,XUP
   STOP
305   UZTWC = AMIN1(UZTWC,XUP)
      XMP(IP) = UZTWC
      INDX(IP) = 19
      IF (IP.GT.NPOP) GO TO 460
      XLO = 0.0
      GO TO 430
310   LZTWC = XMP(IP)
      LZTWC = AMAX1(LZTWC,0.0)
      XUP = LZTWM
   IF(XUP.NE.-99.0) GO TO 315
   XUP=XMAX(IP)
   IF(XUP.NE.0.0.AND.XUP.GT.LZTWC) GO TO 315
   WRITE(IOUB,560) PNAME(IP),LZTWC,XUP
   STOP
315   LZTWC = AMIN1(LZTWC,XUP)
      XMP(IP) = LZTWC
      INDX(IP) = 20
      IF (IP.GT.NPOP) GO TO 460
      XLO = 0.0
      GO TO 430
320   UZFWC = XMP(IP)
      UZFWC = AMAX1(UZFWC,0.0)
      XUP = UZFWM
   IF(XUP.NE.-99.0) GO TO 325
   XUP=XMAX(IP)
   IF(XUP.NE.0.0.AND.XUP.GT.UZFWC) GO TO 325
   WRITE(IOUB,560) PNAME(IP),UZFWC,XUP
   STOP
325   UZFWC = AMIN1(UZFWC,XUP)
      XMP(IP) = UZFWC
      INDX(IP) = 21
```

```
       IF (IP.GT.NPOP) GO TO 460
       XLO = 0.0
       GO TO 430
330    LZFSC = XMP(IP)
       LZFSC = AMAX1(LZFSC,0.0)
       XUP = LZFSM
    IF(XUP.NE.-99.0) GO TO 335
    XUP=XMAX(IP)
    IF(XUP.NE.0.0.AND.XUP.GT.LZFSC) GO TO 335
    WRITE(IOUB,560) PNAME(IP),LZFSC,XUP
    STOP
335    LZFSC = AMIN1(LZFSC,XUP)
       XMP(IP) = LZFSC
       INDX(IP) = 22
       IF (IP.GT.NPOP) GO TO 460
       XLO = 0.0
       GO TO 430
340    LZFPC = XMP(IP)
       LZFPC = AMAX1(LZFPC,0.0)
       XUP = LZFPM
    IF(XUP.NE.-99.0) GO TO 345
    XUP=XMAX(IP)
    IF(XUP.NE.0.0.AND.XUP.GT.LZFPC) GO TO 345
    WRITE(IOUB,560) PNAME(IP),LZFPC,XUP
    STOP
345    LZFPC = AMIN1(LZFPC,XUP)
       XMP(IP) = LZFPC
       INDX(IP) = 23
       IF (IP.GT.NPOP) GO TO 460
       XLO = 0.0
       GO TO 430
350    ADIMC = XMP(IP)
       XLO = UZTWC
    IF(XLO.EQ.-99.0) XLO = 0.0001
       XUP = UZTWM + LZTWM
    IF(UZTWM.NE.-99.0.AND.LZTWM.NE.-99.0) GO TO 355
    XUP=XMAX(IP)
    IF(XUP.NE.0.0.AND.XUP.GT.ADIMC) GO TO 355
    WRITE(IOUB,560) PNAME(IP),ADIMC,XUP
    STOP
355    ADIMC = AMAX1(ADIMC,XLO)
       ADIMC = AMIN1(ADIMC,XUP)
       XMP(IP) = ADIMC
       INDX(IP) = 24
       IF (IP.GT.NPOP) GO TO 460
       GO TO 430
420    XLO = 0.0001
       XUP = 1.0
430    XMIN(IP) = AMAX1(XMIN(IP),XLO)
       XMAX(IP) = AMIN1(XMAX(IP),XUP)
440    IF (XMAX(IP).GT.XMIN(IP).AND.(XMAX(IP) - XMIN(IP)).NE.0.0) GO T
   1   O 450
       WRITE (IOUB,510) PNAME(IP),XMIN(IP),XMAX(IP)
       STOP
450    IF (ESS(IP).NE.0.0) GO TO 460
       ESS(IP) = ABS(XMAX(IP) - XMIN(IP))/20.0
```

```
         WRITE (IOUB,520) PNAME(IP),ESS(IP)
 460  CONTINUE
      IP = 0
      IF (NPOP.EQ.0) GO TO 480
      WRITE (IOUB,530)
      DO 470 I = 1,NPOP
         IP = IP + 1
 470  WRITE (IOUB,550) IP,PNAME(IP),XMP(IP),XMIN(IP),XMAX(IP),ESS(IP)
 480  IF (NPMC.EQ.0) RETURN
      WRITE (IOUB,540)
      DO 490 I = 1,NPMC
         IP = IP + 1
 490  WRITE (IOUB,550) IP,PNAME(IP),XMP(IP)
      RETURN
C
C
C
 500  FORMAT (/2X,10HPARAMETER ,A5,21H IS NOT IN DICTIONARY,//2X,20HEXEC
     1UTION TERMINATED,/)
 510  FORMAT (/2X,10HPARAMETER ,A5,10H HAS MIN =,F10.3,10H AND MAX =,F10
     1.3,/2X,43HWHICH IS A VIOLATION - EXECUTION TERMINATED,/)
 520  FORMAT (/2X,10HPARAMETER ,A5,34H WITH STEP SIZE ESS = 0.0 IS RESET
     1,/2X,8HTO ESS =,F10.5,29H TAKEN FROM ABS(MAX-MIN)/20.0,/)
 530  FORMAT (/2X,41HPARAMETERS TO BE OPTIMIZED AFTER CHECKING,//3X,11H
     1 ITEM NAME,5X,5HVALUE,6X,7HMINIMUM,4X,19HMAXIMUM  STEP SIZES,/)
 540  FORMAT (/2X,45HPARAMETERS MANUALLY CALIBRATED AFTER CHECKING,//3X,
     110H ITEM NAME,5X,5HVALUE,/)
 550  FORMAT (3X,I3,2X,A5,2X,4F12.5)
 560  FORMAT(/2X,'PARAMETER ',A5,' =',G12.6,' AND MAX =',G12.6//
     1 2X,'EXECUTION TERMINATED. THE FOLLOWING ACTIONS MAY BE TAKEN:'/
     2 2X,'IF PARAMETER IS OPTIMIZED:'/
     3 4X,'-CHECK SPECIFIED XMAX'/
     4 4X,'-CHECK IF SOIL MOISTURE CONTENT IS CONSISTENT WITH CORREPONDIN
     5G CAPACITIES'/
     6 2X,'IF PARAMETER IS NOT OPTIMIZED:'/
     7 4X,'-INPUT CORRESPONDING CAPACITIES BEFORE CONTENTS, OTHERWISE'/
     8 4X,' SPECIFY XMAX AS IN OPTIMIZED PARAMETERS'//
     9 2X,'EXECUTION TERMINATED')
      END
      SUBROUTINE SACSMA (IPRINT)
C
C     THIS IS THE MAINLINE ROUTINE FOR SACRAMENTO SOIL-MOISTURE MODEL
C
      COMMON /CMIOP/        IOUA          , IOUB          ,
     1          NHOUR       ,NDATA        ,
     2          NTIME,NHRP,NHRQ,NDTQ,INPQ,NBASIN,IWBLNC,IPFRQR,IPFRQQ
      COMMON /CMPRM/        NPARM         , NPOP          , IOBF          ,
     1          MXITER      , NSTEP       , ERROR         , IPROP         ,
     2          INDX(50)    , XMP(50)     , XMIN(50)      , XMAX(50)      ,
     3    ESS(50),OBJFV
      COMMON /FDK00/ TAREA,TRMN,TRHR,METRC,IEL,NQ,MXNDX,MXNDT
      COMMON /FDK01/ CHLNG(5),SLOPE(5),RCMAN(5),PAREA(5),ISHAPE(5),
     1 CHWDT(5),ZLNG(5),ALPME(5),EMDEQ(5),DXROF(5),DXFLO(5),DTKWR(5),
     2 DXKWR(5),IRUPF(5),SAREA(5),FLOIC(5)
      COMMON /FDK02/ EXCSR(1224),Q(1224),
     1 QK(1224),QUB(1224),QBF(1224)
```

```
      COMMON /CMDAT/ RDT(1224),PDT(1224),QDT(1224)
      REAL                    LZTWM      , LZFSM      , LZFPM      ,
     1         LZSK         , LZPK       , LZTWC      , LZFSC      ,
     2         LZFPC
      COMMON /CMSMP/          PXADJ      , PEADJ      , UZTWM      ,
     1         UZFWM        , UZK        , PCTIM      , ADIMP      ,
     2         RIVA         , RSERV      , ZPERC      , REXP       ,
     3         LZTWM        , LZFSM      , LZFPM      , LZSK       ,
     4         LZPK         , PFREE      , SIDE       , SAVED      ,
     5         PCIAR
      COMMON /CMSMC/          UZTWC      , UZFWC      , LZTWC      ,
     1         LZFSC        , LZFPC      , ADIMC      , RSUM(7)
      COMMON /CMSMS/          SROT,  SRECHT,  SETT
      DIMENSION               EPDIST(24)
C
      IF(NHRP.NE.NHOUR) GO TO 101
C     ASSUME UNIFORM ET-DISTRIBUTION
      DEP = FLOAT(NHOUR)/FLOAT(NHRP)
      NHRE=NHRP/NHOUR
      DEP=1.0/FLOAT(NHRE)
      DO 100 IHRE = 1,NHRE
  100 EPDIST(IHRE) = DEP
C
C     STORE INITIAL CARRYOVER
  101    UZTWC1 = UZTWC
         UZFWC1 = UZFWC
         LZTWC1 = LZTWC
         LZFSC1 = LZFSC
         LZFPC1 = LZFPC
         ADIMC1 = ADIMC
C
C     COMPUTED SOIL-MOISTURE PARAMETERS
         SAVED = RSERV * (LZFPM + LZFSM)
         PCIAR = 1.0 - PCTIM - ADIMP
         PBASE = LZFSM * LZSK + LZFPM * LZPK
C
C     NOTE: PBASE IS NOT USE IN ACTUAL COMPUTATIONS
C
C     INITIALIZE SUMS
         SRECHT = 0.0
         SROT = 0.0
         SETT = 0.0
         SPRT = 0.0
         DO 110 I = 1,7
  110    RSUM(I) = 0.0
C
C     PRINT INITIAL VALUES
         IF (IPRINT.EQ.0) GO TO 120
         WRITE (IOUB,170)
         WRITE (IOUB,180) PXADJ,PEADJ,UZTWM,UZFWM,UZK,PCTIM,ADIMP,RIVA
         WRITE (IOUB,190) PBASE,ZPERC,REXP,LZTWM,LZFSM,LZFPM,LZSK,LZPK,P
     1   FREE,RSERV,SIDE
         WRITE (IOUB,200) UZTWC,UZFWC,LZTWC,LZFSC,LZFPC,ADIMC
         WRITE (IOUB,210)
C
C     BEGIN TIME LOOP
```

```
C
  120 DELT=NHOUR/24.0
      NTIME=0
         DO 150 IHOUR = 1,NDATA
            PXV = PXADJ * RDT(IHOUR)
            NTIME=NTIME+NHOUR
            SPRT = SPRT + PXV
            IF (NHRP.NE.NHOUR) GO TO 130
            EP = PEADJ * PDT(IHOUR)
            GO TO 140
  130       IHRP=(NTIME-1)/NHRP+1
            IHRE=IHOUR-(IHRP-1)*NHRE
            EP = PEADJ * EPDIST(IHRE) * PDT(IHRP)
  140       CALL SMAONE (DELT,PXV,EP,IHOUR,IPRINT)
C
C     WATER BALANCE FOR DESIRED PERIOD
         IF (IPRINT.EQ.0) GO TO 150
         IF (MOD(IHOUR,IWBLNC).NE.0) GO TO 150
         WBAL = (UZTWC + UZFWC + LZTWC + LZFPC + LZFSC - UZTWC1 - UZFWC1
     1    - LZTWC1 - LZFPC1 - LZFSC1) * PCIAR + (ADIMC - ADIMC1) * ADIMP
     2    + SROT + SRECHT + SETT - SPRT
         WRITE (IOUB,220) (RSUM(I),I = 1,7)
         WRITE (IOUB,230) WBAL
C
C     RESTORE INITIAL CARRYOVER
         UZTWC1 = UZTWC
         UZFWC1 = UZFWC
         LZTWC1 = LZTWC
         LZFSC1 = LZFSC
         LZFPC1 = LZFPC
         ADIMC1 = ADIMC
C
C     REINITIALIZE SUMS
         SRECHT = 0.0
         SROT = 0.0
         SETT = 0.0
         SPRT = 0.0
         DO 112 I = 1,7
  112    RSUM(I) = 0.0
  150 CONTINUE
      RETURN
C
C
C
  170 FORMAT (1H1/1X,'SACRAMENTO SOIL-MOISTURE ACCOUNTING OPERATION'/)
  180 FORMAT (1X,40HPARAMETER VALUES - CAPACITIES ARE IN MM.,//4X,6HPX-A
     1DJ,4X,6HPE-ADJ,5X,5HUZTWM,5X,5HUZFWM,7X,3HUZK,5X,5HPCTIM,5X,5HADIM
     2P,6X,4HRIVA,/8F10.3//1X,30HDAILY ET DIST. ASSUMED UNIFORM,/)
  190 FORMAT (5X,5HPBASE,5X,5HZPERC,6X,4HREXP,5X,5HLZTWM,5X,5HLZFSM,5X,5
     1HLZFPM,6X,4HLZSK,6X,5HLZPK ,5X,5HPFREE,5X,5HRSERV,6X,4HSIDE,/11F10
     2.3/)
  200 FORMAT (/1X,27HSOIL-MOISTURE CONTENTS (MM),//5X,5HUZTWC,5X,5HUZFWC
     1,5X,5HLZTWC,5X,5HLZFSC,5X,5HLZFPC,5X,5HADIMC,/6F10.3/)
  210 FORMAT (/1X,71HDETAILED SOIL-MOISTURE ACCOUNTING OUTPUT
     1    UNITS ARE IN MM.,//4X,3HDAY,1X,2HHR,2X,5HUZTWC,2X,5HUZFWC,2X,5
     2HLZTWC,2X,5HLZFSC,2X,5HLZFPC,2X,5HADIMC,3X,4HPERC,4X,3HIMP,4X,3HDI
```

```
     3R,4X,3HSUR,4X,3HINT,4X,3HSUP,4X,3HPRI,2X,6HTOT-RO,2X,6HET-DMD,1X,6
     4HACT-ET,3X,4HRAIN,/)
  220 FORMAT (/2X,22HTOTAL CHANNEL INFLOW =,F12.4 /2X,35HCOMPONENTS OF T
     1OTAL CHANNEL INFLOWS, /3X,39HRUNOFF FROM PERMANENT IMPERVIOUS AREA
     2 =,F12.4/3X,39HRUNOFF FROM TEMPORARY IMPERVIOUS AREA =,F12.4/3X,35
     3HSURFACE RUNOFF WHEN UZFWS IS FULL =,F12.4/3X,42HINTERFLOW FROM LA
     4TERAL DRAINAGE OF UZFWS =,F12.4/3X,24HSUPPLEMENTARY BASEFLOW =,F12
     5.4/3X,18HPRIMARY BASEFLOW =,F12.4)
  230 FORMAT (2X,41HWATER BALANCE RESIDUAL (IDEALLY EQ 0.0) =,F10.5/)
      END
      SUBROUTINE SMAONE (DELT,PXV,EP,IHOUR,IPRINT)
C
C     THIS SUBROUTINE EXECUTES THE "SAC-SMA " OPERATION FOR ONE TIME
C             PERIOD.
C     SUBROUTINE INITIALLY WRITTEN BY. . .
C           ERIC ANDERSON - HRL     APRIL 1979     VERSION 1
C
      COMMON /CMIOP/          IOUA          , IOUB          ,
     1        NHOUR        ,NDATA          ,
     2       NTIME,NHRP,NHRQ,NDTQ,INPQ,NBASIN,IWBLNC,IPFRQR,IPFRQQ
      COMMON /CMPRM/          NPARM         , NPOP          , IOBF          ,
     1       MXITER       , NSTEP         , ERROR         , IPROP         ,
     2       INDX(50)     , XMP(50)       , XMIN(50)      , XMAX(50)      ,
     3    ESS(50),OBJFV
      COMMON /FDK00/ TAREA,TRMN,TRHR,METRC,IEL,NQ,MXNDX,MXNDT
      COMMON /FDK01/ CHLNG(5),SLOPE(5),RCMAN(5),PAREA(5),ISHAPE(5),
     1 CHWDT(5),ZLNG(5),ALPME(5),EMDEQ(5),DXROF(5),DXFLO(5),DTKWR(5),
     2 DXKWR(5),IRUPF(5),SAREA(5),FLOIC(5)
      COMMON /FDK02/ EXCSR(1224),Q(1224),
     1 QK(1224),QUB(1224),QBF(1224)
      COMMON /CMDAT/ RDT(1224),PDT(1224),QDT(1224)
      REAL                    LZTWM         , LZFSM         , LZFPM         ,
     1       LZSK         , LZPK          , LZTWC         , LZFSC         ,
     2       LZFPC
      COMMON /CMSMP/          PXADJ         , PEADJ         , UZTWM         ,
     1       UZFWM        , UZK           , PCTIM         , ADIMP         ,
     2       RIVA         , RSERV         , ZPERC         , REXP          ,
     3       LZTWM        , LZFSM         , LZFPM         , LZSK          ,
     4       LZPK         , PFREE         , SIDE          , SAVED         ,
     5       PCIAR
      COMMON /CMSMC/          UZTWC         , UZFWC         , LZTWC         ,
     1       LZFSC        , LZFPC         , ADIMC         , RSUM(7)
      COMMON /CMSMS/          SROT,   SRECHT,   SETT
C
C     COMPUTE EVAPOTRANSPIRATION LOSS FOR THE TIME INTERVAL.
C        EDMND IS THE ET-DEMAND FOR THE TIME INTERVAL
      EDMND = EP
C
C     COMPUTE ET FROM UPPER ZONE.
      E1 = EDMND * (UZTWC/UZTWM)
      RED = EDMND - E1
C
C     RED IS RESIDUAL EVAP DEMAND
      UZTWC = UZTWC - E1
      E2 = 0.0
      IF (UZTWC.GE.0.) GO TO 110
```

```
C
C     E1 CAN NOT EXCEED UZTWC
      E1 = E1 + UZTWC
      UZTWC = 0.0
      RED = EDMND - E1
      IF (UZFWC.GE.RED) GO TO 100
C
C     E2 IS EVAP FROM UZFWC.
      E2 = UZFWC
      UZFWC = 0.0
      RED = RED - E2
      GO TO 120
  100 E2 = RED
      UZFWC = UZFWC - E2
      RED = 0.0
  110 IF ((UZTWC/UZTWM).GE.(UZFWC/UZFWM)) GO TO 120
C
C     UPPER ZONE FREE WATER RATIO EXCEEDS UPPER ZONE
C     TENSION WATER RATIO, THUS TRANSFER FREE WATER TO TENSION
      UZRAT = (UZTWC + UZFWC)/(UZTWM + UZFWM)
      UZTWC = UZTWM * UZRAT
      UZFWC = UZFWM * UZRAT
  120 IF (UZTWC.LT.0.00001) UZTWC = 0.0
C
C     COMPUTE ET FROM THE LOWER ZONE.
C     COMPUTE ET FROM LZTWC (E3)
      E3 = RED * (LZTWC/(UZTWM + LZTWM))
      LZTWC = LZTWC - E3
      IF (LZTWC.GE.0.0) GO TO 130
C
C     E3 CAN NOT EXCEED LZTWC
      E3 = E3 + LZTWC
      LZTWC = 0.0
  130 RATLZT = LZTWC/LZTWM
      RATLZ = (LZTWC + LZFPC + LZFSC - SAVED)/(LZTWM + LZFPM + LZFSM - S
     1AVED)
      IF (RATLZT.GE.RATLZ) GO TO 140
C
C     RESUPPLY LOWER ZONE TENSION WATER FROM LOWER
C     ZONE FREE WATER IF MORE WATER AVAILABLE THERE.
      DEL = (RATLZ - RATLZT) * LZTWM
C
C     TRANSFER FROM LZFSC TO LZTWC.
      LZTWC = LZTWC + DEL
      LZFSC = LZFSC - DEL
      IF (LZFSC.GE.0.0) GO TO 140
C
C     IF TRANSFER EXCEEDS LZFSC THEN REMAINDER COMES FROM LZFPC
      LZFPC = LZFPC + LZFSC
      LZFSC = 0.0
  140 IF (LZTWC.LT.0.00001) LZTWC = 0.0
C
C     COMPUTE ET FROM ADIMP AREA.-E5
      E5 = E1 + (RED + E2) * ((ADIMC - E1 - UZTWC)/(UZTWM + LZTWM))
C
C      ADJUST ADIMC,ADDITIONAL IMPERVIOUS AREA STORAGE, FOR EVAPORATION.
```

```
      ADIMC = ADIMC - E5
      IF (ADIMC.GE.0.0) GO TO 150
C
C     E5 CAN NOT EXCEED ADIMC.
      E5 = E5 + ADIMC
      ADIMC = 0.0
  150 E5 = E5 * ADIMP
C
C     E5 IS ET FROM THE AREA ADIMP.
C
C     COMPUTE PERCOLATION AND RUNOFF AMOUNTS.
      TWX = PXV + UZTWC - UZTWM
C
C     TWX IS THE TIME INTERVAL AVAILABLE MOISTURE IN EXCESS
C     OF UZTW REQUIREMENTS.
      IF (TWX.GE.0.0) GO TO 160
C
C     ALL MOISTURE HELD IN UZTW--NO EXCESS.
      UZTWC = UZTWC + PXV
      TWX = 0.0
      GO TO 170
C
C      MOISTURE AVAILABLE IN EXCESS OF UZTW STORAGE.
  160 UZTWC = UZTWM
  170 ADIMC = ADIMC + PXV - TWX
C
C     COMPUTE IMPERVIOUS AREA RUNOFF.
      ROIMP = PXV * PCTIM
C
C      ROIMP IS RUNOFF FROM THE MINIMUM IMPERVIOUS AREA.
C
C     INITIALIZE TIME INTERVAL SUMS.
      SBF = 0.0
      SSUR = 0.0
      SIF = 0.0
      SPERC = 0.0
      SDRO = 0.0
      SPBF = 0.0
C
C     DETERMINE COMPUTATIONAL TIME INCREMENTS FOR THE BASIC TIME
C     INTERVAL
      NINC = 1.0 + 0.2 * (UZFWC + TWX)
C
C     NINC=NUMBER OF TIME INCREMENTS THAT THE TIME INTERVAL
C     IS DIVIDED INTO FOR FURTHER
C     SOIL-MOISTURE ACCOUNTING.  NO ONE INCREMENT
C     WILL EXCEED 5.0 MILLIMETERS OF UZFWC+PAV
      DINC = (1.0/NINC) * DELT
C
C     DINC=LENGTH OF EACH INCREMENT IN DAYS.
      PINC = TWX/NINC
C
C     PINC=AMOUNT OF AVAILABLE MOISTURE FOR EACH INCREMENT.
C      COMPUTE FREE WATER DEPLETION FRACTIONS FOR
C     THE TIME INCREMENT BEING USED-BASIC DEPLETIONS
C      ARE FOR ONE DAY
```

```
      DUZ = 1.0 - ((1.0 - UZK) *  * DINC)
      DLZP = 1.0 - ((1.0 - LZPK) *  * DINC)
      DLZS = 1.0 - ((1.0 - LZSK) *  * DINC)
C
C     START INCREMENTAL DO LOOP FOR THE TIME INTERVAL.
      DO 300 I = 1,NINC
        ADSUR = 0.0
C
C     COMPUTE DIRECT RUNOFF (FROM ADIMP AREA).
        RATIO = (ADIMC - UZTWC)/LZTWM
        IF (RATIO.LT.0.0) RATIO = 0.0
        ADDRO = PINC * (RATIO *  * 2)
C
C     ADDRO IS THE AMOUNT OF DIRECT RUNOFF FROM THE AREA ADIMP.
C
C     COMPUTE BASEFLOW AND KEEP TRACK OF TIME INTERVAL SUM.
        BF = LZFPC * DLZP
        LZFPC = LZFPC - BF
        IF (LZFPC.GT.0.0001) GO TO 180
        BF = BF + LZFPC
        LZFPC = 0.0
  180   SBF = SBF + BF
        SPBF = SPBF + BF
        BF = LZFSC * DLZS
        LZFSC = LZFSC - BF
        IF (LZFSC.GT.0.0001) GO TO 190
        BF = BF + LZFSC
        LZFSC = 0.0
  190   SBF = SBF + BF
C
C      COMPUTE PERCOLATION-IF NO WATER AVAILABLE THEN SKIP
        IF ((PINC + UZFWC).GT.0.01) GO TO 200
        UZFWC = UZFWC + PINC
        GO TO 280
  200   PERCM = LZFPM * DLZP + LZFSM * DLZS
        PERC = PERCM * (UZFWC/UZFWM)
        DEFR = 1.0 - ((LZTWC + LZFPC + LZFSC)/(LZTWM + LZFPM + LZFSM))
C
C     DEFR IS THE LOWER ZONE MOISTURE DEFICIENCY RATIO
        PERC = PERC * (1.0 + ZPERC * (DEFR *  * REXP))
C     NOTE...PERCOLATION OCCURS FROM UZFWC BEFORE PAV IS ADDED.
        IF (PERC.LT.UZFWC) GO TO 210
C
C      PERCOLATION RATE EXCEEDS UZFWC.
        PERC = UZFWC
C
C     PERCOLATION RATE IS LESS THAN UZFWC.
  210   UZFWC = UZFWC - PERC
C
C     CHECK TO SEE IF PERCOLATION EXCEEDS LOWER ZONE DEFICIENCY.
        CHECK = LZTWC + LZFPC + LZFSC + PERC - LZTWM - LZFPM - LZFSM
        IF (CHECK.LE.0.0) GO TO 220
        PERC = PERC - CHECK
        UZFWC = UZFWC + CHECK
  220   SPERC = SPERC + PERC
C
```

```
C     SPERC IS THE TIME INTERVAL SUMMATION OF PERC
C
C     COMPUTE INTERFLOW AND KEEP TRACK OF TIME INTERVAL SUM.
C     NOTE...PINC HAS NOT YET BEEN ADDED
         DEL = UZFWC * DUZ
         SIF = SIF + DEL
         UZFWC = UZFWC - DEL
C
C     DISTRIBUTE PERCOLATED WATER INTO THE LOWER ZONES
C     TENSION WATER MUST BE FILLED FIRST EXCEPT FOR THE PFREE AREA.
C     PERCT IS PERCOLATION TO TENSION WATER AND PERCF IS PERCOLATION
C         GOING TO FREE WATER.
         PERCT = PERC * (1.0 - PFREE)
         IF ((PERCT + LZTWC).GT.LZTWM) GO TO 230
         LZTWC = LZTWC + PERCT
         PERCF = 0.0
         GO TO 240
  230    PERCF = PERCT + LZTWC - LZTWM
         LZTWC = LZTWM
C
C      DISTRIBUTE PERCOLATION IN EXCESS OF TENSION
C      REQUIREMENTS AMONG THE FREE WATER STORAGES.
  240    PERCF = PERCF + PERC * PFREE
         IF (PERCF.EQ.0.0) GO TO 260
         HPL = LZFPM/(LZFPM + LZFSM)
C
C     HPL IS THE RELATIVE SIZE OF THE PRIMARY STORAGE
C     AS COMPARED WITH TOTAL LOWER ZONE FREE WATER STORAGE.
         RATLP = LZFPC/LZFPM
         RATLS = LZFSC/LZFSM
C
C     RATLP AND RATLS ARE CONTENT TO CAPACITY RATIOS, OR
C     IN OTHER WORDS, THE RELATIVE FULLNESS OF EACH STORAGE
         FRACP = (HPL * 2.0 * (1.0 - RATLP))/((1.0 - RATLP) + (1.0 - RAT
     1   LS))
C
C     FRACP IS THE FRACTION GOING TO PRIMARY.
         IF (FRACP.GT.1.0) FRACP = 1.0
         PERCP = PERCF * FRACP
         PERCS = PERCF - PERCP
C
C     PERCP AND PERCS ARE THE AMOUNT OF THE EXCESS
C     PERCOLATION GOING TO PRIMARY AND SUPPLEMENTAL
C      STORGES,RESPECTIVELY.
         LZFSC = LZFSC + PERCS
         IF (LZFSC.LE.LZFSM) GO TO 250
         PERCS = PERCS - LZFSC + LZFSM
         LZFSC = LZFSM
  250    LZFPC = LZFPC + (PERCF - PERCS)
C
C     CHECK TO MAKE SURE LZFPC DOES NOT EXCEED LZFPM.
         IF (LZFPC.LE.LZFPM) GO TO 260
         EXCESS = LZFPC - LZFPM
         LZTWC = LZTWC + EXCESS
         LZFPC = LZFPM
C
```

```
C     DISTRIBUTE PINC BETWEEN UZFWC AND SURFACE RUNOFF.
  260    IF (PINC.EQ.0.0) GO TO 280
C
C     CHECK IF PINC EXCEEDS UZFWM
         IF ((PINC + UZFWC).GT.UZFWM) GO TO 270
C
C     NO SURFACE RUNOFF
         UZFWC = UZFWC + PINC
         GO TO 280
C
C     COMPUTE SURFACE RUNOFF (SUR) AND KEEP TRACK OF TIME INTERVAL SUM.
  270    SUR = PINC + UZFWC - UZFWM
         UZFWC = UZFWM
         SSUR = SSUR + SUR * PCIAR
         ADSUR = SUR * (1.0 - ADDRO/PINC)
C
C     ADSUR IS THE AMOUNT OF SURFACE RUNOFF WHICH COMES
C     FROM THAT PORTION OF ADIMP WHICH IS NOT
C     CURRENTLY GENERATING DIRECT RUNOFF.  ADDRO/PINC
C     IS THE FRACTION OF ADIMP CURRENTLY GENERATING
C     DIRECT RUNOFF.
         SSUR = SSUR + ADSUR * ADIMP
C
C     ADIMP AREA WATER BALANCE -- SDRO IS THE 6 HR SUM OF
C        DIRECT RUNOFF.
  280    ADIMC = ADIMC + PINC - ADDRO - ADSUR
         IF (ADIMC.LE.(UZTWM + LZTWM)) GO TO 290
         ADDRO = ADDRO + ADIMC - (UZTWM + LZTWM)
         ADIMC = UZTWM + LZTWM
  290    SDRO = SDRO + ADDRO * ADIMP
         IF (ADIMC.LT.0.00001) ADIMC = 0.0
  300 CONTINUE
C
C     END OF INCREMENTAL DO LOOP.
C
C     COMPUTE SUMS AND ADJUST RUNOFF AMOUNTS BY THE AREA OVER
C     WHICH THEY ARE GENERATED.
      EUSED = E1 + E2 + E3
C
C     EUSED IS THE ET FROM PCIAR WHICH IS 1.0-ADIMP-PCTIM
      SIF = SIF * PCIAR
C
C     SEPARATE CHANNEL COMPONENT OF BASEFLOW
C     FROM THE NON-CHANNEL COMPONENT
      TBF = SBF * PCIAR
C
C     TBF IS TOTAL BASEFLOW
      BFCC = TBF * (1.0/(1.0 + SIDE))
C
C     BFCC IS BASEFLOW, CHANNEL COMPONENT
      BFP = SPBF * PCIAR/(1.0 + SIDE)
      BFS = BFCC - BFP
      IF (BFS.LT.0.0) BFS = 0.0
      BFNCC = TBF - BFCC
C
C     BFNCC IS BASEFLOW,NON-CHANNEL COMPONENT
```

```
     3    ESS(50),OBJFV
      COMMON /FDK00/ TAREA,TRMN,TRHR,METRC,IEL,NQ,MXNDX,MXNDT
      COMMON /FDK01/ CHLNG(5),SLOPE(5),RCMAN(5),PAREA(5),ISHAPE(5),
     1 CHWDT(5),ZLNG(5),ALPME(5),EMDEQ(5),DXROF(5),DXFLO(5),DTKWR(5),
     2 DXKWR(5),IRUPF(5),SAREA(5),FLOIC(5)
      COMMON /FDK02/ EXCSR(1224),Q(1224),
     1 QK(1224),QUB(1224),QBF(1224)
      COMMON /CMDAT/ RDT(1224),PDT(1224),QDT(1224)
      REAL                     LZTWM     , LZFSM     , LZFPM     ,
     1          LZSK         , LZPK      , LZTWC     , LZFSC     ,
     2          LZFPC
      COMMON /CMSMP/           PXADJ     , PEADJ     , UZTWM     ,
     1          UZFWM        , UZK       , PCTIM     , ADIMP     ,
     2          RIVA         , RSERV     , ZPERC     , REXP      ,
     3          LZTWM        , LZFSM     , LZFPM     , LZSK      ,
     4          LZPK         , PFREE     , SIDE      , SAVED     ,
     5          PCIAR
      COMMON /CMSMC/           UZTWC     , UZFWC     , LZTWC     ,
     1          LZFSC        , LZFPC     , ADIMC     , RSUM(7)
      DIMENSION                AL(50)    , D(50)     , H(50)     ,
     1          PH(50)       , EINT(50)  , SA(50)    , B(50,50)  ,
     2          V0(50,50)    , V1(50,50)
C
      WRITE (IOUB,500)
C     DEFINITION OF SOME TERMS
C      M = -1 SIGNIFIES MINIMIZE OBJECTIVE FUNCTION
C      NP = NUMBER OF PARAMETERS TO BE OPTIMIZED
C      NC = NUMBER OF CONTRAINTS
C      MXITER = MAXIMUM NUMBER OF ITERATIONS
C      ERROR = CONVERGENCE CRITERION SUCH THAT ABS((F1-F0)/F1) LT ERROR
C      IPROP = PRINTING FREQUENCY BETWEEN STAGE EVALUATION
      M =  - 1
      NP = NPOP
      NC = NP
C
      IF (MXITER.EQ.0) MXITER = 10
      ERROR = AMAX1(ERROR,0.000001)
      IPROP = MAX0(IPROP,1)
C
C     INITIALIZE COUNTERS
      KIPR = IPROP - 1
      KITER = 0
      ISW = 0
      INIT = 0
      KOUNT = 0
      ICNVG = 0
      F1 = 0.0
      DO 100 K = 1,NC
  100 AL(K) = (XMAX(K) - XMIN(K)) * 0.0001
      DO 120 I = 1,NP
         DO 110 J = 1,NP
  110    V0(I,J) = 0.0
  120 V0(I,I) = 1.0
      DO 130 K = 1,NP
  130 EINT(K) = ESS(K)
C
```

```
  140 DO 150 J = 1,NP
          IF (NSTEP.EQ.0) ESS(J) = EINT(J)
          SA(J) = 2.0
  150 D(J) = 0.0
      FBEST = F1
  160 I = 1
      IF (INIT.EQ.0) GO TO 200
  170 DO 180 K = 1,NP
  180 XMP(K) = XMP(K) + ESS(I) * VO(I,K)
      DO 190 K = 1,NC
  190 H(K) = F0
C
  200 KOUNT = KOUNT + 1
      CALL SACROUT (0,IPRINT)
      F1 = M * OBJFV
      IF (ISW.EQ.0) F0 = F1
      ISW = 1
      IF (ABS((FBEST - F1)/F1).GT.ERROR) GO TO 210
      ICNVG = 1
      GO TO 460
C
  210 J = 1
  220 XV = XMP(J)
      XL = XMIN(J)
      XU = XMAX(J)
      IF (XV.LE.XL) GO TO 430
      IF (XV.GE.XU) GO TO 430
      IF (F1.LT.F0) GO TO 430
      IF (XV.LT.(XL + AL(J))) GO TO 230
      IF (XV.GT.(XU - AL(J))) GO TO 230
      H(J) = F0
      GO TO 290
C
  230 BW = AL(J)
      IF (XV.LE.XL.OR.XU.LE.XV) GO TO 240
      IF (XL.LT.XV.AND.XV.LT.(XL + BW)) GO TO 250
      IF ((XU - BW).LT.XV.AND.XV.LT.XU) GO TO 260
      PH(J) = 1.0
      GO TO 290
C
  240 PH(J) = 0.0
      GO TO 280
  250 PW = (XL + BW - XV)/BW
      GO TO 270
  260 PW = (XV - XU + BW)/BW
  270 PH(J) = 1.0 - 3.0 * PW + 4.0 * PW * PW - 2.0 * PW * PW * PW
  280 F1 = H(J) + (F1 - H(J)) * PH(J)
C
  290 IF (J.EQ.NC) GO TO 300
      J = J + 1
      GO TO 220
C
  300 INIT = 1
      IF (F1.LT.F0) GO TO 430
      D(I) = D(I) + ESS(I)
C
```

```
C     NOTE : SCALING FACTOR FOR STEP SIZE INCREASE ALPHA IS SET AT,
      ALPHA = 2.0
      ESS(I) = ALPHA * ESS(I)
      F0 = F1
      IF (SA(I).GE.1.5) SA(I) = 1.0
      GO TO 310
C
  430 IF (INIT.EQ.0) GO TO 460
      DO 440 IC = 1,NP
  440 XMP(IC) = XMP(IC) - ESS(I) * V0(I,IC)
C
C     NOTE : SCALING FACTOR FOR STEP SIZE REDUCTION BETA IS SET AT,
      BETA = 0.5
      ESS(I) =  - BETA * ESS(I)
      IF (SA(I).LT.1.5) SA(I) = 0.0
C
  310 DO 320 K = 1,NP
         IF (SA(K).GE.0.5) GO TO 450
  320 CONTINUE
C
C     AXES ROTATION
C
      DO 330 IR = 1,NP
      DO 330 IC = 1,NP
  330 V1(IR,IC) = 0.0
      DO 350 IR = 1,NP
      DO 350 IC = 1,NP
         DO 340 K = IR,NP
  340    V1(IR,IC) = V1(IR,IC) + D(K) * V0(K,IC)
  350 B(IR,IC) = V1(IR,IC)
      SBM1 = 0.0
      DO 360 IC = 1,NP
         SBM1 = SBM1 + B(1,IC) * B(1,IC)
  360 CONTINUE
      SBM1 = SQRT(SBM1)
      DO 370 IC = 1,NP
  370 V0(1,IC) = B(1,IC)/SBM1
      DO 400 IR = 2,NP
         IR1 = IR - 1
      DO 400 IC = 1,NP
         SUMB = 0.0
         DO 390 KR = 1,IR1
            SUMA = 0.0
            DO 380 KC = 1,NP
  380       SUMA = SUMA + V1(IR,KC) * V0(KR,KC)
  390    SUMB = SUMB + SUMA * V0(KR,IC)
  400 B(IR,IC) = V1(IR,IC) - SUMB
      DO 420 IR = 2,NP
         SBM2 = 0.0
         DO 410 K = 1,NP
  410    SBM2 = SBM2 + B(IR,K) * B(IR,K)
         SBM2 = SQRT(SBM2)
      DO 420 IC = 1,NP
  420 V0(IR,IC) = B(IR,IC)/SBM2
      KITER = KITER + 1
      KIPR = KIPR + 1
```

```
      IF (KIPR.EQ.IPROP) GO TO 460
      GO TO 140
C
  450 IF (I.EQ.NP) GO TO 160
      I = I + 1
      GO TO 170
C
  460 WRITE (IOUB,510)
      WRITE (IOUB,520) KITER,F0,SBM1,SBM2
      WRITE (IOUB,530) KOUNT
      WRITE (IOUB,540)
C
C     PRINT CURRENT VALUES OF XMP
C
      WRITE (IOUB,550) (K,XMP(K),K = 1,NP)
C
      KIPR = 0
      IF (INIT.EQ.0) GO TO 470
      IF (ICNVG.EQ.1) GO TO 480
      IF (KITER.GE.MXITER) GO TO 480
      GO TO 140
C
  470 WRITE (IOUB,560)
  480 CONTINUE
      WRITE (IOUB,570)
      DO 490 J = 1,NP
  490 WRITE (IOUB,580) (J,I,V0(J,I),I = 1,NP)
      WRITE (IOUB,590)
      WRITE (IOUB,600) (J,ESS(J),J = 1,NP)
      RETURN
C
C
C
  500 FORMAT (1H1/10X,46HOPTIMIZATION BY ROSENBROCK HILLCLIMB PROCEDURE,
     1/)
  510 FORMAT (//2X,5HSTAGE,8X,8HFUNCTION,12X,8HPROGRESS,9X,16HLATERAL PR
     1OGRESS)
  520 FORMAT (1H ,I5,3E20.8)
  530 FORMAT (/2X,33HNUMBER OF FUNCTION EVALUATIONS = ,I8)
  540 FORMAT (/2X,28HVALUES OF X(.) AT THIS STAGE)
  550 FORMAT (3(4X,2HX(,I2,4H) = ,E15.6))
  560 FORMAT (/2X,52HTHE STARTING POINTS MUST NOT VIOLATE THE CONSTRAINT
     1S,/2X,26HIT APPEARS TO HAVE DONE SO,/)
  570 FORMAT (/2X,29HFINAL DIRECTION VECTOR MATRIX)
  580 FORMAT (3(4X,2HV(,I2,1H,,I2,4H) = ,F10.8))
  590 FORMAT (/2X,16HFINAL STEP SIZES)
  600 FORMAT (3(4X,2HS(,I2,4H) = ,E15.6))
      END
      FUNCTION FPOBJ(QOBS,QCOM)
C
C     ROUTINE TO EVALUATE EACH SUMMATION TERM OF OBJECTIVE FUNCTION
C
      COMMON /CMPRM/          NPARM       , NPOP        , IOBF        ,
     1          MXITER      , NSTEP       , ERROR       , IPROP       ,
     2          INDX(50)    , XMP(50)     , XMIN(50)    , XMAX(50)    ,
     3    ESS(50),OBJFV
```

```
      GO TO (100,110,120,130,140), IOBF
  100 FPOBJ = (QOBS - QCOM) *  * 2
      RETURN
  110 FPOBJ = ABS(QOBS - QCOM)
      RETURN
  120 IF (QOBS.EQ.0.0) QOBS = 0.0000001
      FPOBJ = ((QOBS - QCOM)/QOBS) *  * 2
      RETURN
  130 FPOBJ = (QOBS *  * 0.3333333 - QCOM *  * 0.3333333) *  * 2
      RETURN
  140 FPOBJ = (QOBS *  * 0.5 - QCOM *  * 0.5) *  * 2
      RETURN
      END
      SUBROUTINE SACROUT (IUPDF,IPRINT)
C
C     THIS ROUTINE CONTROLS THE TIMING SEQUENCE FOR SACRAMENTO SOIL-
C     MOISTURE ACCOUNTING AND STREAMFLOW ROUTING
C
      COMMON /CMIOP/          IOUA          , IOUB          ,
     1          NHOUR        ,NDATA         ,
     2         NTIME,NHRP,NHRQ,NDTQ,INPQ,NBASIN,IWBLNC,IPFRQR,IPFRQQ
      COMMON /CMPRM/          NPARM         , NPOP          , IOBF          ,
     1         MXITER       , NSTEP         , ERROR         , IPROP         ,
     2         INDX(50)     , XMP(50)       , XMIN(50)      , XMAX(50)      ,
     3     ESS(50),OBJFV
      COMMON /FDK00/ TAREA,TRMN,TRHR,METRC,IEL,NQ,MXNDX,MXNDT
      COMMON /FDK01/ CHLNG(5),SLOPE(5),RCMAN(5),PAREA(5),ISHAPE(5),
     1 CHWDT(5),ZLNG(5),ALPME(5),EMDEQ(5),DXROF(5),DXFLO(5),DTKWR(5),
     2 DXKWR(5),IRUPF(5),SAREA(5),FLOIC(5)
      COMMON /FDK02/ EXCSR(1224),Q(1224),
     1 QK(1224),QUB(1224),QBF(1224)
      COMMON /CMDAT/ RDT(1224),PDT(1224),QDT(1224)
      REAL                    LZTWM         , LZFSM         , LZFPM         ,
     1         LZSK         , LZPK          , LZTWC         , LZFSC         ,
     2         LZFPC
      COMMON /CMSMP/          PXADJ         , PEADJ         , UZTWM         ,
     1         UZFWM        , UZK           , PCTIM         , ADIMP         ,
     2         RIVA         , RSERV         , ZPERC         , REXP          ,
     3         LZTWM        , LZFSM         , LZFPM         , LZSK          ,
     4         LZPK         , PFREE         , SIDE          , SAVED         ,
     5         PCIAR
      COMMON /CMSMC/          UZTWC         , UZFWC         , LZTWC         ,
     1         LZFSC        , LZFPC         , ADIMC         , RSUM(7)
      DIMENSION               QPLOT(81)
      DATA CHAR0,CHAR1,CHAR2,CHAR3/1H ,1HC,1HO,1HE/
      DO 400 IP = 1,NPARM
         KP = INDX(IP)
         GO TO (100,110,120,130,140,150,160,170,180,190,200,210,220,230,
     1   240,250,260,270,280,290,300,310,320,330), KP
  100    PXADJ = XMP(IP)
         GO TO 400
  110    PEADJ = XMP(IP)
         GO TO 400
  120    PCTIM = XMP(IP)
         GO TO 400
  130    ADIMP = XMP(IP)
```

```
      ADIMP = AMIN1(ADIMP,(1.0 - PCTIM))
      IF (IP.GT.NPOP) GO TO 400
      XMAX(IP) = AMIN1(XMAX(IP),(1.0 - PCTIM))
      GO TO 400
140   RIVA = XMP(IP)
      IF (IP.GT.NPOP) GO TO 400
      RIVA = AMAX1(RIVA,XMIN(IP))
      RIVA = AMIN1(RIVA,XMAX(IP))
      GO TO 400
150   UZK = XMP(IP)
      IF (IP.GT.NPOP) GO TO 400
      UZK = AMAX1(UZK,XMIN(IP))
      UZK = AMIN1(UZK,XMAX(IP))
      GO TO 400
160   LZSK = XMP(IP)
      IF (IP.GT.NPOP) GO TO 400
      LZSK = AMAX1(LZSK,XMIN(IP))
      LZSK = AMIN1(LZSK,XMAX(IP))
      GO TO 400
170   LZPK = XMP(IP)
      IF (IP.GT.NPOP) GO TO 400
      LZPK = AMAX1(LZPK,XMIN(IP))
      LZPK = AMIN1(LZPK,XMAX(IP))
      GO TO 400
180   PFREE = XMP(IP)
      IF (IP.GT.NPOP) GO TO 400
      PFREE = AMAX1(PFREE,XMIN(IP))
      PFREE = AMIN1(PFREE,XMAX(IP))
      GO TO 400
190   RSERV = XMP(IP)
      IF (IP.GT.NPOP) GO TO 400
      RSERV = AMAX1(RSERV,XMIN(IP))
      RSERV = AMIN1(RSERV,XMAX(IP))
      GO TO 400
200   ZPERC = XMP(IP)
      GO TO 400
210   REXP = XMP(IP)
      GO TO 400
220   SIDE = XMP(IP)
      GO TO 400
230   UZTWM = XMP(IP)
      GO TO 400
240   UZFWM = XMP(IP)
      GO TO 400
250   LZTWM = XMP(IP)
      GO TO 400
260   LZFSM = XMP(IP)
      GO TO 400
270   LZFPM = XMP(IP)
      GO TO 400
280   UZTWC = XMP(IP)
      IF (IP.GT.NPOP) GO TO 400
      XMAX(IP) = AMIN1(XMAX(IP),UZTWM)
      GO TO 400
290   LZTWC = XMP(IP)
      IF (IP.GT.NPOP) GO TO 400
```

```
       XMAX(IP) = AMIN1(XMAX(IP),LZTWM)
       GO TO 400
300    UZFWC = XMP(IP)
       IF (IP.GT.NPOP) GO TO 400
       XMAX(IP) = AMIN1(XMAX(IP),UZFWM)
       GO TO 400
310    LZFSC = XMP(IP)
       IF (IP.GT.NPOP) GO TO 400
       XMAX(IP) = AMIN1(XMAX(IP),LZFSM)
       GO TO 400
320    LZFPC = XMP(IP)
       IF (IP.GT.NPOP) GO TO 400
       XMAX(IP) = AMIN1(XMAX(IP),LZFPM)
       GO TO 400
330    ADIMC = XMP(IP)
       IF (IP.GT.NPOP) GO TO 400
       XMIN(IP) = AMAX1(XMIN(IP),UZTWC)
       XMAX(IP) = AMIN1(XMAX(IP),(UZTWM + LZTWM))
400 CONTINUE
    CALL SACSMA (IPRINT)
    IF (IUPDF.EQ.0) GO TO 480
    DO 470 IP = 1,NPARM
       KP = INDX(IP)
       GO TO (470,470,470,470,470,470,470,470,470,470,470,470,470,470,470,
   1   470,470,470,470,410,420,430,440,450,460), KP
410    XMP(IP) = UZTWC
       GO TO 470
420    XMP(IP) = LZTWC
       GO TO 470
430    XMP(IP) = UZFWC
       GO TO 470
440    XMP(IP) = LZFSC
       GO TO 470
450    XMP(IP) = LZFPC
       GO TO 470
460    XMP(IP) = ADIMC
470 CONTINUE
480 NQ=NDATA
    TRHR=NHOUR
    CALL KINWAVE (IPRINT)
    DO 500 I = 1,81
500 QPLOT(I) = CHARO
    OBJFV = 0.0
    QMIN = 9999999.0
    QMAX =  - QMIN
    ANQ=0.0
    IF (NHOUR.NE.NHRQ) GO TO 520
    DO 510 IHOUR = 1,NDATA
       QOUTI = Q(IHOUR)
       QMIN = AMIN1(QMIN,QOUTI)
       QMAX = AMAX1(QMAX,QOUTI)
       IF (INPQ.EQ.0) GO TO 510
       QDTI = QDT(IHOUR)
       IF(QDTI.LT.0.0) GO TO 510
       ANQ=ANQ+1.0
       QMIN = AMIN1(QMIN,QDTI)
```

```
        QMAX = AMAX1(QMAX,QDTI)
        OBJFV = OBJFV + FPOBJ(QDTI,QOUTI)
510 CONTINUE
    IF(INPQ.NE.0) OBJFV=OBJFV/ANQ
    GO TO 560
520 NRQ = NHRQ/NHOUR
    DN = NRQ
        IHOUR = 0
        DO 540 IHRQ = 1,NDTQ
            SUM = 0.0
            DO 530 IRQ = 1,NRQ
                IHOUR = IHOUR + 1
530         SUM = SUM + Q(IHOUR)
            QOUTI = SUM/DN
            Q(IHRQ) = QOUTI
            QMIN = AMIN1(QMIN,QOUTI)
            QMAX = AMAX1(QMAX,QOUTI)
            IF (INPQ.EQ.0) GO TO 540
            QDTI = QDT(IHRQ)
            IF(QDTI.LT.0.0) GO TO 540
            ANQ=ANQ+1.0
            QMIN = AMIN1(QMIN,QDTI)
            QMAX = AMAX1(QMAX,QDTI)
            OBJFV = OBJFV + FPOBJ(QDTI,QOUTI)
540     CONTINUE
        IF(INPQ.NE.0) OBJFV=OBJFV/ANQ
560 IF (IPRINT.EQ.0) RETURN
    IF (INPQ.NE.0) WRITE (IOUB,650) IOBF,OBJFV
    IF (INPQ.EQ.0) WRITE (IOUB,660)
    QCON = 80.0/(QMAX - QMIN)
    NTMQ=0
    DO 610 IHRQ = 1,NDTQ
    NTMQ=NTMQ+NHRQ
    IDAY=(NTMQ-1)/24+1
        QOUTI = Q(IHRQ)
        NQO = 1 + IFIX((QOUTI - QMIN) * QCON)
        QPLOT(NQO) = CHAR1
        NQD = NQO
        IF (INPQ.EQ.0) GO TO 600
        QDTI = QDT(IHRQ)
        IF (QDTI.LT.0.0) GO TO 570
        NQD = 1 + IFIX((QDTI - QMIN) * QCON)
        IF (NQO.NE.NQD) QPLOT(NQD) = CHAR2
        IF (NQO.EQ.NQD) QPLOT(NQD) = CHAR3
570     IF(MOD(NTMQ,IPFRQQ).EQ.0)
   1    WRITE (IOUB,670) IDAY,NTMQ,QDTI,QOUTI,(QPLOT(I),I = 1,81)
        QPLOT(NQO) = CHAR0
        QPLOT(NQD) = CHAR0
        GO TO 610
600     IF(MOD(NTMQ,IPFRQQ).EQ.0)
   1    WRITE (IOUB,680) IDAY,NTMQ,QOUTI,(QPLOT(I),I = 1,81)
        QPLOT(NQO) = CHAR0
610 CONTINUE
    WRITE (IOUB,690) QMIN,QMAX
    WRITE (IOUB,700) CHAR1,CHAR2,CHAR3
    RETURN
```

```
C
C
  650 FORMAT (/5X,29HVALUE OF OBJECTIVE FUNCTION (,I1,3H) =,F15.5//4X, 3
     12HDAY  HOUR  OBSERVED  COMPUTED  I,81(  1H-),  1HI)
  660 FORMAT (//4X, 32HDAY  HOUR  OBSERVED  COMPUTED  I,81(  1H-),  1HI)
  670 FORMAT (2X,I4,I6,1X,2F10.3,2X,  1HI,81A1,  1HI)
  680 FORMAT (2X,I4,I6,7X,  1H*,3X,F10.3,2X,  1HI,81A1,  1HI)
  690 FORMAT (35X,  1HI,81(  1H-),  1HI,//5X, 18HMINIMUM ORDINATE =,F10.
     12/5X, 18HMAXIMUM ORDINATE =,F10.2)
  700 FORMAT (/5X, 13HSYMBOLS USED:,/6X, 11HCOMPUTED - ,A1/6X, 11HOBSERV
     1ED - ,A1/6X, 11HIF EQUAL - ,A1////1X, 18HNORMAL TERMINATION,/)
      END
      SUBROUTINE KINWAVE (IPRINT)
C
C     THIS SUBROUTINE CONTROL THE TIMING AND SEQUENCING OF
C     KINEMATIC WAVE ROUTING METHODOLOGY
C
      COMMON /CMIOP/          IOUA          , IOUB          ,
     1          NHOUR        ,NDATA         ,
     2          NTIME,NHRP,NHRQ,NDTQ,INPQ,NBASIN,IWBLNC,IPFRQR,IPFRQQ
      COMMON /FDK00/ TAREA,TRMN,TRHR,METRC,IEL,NQ,MXNDX,MXNDT
      COMMON /FDK01/ CHLNG(5),SLOPE(5),RCMAN(5),PAREA(5),ISHAPE(5),
     1 CHWDT(5),ZLNG(5),ALPME(5),EMDEQ(5),DXROF(5),DXFLO(5),DTKWR(5),
     2 DXKWR(5),IRUPF(5),SAREA(5),FLOIC(5)
      COMMON /FDK02/ EXCSR(1224),Q(1224),
     1 QK(1224),QUB(1224),QBF(1224)
      DIMENSION DOPER(4),QS(3672),WBF(50)
      DATA DOPER/5HROUTE,5HADD  ,5HBASEF,5HEND  /
      DATA METRC/1/,MXNDX/51/,MXNDT/1224/
C
      IF(IPRINT.NE.0) WRITE(IOUB,99)
C
      CFQ=1.0
C
C     CONVERSION FROM SQ MI-IN TO CFS
C
      CATOQ=645.333/TRHR
      IF (METRC.LE.0) GO TO 01
      CFQ=35.31
C
C     CONVERSION FROM SQ KM-MM TO CUBIC METERS PER SECOND
C
      CATOQ=1.0/(3.6*TRHR)
C
   01 TRMN=TRHR*60.0
      REWIND 10
      NSQ=0
      NSB=0
   45 READ(10,100,END=90) ROPER,IOPER
      DO 05 IOP=1,4
      IF(DOPER(IOP).EQ.ROPER) GO TO 10
   05 CONTINUE
      WRITE(IOUB,105) ROPER
      STOP
   10 GO TO (25,50,70,90), IOP
C
```

```
C     KINEMATIC WAVE ROUTING
C
   25 DO 30 I=1,5
      CHLNG(I)=0.0
      SLOPE(I)=0.0
      RCMAN(I)=0.0
      PAREA(I)=0.0
      ISHAPE(I)=0
      CHWDT(I)=0.0
      ZLNG(I)=0.0
      ALPME(I)=0.0
      EMDEQ(I)=0.0
      DXROF(I)=0.0
      DXFLO(I)=0.0
      DTKWR(I)=0.0
      DXKWR(I)=0.0
      FLOIC(I)=0.0
      SAREA(I)=0.0
      IRUPF(I)=0
   30 CONTINUE
      NSB=NSB+1
      SBA=0.0
      IEL=2
      READ(10,110) TAREA
      READ(10,110) CHLNG(1),SLOPE(1),RCMAN(1),PAREA(1)
      IF(IPRINT.EQ.0) GO TO 33
      WRITE(IOUB,115) NSB, TAREA
      IELP=1
      WRITE(IOUB,116) IELP,CHLNG(1),SLOPE(1),RCMAN(1),PAREA(1)
   33 IF(PAREA(1).GE.99.5) GO TO 35
      READ(10,110) CHLNG(2),SLOPE(2),RCMAN(2),PAREA(2)
      IF(IPRINT.EQ.0) GO TO 35
      IELP=2
      WRITE(IOUB,116) CHLNG(2),SLOPE(2),RCMAN(2),PAREA(2)
   35 IEL=IEL+1
      READ(10,110) CHLNG(IEL),SLOPE(IEL),RCMAN(IEL),SAREA(IEL)
      READ(10,110) ASHAPE,CHWDT(IEL),ZLNG(IEL),FLOIC(IEL),ARUPF
      IF(SAREA(IEL).EQ.0.0) SAREA(IEL)=TAREA
      ISHAPE(IEL)=ASHAPE
      IRUPF(IEL)=ARUPF
      IF(IPRINT.EQ.0) GO TO 36
      IELP=IEL-2
      IF(SAREA(IEL).NE.TAREA) WRITE(IOUB,117) IELP
      IF(SAREA(IEL).EQ.TAREA) WRITE(IOUB,118)
      WRITE(IOUB,119) CHLNG(IEL),SLOPE(IEL),RCMAN(IEL),SAREA(IEL),
     1 ISHAPE(IEL),CHWDT(IEL),ZLNG(IEL),FLOIC(IEL)
      IF(IRUPF(IEL).EQ.1) WRITE(IOUB,121)
   36 SBA=SBA+SAREA(IEL)
      IF(SBA.LT.TAREA) GO TO 35
      NSQ=NSQ+1
      IF(IRUPF(IEL).NE.1) GO TO 37
      IF(NSQ.GE.2) GO TO 39
      DO 41 N=1,NQ
   41 QK(N)=QUB(N)
      GO TO 37
   39 ISQ=(NSQ-2)*NQ
```

```
      DO 42 N=1,NQ
   42 QK(N)=QS(ISQ+N)
   37 CALL KINOFF (CFQ,IPRINT)
      ISQ=(NSQ-1)*NQ
      DO 40 N=1,NQ
   40 QS(ISQ+N)=Q(N)
      GO TO 45
C
C     ADD PREVIOUS (IOPER) FLOWS
C
   50 NS1=NSQ-IOPER+1
      NSB1=NSB-IOPER+1
      IF(IPRINT.NE.0) WRITE(IOUB,120) (ISB,ISB=NSB1,NSB)
      ISQ1=(NS1-1)*NQ
      DO 55 N=1,NQ
      SQA=0.0
      DO 60 IS=NS1,NSQ
      ISQ=(IS-1)*NQ
   60 SQA=SQA+QS(ISQ+N)
   55 QS(ISQ1+N)=SQA
      NSQ=NS1
      GO TO 45
C
C     ADD BASEFLOW
C
   70 IWBF=IOPER+1
      READ(10,110) (WBF(I),I=1,IWBF)
      IF(IPRINT.NE.0) WRITE(IOUB,125) NSB, IOPER, (WBF(I),I=1,IWBF)
      ISQ=(NSQ-1)*NQ
      DO 75 N=1,NQ
      SBF=0.0
      DO 80 I=1,IWBF
      L=I-1
      IF(N.LE.L) GO TO 80
      SBF=SBF+WBF(I)*QBF(N-L)
   80 CONTINUE
      SBF=SBF*CATOQ*TAREA+QS(ISQ+N)
   75 QS(ISQ+N)=SBF
      GO TO 45
C     STORE FINAL COMPUTED FLOWS IN Q(.)
   90 ISQ=(NSQ-1)*NQ
      DO 85 N=1,NQ
      Q(N)=QS(ISQ+N)
      QK(N)=Q(N)
      IF(IPRINT.NE.0) QUB(N)=Q(N)
   85 CONTINUE
      RETURN
   99 FORMAT(1H1)
  100 FORMAT(A5,I5)
  105 FORMAT(//3X,'***** EXECUTION TERMINATED - INPUT LIST ',A5,' IS AN
     1UNRECOGNIZED OPERATION'/3X,'IN KINEMATIC WAVE ROUTING *****')
  115 FORMAT(//1X,'KINEMATIC WAVE ROUTING FOR SUBBASIN',I3/
     1 /2X,'TOTAL AREA =',F10.2)
  116 FORMAT(/1X,'OVERLAND FLOW ELEMENT',I2//2X,'CHLNG =',F10.2/
     1 2X,'SLOPE =',F10.5/2X,'RCMAN =',F10.5/2X,'PAREA =',F10.3/)
  117 FORMAT(/1X,'COLLECTOR CHANNEL',I3)
```

```
  118 FORMAT(/1X,'MAIN CHANNEL')
  119 FORMAT(/2X,'CHLNG =',F10.2/2X,'SLOPE =',F10.5/2X,'RCMAN =',
     1 F10.5/2X,'SAREA =',F10.3//2X,'ISHAPE=',I10/2X,'CHWDT =',
     2 F10.3/2X,'ZLNG  =',F10.3//2X,'FLOIC =',F10.3)
  121 FORMAT(/1X,'ROUTE UPSTREAM FLOW'/)
  110 FORMAT(5G10.4)
  120 FORMAT(/1X,'ADD FLOWS OF SUBBASINS ',I3,10(',',I3))
  125 FORMAT(/1X,'ADD BASEFLOW TO SUBBASIN',I3,' USING A LINEAR DECAY FU
     1NCTION OF THE FORM:'//2X,'ADDED BF AT TIME T = SUM OF W(L) * BF(T-
     2L) FOR L = 0 TO',I3,' ; WHERE'//2X,'W(L): ',8G11.4,10(/8X,8G11.4))
      END
      SUBROUTINE KINOFF (CFQ,IPRINT)
C
C
C         SUBROUTINE 'KINOFF' DETERMINES THE SUB-AREA RUNOFF HYDROGRAPH
C         THROUGH THE FINITE DIFFERENCE/KINEMATIC WAVE METHODOLOGY.
C         SUBROUTINE 'KINOFF' CALLS THE FOLLOWING SUBROUTINES
C                       SUBROUTINE 'ROFGRD'
C                       SUBROUTINE 'FDKRUT'
C                       SUBROUTINE 'FLOGRD'
C
C                       SUBROUTINE 'FRMMTC'
C                       SUBROUTINE 'TOMTRC'
C
C         'KINOFF' USES THE EXCESS RAINFALL FROM THE 'EXCSR()' ARRAY AND
C         THE ASSUMPTION OF AN INITIALLY DRY SURFACE TO PRODUCE A RUNOFF
C         HYDROGRAPH - THIS HYDROGRAPH IS PLACED IN THE 'Q' ARRAY.
C
      COMMON /CMIOP/           IOUA          , IOUB          ,
     1          NHOUR         ,NDATA         ,
     2         NTIME,NHRP,NHRQ,NDTQ,INPQ,NBASIN,IWBLNC,IPFRQR,IPFRQQ
      COMMON /FDK00/ TAREA,TRMN,TRHR,METRC,IEL,NQ,MXNDX,MXNDT
      COMMON /FDK01/ CHLNG(5),SLOPE(5),RCMAN(5),PAREA(5),ISHAPE(5),
     1 CHWDT(5),ZLNG(5),ALPME(5),EMDEQ(5),DXROF(5),DXFLO(5),DTKWR(5),
     2 DXKWR(5),IRUPF(5),SAREA(5),FLOIC(5)
      COMMON /FDK02/ EXCSR(1224),Q(1224),
     1 QK(1224),QUB(1224),QBF(1224)
C
C
      DIMENSION QLAT(1225),QUPST(1225),ADS(51),
     1 RNOFF1(1225),RNOFF2(1225),RUNOFF(1225),FLDFLO(1225)
C
      REAL MC, MS
C
C         SUBROUTINE 'FRMMTC' CONVERTS METRIC UNITS TO ENGLISH UNITS.
C         THIS CALL IS BYPASSED IF ENGLISH UNITS ARE ALREADY BEING USED.
C
      IF(METRC.NE.0) CALL FRMMTC
C
C         DETERMINE THE KINEMATIC PARAMETERS ALPHA & M FOR CATCHMENTS #1
C         BYPASS CALCULATIONS FOR CATCHMENT #2 IF CATCHMENT #1 REPRESENTS
C         MORE THAN 99.5% OF THE CURRENT SUB-BASIN
C
      MC=5./3.
      EMDEQ(1)=MC
      EMDEQ(2)=MC
```

```
      ALPME(2)=0.
      ALPH1=(1.49/RCMAN(1))*SLOPE(1)**0.5
      ALPME(1)=ALPH1
      IF (PAREA(1).GT.99.5) ALPH2=ALPH1
      IF (PAREA(1).GT.99.5) GO TO 1030
      ALPH2=(1.49/RCMAN(2))*SLOPE(2)**0.5
      ALPME(2)=ALPH2
 1030 CONTINUE
C
C
C        SUBROUTINE 'ROFGRD' COMPUTES THE NUMBER AND MAGNITUDE OF THE
C        DX AND DT INTERVALS IN THE FINITE DIFFERENCE GRID FOR
C        OVERLAND FLOW.
C
      CALL ROFGRD (NDX1,NDX2,NDT,KINERR,IPRINT)
      IF (KINERR.EQ.0) GO TO 1050
C
C         NO EXCESS,
C         SET RUNOFF TO ZERO,
C         ROUTE UPSTREAM HYDROGRAPH IF REQUESTED,
C         OTHERWISE SKIP TO END OF ROUTING
C
      KINERR=0
      DO 1040 I=1,NDT
      RUNOFF(I)=0.
      FLDFLO(I)=0.
 1040 CONTINUE
      IF (IRUPF(IEL).NE.1) GO TO 1340
      JEL=IEL-1
      GO TO 1180
C
C
C        THE FOLLOWING DEFINES THE APPLIED RAINFALL (QLAT) AND SETS THE
C        UPSTREAM INFLOW ARRAY (QUPST) EQUAL TO ZERO. INITIAL CONDITIONS
C        ARE ASSUMED TO BE THAT OF A DRY SURFACE,AS INDICATED BY SETTING
C        ALL ELEMENTS OF ARRAY ADS(.) EQUAL TO ZERO.
C
 1050 JR=(NDT-1)/(NQ-1)
      RJR=JR
      TEMP=1./(RJR*12.*DTKWR(1))
      QUPST(1)=0.
      QLAT(1)=EXCSR(1)*TEMP
      M=1
      DO 1060 J=1,NQ
      TMP=EXCSR(J)*TEMP
      DO 1060 K=1,JR
      M=M+1
      QLAT(M)=TMP
      QUPST(M)=0.0
 1060 CONTINUE
      DO 1070 J=1,NDX1
 1070 ADS(J)=0.0
      SUMA=0.
C
C
C         'FDKRUT' IS THE FINITE DIFFERENCE SOLUTION SCHEME.  IN THIS
```

```
C        INSTANCE IT IS USED TO COMPUTE THE OVERLAND FLOW HYDROGRAPH.
C
      CALL FDKRUT (NDX1,NDT,1,SUMA,ADS,QLAT,QUPST,RNOFF1)
C
C
      IF (PAREA(1).GT.99.5) GO TO 1120
C
C         DISTRIBUTE EXCESS FROM SECOND STRIP,
C         AND COMPUTE RUNOFF FROM STRIP
C
      TEMP=1./(RJR*12.*DTKWR(2))
      QUPST(1)=0.
      QLAT(1)=EXCSR(1)*TEMP
      M=1
      DO 1100 J=2,NQ
      TMP=EXCSR(J)*TEMP
      DO 1090 K=1,JR
      M=M+1
      QLAT(M)=TMP
      QUPST(M)=0.
 1090 CONTINUE
 1100 CONTINUE
      DO 1110 J=1,NDX2
      ADS(J)=0.
 1110 CONTINUE
      CALL FDKRUT (NDX2,NDT,2,SUMA,ADS,QLAT,QUPST,RNOFF2)
C
C        THE EFFECTIVE STREAM LENGTH IS COMPUTED BASED ON GIVEN OVERLAND
C        FLOW DISTANCES AND DRAINAGE AREA OF THE SUB-AREA.  THE RUNOFF
C        HYDROGRAPH IS ADJUSTED BY THE RATIO OF EFFECTIVE TO ACTUAL
C        STREAM LENGTH.
C
C     USE AREA SERVED BY COLLECTOR SYSTEM
 1120 IF (SAREA(3).LE.0.0) SAREA(3)=TAREA
      IF (IEL.EQ.3) SAREA(3)=TAREA
      ASZE=5280.*5280.*SAREA(3)
      AREA1=PAREA(1)*ASZE/100.
      EL1=AREA1/CHLNG(1)
      EL2=0.0
      IF (PAREA(1).GT.99.5) GO TO 1140
      EL2=(ASZE-AREA1)/CHLNG(2)
      EL3=(EL1*PAREA(1))/100.+(EL2*PAREA(2))/100.
      DO 1130 J=1,NDT
 1130 RUNOFF(J)=(RNOFF1(J)*EL1+RNOFF2(J)*EL2)/EL3
      GO TO 1160
 1140 EL3=EL1
      DO 1150 J=1,NDT
 1150 RUNOFF(J)=RNOFF1(J)
 1160 DO 1170 J=1,NDT
 1170 RUNOFF(J)=RUNOFF(J)*EL3/CHLNG(3)
C
C     LOOP FOR MULT COLLECTOR CHANNELS
      JEL=2
 1180 JEL=JEL+1
C
C        ALPHA AND M FOR THE STREAM BASED ON CROSS-SECTION SHAPE.
```

```
C
      J=ISHAPE(JEL)
      GO TO (1190,1200,1210,1220,1230),J
C
C
C        CIRCULAR CROSS-SECTION
C
 1190 MS=5./4.
      ARG=1./6.
      ALPHS=CHWDT(JEL)**ARG*SLOPE(JEL)**0.5*0.804/RCMAN(JEL)
      GO TO 1240
C
C        TRIANGULAR CROSS-SECTION
C
 1200 MS=4./3.
      ARG=1./3.
      ALPHS=(ZLNG(JEL)/(ZLNG(JEL)**2+1.))**ARG*
     1      SQRT(SLOPE(JEL))*0.94/RCMAN(JEL)
      GO TO 1240
C
C        SQUARE CROSS-SECTION
C
 1210 MS=4.0/3.
      ALPHS=SLOPE(JEL)**0.5*0.72/RCMAN(JEL)
      GO TO 1240
C
C        RECTANGULAR CROSS-SECTION
C
 1220 MS=5./3.
      ARG=-2./3.
      ALPHS=CHWDT(JEL)**ARG*SLOPE(JEL)**0.5*1.49/RCMAN(JEL)
      GO TO 1240
C
C        TRAPEZOIDAL CROSS-SECTION
C
 1230 Y1=0.5
      Y2=5.0
      W=CHWDT(JEL)
      Z=ZLNG(JEL)
      ZZ=2.*SQRT(1.+Z*Z)
      A1=Y1*(W+Z*Y1)
      A2=Y2*(W+Z*Y2)
      Q1=A1**1.6667*(1./(W+Y1*ZZ))**0.6666667
      Q2=A2**1.6667*(1./(W+Y2*ZZ))**0.6666667
      MS=(ALOG10(Q2)-ALOG10(Q1))/(ALOG10(A2)-ALOG10(A1))
      ALP=Q2/(A2**MS)
      ALPHS=1.49/RCMAN(JEL)*SQRT(SLOPE(JEL))*ALP
 1240 ALPME(JEL)=ALPHS
      EMDEQ(JEL)=MS
C
C        STREAM LATERAL INFLOW IS SET EQUAL TO THE ADJUSTED RUNOFF
C        HYDROGRAPH, UPSTREAM INFLOW IS SET EQUAL TO ZERO, AND THE
C        INITIAL CONDITIONS ARE DERIVED FROM THE INITIAL DISCHARGE
C        SPECIFIED
C
      DO 1250 J=1,NDT
```

```
      QLAT(J)=RUNOFF(J)
 1250 QUPST(J)=0.0
      IF (IRUPF(JEL).NE.1) GO TO 1300
C
C     DEFINE UPSTREAM FLOWS QK(.)
      K=0
      K=K+1
      QUPST(1)=QK(K)*CFQ
      L=1
      DO 1280 I=2,NQ
      TMP1=QK(K)
      K=K+1
      TMP2=(QK(K)-TMP1)/RJR
      DO 1270 J=1,JR
      L=L+1
      QUPST(L)=(TMP1+TMP2*FLOAT(J))*CFQ
 1270 CONTINUE
 1280 CONTINUE
C
C          SET RUNOFF TO SUM OF UPSTREAM AND LATERAL INFLOW,
C          THEN USE FLOGRD TO COMPUTE DELTA X
C
      DO 1290 J=1,NDT
      RUNOFF(J)=QUPST(J)+QLAT(J)
 1290 CONTINUE
C
C         FLOGRD COMPUTES THE MAGNITUDE AND NUMBER OF DX INTERVALS IN THE
C         FINITE DIFFERENCE GRID FOR THE KINEMATIC STREAM ROUTING OF THE
C         RUNOFF HYDROGRAPH.
C
 1300 CALL FLOGRD (NDT,RUNOFF,NDX,JEL,KINERR,IPRINT)
      IF (KINERR.NE.0) RETURN
C     SET INITIAL CONDITIONS TO FIRST FLOW
      IF (FLOIC(JEL).LE.0.) FLOIC(JEL)=QUPST(1)
      RMS=1./MS
      IF (FLOIC(JEL).LE.0.0) AINIT=0.0
      IF (FLOIC(JEL).LE.0.0) GO TO 1310
      AINIT=(FLOIC(JEL)/ALPHS)**RMS
 1310 DO 1320 J=1,NDX
 1320 ADS(J)=AINIT
C
      SUMA=FLOAT(NDX)*AINIT
C        FDKRUT IS USED HERE TO COMPUTE THE SUB-AREA OUTFLOW HYDROGRAPH
C
      CALL FDKRUT (NDX,NDT,JEL,SUMA,ADS,QLAT,QUPST,FLDFLO)
C
      IF (JEL.GE.IEL) GO TO 1340
      AX=SAREA(JEL)
      IF (AX.LE.0.0) AX=TAREA
C     RESET RUNOFF AS FLDFLO RATIOED BY AREA SERVED
      TA=SAREA(JEL+1)
      IF (TA.LE.0.0) TA=TAREA
      IF (JEL+1.EQ.IEL) TA=TAREA
      DO 1330 I=1,NDT
 1330 RUNOFF(I)=FLDFLO(I)*TA/AX/CHLNG(JEL+1)
      GO TO 1180
```

```
 1340 CONTINUE
C
C         STORE FLOWS CORRESPONDING TO STANDARD TIME INTERVAL IN Q(.)
C
      L=0
      DO 1355 J=1,NDT,JR
      TMP=FLDFLO(J)
      IF (TMP.LE.0.0) TMP=0.0
      L=L+1
      Q(L)=TMP
 1355 CONTINUE
C
C        SUBROUTINE 'TOMTRC' CONVERTS ENGLISH UNITS TO METRIC UNITS.
C
      IF (METRC.LE.0) GO TO 1360
      CALL TOMTRC
 1360 CONTINUE
C
      IF(IPRINT.EQ.0) RETURN
C
C        PRINT INPUT DATA AND COMPUTED KINEMATIC PARAMETERS FOR THE
C        CURRENT SUB-AREA BEING SIMULATED.
C
      IF(METRC.EQ.0) WRITE(IOUB,1370)
      IF(METRC.NE.0) WRITE(IOUB,1371)
      IELP=0
      DO 1390 I=1,IEL
      IF (I.EQ.2 .AND. PAREA(1).GT.99.5) GO TO 1390
      DTKWR(I)=DTKWR(I)/60.
      IF(METRC.NE.0) DXKWR(I)=DXKWR(I)/3.28
      IELP=IELP+1
      WRITE(IOUB,1380) IELP,ALPME(I),EMDEQ(I),DTKWR(I),DXKWR(I)
 1390 CONTINUE
C
      RETURN
 1370 FORMAT(/ 1X, 29HCOMPUTED KINEMATIC PARAMETERS//2X, 50HELEMENT
     1ALPHA          M          DT (MIN)     DX (FT))
 1371 FORMAT(/ 1X, 29HCOMPUTED KINEMATIC PARAMETERS//2X, 50HELEMENT
     1ALPHA          M          DT (MIN)     DX (MT))
 1380 FORMAT(2X,I4,3X,F10.4,F9.3,F12.2,F12.2)
      END
      SUBROUTINE FDKRUT (NDX,NDT,IL,SUM,A,QLAT,QUPST,DSCHRG)
C
C
C        SUBROUTINE 'FDKRUT' IS THE FINITE DIFFERENCE SOLUTION SCHEME.
C        GENERATES OVERLAND FLOW RUNOFF HYDROGRAPHS OR STREAM DISCHARGE
C        HYDROGRAPHS.
C
C        THIS SUBROUTINE IS CALLED BY SUBROUTINES 'KINOFF'.
C
C        FDKRUT REQUIRES A LATERAL INFLOW HYDROGRAPH, AN UPSTREAM INFLOW
C        HYDROGRAPH AND A SET OF INITIAL CONDITIONS.THESE QUANTITIES ARE
C        CALCULATED IN THE CALLING SUBROUTINES AND PASSED TO 'FDKRUT'.
C
      COMMON /FDK01/ CHLNG(5),SLOPE(5),RCMAN(5),PAREA(5),ISHAPE(5),
     1 CHWDT(5),ZLNG(5),ALPME(5),EMDEQ(5),DXROF(5),DXFLO(5),DTKWR(5),
```

```
     2 DXKWR(5),IRUPF(5),SAREA(5),FLOIC(5)
C
      DIMENSION A(51),QLAT(1225),QUPST(1225),DSCHRG(1225)
      REAL M
C
C        ASSIGN VALUES TO KINEMATIC PARAMETERS
C
      M=EMDEQ(IL)
      ALPH=ALPME(IL)
      RM=1./M
      EXM=M-1.
      NDT1=NDT+1
C
C        START OF COMPUTATION LOOP TO GENERATE HYDROGRAPH.
C
      DO 1060 I=2,NDT1
      K=I-1
      ASAV1=A(1)
      QNEW=QUPST(K)
      IF (QNEW.LT.0.0) QNEW=0.0
      IF (QNEW.LE.0.0) A(1)=0.0
      IF (QNEW.LE.0.0) GO TO 1000
      A(1)=(QNEW/ALPH)**RM
 1000 ASAVE=A(1)
      ALAT=QLAT(K)*DTKWR(IL)
      ANDX=A(NDX)
      IF (ANDX.LT.1.0E-20) ANDX=0.0
C
C     ESTIMATE SPEED OF 'DISTURBANCE' TO SELECT APPROPRIATE COMPUTATION
C        SCHEME.
C
      WAVEQ=(QNEW-ALPH*ANDX**M)/CHLNG(IL)+ALAT+SUM/FLOAT(NDX)
      CELER=ALPH*M*WAVEQ**EXM
      SUM=A(1)
      IF (CELER.GT.(DXKWR(IL)/DTKWR(IL))) GO TO 1030
C
C                  STANDARD FORM OF FINITE DIFFERENCE
C
      DO 1020 J=2,NDX
      AZ=(ASAVE+A(J))/2.
      IF (AZ.LT.1.0E-20) AZ=0.
      IF (AZ.LT.1.0E-20) THETA=0.0
      IF (AZ.LT.1.0E-20) GO TO 1010
      THETA=(ALPH*M*DTKWR(IL)/DXKWR(IL))*AZ**EXM
 1010 ANEW=ALAT+A(J)-THETA*(A(J)-ASAVE)
      IF (ANEW.LT.0.0) ANEW=0.0
      ASAVE=A(J)
      A(J)=ANEW
 1020 SUM=SUM+ANEW
      GO TO 1050
C
C                  CONSERVATION FORM OF FINITE DIFFERENCE
C
 1030 QLATCV=ALAT*DXKWR(IL)/DTKWR(IL)
      DO 1040 J=2,NDX
      QNEW=QNEW+QLATCV-((DXKWR(IL)/DTKWR(IL))*(A(J-1)-ASAV1))
```

```
      IF (QNEW.LT.0.0) QNEW=0.0
      ASAV1=A(J)
      A(J)=(QNEW/ALPH)**RM
 1040 SUM=SUM+A(J)
C
C        'A(NDX)' IS CONCENTRATION AT DOWNSTREAM LIMIT OF ELEMENT BEING
C        SIMULATED.  DISCHARGE IS GIVEN BY KINEMATIC WAVE FORMULA.
C
 1050 IF (A(NDX).LT.1.0E-20) A(NDX)=0.
      DSCHRG(K)=ALPH*A(NDX)**M
 1060 CONTINUE
C
C
      RETURN
      END
      SUBROUTINE FLOGRD (NDT,RUNOFF,NDX,IL,KINERR,IPRINT)
C
C        SUBROUTINE 'FLOGRD' COMPUTES THE NUMBER AND MAGNITUDE OF THE
C        DX INTERVALS USED IN THE STREAM ROUTING PORTION OF THE SUB-AREA
C        RUNOFF COMPUTATIONS BY THE KINEMATIC ROUTINES.
C
C        THIS SUBROUTINE IS CALLED BY SUBROUTINE 'KINOFF'.
C
C        'FLOGRD' USES THE SAME NUMBER AND MAGNITUDE FOR THE DT
C        INTERVAL FOR STREAM ROUTING AS WAS COMPUTED IN 'ROFGRD' FOR
C        CATCHMENT OVERLAND FLOW ROUTING.  THE NUMBER OF DX INTERVALS
C        IS THEN COMPUTED AS A FUNCTION OF DT AND ADJUSTED SO THAT
C        THERE ARE AT LEAST 2 BUT NO MORE THAN MXNDX DX INTERVALS.
C        MXNDX MAY BE CHANGED IN DATA STATEMENT IN SUBROUTINE
C        KINWAVE AND VARIABLES ADS(MXNDX+1) AND A(MXNDX+1) IN
C        SUBROUTINES KINOFF AND FDKRUT, RESPECTIVELY SHOULD HAVE
C        CORRESPONDING DIMENSIONS CHANGED.
C
      COMMON /CMIOP/          IOUA          , IOUB          ,
     1         NHOUR          ,NDATA        ,
     2        NTIME,NHRP,NHRQ,NDTQ,INPQ,NBASIN,IWBLNC,IPFRQR,IPFRQQ
      COMMON /FDK00/ TAREA,TRMN,TRHR,METRC,IEL,NQ,MXNDX,MXNDT
      COMMON /FDK01/ CHLNG(5),SLOPE(5),RCMAN(5),PAREA(5),ISHAPE(5),
     1 CHWDT(5),ZLNG(5),ALPME(5),EMDEQ(5),DXROF(5),DXFLO(5),DTKWR(5),
     2 DXKWR(5),IRUPF(5),SAREA(5),FLOIC(5)
C
      DIMENSION  RUNOFF(1225)
C
      REAL MS
C
C        ASSIGN VALUES TO KINEMATIC PARAMETERS.
C
      ALPHS=ALPME(IL)
      MS=EMDEQ(IL)
      DMS=(MS-1.)/MS
      EMS=MS-1.
      RMS=1./MS
C
C        DETERMINE AVERAGE RATE OF LATERAL INFLOW.
C
      PEAK=0.
```

```
      RATE=0.
      DURATN=0.
      DO 900 I=1,NDT
      IF(RUNOFF(I).GT.PEAK)PEAK=RUNOFF(I)
  900 CONTINUE
      FMIN=.01*PEAK
      DO 1000 I=1,NDT
C
      IF(RUNOFF(I).LT.FMIN)GO TO 1000
      DURATN=DURATN+DTKWR(1)
      RATE=RATE+RUNOFF(I)*CHLNG(IL)
 1000 CONTINUE
      KINERR=0
      IF (DURATN.GT.0.) GO TO 1020
C
C        PROBABLE ERROR IN PREVIOUS SUBROUTINE - PRINT DIAGNOSTIC
C        MESSAGE AND RETURN.
C
      KINERR=1
      IF(IPRINT.NE.0) WRITE(IOUB,1010)
      RETURN
C
 1020 AVGIN=RATE/DURATN
      TC=((CHLNG(IL)/(3.2*ALPHS*MS*AVGIN**EMS)))**RMS*3.2
      DIMT=DTKWR(1)/TC
C
C        COMPUTE DX FOR STREAM ROUTING.
C
      DX1=CHLNG(IL)*DIMT*3.2**DMS*MS**DMS
      DTKWR(IL)=DTKWR(1)
      DXFLO(IL)=DX1
C
C        ADJUST DX TO BE INTEGER MULTIPLE OF STREAM LENGTH BETWEEN 2 & 5
C
      DXMAX=CHLNG(IL)/2.
      DXMIN=CHLNG(IL)/FLOAT(MXNDX-1)
      IF (DX1.GE.DXMAX) GO TO 1030
      IF (DX1.LE.DXMIN) GO TO 1040
      NDX=CHLNG(IL)/DX1
      NDX=NDX+1
      RNDX=NDX-1
      DXKWR(IL)=CHLNG(IL)/RNDX
      RETURN
 1030 NDX=3
      DXKWR(IL)=CHLNG(IL)/2.
      RETURN
 1040 NDX=MXNDX
      DXKWR(IL)=CHLNG(IL)/FLOAT(MXNDX-1)
      RETURN
C
 1010 FORMAT(//2X,'NOTE: NO RUNOFF FROM CATCHMENT(S)'/)
      END
      SUBROUTINE FRMMTC
C
C
C        SUBROUTINE 'FRMMTC' CONVERTS THE REQUIRED INPUT DATA TO KINOFF
```

```
C        FROM METRIC TO ENGLISH UNITS WHEN METRC IS EQUAL TO 1.
C        THIS SUBROUTINE IS CALLED FROM SUBROUTINE 'KINOFF'
C
      COMMON /FDK00/ TAREA,TRMN,TRHR,METRC,IEL,NQ,MXNDX,MXNDT
      COMMON /FDK01/ CHLNG(5),SLOPE(5),RCMAN(5),PAREA(5),ISHAPE(5),
     1 CHWDT(5),ZLNG(5),ALPME(5),EMDEQ(5),DXROF(5),DXFLO(5),DTKWR(5),
     2 DXKWR(5),IRUPF(5),SAREA(5),FLOIC(5)
      COMMON /FDK02/ EXCSR(1224),Q(1224),
     1 QK(1224),QUB(1224),QBF(1224)
C
C         CONVERT EXCESS FROM MM TO INCHES
      DO 1000 J=1,NQ
      EXCSR(J)=0.03937*EXCSR(J)
 1000 CONTINUE
C
C         CONVERT CHANNEL LENGTH, WIDTH, AND SERVICE AREA
      DO 1010 I=1,5
      CHLNG(I)=CHLNG(I)/0.3048
      CHWDT(I)=CHWDT(I)/0.3048
      SAREA(I)=SAREA(I)/2.590
 1010 CONTINUE
C
      TAREA=TAREA/2.589988
C
      RETURN
      END
      SUBROUTINE ROFGRD (NDX1,NDX2,NDT,KINERR,IPRINT)
C
C        SUBROUTINE 'ROFGRD' COMPUTES THE NUMBER OF DX & DT INTERVALS IN
C        THE FINITE DIFFERENCE GRID FOR OVERLAND FLOW.IT ALSO CALCULATES
C        THE MAGNITUDE OF EACH INTERVAL IN FEET OR SECONDS.
C
C        THIS SUBROUTINE IS CALLED FROM SUBROUTINE 'KINOFF'.
C
C        'ROFGRD' REQUIRES THE NUMBER OF COMPUTATION INTERVALS 'NQ' .
C        THE NUMBER OF DT INTERVALS GIVEN BY 'ROFGRD' WILL
C        BE NO LESS THAN 'NQ' BUT NO MORE THAN 1224. IF MORE THAN 'NQ'
C        INTERVALS ARE USED THE NUMBER OF INTERVALS WILL BE AN INTEGER
C        MULTIPLE OF 'NQ'.
C
C        THE NUMBER OF DX INTERVALS WILL BE A FUNCTION OF THE VALUE OF
C        DT BUT WILL BE NO LESS THAN 2 NOR MORE THAN 50.
C
      COMMON /CMIOP/         IOUA          , IOUB          ,
     1          NHOUR       ,NDATA         ,
     2         NTIME,NHRP,NHRQ,NDTQ,INPQ,NBASIN,IWBLNC,IPFRQR,IPFRQQ
      COMMON /FDK00/ TAREA,TRMN,TRHR,METRC,IEL,NQ,MXNDX,MXNDT
      COMMON /FDK01/ CHLNG(5),SLOPE(5),RCMAN(5),PAREA(5),ISHAPE(5),
     1 CHWDT(5),ZLNG(5),ALPME(5),EMDEQ(5),DXROF(5),DXFLO(5),DTKWR(5),
     2 DXKWR(5),IRUPF(5),SAREA(5),FLOIC(5)
      COMMON /FDK02/ EXCSR(1224),Q(1224),
     1 QK(1224),QUB(1224),QBF(1224)
C
      REAL MC
C
C        ASSIGN VALUES TO KINEMATIC PARAMETERS AND TO 'NDX2'
```

```
C
      MC=EMDEQ(1)
      RMC=1./MC
      EMC=MC-1.
      DMC=(MC-1.)/MC
      DT2=1.0E20
      ALPH1=ALPME(1)
      ALPH2=ALPME(2)
      NDX2=0
C
C
C         DETERMINE RAINFALL VOLUME AND AVERAGE INTENSITY
C
      PEAK=0.
      AMT1=0.
      AMT2=0.
      AVGRN1=0.
      AVGRN2=0.
      DURTN1=0.
      DURTN2=0.
      DO 900 I=1,NQ
      IF(EXCSR(I).GT.PEAK)PEAK=EXCSR(I)
  900 CONTINUE
      EMIN=.1*PEAK
      DO 1000 I=1,NQ
      IF(EMIN.GT.EXCSR(I))GO TO 1000
      AMT1=AMT1+EXCSR(I)
      DURTN1=DURTN1+TRMN
 1000 CONTINUE
      IF(PAREA(1).GT.99.5) GO TO 950
      AMT2=AMT1
      AVGRN2=AVGRN1
      DURTN2=DURTN1
  950 KINERR=0
      IF((AMT1+AMT2).GT.0.0.AND.(DURTN1+DURTN2).GT.0.0) GO TO 1020
C
C         NO EXCESS RAIN OR PROBABLE INPUT ERROR - PRINT DIAGNOSTIC
C                    MESSAGE AND RETURN
C
      KINERR=1
      IF (KINERR.EQ.1.AND.IPRINT.NE.0) WRITE(IOUB,1010)
      DT=TRMN*60.
      DTKWR(1)=DT
      DTKWR(2)=DT
      NDT=NQ
      RETURN
C
C
C          COMPUTE AVERAGE EXCESS IN FEET PER SECOND
C
 1020 IF (DURTN1.GT.0.) AVGRN1=AMT1/(720.*DURTN1)
      IF (DURTN2.GT.0.) AVGRN2=AMT2/(720.*DURTN2)
C
C
C         SET VALUES FOR ESTIMATING DX & DT.
C
```

```
      SCALEQ=1.0
      SCALEX=1.0
      XQ=AVGRN1*SCALEQ
C
C
C        DETERMINE THE MAXIMUM NUMBER OF DT INTERVALS AND THE MINIMUM
C        VALUE OF DT.  FOR MORE INTERVALS OR SMALLER DT INCREASE
C        THE DIMENSIONS OF ARRAYS QLAT(.), QUPST(.), RNOFF1(.),
C        RNOFF2(.), RUNOFF(.), FLDFLO(.), AND DSCHRG(.) WHICH ARE
C        CURRENTLY SET TO 1225 (=MXNDT, SEE DATA STATEMENT IN 'KINWAVE')
C
      INDEX=(MXNDT-1)/(NQ-1)
      DTMIN=TRMN*60./FLOAT(INDEX)
C
C        DETERMINE DX & DT VALUES BASED ON KINEMATIC WAVE AND APPLIED
C        RAINFALL.
C
      IF (AVGRN1.GT.0.) GO TO 1050
      DT1=TRMN*60.
      GO TO 1060
 1050 XL=CHLNG(1)*SCALEX
      DT1=(XL/(3.2*ALPH1*MC*(XQ**EMC)))**RMC
      DT1=DT1*3.2
 1060 DXROF(1)=DT1
C
      IF (PAREA(1).GT.99.5) GO TO 1090
C
      IF (AVGRN2.GT.0.) GO TO 1070
      DT2=TRMN*60.
      GO TO 1080
 1070 XQ=AVGRN2*SCALEQ
      XL=CHLNG(2)*SCALEX
      DT2=(XL/(3.2*ALPH2*MC*(XQ**EMC)))**RMC
      DT2=DT2*3.2
 1080 DXROF(2)=DT2
C
C        COMPARE MINIMUM DT VALUE BASED ON RAINFALL/KINEMATIC TO THE
C        MINIMUM VALUE OF DT AS CONTROLLED BY THE CURRENT DIMENSION
C        STATEMENTS OF THE APPROPRIATE ARRAYS.
C
 1090 CONTINUE
      TRYT=DT1
      IF (DT2.LT.DT1) TRYT=DT2
      IF (TRYT.LT.DTMIN) TRYT=DTMIN
C
C
C        ADJUST COMPUTED DT TO BE AN INTEGER MULTIPLE OF 'NQ' AND
C        COMPATIBLE WITH CURRENT DIMENSIONS.
C
      INDEX=TRMN*60./TRYT+0.5
      IF (INDEX.LT.1) INDEX=1
      DT=TRMN*60./FLOAT(INDEX)
      NDT=INDEX*(NQ-1)+1
C
      DTKWR(1)=DT
      DTKWR(2)=DT
```

```
C
C
C        DETERMINE DX FOR THE FIRST CATCHMENT ELEMENT.
C
      DIMT=DT/DT1
      DX1=CHLNG(1)*DIMT*3.2**DMC*MC**DMC
      DXFLO(1)=DX1
C
C        ADJUST DX TO BE AN INTEGER MULTIPLE OF CATCHMENT LENGTH BETWEEN
C        2 AND MXNDX (SEE COMMENTS IN SUBROUTINE FLOGRD).
C
      DXMIN=CHLNG(1)/FLOAT(MXNDX-1)
      DXMAX=CHLNG(1)/2.
      IF (DX1.GE.DXMAX) GO TO 1120
      IF (DX1.LE.DXMIN) GO TO 1130
      NDX1=CHLNG(1)/DX1
      NDX1=NDX1+1
      RNDX1=NDX1-1
      DXKWR(1)=CHLNG(1)/RNDX1
      GO TO 1140
 1120 NDX1=3
      DXKWR(1)=CHLNG(1)/2.
      GO TO 1140
 1130 NDX1=MXNDX
      DXKWR(1)=CHLNG(1)/FLOAT(MXNDX-1)
C
C
C        DETERMINE DX FOR SECOND CATCHMENT ELEMENT.
C
 1140 CONTINUE
      IF (PAREA(1).GT.99.5) RETURN
      DIMT=DT/DT2
      DX2=CHLNG(2)*DIMT*3.2**DMC*MC**DMC
      DXFLO(2)=DX2
C
C
C        ADJUST DX TO BE AN INTEGER MULTIPLE OF CATCHMENT LENGTH BETWEEN
C        2 AND MXNDX (SEE COMMENTS IN SUBROUTINE FLOGRD).
C
      DXMIN=CHLNG(2)/FLOAT(MXNDX-1)
      DXMAX=CHLNG(2)/2.
      IF (DX2.GE.DXMAX) GO TO 1150
      IF (DX2.LE.DXMIN) GO TO 1160
      NDX2=CHLNG(2)/DX2
      NDX2=NDX2+1
      RNDX=NDX2-1
      DXKWR(2)=CHLNG(2)/RNDX
      RETURN
 1150 NDX2=3
      DXKWR(2)=CHLNG(2)/2.
      RETURN
 1160 NDX2=MXNDX
      DXKWR(2)=CHLNG(2)/FLOAT(MXNDX-1)
      RETURN
C
 1010 FORMAT(//2X,'NOTE: NO RAINFALL EXCESS FOR SUBAREA'/8X,
```

```
     1 'RUNOFF SET EQUAL TO ZERO.'/)
C
      END
      SUBROUTINE TOMTRC
C
C        SUBROUTINE 'TOMTRC' CONVERTS THE ORIGINAL INPUT DATA TO 'KINOFF
C        THE COMPUTED HYDROGRAPH TO METRIC UNITS
C        THIS SUBROUTINE IS CALLED FROM SUBROUTINE 'KINOFF'.
C
      COMMON /FDK00/ TAREA,TRMN,TRHR,METRC,IEL,NQ,MXNDX,MXNDT
      COMMON /FDK01/ CHLNG(5),SLOPE(5),RCMAN(5),PAREA(5),ISHAPE(5),
     1 CHWDT(5),ZLNG(5),ALPME(5),EMDEQ(5),DXROF(5),DXFLO(5),DTKWR(5),
     2 DXKWR(5),IRUPF(5),SAREA(5),FLOIC(5)
      COMMON /FDK02/ EXCSR(1224),Q(1224),
     1 QK(1224),QUB(1224),QBF(1224)
C
C
      CFS=(0.0254*12.)**3
      DO 1000 J=1,NQ
      EXCSR(J)=EXCSR(J)/0.03937
      Q(J)=Q(J)*CFS
 1000 CONTINUE
      DO 1010 I=1,5
      CHLNG(I)=CHLNG(I)*.3048
      CHWDT(I)=CHWDT(I)*.3048
      SAREA(I)=SAREA(I)*2.590
 1010 CONTINUE
      TAREA=TAREA*2.590
C
      RETURN
      END
~eor
```

APPENDIX 1.8.C

PROGRAM INPUT REQUIREMENTS AND DESCRIPTION

Data Set 1. Model run information

This data set is contained in one record and read in variable TITLE(.) usign Fortran FORMAT(10A8). No data set identifier is specified.

Data Set 2. Control parameters

This data set is also contained in one record to read the following variables using FORMAT(5I5):

NPOP - number of SAC model parameters to be optimized

IUPDF - generates updated input file

IWBLNC - number of time steps water balance are made

IPFRQR - printing frequency of SAC results

IPFRQQ - printing frequency of streamflow

This data set has no record identifier.

Data Set 3. Optimization parameters

This data set is needed if optimization is desired by specifying NPOP not equal to zero. The values of the variables below are read using FORMAT (F10.0,4I5) with no record identifier.

ERROR - error criterion of relative difference of old and new objective function value

IOBF - type of objective function

MXITER - maximum number of iterations

NSTEP - step size update option, equals 1 if updated, otherwise equal to 0

IPROP - printing frequency of results at each stage evaluation

Note: For the option and types of objective functions available, see comment statement in program listing.

Data Set 4. Soil-moisture accounting model parameters

In this data set, the 24 SAC model parameters are read which could be any order. The value of each parameter is contained in one record with a record identifier. If a parameter is to be optimized, the record string should include some specified minimum and maximum values as well as the step size since these latter three values are required in the optimization routine. For each record, the following variables are read using FORMAT (2A5,4F10.0)

PNAME(.) - variable name of model parameter which is also the record identifier

DUM - dummy variable which is not used in the program but simply read for "echo" printing purposes

XMP(.) - value of parameter

XMIN(.) - lower found of parameter

XMAX(.) - upper bound of parameter

ESS(.) - parameter step size

A record containing the word "END" should be placed at the bottom of this data set.

The variable name of the 24 model parameters are listed below with brief descriptions of each. These variable names are also used as identifiers and read in PNAME(.).

1. PXADJ - precipitation adjustment factor
2. PEADJ - evapotranspiration demand adjustment factor
3. PCTIM - fraction of permanent inpervious area

4. ADIMP - fraction of impervious area when all tension storage water are met
5. RIVA - fraction of basin covered by streams, lakes and riparian vegetation
6. UZK - upper zone for water storage depletion coefficient
7. LZSK - lower zone supplementary storage depletion coefficient
8. LZPK - lower zone primary storage depletion coefficient
9. PFREE - fraction of percolated water transmitted directly to the lower zone free water
10. RSERV - fraction of lower zone free water unavailable for transpiration purposes
11. ZPERC - proportionality constant in increasing percolation from saturated to dry condition
12. REXP - exponent defining curvature in percolation curve with changes in the lower zone soil moisture deficiency
13. SIDE - portion of baseflow not observed in the channel
14. UZTWM - upper zone tension water storage content
15. UZFWM - upper zone free water storage content
16. LZTWM - lower zone tension water storage content
17. LZTSM - lower zone supplementary water storage content
18. LZFPM - lower zone primary water storage content
19. UZTWC - upper zone tension water storage capacity
20. UZFWC - upper zone free water storage capacity
21. LZTWC - lower zone tension water storage capacity
22. LZFSC - lower zone supplementary water storage capacity
23. LZFPC - lower zone primary water storage capacity

24. ADIMC - additional impervious area storage capacity usually taken as UZTWM + LZTWM

There are two rules to be followed in inputting the above data set.

1. If some model parameters are to be optimized, they must be placed on top of the others.

2. The model parameters containing the initial soil-moisture contents should be placed after those containing the soil-moisture capacities. This is done when the soil-moisture content parameters are not optimized since otherwise the maximum values are specified.

Data Set 5. Kinematic wave routing parameters

The manner in which the kinematic wave model parameters are inputted is based on the physical configuration of the basin. For this purpose, three types of operations have been designated which accommodates practically any basin configuration. These three operations are "ROUTE", "ADD" and "BASEF" which are also used as record identifiers. In inputting a parameter set corresponding to an operation, the first record contains either one of the three operations with an integer variable which are read into ROPER and IOPER using FORMAT (A5, I5). This record may be followed by some input parameters depending on the type of operation as described below.

ROUTE Operation. This operation computes the flow hydrograph from overland plane to channel outlet. As many as two, overland flow planes and collector channels plus a main channel are used to represent a subbasin (second-level). The input parameter sets and sequence are as follow:

Parameter Set 1: Basin Area

TAREA - total subbasin area which is read as (F10.0)

Parameter Set 2: Overland flow element (one record and read as 4F10.10)

CHLNG(.) - overland flow length

SLOPE(.) - slope

RCMAN(.) - roughness coefficient

PAREA(.) - percent of subbasin area

If PAREA(1) is less than 99.5% a second overland-flow element is expected and the same parameters above are required for this second one.

Parameter Set 3: Collector and Main Channel (two records using 5F10.0)

Record 1: CHLNG(.) - channel length
SLOPE(.) - slope
RCMAN(.) - roughness coefficient
SAREA(.) - contributing area

Record 2: ASHAPE(.) - shape of channel used
CHWDT(.) - channel width
ZLNG(.) - side slope
FLOIC(.) - initial flows at outlet
ARUPF(.) - indicator if upstream flow from another subbasin is routed (applicable only in the main channel)

At least one collector channel and the main channel must be specified in a subbasin. A second collector channel is specified if SAREA(.) of the first collector channel is less than the total area

TAREA(.). However, the program assumes that there is only one collector channel if SAREA(1) is inputted as zero.

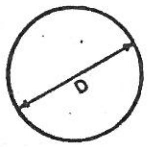
Variable ASHAPE(.) specifies the shape of collector or main channel. These are shown in Figure 1.8.C.1. The variable ASHAPE(.) is set equal to: 1.0 for circular, 2.0 for triangular, 3.0 for square, 4.0 for rectangular, and 5.0 for trapezoidal. Depending on channel shape specified, either ZLNG(.) or CHWDT(.) may be left blank. In the case of a circular channel, the diameter D is specified in CHWDT(.). Only in the case of triangular and trapezoidal channel shapes where ZLNG(.) is required. However, CHWDT(.) is not required for triangular channels.

Depending on the storage space (array dimension) fixed in the program, several ROUTE operations can be issued for a subwatershed (first-level partitioning). For example, if there are three subbasins (at second-level partitioning) that are separated from each other three ROUTE operations have to be made and possibly "ADD" the three routed flows after.

<u>ADD operation.</u> This operation adds the previous IOPER flow hydrograph processed in the "ROUTE" operation. The "ADD" operation can only be used after two or more flow hydrographs have already been computed.

<u>BASE operation.</u> This operation adds the baseflow component to the surface flow hydrograph at a subbasin outlet. Usually this operation is done after a "ROUTE" operation. The baseflow hydrograph component is computed using a linear weighted function of current and previous IOPER baseflow runoff components (obtained in SAC). One or more records should follow the "BASEF" record which contains the weights WBF(I), for I = 1,...,IOPER + 1 which is read using FORMAT (5G10.0).

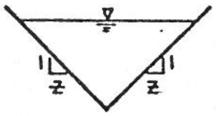
CIRCULAR



$$\alpha = \frac{.804}{n} S^{1/2} D^{1/6}$$

$$m = 5/4$$

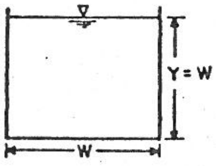
TRIANGULAR



$$\alpha = \frac{0.94}{n} S^{1/2} \left(\frac{Z}{1+Z^2}\right)^{1/3}$$

$$m = 4/3$$

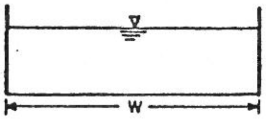
SQUARE



$$\alpha = \frac{.72}{n} S^{1/2}$$

$$m = 4/3$$

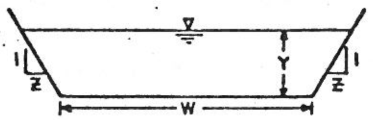
RECTANGULAR



$$\alpha = \frac{1.49}{n} S^{1/2} W^{-2/3}$$

$$m = 5/3$$

TRAPEZOIDAL



$$Q = \frac{1.49}{n} S^{1/2} A^{5/3} \left(\frac{1}{W+2Y\sqrt{1+Z^2}}\right)^{2/3}$$

Figure 1.8.C.1. Kinematic wave parameters for various channel shapes.

The usage, sequencing and combinations of ROUTE, ADD and BASEF to represent a certain basin or subbasin configuration will be further explained in the sample model application.

As in data set 4, a record with "END" should be placed at the bottom of this data set 5.

Data Set 6. Hydrologic input data

Three types of hydrologic data that may be required in the model are rainfall, evapotranspiration (ET) demand, and streamflow. Rainfall data is always required in running the model. The ET data when not inputted is assumed to be zero. The streamflow data may not be inputted unless model parameter optimization is desired. Any hydrologic input data is read by issuing an identification record with identifiers "RAIN", "ETDAT" or "FLOW". Each record is followed by some input control parameters as follow.

RAIN input. This is followed by a record with control parameters (read as 5I5):

NHOUR - time interval in hours

NDATA - number of data points

IOUC - input device unit number

KFMT - read format option, if KFMT = 0, read format in (8F10.0), otherwise it is read in the next record

IREW - data file rewind option, if IREW is not = 0, the data file is rewound

If KFMT is not equal to 0 another record is expected containing the read format FMT(.) which is read as (10A8).

ETDAT input. To read the ET demand data, the following control parameters are read in the next record (read as 4I5):

NHRP - time interval in hours

IOUC - input device unit number

KFMT - read format option

IREW - data file rewind option

As in "RAIN" input, if KFMT is not equal to 0, a record containing the read format follows.

FLOW input. Inputting the streamflow requires the following parameters:

NHRQ - time interval in hours

INPQ - indicates if streamflow is available (if not available INPQ = 0, otherwise, INPQ is nonzero)

IOUC - read device unit number

KFMT - read format option

IREW - data file rewind option

If a FLOW record is not issued, the streamflows are computed with the same time interval as rainfall. If one is interested in a different time interval (specified in NHRQ), and no streamflow data is available, the FLOW record can be issued with INPQ nonzero.

Some items above need further clarification as follows:

1. Given the number of data points NDATA for rainfall, the number of data points required for ET demand or flow, if inputted are: NDATA/NHRP and NDATA/NHRQ, respectively.

2. The read device unit number IOUC provides a control if a hydrologic data is to be read from another file. If IOUC is set equal to 5 or 0, the data is read as part of all other data sets (control parameters, model parameters, etc.). In this case the hydrologic data should be placed after the "Data Set 6" records.

3. The data file rewind option specified in IREW is desirable when two or more subwatersheds (first-level partitioning) with different hydrologic time series are stored in a file where values for the different subwatersheds at each time period (sampling time) are contained in one record. For example, an areally averaged rainfall for the first subwatershed can be read first with say, FORMAT (F10.0). Then the rainfall for the second subwatershed can be read, say as FORMAT (10X,F10.0) after rewinding the same file.

At the bottom of this data set 6, an "END" record should be placed.

1.9 STOCHASTIC GENERATION OF STREAMFLOWS AND TURBINE OPERATING HOURS

1.9.1 INTRODUCTION

This report presents the stochastic modeling and data generation of monthly and weekly streamflows in the Nizao Basin, Dominican Republic and monthly turbine operating hours for Valdesia reservoir. For streamflow modeling three gaging stations were selected for analysis, namely: Palo de Caja, Paso del Ermitaño and Rancho Arriba. Prior to data analysis, the gaps in the historical data were filled-in and short records were extended to improve the reliability of statistical parameters to be used in modeling. The stochastic models used for both monthly and weekly streamflows were developed following standard (currently used) modeling procedures. The modeling and generation of monthly turbine operating hours were based on the monthly flows of Paso del Ermitaño.

The report presented herein is divided into four major sections, namely: 1) description of hydrologic data used, 2) filling-in and extension of historical data, 3) stochastic modeling of streamflows, 4) streamflow data generation, and, 5) modeling and generation of turbine operating hours. Some general remarks are given at the end of this report as well as literature cited and appendices.

1.9.2 DESCRIPTION OF HYDROLOGIC DATA USED

Daily data from four streamflow stations and two rainfall stations provided by Dominican Republic were used in this study. The six gaging stations are listed in Table 1.9.1 and their corresponding years of records. The locations of these stations are shown in Fig. 1.9.1

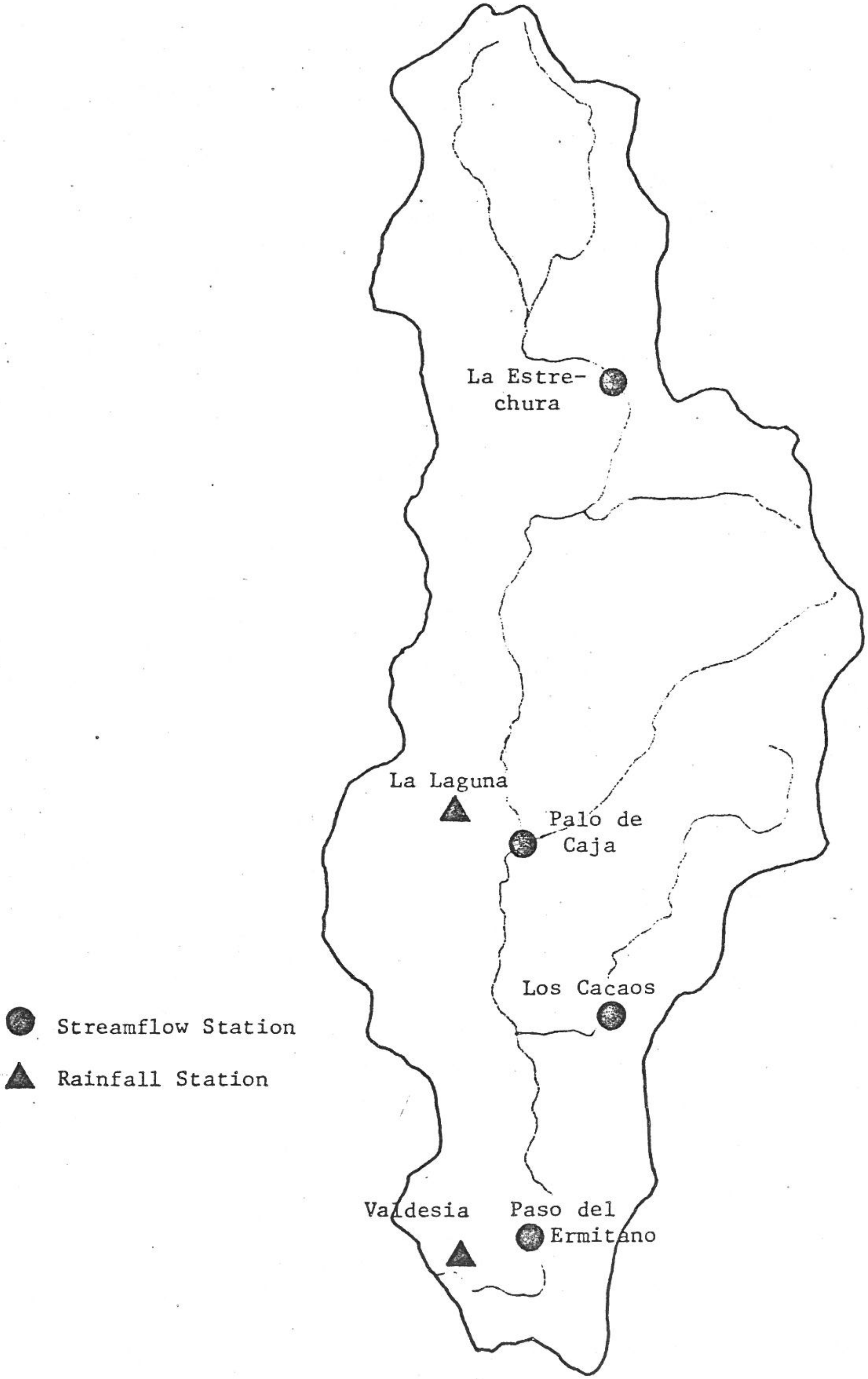


Figure 1.9.1. Map showing Nizao basin and gaging stations used in this study.

indicated by station names. For purposes of this study, the monthly data were derived from averaging the daily data of each month. The weekly data were derived from averaging daily data every seven days starting in January 1 (e.g., January 1-7 is first week, January 8-14 is second week, etc.) except for the last or 52nd week of the year (i.e., December 26 to 31) which is an eight-day average. In the case of leap years, the 9th weeks data is average from eight days comprising February 26, 27, 28 and 29, and March 1, 2, 3 and 4. Time series plots on a monthly basis for each station are given in Figs. 1.9.2 through 1.9.7. The weekly time series plots are not given due to space limitations. It has been seen however, that the basic seasonal and other time series patterns observed in the monthly time series are likewise exhibited in the weekly series.

Table 1.9.1. List of gaging stations used in this study.

Station Name	Location			
	Latitude	Longitude	Period of Record	Type of Data
Palo de Caja	18°33'17"	70°22'52"	Sept. 1956 - July, 1979	Streamflow
Paso del Ermitaño	18°26'02"	70°15'43"	Dec. 1967 - Oct. 1975	Streamflow
Rancho Arriba	18°42'58"	70°27'59"	Mar. 1959 - Oct. 1966	Streamflow
El Cacao*	18°31'44"	70°17'59"	Jan. 1962 - Dec. 1981	Streamflow
La Laguna	18°32'30"	70°24'45"	Jan. 1963 - Dec. 1979	Rainfall
Valdesia	18°24'30"	70°16'50"	Feb. 1963 - Aug. 1984	Rainfall

*Records fragmentary between 1966 to 1979.

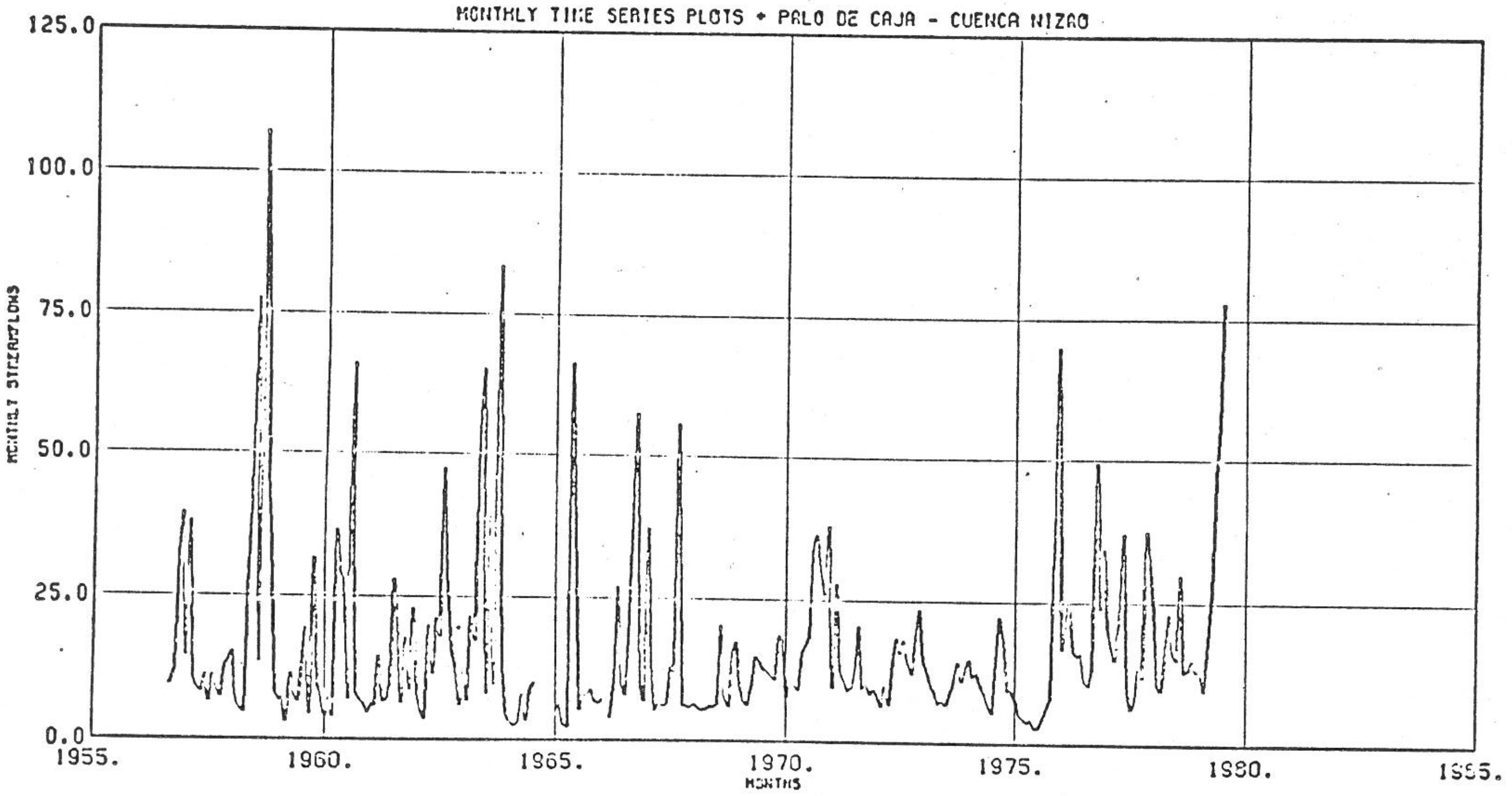


Figure 1.9.2. Time series plots of monthly streamflows of Palo de Caja.

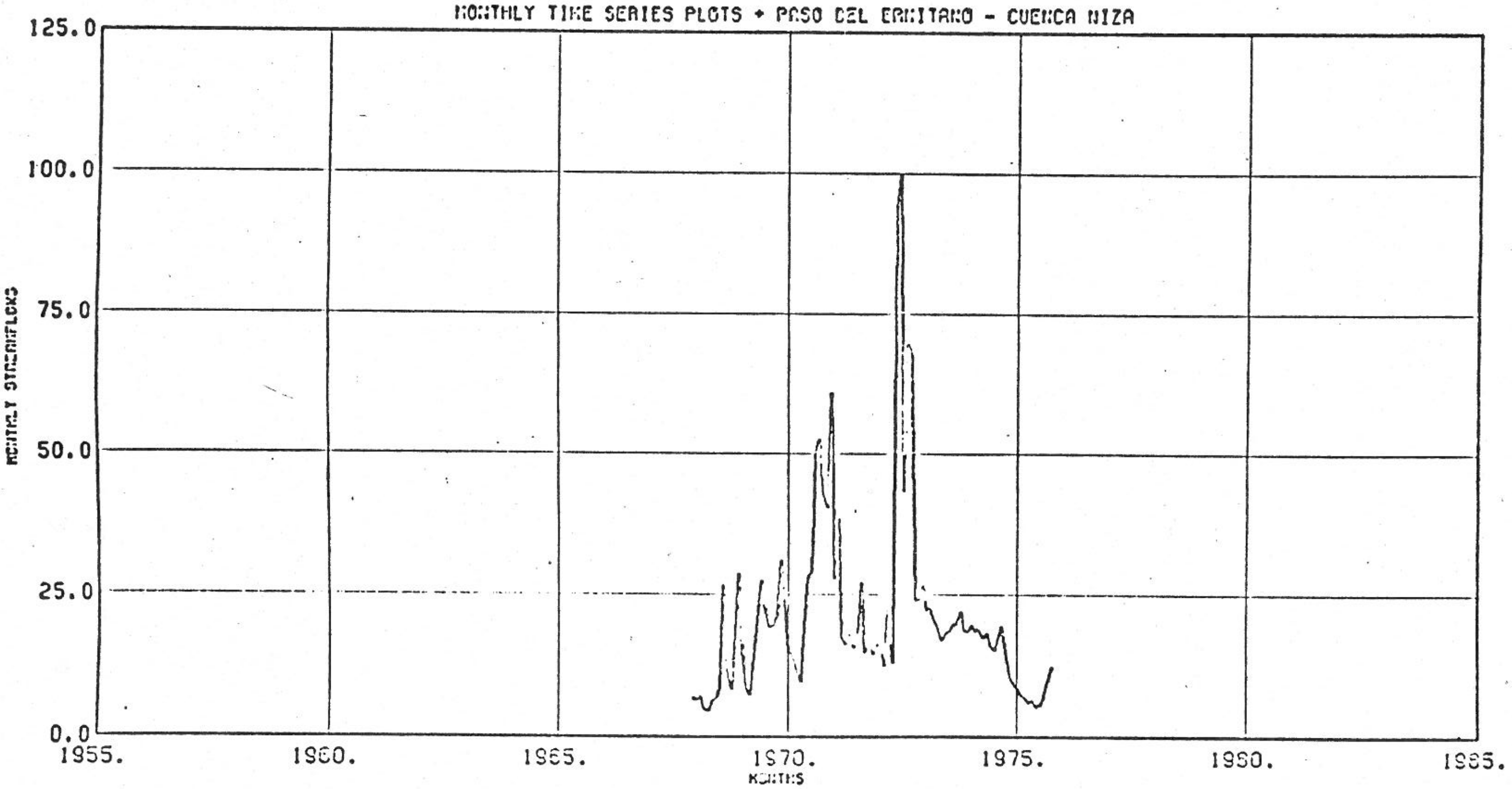


Figure 1.9.3. Time series plots of monthly streamflows of Paso del Ermitaño.

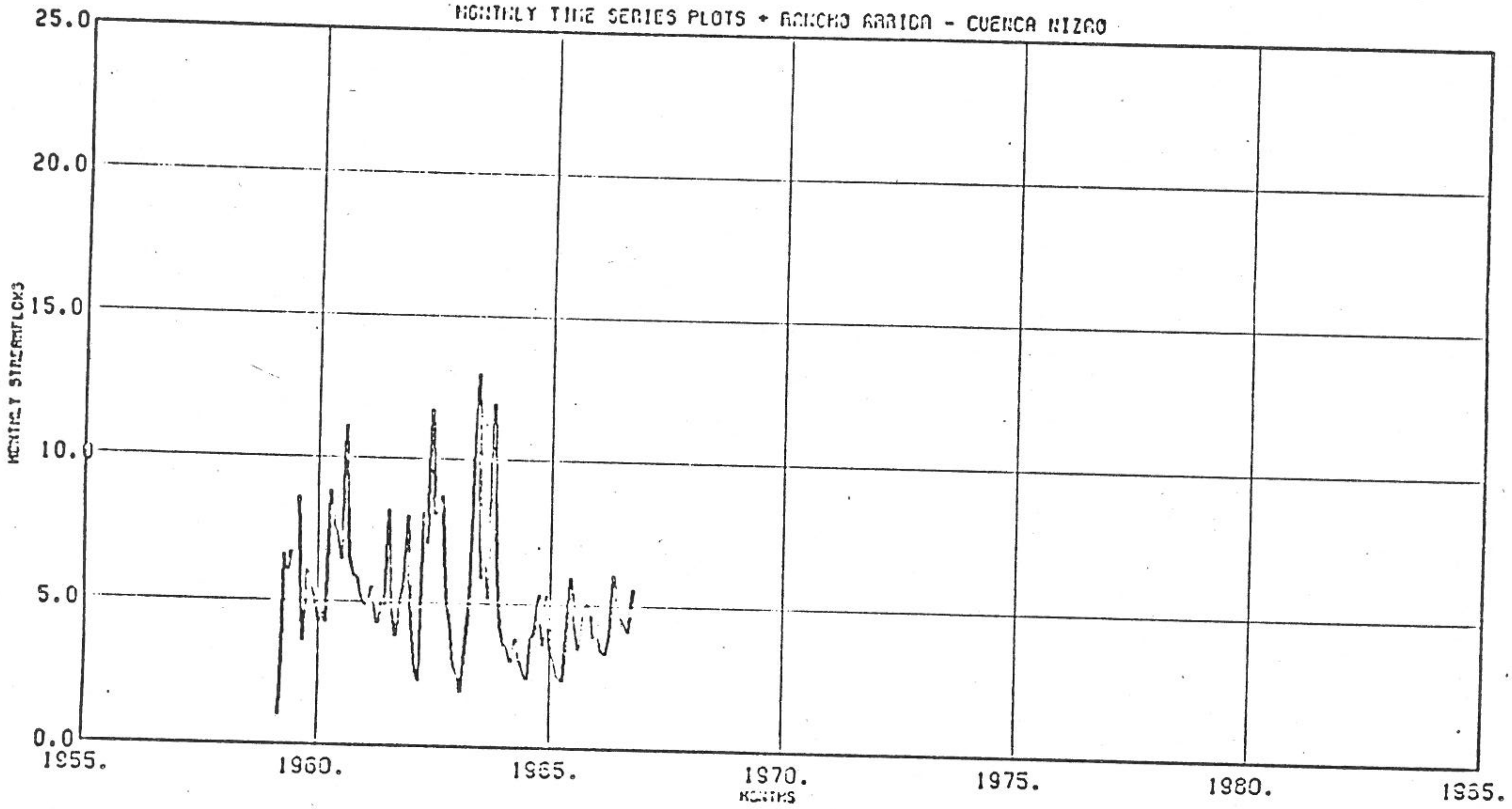


Figure 1.9.4. Time series plots of monthly streamflows of Rancho Arriba.

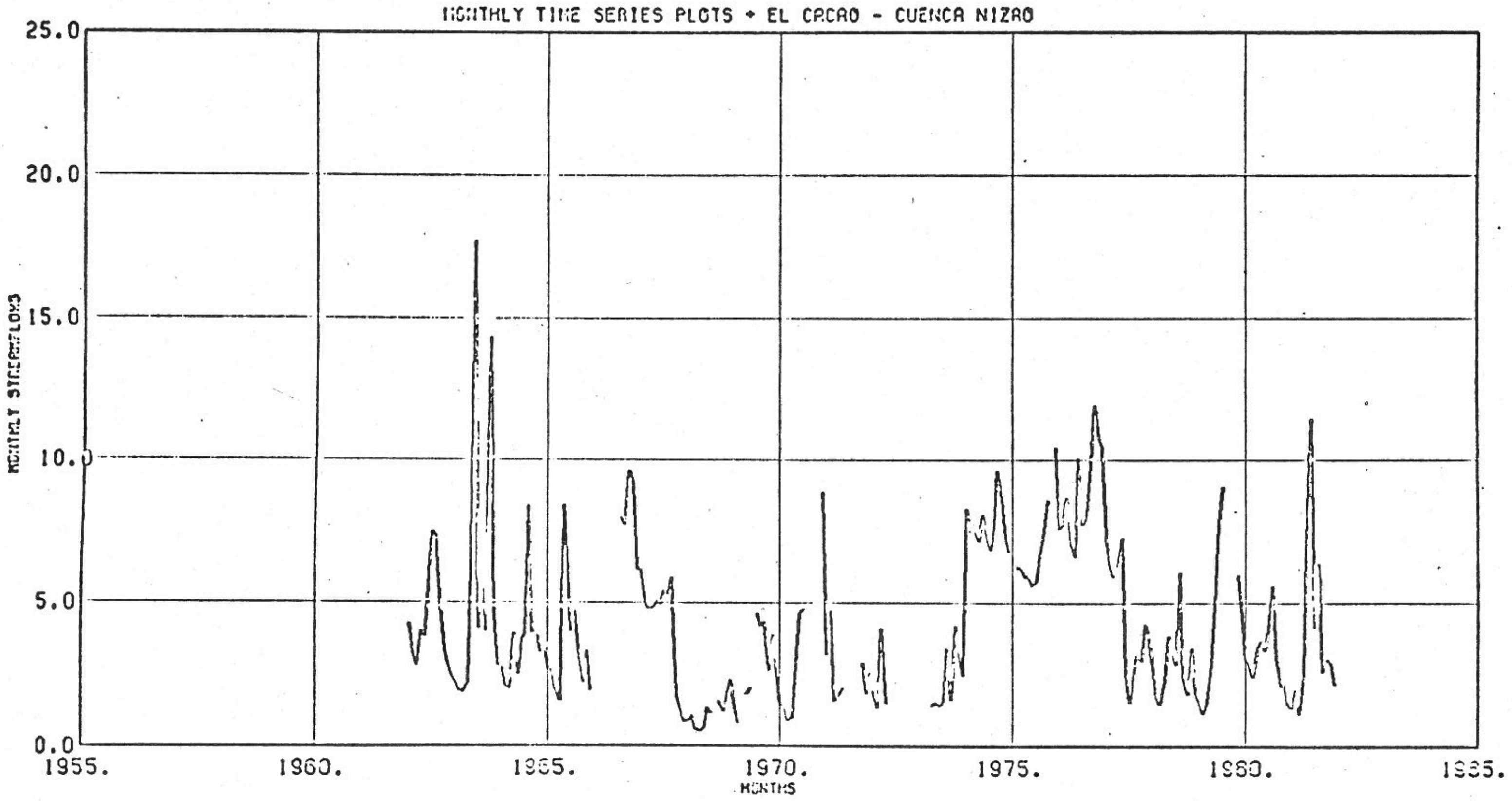


Figure 1.9.5. Time series plots of monthly streamflows of El Cacao.

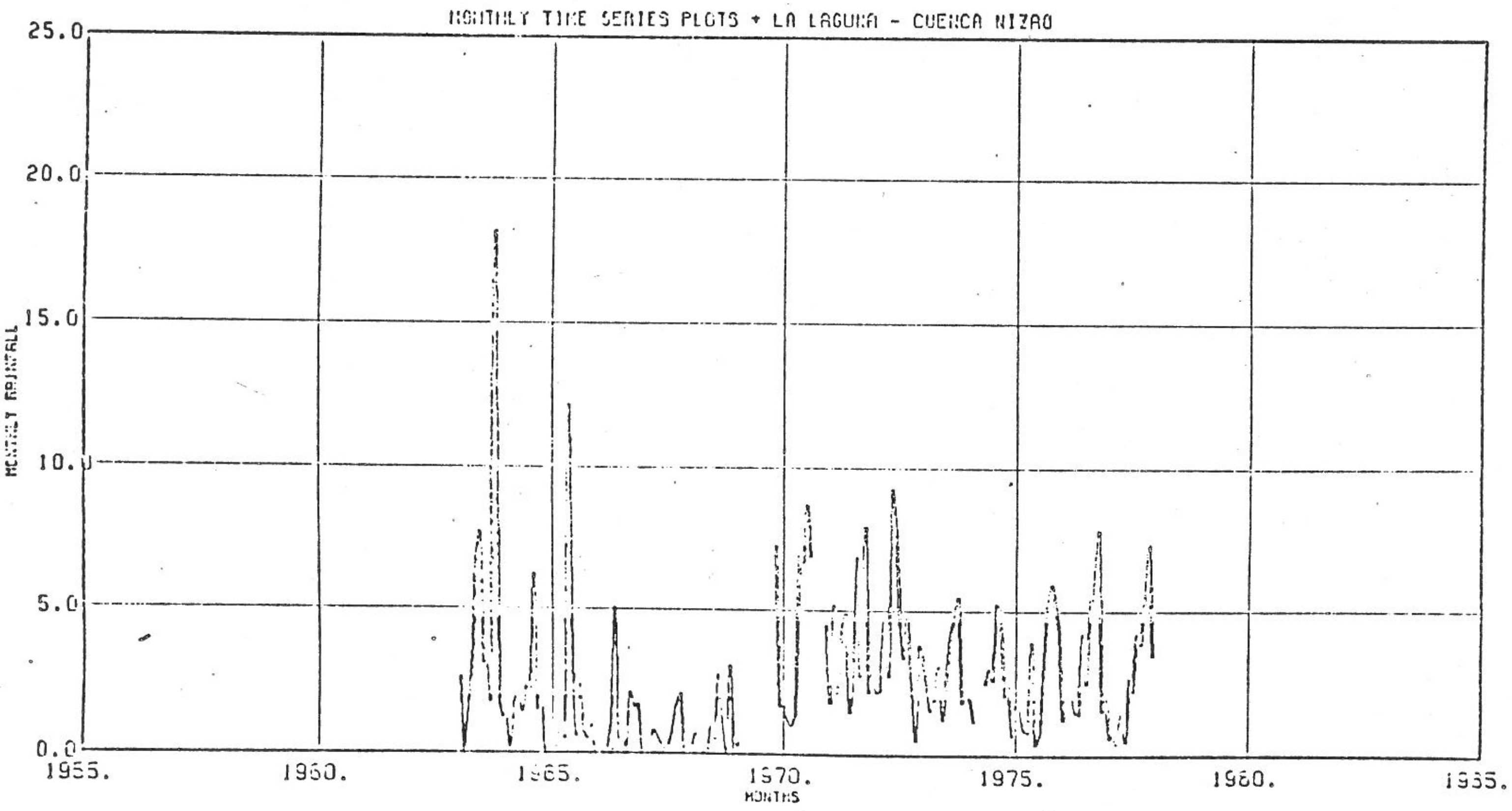


Figure 1.9.6. Time series plots of monthly rainfall of La Laguna.

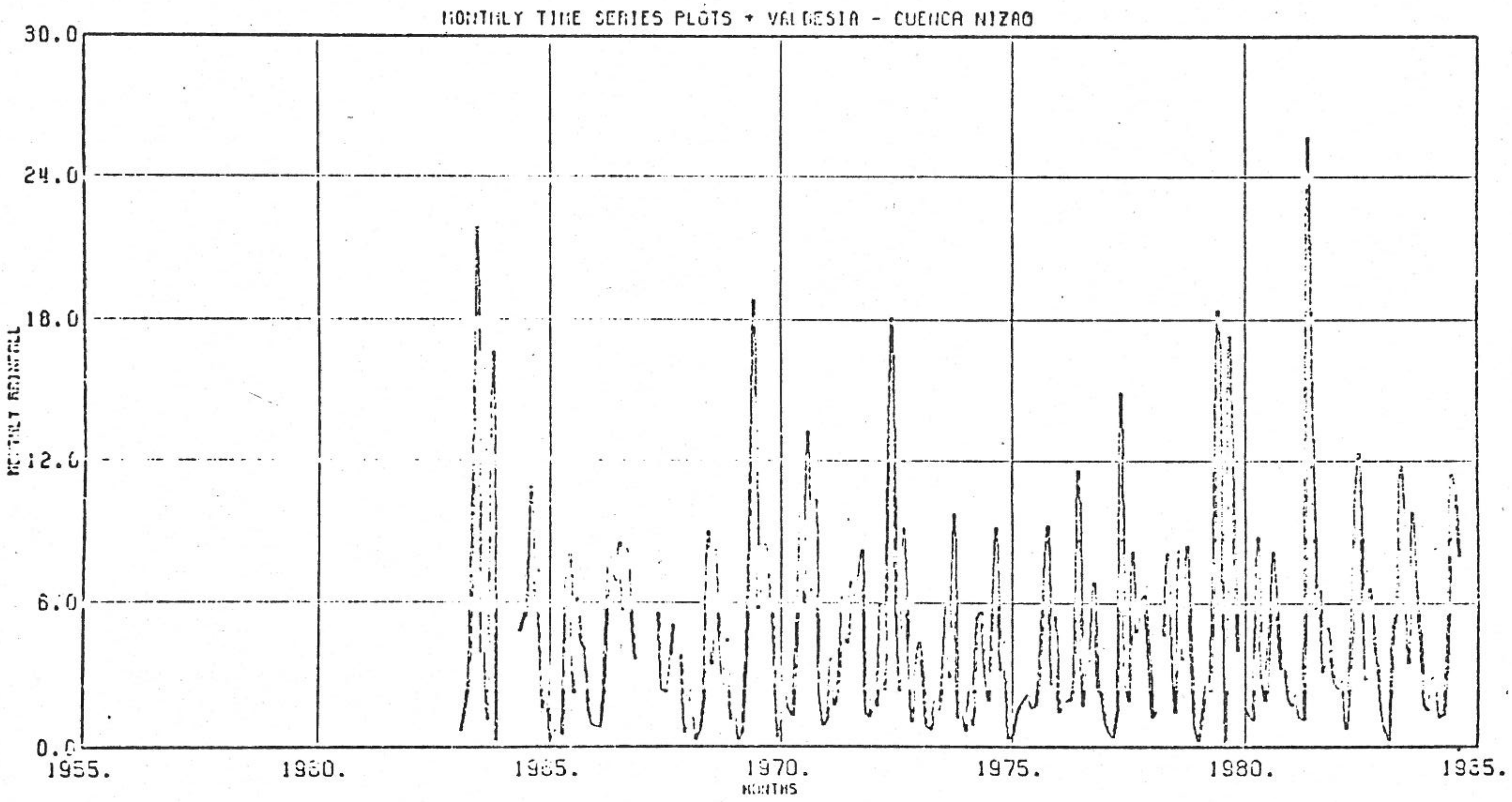


Figure 1.9.7. Time series plots of monthly rainfall of Valdesia.

1.9.3 FILLING-IN AND EXTENSION OF HISTORICAL DATA

To improve the reliability of statistical parameters such as the means, variances, skewness, autocorrelations and cross correlations which will be used for stochastic modeling, the historical data of each station are filled-in and/or extended first based on other stations. The monthly and weekly streamflows of Palo de Caja contain only some data gaps in years 1964 and 1966 thus requiring only minor filling-in of missing data. However, both Paso del Erimitaño and and Rancho Arriba require major data extension due to their shortness of records. The succeeding subsections present filling-in of missing data of Palo de Caja and extension of records of Paso del Ermitaño and Rancho Arriba respectively.

1.9.3.1 Filling-in of Missing Data of Palo de Caja

On a monthly basis, the data of months August, October and December of year 1964 and February 1966 are missing. On a weekly basis, weeks 33, 34, 35, 42, 43, 44, 51 and 52 of year 1964 and weeks 6 and 7 of 1966 are missing. It is decided that a simple or multiple linear regression model be used in filling-in the missing data of Palo de Caja based on neighboring stations within the Nizao basin. As a requirement to linear regression models, the regression variables must be nominally normally distributed. Thus, prior to fitting these models, the streamflows of Palo de Caja and the time series variables of other stations are suitably transformed to become normal. Five normalizing transformations were tried, namely: 1) square-root, 2) cube root, 3) logarithmic, 4) Wilson-Hilferty, and 5) combined logarithmic and Wilson-Hilferty transformations. Details of the normalization schemes and results for.

each station are given in Appendix 1.9.A. Using the transformed data of each station, the overall monthly and weekly cross correlations between stations were computed to form the basis of choosing the regressor variables. The computed cross correlations for monthly and weekly data are given in Tables 1.9.2 and 1.9.3, respectively. The choice of the regressor variables is also dependent on the availability of data from these stations with respect to those periods of missing data of Palo de Caja and the coefficient of correlation of the fitted regression model.

On the above basis, the monthly missing values of Palo de Caja are filled-in using the bivariate regression model given by

$$Z^{(1)}_{\nu,\tau} = -0.038 + 0358\ Z^{(5)}_{\nu,\tau} + 0.257\ Z^{(6)}_{\nu,\tau} + 0.814\ \epsilon_{\nu,\tau} \qquad (1.9.1)$$

where $Z^{(1)}_{\nu,\tau}$ is the log-Wilson-Hilferty domain streamflow of Palo de Caja of year ν and month τ; $Z^{(5)}_{\nu,\tau}$ and $Z^{(6)}_{\nu,\tau}$ are the Wilson-Hilferty domain rainfalls of La Laguna and Valdesia, respectively; and $\epsilon_{\nu,\tau}$ is an added noise term which is identically and independently distributed standard normal random deviates. The addition of the noise term $\epsilon_{\nu,\tau}$ is necessary because otherwise the variance of the filled-in data may be reduced (Salas, et al., 1980). Equation (1.9.1) has a multiple correlationcoefficient (R) equal to 0.540. Note that in Table 1.9.1, the overall monthly cross-correlation between Palo de Caja and Paso del Ermitaño is the highest. But during those months where Palo de Caja has missing values, the values of Paso del Ermitaño are also missing. The filled-in monthly values of Palo de Caja in the original domain of streamflows are obtained using the inverse log-Wilson-Hilferty transformation (see Appendix 1.9.A or section 1.9.6.1).

Table 1.9.3. Overall weekly cross-correlations of transformed data between stations.

	Palo de Caja	Paso del Ermitaño	Rancho Arriba	El Cacao	La Laguna	Valdesia
Palo de Caja (LWH)	1.000 (1187)*					
Paso del Ermitaño (LWH)	0.766 (417)	1.000 (417)				
Rancho Arriba (LWH)	0.507 (394)	-- (0)	1.000 (404)			
El Cacao (LWH)	0.371 (796)	0.296 (334)	0.477 (225)	1.000 (916)		
La Laguna (WH)	0.287 (714)	0.398 (359)	0.176 (205)	0.228 (626)	1.000 (724)	
Valdesia (WH)	0.190 (795)	0.240 (471)	0.124 (176)	0.180 (800)	0.479 (666)	1.000 (1062)

*Numbers enclosed in parentheses are total number of concurrent observations.

-- denotes no concurrent record between these two stations.

Note: LWH or WH indicates whether data for that station was transformed either by combined log-Wilson-Hilferty transformation or Wilson-Hilferty transformation, respectively.

For filling-in the weekly values of Palo de Caja, the following simple linear regression model is used:

$$Z^{(1)}_{\nu,\tau} = a(\tau,\nu) + b(\tau,\nu)\ Z^{(3)}_{\nu,\tau} + c(\tau,\nu)\ \epsilon_{\nu,\tau} \tag{1.9.2}$$

where $Z^{(1)}_{\nu,\tau}$ and $Z^{(3)}_{\nu,\tau}$ are the weekly log-Wilson-Hilferty domain streamflows of Palo de Caja and Rancho Arriba, respectively and the regression models parameters as a function of year ν and week τ are computed either on a week-to-week basis or overall-weekly basis depending on which of the two give the highest coefficient of correlation (R). Note again that Palo de Caja and Paso del Ermitaño has the highest correlation as shown in Table 1.8.3, but values of Paso del Ermitaño are missing during these weeks when Palo de Caja had missing values. The model coefficients of Eq. (1.9.2) and corresponding coefficient of correlations (R) for each missing year (ν) and weeks (τ) are given in Table 1.9.4. As in monthly filling-in of missing data, the original domain of weekly streamflows of Palo de Caja are obtained using the inverse log-Wilson-Hilferty transformation. Effectively now, the monthly and weekly data available for Palo de Caja is from 1957 to 1978 (1956 and 1979 are excluded since they are incomplete) which is a total of 22 years.

1.9.3.2 Extension of Records of Paso del Ermitaño and Rancho Arriba

For extending the records of Paso del Ermitaño and Rancho Arriba, three model forms are tentatively prescribed in the linear and normal domain of time series variables. These models are: i) nonseasonal multiple regression model, ii) seasonal multiple regression model, and

Table 1.9.4. Regression model parameters of Equation (1.9.2) for filling-in weekly missing values of Palo de Caja.

Year, ν	Week, τ	$a(\nu,\tau)$	$b(\nu,\tau)$	$c(\nu,\tau)$	$R(\nu,\tau)$
1964	33	-0.456	1.143	1.696	0.554
	34	0.363	1.079	0.310	0.971
	35	0.259	0.815	0.576	0.856
	42	0.360	0.809	1.072	0.579
	43	-0.197	0.936	0.776	0.813
	44	-0.324	0.613	0.964	0.507
	51	-0.324	0.613	0.964	0.507
	52	-0.324	0.613	0.964	0.507
1966	6	-0.324	0.613	0.964	0.507
	7	-0.843	0.608	0.882	0.644

iii) nonseasonal bivariate first-order autoregressive model. For the case of nonseasonal models, it is assumed that any inherent seasonality in the data is adequately removed by seasonal standardization which is included in the normalizing transformation used (see Appendix 1.9.A). In the multiple regression models, the choice of regressors were made on the basis of best regression correlation coefficients using one or two stations.

With these three model forms, sample extensions of monthly data were then performed. On this basis, it is found that the nonseasonal bivariate first-order autoregressive model best preserves the means, variances, autocorrelations and cross-correlations of the data. Thus, the short records of Paso del Ermitaño and Rancho Arriba for both monthly and weekly levels were extended using a bivariate first-order autoregressive model with Palo de Caja. In equation form, this model is written as:

$$\begin{bmatrix} z^{(1)}_{\nu,\tau} \\ z^{(2)}_{\nu,\tau} \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} \begin{bmatrix} z^{(1)}_{\nu,\tau-1} \\ z^{(2)}_{\nu,\tau-1} \end{bmatrix} + \begin{bmatrix} b_{11} & 0 \\ b_{21} & b_{22} \end{bmatrix} \begin{bmatrix} \epsilon^{(1)}_{\nu,\tau} \\ \epsilon^{(2)}_{\nu,\tau} \end{bmatrix} \tag{1.9.3a}$$

For purposes of data extension, the equation above is written as:

$$z^{(2)}_{\nu,\tau} = \frac{b_{21}}{b_{11}} z^{(1)}_{\nu,\tau} + (a_{21} - \frac{a_{11}b_{21}}{b_{11}}) z^{(1)}_{\nu,\tau-1}$$

$$+ (a_{22} - \frac{b_{21}a_{12}}{b_{11}}) z^{(2)}_{\nu,\tau-1} + b_{22}\, \epsilon^{(2)}_{\nu,\tau} \tag{1.9.3b}$$

where $z^{(2)}_{\nu,\tau}$ is the data of either Paso del Ermitaño or Rancho Arriba, $z^{(1)}_{\nu,\tau}$ is the data of Palo de Caja, $\epsilon^{(2)}_{\nu,\tau}$ is a standard normal random number, and the a's and b's are model parameters.

Since the data of Paso del Ermitaño and Rancho Arriba are to be extended forward in time and backward in time to coincide with those of Palo de Caja (see Table 1.9.1 for periods of available records), the model in Eqs. (1.9.3) are applied likewise forward and backward in time as the case requires. This scheme is possible for linear-normal time series models owing to the notions of time-reversibility and distributional symmetry in the linear and normal domain of time series variables.

The model parameters of Eqs. (1.9.3) are estimated using the method of moments (Salas, et al.; 1980). Tables 1.9.5 and 1.9.6 show the model parameters for monthly and weekly levels, respectively. Referring to

Table 1.9.5. Model parameters for monthly data extensions.

Forward in Time	A		B	
Paso del Ermitaño and	-0.0459	0.6325	0.8023	0.0
Palo de Caja	0.0214	0.8250	0.3574	0.4040
Rancho Arriba and	0.5817	-0.2896	0.8531	0.0
Palo de Caja	-0.0757	0.5493	0.5819	0.6253

Backward in Time	A		B	
Paso del Ermitaño and	-0.2035	0.8324	0.7300	0.0
Palo de Caja	-0.1783	0.9825	0.2863	0.4440
Ranch Arriba and	0.4710	-0.0408	0.8909	0.0
Palo de Caja	-0.3245	0.6601	0.5396	0.5988

Table 1.9.6. Model parameters for weekly data extensions.

Forward in Time	A		B	
Paso del Ermitaño and	0.5755	0.1963	0.6765	0.0
Palo de Caja	0.0537	0.7764	0.3423	0.4620
Rancho Arriba and	0.7617	-0.0725	0.6853	0.0
Palo de Caja	-0.0382	0.7756	0.4206	0.4997

Backward in Time	A		B	
Paso del Ermitaño and	0.5553	0.2226	0.6731	0.0
Palo de Caja	0.0273	0.7965	0.3404	0.4644
Ranch Arriba and	0.7343	-0.0176	0.6881	0.0
Palo de Caja	-0.0932	0.8030	0.4164	0.4977

Eq. (1.9.3b), the extension of records is done by generating the normal standard random noise $\epsilon^{(2)}_{\nu,\tau}$ to obtain $z^{(2)}_{\nu,\tau}$, then followed by back transformation to the original domain of flows. Due to the addition of the random term, a single series is only one possible (equally likely) sequence that may have occurred. In view of this, fifty data extensions are made. The intent here is simply to utilize the fifty extended series for improving the estimates of the parameters to be used in modeling and data generation.

For each extended series, the seasonal statistics are then computed constituting a total of 50 samples of statistics for each season. From these, the averages and standard errors of each statistic are determined. The averages in this case are considered as the improved estimates representing the seasonal statistic while their corresponding standard errors indicate the degree of variation of each statistic from the averages. The computed averages and standard errors for monthly and weekly statistics are given in Appendix 1.9.B.

A reliability test for the improvement of the means and variances was performed after extending the records of Paso del Ermitaño and Rancho Arriba. The test is that the variances of historical means or variances should be greater than those of the extended ones under the null hypothesis that these statistics are improved. The variances of historical means and variances for seasonally autocorrelated processes are given respectively as:

$$\mathrm{var}(\bar{x}_\tau) = \frac{S_\tau^2}{N}\left[1 + \frac{2}{N}\sum_{\nu=1}^{N-1}(N - \nu)\rho_\tau(w\nu)\right] \tag{1.9.4a}$$

and

$$\mathrm{var}(S_\tau^2) = 2\,S_\tau^4\left[\frac{N}{1 + \sum_{\nu=1}^{N-1}\rho_\tau^2(w\nu)} - 1\right]^{-1} \tag{1.9.4b}$$

where S_τ^2 is the historical variance at season τ, N is the number of years of record, w is the number of seasons and $\rho_\tau(w\nu)$ is the seasonal autocorrelation at lag $w\nu$. Assuming that the historical series follows a seasonal first-order autoregressive process, the

$$\rho_{\tau}(w\nu) = \rho_{\tau}(1)\ \rho_{\tau-1}(1)\ \ldots\ \rho_{\tau-w\nu+1}(1)$$

in which $\rho_{\tau}(1)$ is the lag-1 autocorrelation at season τ. The variances of the extended series statistics are the square of the standard errors computed from each statistic based on fifty series extensions.

Results from these tests show that for all monthly means and variances, all extended statistics are improved. For the weekly statistics, a maximum of 2 weeks out of 52 weeks failed the test. For all practical purposes, the extention of records has definitely improved the reliability of statistical parameters.

1.9.4 STOCHASTIC MODELING OF STREAMFLOWS

The stochastic models for both monthly and weekly streamflows adopted herein to be eventually used in data generation belong to the family of multivariate linear models. Similar to the models used in extension, the models are developed by first normalizing and standardizing each series. Thereafter the correlation structure of the residual series is derived to form the basis of the stochastic model. In normalization, the combination of logarithmic and Wilson-Hilferty transformations is used for both monthly and weekly streamflows. For Wilson-Hilferty transformation, the seasonal skewness coefficients (in the logarithmic domain of flows) are Fourier fitted functions using the first two harmonics for monthly skews and first four harmonics for weekly skews. The skewness coefficients were also corrected for bias under the assumption that the process in the log domain are approximately gamma distributed. Details of the Fourier series fitting of the seasonal skewness coefficients are given in Appendix 1.9.C.

Three alternative stochastic model formulations were tried in this study. The first model, referred to here as "MODEL A," is a contemporaneous seasonal mixed autoregressive-moving average model (ARMA) which involves fitting first appropriate seasonal univariate ARMA models to each series. The model residuals of each series are then obtained and fitted to a zero-order multivariate model. In equation form, the univariate seasonal ARMA model can be generally written as:

$$z_{\nu,\tau}^{(s)} = \sum_{i=1}^{p} \phi_{\tau,i}^{(s)} z_{\nu,\tau-i}^{(s)} + \sum_{j=1}^{q} \theta_{\tau,j}^{(s)} e_{\nu,\tau-j}^{(s)} + e_{\nu,\tau}^{(s)} \qquad (1.9.5)$$

where $z_{\nu,\tau}^{(s)}$ is the normalized and standardized series of station s, year ν and season τ; $e_{\nu,\tau}^{(s)}$ is the residual series independent in time but the residuals of each station are contemporaneously correlated with each; and $\phi_{\tau,i}^{(s)}$ and $\theta_{\tau,j}^{(s)}$ are model parameters of orders p and q, respectively. For both monthly and weekly streamflows, the model parameters are estimated based on Fourier fitted functions of the seasonal sample autocorrelations. Details of the Fourier series fitting of autocorrelations for monthly and weekly levels of the three stations are given in Appendix 1.9.C. The autocorrelations fitted with the first two harmonics were used for monthly models and the fitted first four harmonics were used for weekly models. The zero-order multivariate model written for three stations takes the form below:

$$\begin{bmatrix} e_{\nu,\tau}^{(1)} \\ e_{\nu,\tau}^{(2)} \\ e_{\nu,\tau}^{(3)} \end{bmatrix} = \begin{bmatrix} b_{11} & 0 & 0 \\ b_{21} & b_{22} & 0 \\ b_{31} & b_{32} & b_{33} \end{bmatrix} \begin{bmatrix} \epsilon_{\nu,\tau}^{(1)} \\ \epsilon_{\nu,\tau}^{(2)} \\ \epsilon_{\nu,\tau}^{(3)} \end{bmatrix} \qquad (1.9.6)$$

where $\epsilon_{\nu,\tau}^{(s)}$'s are identically and independently distributed normal deviates and the b's are nonseasonal model parameters. The second model tried in this study uses both Eqs. (1.9.5) and (1.9.6) except that in Eq. (1.9.6), the model parameter b's are allowed to vary seasonally. This latter model is referred to here as "MODEL B." The third model, referred to as "MODEL C," is a nonseasonal vector first-order autoregressive model written for three stations as:

$$\begin{bmatrix} e_{\nu,\tau}^{(1)} \\ e_{\nu,\tau}^{(2)} \\ e_{\nu,\tau}^{(3)} \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix} \begin{bmatrix} z_{\nu,\tau-1}^{(1)} \\ z_{\nu,\tau-1}^{(2)} \\ z_{\nu,\tau-1}^{(3)} \end{bmatrix} + \begin{bmatrix} b_{11} & 0 & 0 \\ b_{21} & b_{22} & 0 \\ b_{31} & b_{32} & b_{33} \end{bmatrix} \begin{bmatrix} \epsilon_{\nu,\tau}^{(1)} \\ \epsilon_{\nu,\tau}^{(2)} \\ \epsilon_{\nu,\tau}^{(3)} \end{bmatrix} \qquad (1.9.7)$$

where the a's are nonseasonal model parameters and the other notations are defined as in Eqs. (1.9.5) and (1.9.6).

For the three tentative models above, the model parameters were estimated using the method of moments presented in Salas, et al., 1980. In choosing the appropriate model order of univariate seasonal ARMA in Eq. 1.9.5, the computer program UMOSE1 developed by Salas and Smith (1981) was used. A seasonal ARMA(1,0) or AR(1) model is found adequate and parsimonious to describe both monthly and weekly flows.

1.9.5 STREAMFLOW DATA GENERATION

1.9.5.1 Data Generation Scheme

For the three alternative stochastic models given previously, the data generation commences by generating the sequence $\epsilon_{\nu,\tau}^{(s)}$ using the Box-Muller formula written as (Salas, et al., 1980):

$$\epsilon_1 = [2\ \ell n\ (1/u_1)]^{1/2} \cos\ (2\pi\ u_2) \tag{1.9.8a}$$

and

$$\epsilon_1 = [2\ \ell n\ (1/u_1)]^{1/2} \sin\ (2\pi\ u_2) \tag{1.9.8b}$$

where u_1 and u_2 are two independent uniformly distributed (0,1) random numbers. Note that two random numbers can be generated at one time. Then these generated values are applied to either Eq. (1.9.6) or (1.9.7). For models A and B, Eq. (1.9.6) is used with nonseasonal or seasonal b's respectively to obtain $e_{\nu,\tau}^{(s)}$, followed by Eq. (1.9.5) to arrive at $z_{\nu,\tau}^{(2)}$. For model C, Eq. (1.9.7) is used to arrive at $z_{\nu,\tau}^{(s)}$.

Having obtained the sequence $z_{\nu,\tau}^{(s)}$ for any model, the backward Wilson-Hilferty transformation is applied using the inverse of Eq. (1.9.A.6) such that

$$x'^{(s)}_{\nu,\tau} = \frac{2}{G_\tau^{(s)}(x)} \left\{ \frac{G_\tau^{(s)}(x)}{6} \left[z_{\nu,\tau}^{(s)} - \frac{G_\tau^{(s)}(x)}{6} \right] + 1 \right\}^3 - \frac{2}{G_\tau^{(s)}(x)} \tag{1.9.9}$$

in which $G_\tau^{(s)}(x) \neq 0$, where $G_\tau^{(s)}(x)$ is the seasonal Fourier fitted skewness coefficient in the log domain. The variable $x_{\nu,\tau}^{(s)}$ is further transformed by

$$x_{\nu,\tau}^{(s)} = \begin{cases} \max\left[x'^{(s)}_{\nu,\tau}, \; -2/G_{\tau}^{(s)}(x)\right] & \text{if } G_{\tau}^{(s)}(x) > 0 \\ \min\left[x'^{(s)}_{\nu,\tau}, \; -2/G_{\tau}^{(s)}(x)\right] & \text{if } G_{\tau}^{(s)}(x) < 0 \end{cases}$$

and

$$x_{\nu,\tau}^{(s)} = z_{\nu,\tau}^{(s)} \qquad \text{if } G_{\tau}^{(s)}(x) = 0 \qquad (1.9.10)$$

where $x_{\nu,\tau}^{(s)}$ is the generated data in the log domain. Finally, the data $y_{\nu,\tau}^{(s)}$ in the actual or original domain is obtained from

$$w_{\nu,\tau}^{(s)} = \bar{w}_{\tau}^{(s)} + S_{\tau}^{(s)}(w)\; x_{\nu,\tau}^{(s)} \qquad (1.9.11)$$

and

$$y_{\nu,\tau}^{(s)} = \exp\left[w_{\nu,\tau}^{(s)}\right] \qquad (1.9.12)$$

where $\bar{w}_{\tau}^{(s)}$ and $S_{\tau}^{(s)}(w)$ are the seasonal mean and standard deviation in the log-domain of flows.

The program GENSEA developed by Salas and Smith (1981) was utilized for data generation which was slightly modified for purposes here.

1.9.5.2 Analysis of Generated Data

A total of 50 samples of size 22 years each of monthly and weekly streamflows were generated using the three alternative model formulations above. The best monthly and weekly models were then selected based on the comparison of historical and generated seasonal means, standard deviations, skewness coefficients, autocorrelations, and cross-correlations. For each generated sample, the above mentioned statistical properties are computed, then the arithmetic averages and standard errors for all samples are determined. Given in Appendix 1.9.D are plots of the monthly and weekly historical and generated statistics of the three models in the original domain of flows. Only the computed averages are shown for clarity in presentation. Based on these plots, the best model selected for both monthly and weekly streamflows is MODEL B (i.e., univariate seasonal first-order autoregressive process with seasonal multivariate zero-order station-to-station dependence).

Given in Appendix 1.9.E are the monthly and weekly, historical and generated statistics of MODEL B in the three domains of streamflows, namely: original domain, log domain, and log-Wilson-Hilferty domain. Plotted along the generated average statistics are the positive and negative one-standard errors relative to these averages. In general, the results show that the historical statistics are satisfactorily reproduced in the different domain of flows. Notice that in almost all cases, the confidence bands of the generated statistics encloses the historical statistics. It may be noted also that in the different domain of flows, the mean, standard deviations are best reproduced in the log-domain while the auto- and cross-correlations are best reproduced in the log-Wilson-Hilferty domain. This is only logical since such statitical properties are parameterized in the model at these corresponding domain of flows.

1.9.6 MODELING AND GENERATION OF TURBINE OPERATING HOURS

A preliminary analysis done in this study showed that the monthly inflows to Valdesia reservoir is significantly correlated to the monthly turbine operating hours of the said reservoir based on 9 years of data covering the period of 1976 to 1984. On this basis, it is decided to model and generate the turbine operating hours monthly time series based on reservoir inflows. Due to the proximity of Paso del Ermitaño and

Valdesia reservoir, it is assumed that the said reservoir inflows are the same streamflows as those of Paso del Ermitaño. Subsequently, the turbine operating hours can be generated by solely using the generated streamflows of Paso del Ermitaño. However, since the available turbine operating hours (i.e., 1976-1984 period) has no corresponding recorded streamflow at Paso del Ermitaño, the monthly inflow data at Valdesia reservoir are used to derive the stochastic model for data generation.

The model selected for purposes here is a bivariate, contemporaneous, first-order autoregressive model with monthly parameters. Specifically, the model takes the following form:

$$\begin{bmatrix} z^{(1)}_{\nu,\tau} \\ z^{(2)}_{\nu,\tau} \end{bmatrix} = \begin{bmatrix} a_{11,\tau} & 0 \\ 0 & a_{22,\tau} \end{bmatrix} \begin{bmatrix} z^{(1)}_{\nu,\tau-1} \\ z^{(2)}_{\nu,\tau-1} \end{bmatrix} + \begin{bmatrix} b_{11,\tau} & 0 \\ b_{21,\tau} & b_{22,\tau} \end{bmatrix} \begin{bmatrix} \epsilon^{(1)}_{\nu,\tau} \\ \epsilon^{(2)}_{\nu,\tau} \end{bmatrix} \qquad (1.9.13)$$

where $z^{(1)}_{\nu,\tau}$ is the Paso del Ermitaño streamflows, $z^{(2)}_{\nu,\tau}$ is the turbine operating hours, and, a's and b's are model parameters. The model above is similar to the model used for data extension (see Eq. 1.9.3a, Section 1.9.3.2) except for the seasonality of its model parameters and the parametric matrix of a's which renders the model as contemporaneous (Salas et al., 1985). For generating the turbine operating hours $z^{(2)}_{\nu,\tau}$, Eq. (1.9.13) can be rewritten as

$$z^{(2)}_{\nu,\tau} = \frac{b_{21,\tau}}{b_{11,\tau}} z^{(1)}_{\nu,\tau} - \frac{a_{11,\tau} b_{21,\tau}}{b_{11,\tau}} z^{(1)}_{\nu,\tau-1} + a_{22,\tau} z^{(2)}_{\nu,\tau-1} + b_{22,\tau} \epsilon^{(2)}_{\nu,\tau} \qquad (1.9.14)$$

The time series variables $z^{(1)}_{\nu,\tau}$ and $z^{(2)}_{\nu,\tau}$ are monthly normalized and standardized using the Wilson-Hilferty transformation (see Appendix

1.9.A). The use of Wilson-Hilferty (WH) transformation alone for Paso del Ermitaño instead of in combination with logarithmic transformation as done previously is simply for convenience and consistency with respect to the type of transformation used for turbine hours. Besides, either the log-WH or plain WH transformations are valid for Paso del Ermitaño monthly streamflows as shown in Table 1.9.A.1.

The monthly model parameters estimated for Eq. (1.9.14) are given in Table 1.9.7. Data generation of turbine operating hours follows in the same manner as the extension of records in section 1.9.3.2. Once, $z^{(2)}_{\nu,\tau}$ in the Wilson-Hilferty domain of turbine hours are obtained, the backtransformation to its original domain is performed as in section 1.9.5.1 using Eqs. (1.9.9), (1.9.10) and (1.9.11), i.e., without the anti-log operation.

Table 1.9.7. Monthly parameters of turbine operating hours model in Eq. (1.9.14).

Month, τ	$a_{11,\tau}$	$a_{22,\tau}$	$b_{11,\tau}$	$b_{21,\tau}$	$b_{22,\tau}$
1	0.6694	0.9753	0.7429	0.1002	0.1969
2	0.3083	0.1667	0.9513	0.2410	0.9561
3	0.5255	0.2728	0.8508	0.4014	0.8744
4	0.5900	0.6270	0.8074	-0.2026	0.7522
5	0.4592	0.0780	0.8883	0.5654	0.8211
6	0.4547	0.5428	0.8906	0.6946	0.4721
7	0.5435	0.5640	0.8394	0.3352	0.7547
8	0.3396	-0.1422	0.9406	0.4205	0.8961
9	0.1236	0.4279	0.9923	0.6525	0.6254
10	0.3649	0.5630	0.9310	0.3378	0.7543
11	0.1527	0.4804	0.9883	0.2200	0.8490
12	0.4888	0.2435	0.8724	0.7023	0.6690

As in streamflow data generation, 50 samples of 22 years of monthly turbine operation hours were generated. A comparison of important statistical parameters between historical and generated turbine hours.

was also performed. Results of the comparison are shown in Appendix 1.9.F which show satisfactory reproduction of monthly means, standard deviations skewness coefficients, autocorrelations and cross-correlations.

1.9.7 FINAL REMARKS

Considerable data analysis and manipulations have been done prior to data modeling and generation. First of all, the missing data of Palo de Caja has to be filled-in using an appropriate regression model. Then data extension has to be performed for Palo del Ermitaño and Rancho Arriba. In data extension, 50 series extensions are made where in principle, any one of the extended series can be used for deriving the statistical parameters for modeling and data generation. However, since our objective is to improve the reliability of these statitical estimates, the 50 series extensions were used to represent the statistical parameters in terms of averages.

As a requirement for linear normal models in this study, the combination of logarithmic and Wilson-Hilferty transformation is proven to be effective in normalizing the streamflow. It may be noted that the Wilson-Hilferty transformation is developed on the basis of the Pearson Type III (gamma) distribution. Thus, it can be said that streamflow data follows a log-Pearson Type III distribution.

In time series modeling of the extended data, three alternative stochastic models were found. The main reason for tentatively prescribing three model forms is for us to select the best model in terms of model parsimony (i.e., economy of parameters) and overall modeling efficiency without compromising the adequacy and ability of the final model adopted to represent the time series process studied at hand. The paper by Salas, et al., 1985 may be consulted for further elaborations on alternative multivariate models similar to the ones used here, and applications of multivariate models in general.

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APPENDIX 1.9.A

STANDARDIZATION AND NORMALIZATION

The purpose of standardization is to remove the seasonalities in the means and variances of the data. Removal of such seasonalities may be made by using the raw estimates of the means and variances or their corresponding smoothed estimates by say, Fourier series fitting. For this study, the raw estimates of the semi-monthly means and variances are used. As mentioned in section 1.9.3, a transformation is made to render the data normal. Currently, there are various transformations of frequent use in hydrology such as square-root, cube-root, logarithmic, Wilson-Hilferty or log-Wilson-Hilferty transformations. Depending on the type of normalization (transformation) used, standardization is applied before or after transformation. The five normalizing transformations mentioned above were used in this study.

1) Square-root transformation:

Denoting the original time series data by $Y_{\nu,\tau}$ of year ν and season τ, the square-root transformation is done by

$$X_{\nu,\tau} = \sqrt{Y_{\nu,\tau}} \qquad (1.9.A.1)$$

for all $\nu = 1,\ldots,n$ years and $\tau = 1,\ldots,w$ seasons. Then standardization follows given by:

$$Z_{\nu,\tau} = \frac{X_{\nu,\tau} - \bar{X}_{\tau}}{S_{\tau}(x)} \qquad (1.9.A.2)$$

where $\overline{X}_\tau$ and $S_\tau(x)$ are the semi-monthly mean and standard deviation of the square-root transformed data.

2) Cube-root transformation:

In this case, the original series $Y_{\nu,\tau}$ is transformed using the equation

$$X_{\nu,\tau} = Y_{\nu,\tau}^{1/3} \tag{1.9.A.3}$$

then, standardization is performed using Eq. (1.8.A.2) where $\overline{X}_\tau$ and $S_\tau(x)$ are evaluated using the cube-root transformed data.

3) Logarithmic transformation:

The raw series $Y_{\nu,\tau}$ is transformed by

$$X_{\nu,\tau} = \log(Y_{\nu,\tau}) \tag{1.9.A.4}$$

where log stands for the base-e logarithms. This is followed by standardization as in Eq. (1.9.A.2).

4) Wilson-Hilferty transformation:

The original series $Y_{\nu,\tau}$ is first standardized as in Eq. (1.9.A.2) by

$$X_{\nu,\tau} = \frac{Y_{\nu,\tau} - \overline{Y}_\tau}{S_\tau(Y)} \tag{1.9.A.5}$$

where $\overline{Y}_\tau$ and $S_\tau(Y)$ are the semi-monthly mean and standard deviation of the series $\{Y_{\nu,\tau}\}$. The Wilson-Hilferty transformation is given by (Matals, 1967)

$$Z_{\nu,\tau} = \frac{6}{G_\tau(x)} \left\{ \left[\frac{G_\tau(x)\, X'_{\nu,\tau}}{2} + 1 \right]^{1/3} - 1 \right\} + \frac{G_\tau(x)}{6} \qquad (1.9.A.6)$$

which is valid for $G_\tau(x) \neq 0$, where $G_\tau(x)$ is the semi-monthly skewness coefficient of $X_{\nu,\tau}$ and $X'_{\nu,\tau}$ is given by McGinnis and Sammons (1970) as

$$X'_{\nu,\tau} = \begin{cases} \max[X_{\nu,\tau},\ -2/G_\tau(x)] & \text{if } G_\tau(x) \geq 0 \\ \min[X_{\nu,\tau},\ -2/G_\tau(x)] & \text{if } G_\tau(x) < 0 \end{cases} \qquad (1.9.A.7)$$

If $G_\tau(x) = 0$ no transformation is necessary then $Z_{\nu,\tau} = X_{\nu,\tau}$.

5) Log-Wilson-Hilferty transformation:

This transformation is a combination of logarithmic transformation (item 3) and Wilson-Hilferty transformation (item 4). For the sake of clarity, let us rewrite some of the equations above. First the original data $Y_{\nu,\tau}$ is transformed as in Eq. (1.9.A.4) as

$$W_{\nu,\tau} = \log\,(Y_{\nu,\tau}) \qquad (1.9.A.8)$$

Then, standardization is performed using

$$X_{\nu,\tau} = \frac{W_{\nu,\tau} - \overline{W}_\tau}{S_\tau(w)} \qquad (1.9.A.9)$$

where $\bar{W}_\tau$ and $S_\tau(w)$ are the seasonal means and standard deviations of the logarithmic transformed sequence $\{W_{\nu,\tau}\}$. Then, the Wilson-Hilferty transformation is performed using Eqs. (1.9.A.6) and (1.9.A.7) to arrive at $Z_{\nu,\tau}$.

The criteria for selecting the type of normalizing transformation to be used in this study is the skewness test for normality. This test assumes that if the observations are independent and sampled from the normal distribution, then, the sample skewness coefficient must fall within the (1-α) confidence limits

$$[-u_{1-\alpha/2}\sqrt{6/n}\ ,\quad u_{1-\alpha/2}\sqrt{6/n}] \tag{1.9.A.10}$$

where $u_{1-\alpha/2}$ is the $1-\alpha/2$ quantile of the standard normal distribution and n is the sample size. Since we have a total of 12 monthly and 52 weekly skewness coefficients computed after each transformation, the relative number of skews within the confidence limits are counted. The greatest number of passes forms the basis of choice of the suitable transformation used here.

The results of these analysis are given in Tables 1.9.A.1 and 1.9.A.2 for monthly and weekly levels, respectively. From these results it can be concluded that the streamflow data of Palo de Caja, Paso del Ermitaño, Rancho Arriba and El Cacao be normalized using the log-Wilson-Hilferty transformation, while the rainfall data of La Laguna and Valdesia be normalized using Wilson-Hilferty transformation.

Table 1.9.A.1. Relative scores of passing and failing the skewness test on a monthly basis using the five normalizing transformations including no transformation.

	No Transformation	Square-Root	Cube-Root	Logarithmic	Wilson-Hilferty	Log-Wilson-Hilferty
Palo de Caja						
Pass	0	3	6	10	8	12*
Fail	12	9	6	2	4	0
Paso del Ermitaño						
Pass	5	9	10	12	11	12*
Fail	7	3	2	0	1	0
Rancho Arriba						
Pass	10	10	10	10	11	11*
Fail	2	2	2	2	1	1
El Cacao						
Pass	6	12	11	9	12	12*
Fail	6	0	1	3	0	0
La Laguna						
Pass	7	11	8	2	12*	5
Fail	5	1	4	10	0	7
Valdesia						
Pass	5	10	11	9	12*	10
Fail	7	2	1	3	0	2

*Indicate transformation used.

Table 1.9.A.2. Relative scores of passing and failing the skewness test on a weekly basis using the five normalizing transformations including no transformation.

		No Transformation	Square-Root	Cube-Root	Logarithmic	Wilson-Hilferty	Log-Wilson-Hilferty
Palo de Caja							
	Pass	1	30	28	30	28	48*
	Fail	51	22	24	22	24	4
Paso del Ermitaño							
	Pass	33	47	47	48	47	52*
	Fail	19	5	5	4	5	0
Rancho Arriba							
	Pass	36	43	48	43	49	50*
	Fail	16	9	4	9	3	2
El Cacao							
	Pass	29	46	45	48	46	52*
	Fail	23	6	7	4	6	0
La Laguna							
	Pass	10	41	50	41	51*	34
	Fail	42	11	2	11	1	18
Valdesia							
	Pass	7	36	44	37	46*	32
	Fail	45	16	8	15	6	20

*Indicate transformation used.

APPENDIX 1.9.B

HISTORICAL AND EXTENDED SERIES STATISTICS OF MONTHLY AND WEEKLY DATA OF PASO DEL ERMITAÑO AND RANCHO ARRIBA

Note: In the figures given below, the extended series statistics are averages computed from the fifty series extensions and correspondingly the positive and negative one-standard errors relative to these averages.

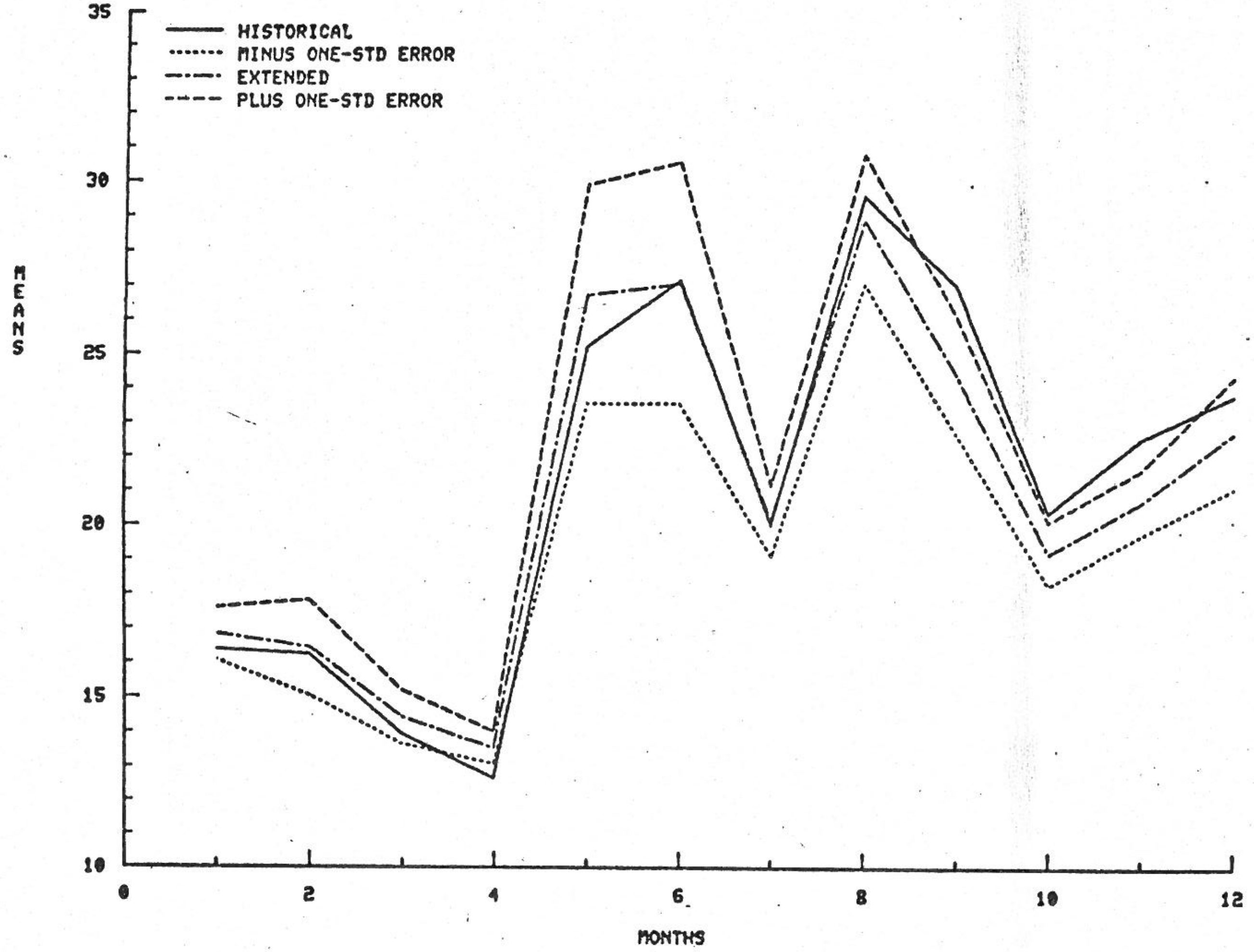


Figure 1.9.B.1. Historical and extended series monthly means of Paso del Ermitaño in original domain of flows.

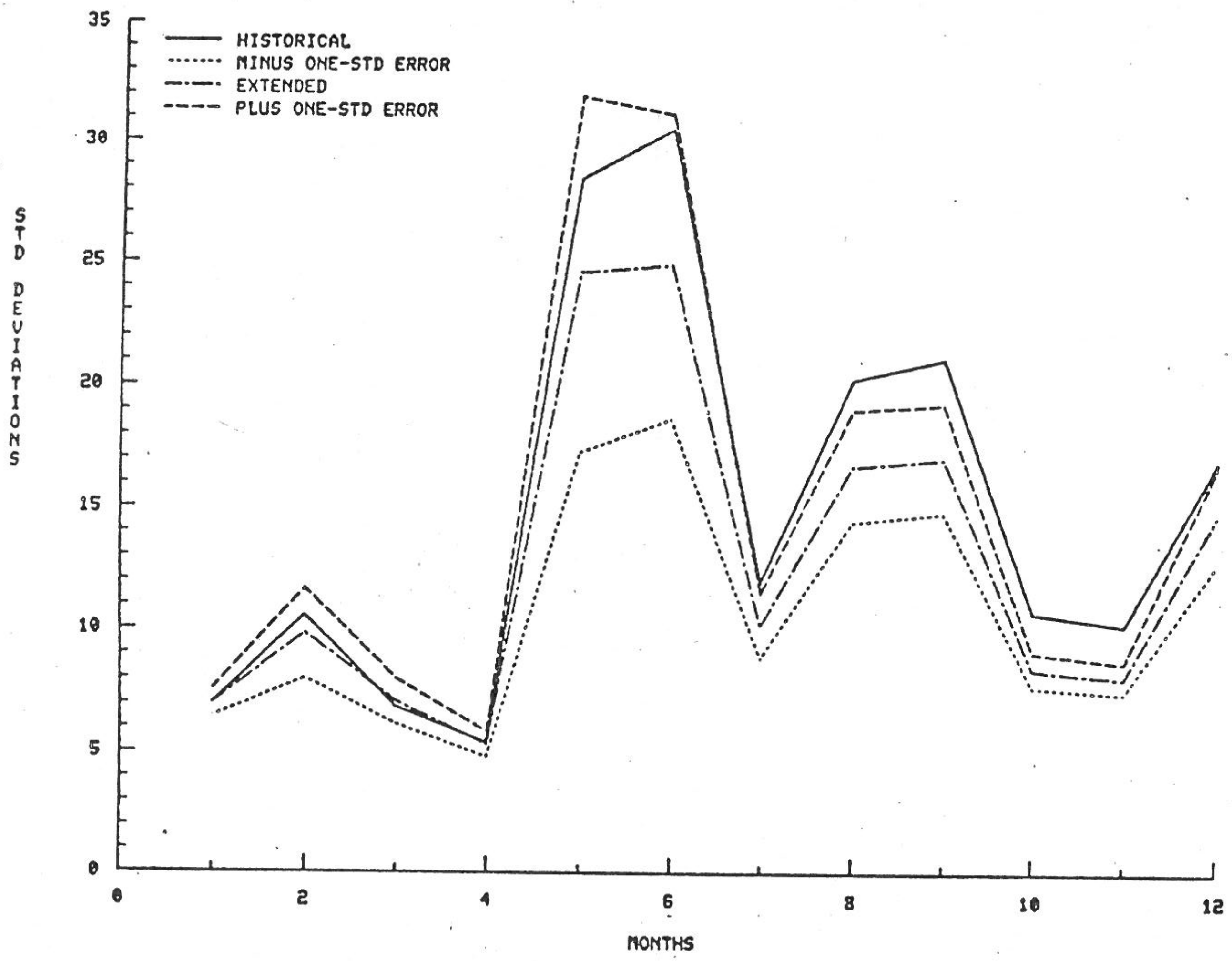


Figure 1.9.B.2. Historical and extended series monthly standard deviations of Paso del Ermitaño in original domain of flows.

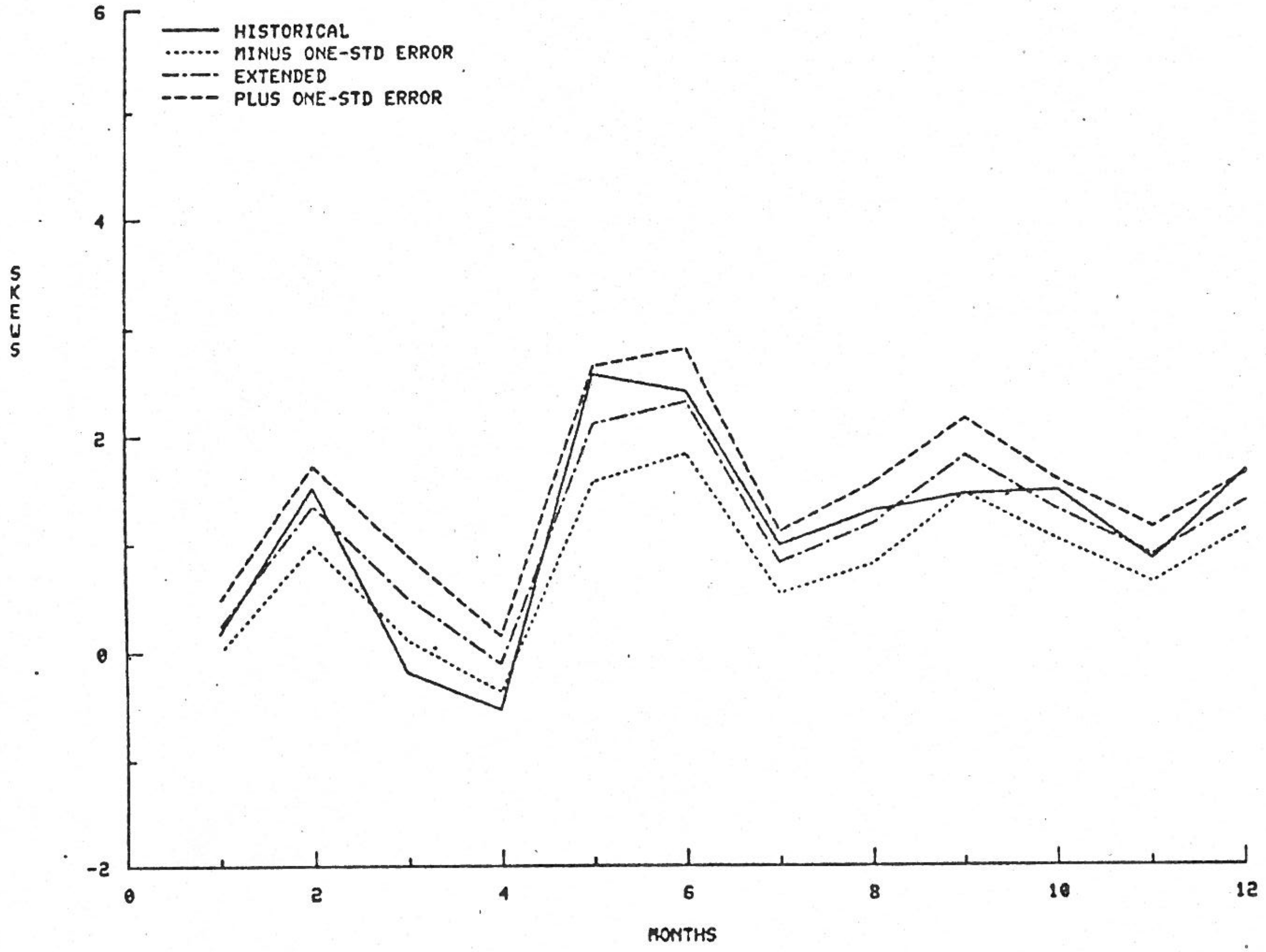


Figure 1.9.B.3. Historical and extended series monthly skewness coefficients of Paso del Ermitaño in original domain of flows.

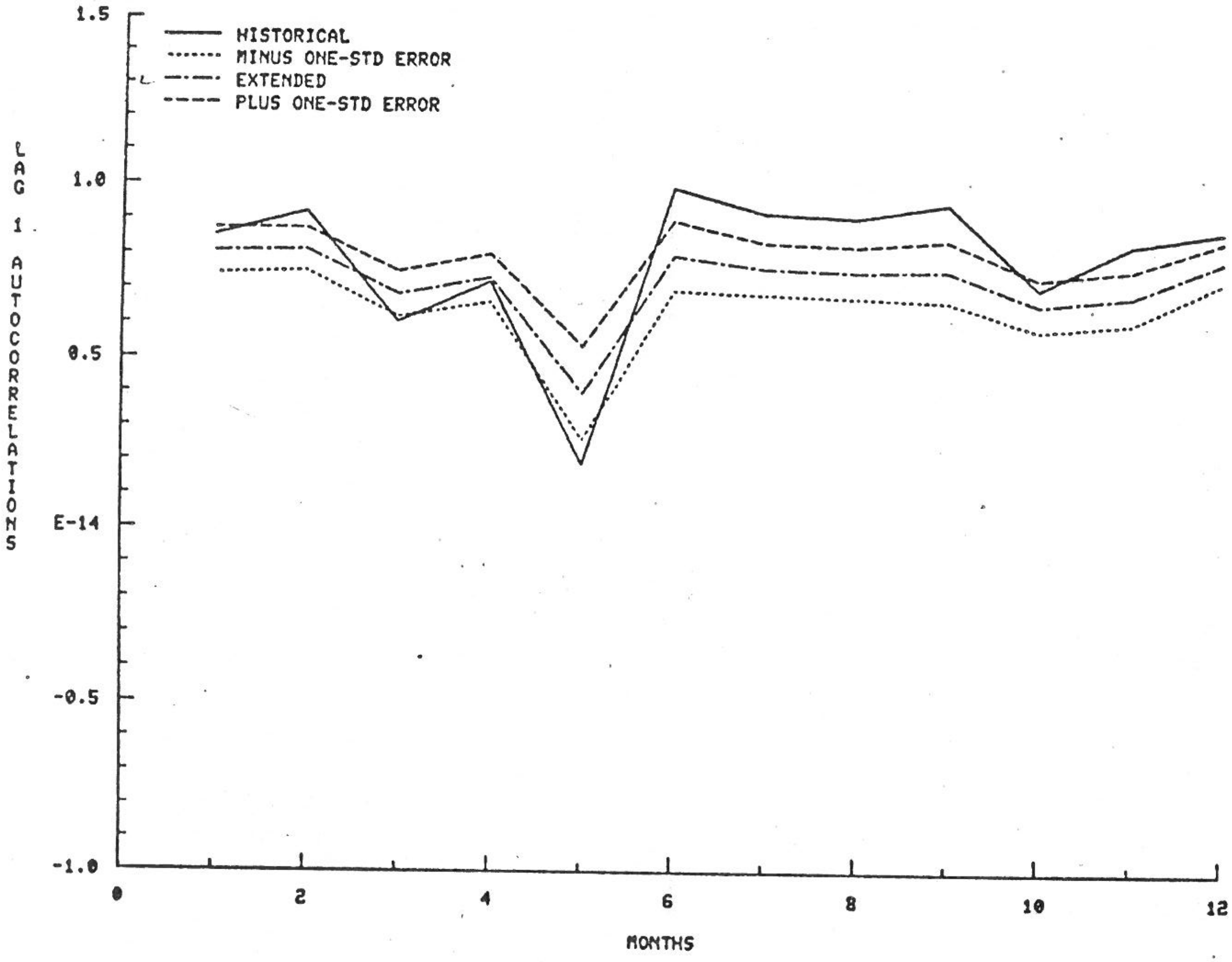


Figure 1.9.B.4. Historical and extended series monthly lag-1 autocorrelation coefficients of Paso del Ermitaño in original domain of flows.

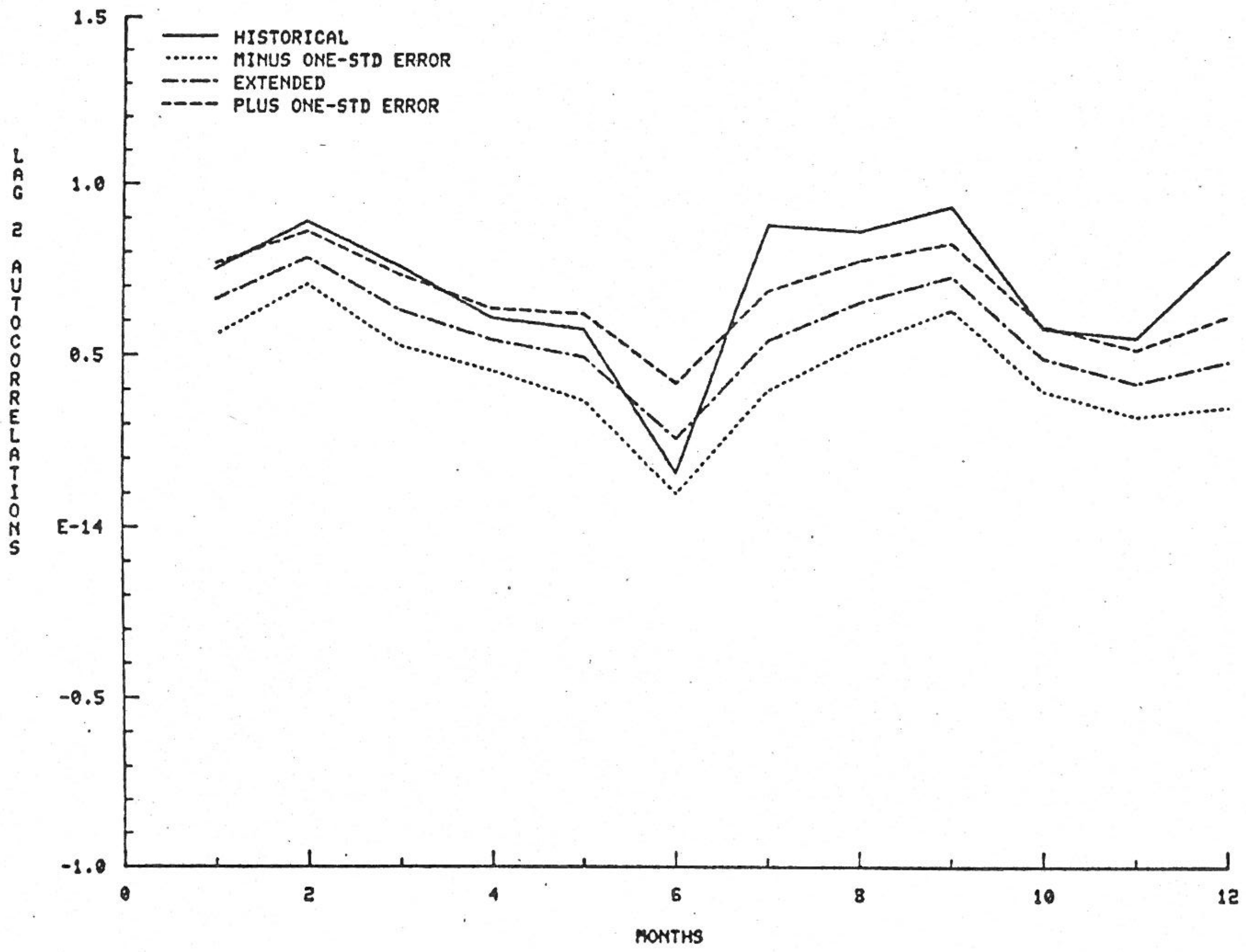


Figure 1.9.B.5. Historical and extended series monthly lag-2 autocorrelation coefficients of Paso del Ermitaño in original domain of flows.

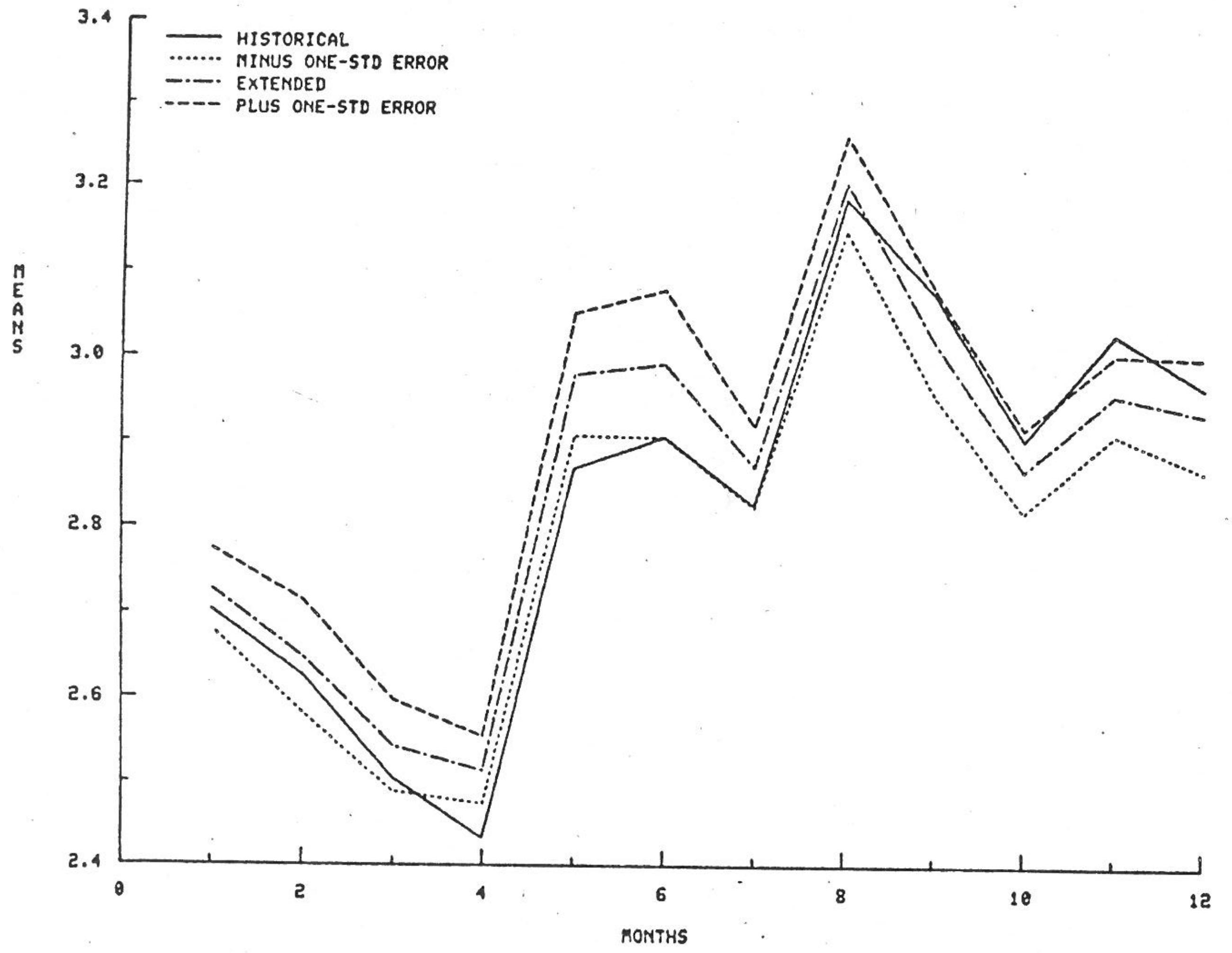


Figure 1.9.B.6. Historical and extended series monthly means of Paso del Ermitaño in logarithmic domain of flows.

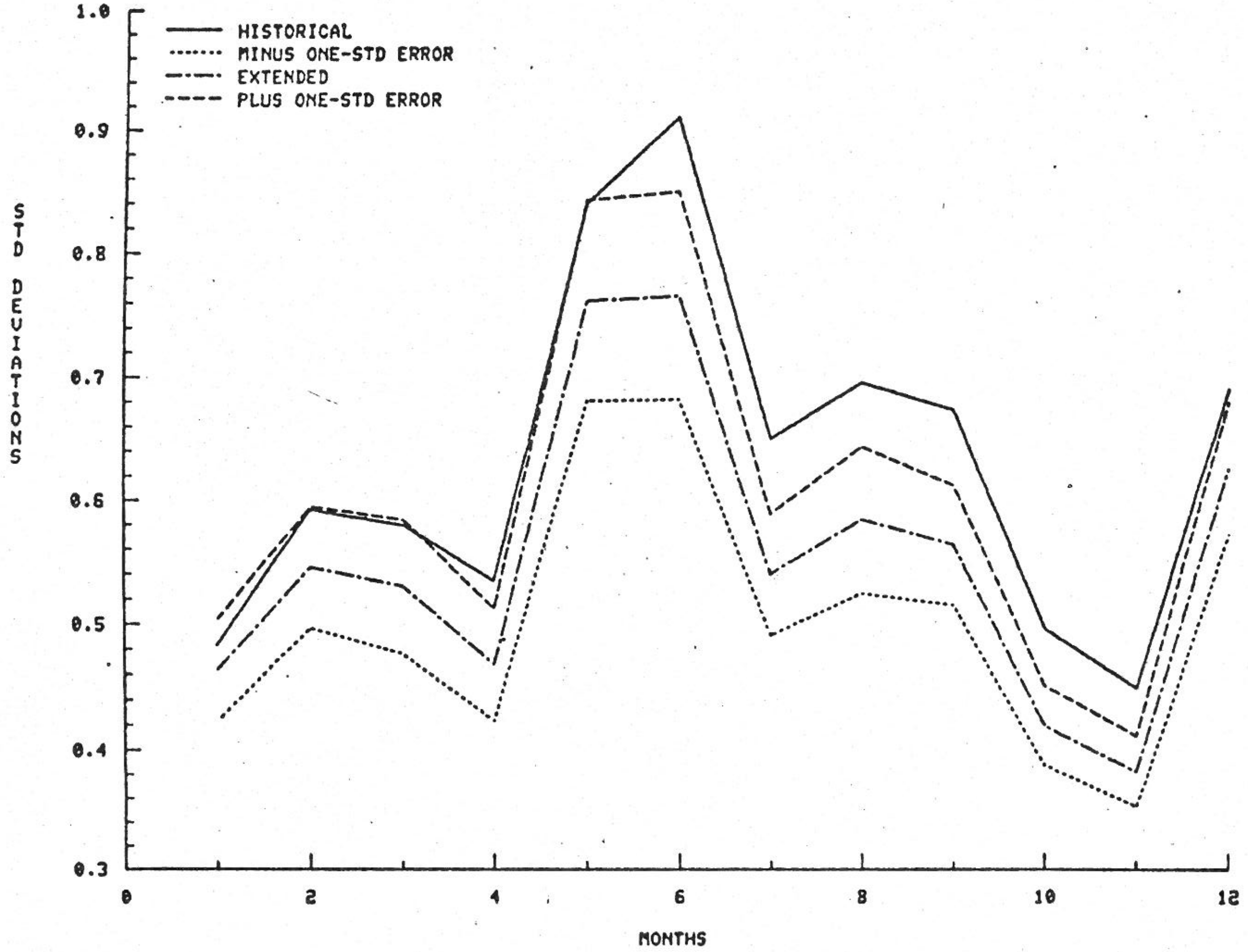


Figure 1.9.B.7. Historical and extended series monthly standard deviations of Paso del Ermitaño in logarithmic domain of flows.

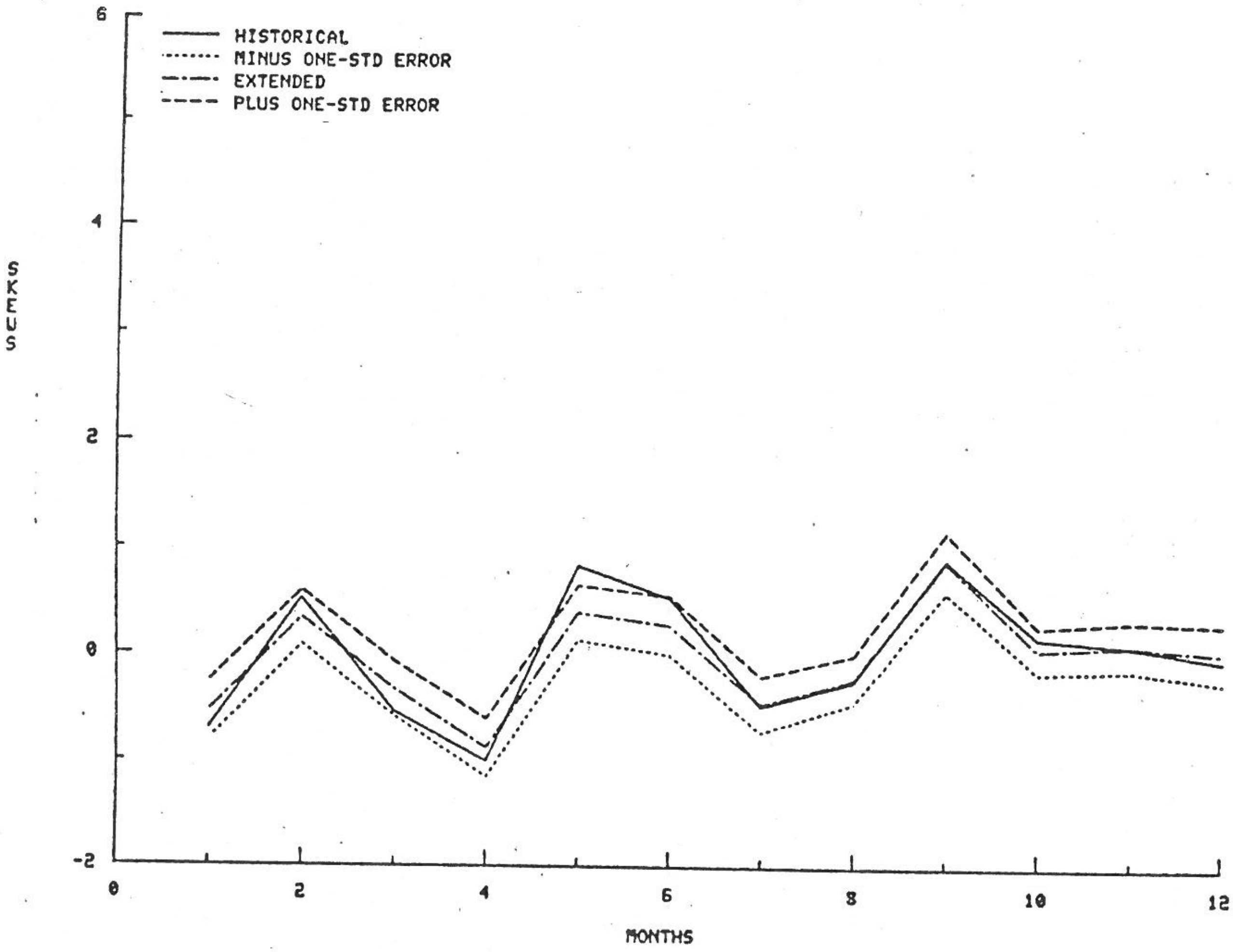


Figure 1.9.B.8. Historical and extended series monthly skewness coefficients of Paso del Ermitaño in logarithmic domain of flows.

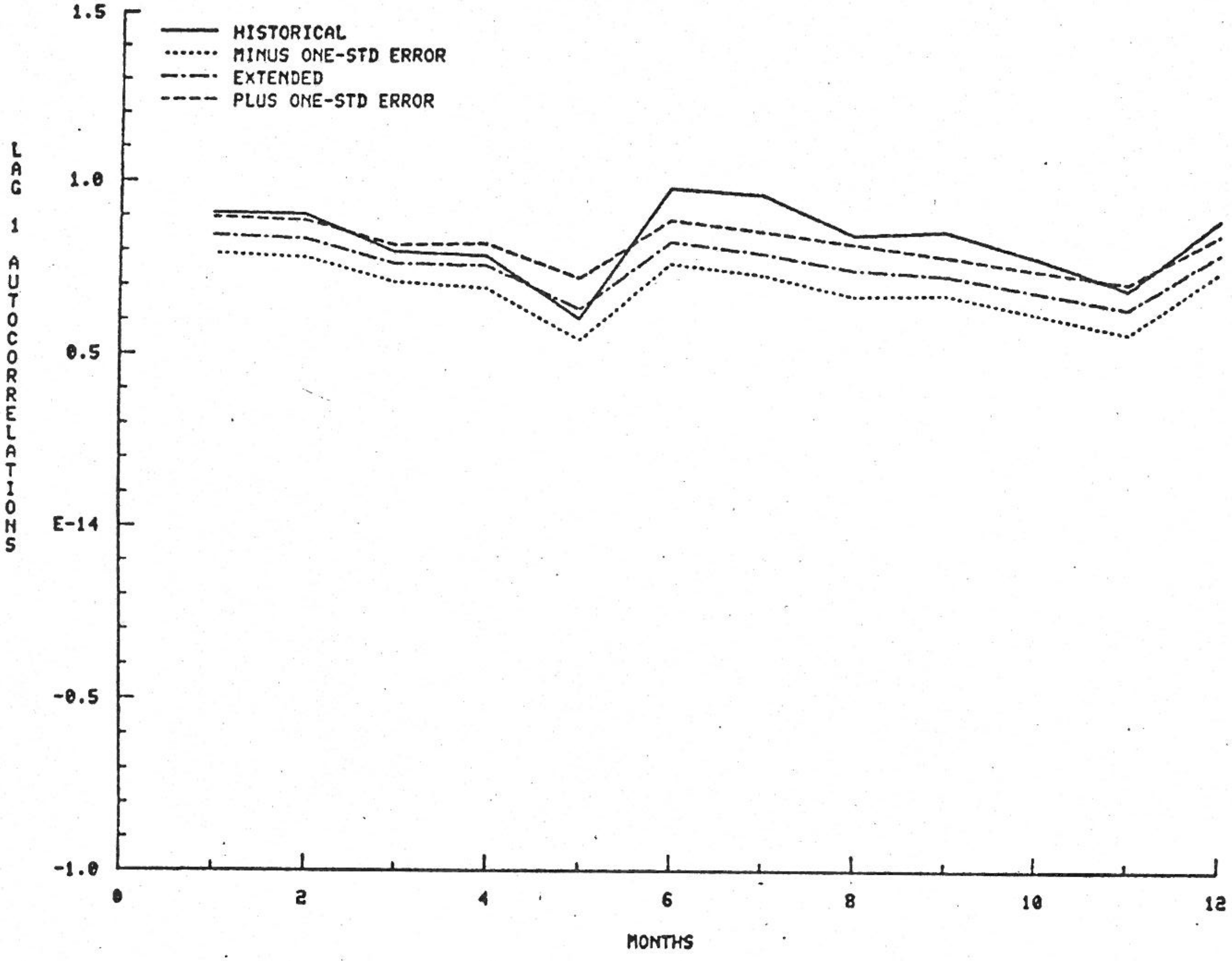


Figure 1.9.B.9. Historical and extended series monthly lag-1 autocorrelation coefficients of Paso del Ermitaño in logarithmic domain of flows.

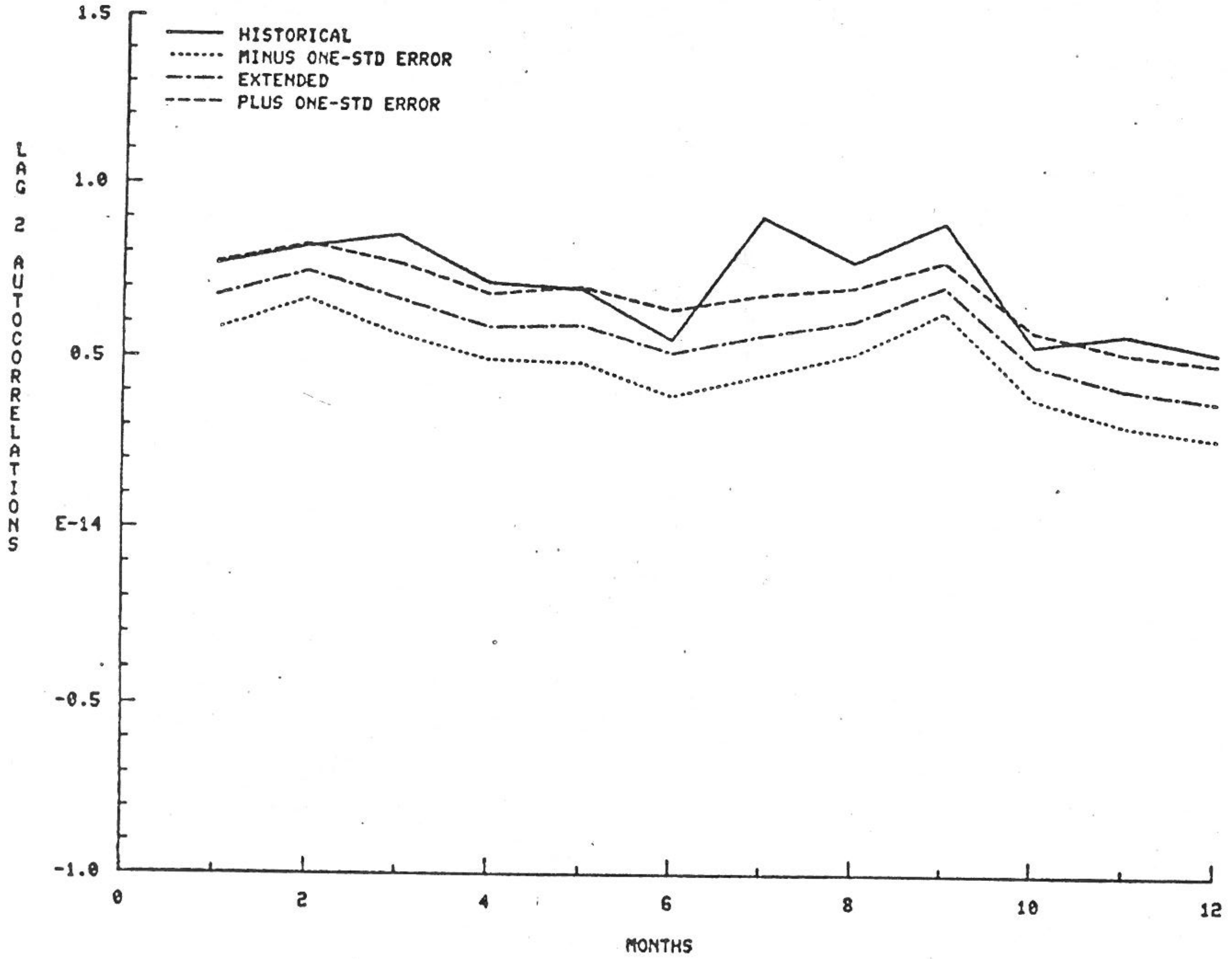


Figure 1.9.B.10. Historical and extended series monthly lag-2 autocorrelation coefficients of Paso del Ermitaño in logarithmic domain of flows.

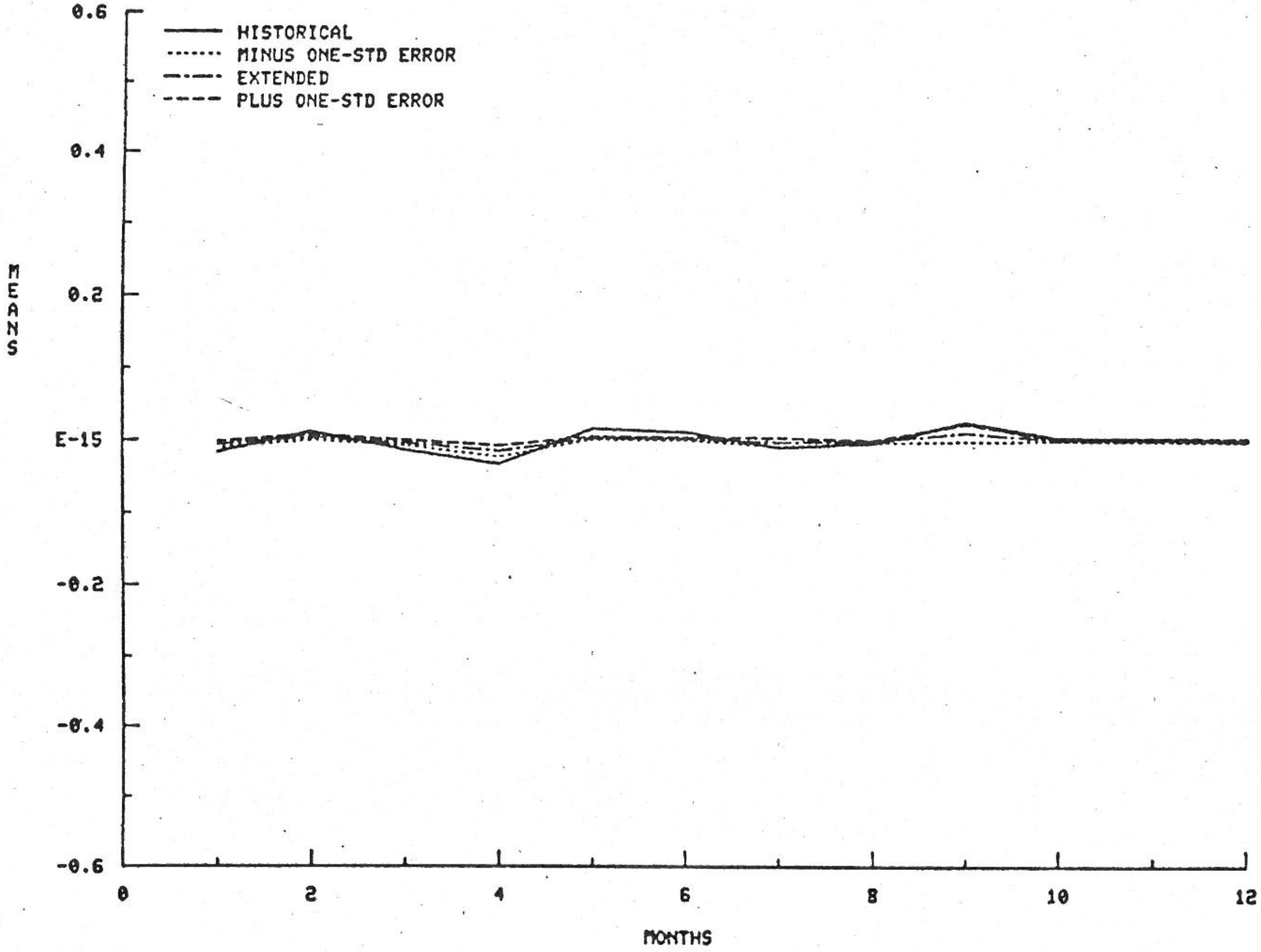


Figure 1.9.B.11. Historical and extended series monthly means of Paso del Ermitaño in log-Wilson-Hilferty domain of flows.

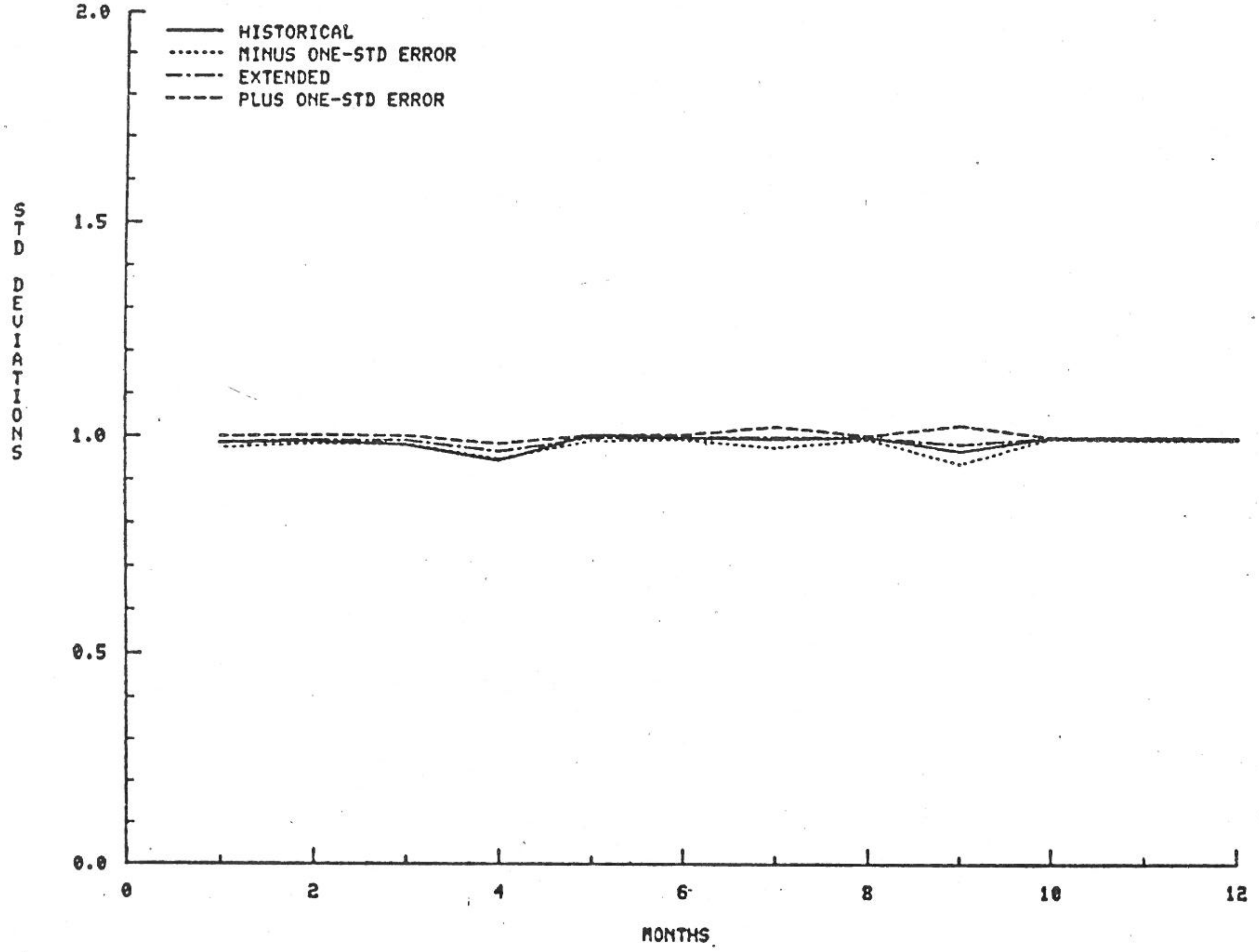


Figure 1.9.B.12. Historical and extended series monthly standard deviations of Paso del Ermitaño in log-Wilson-Hilferty domain of flows.

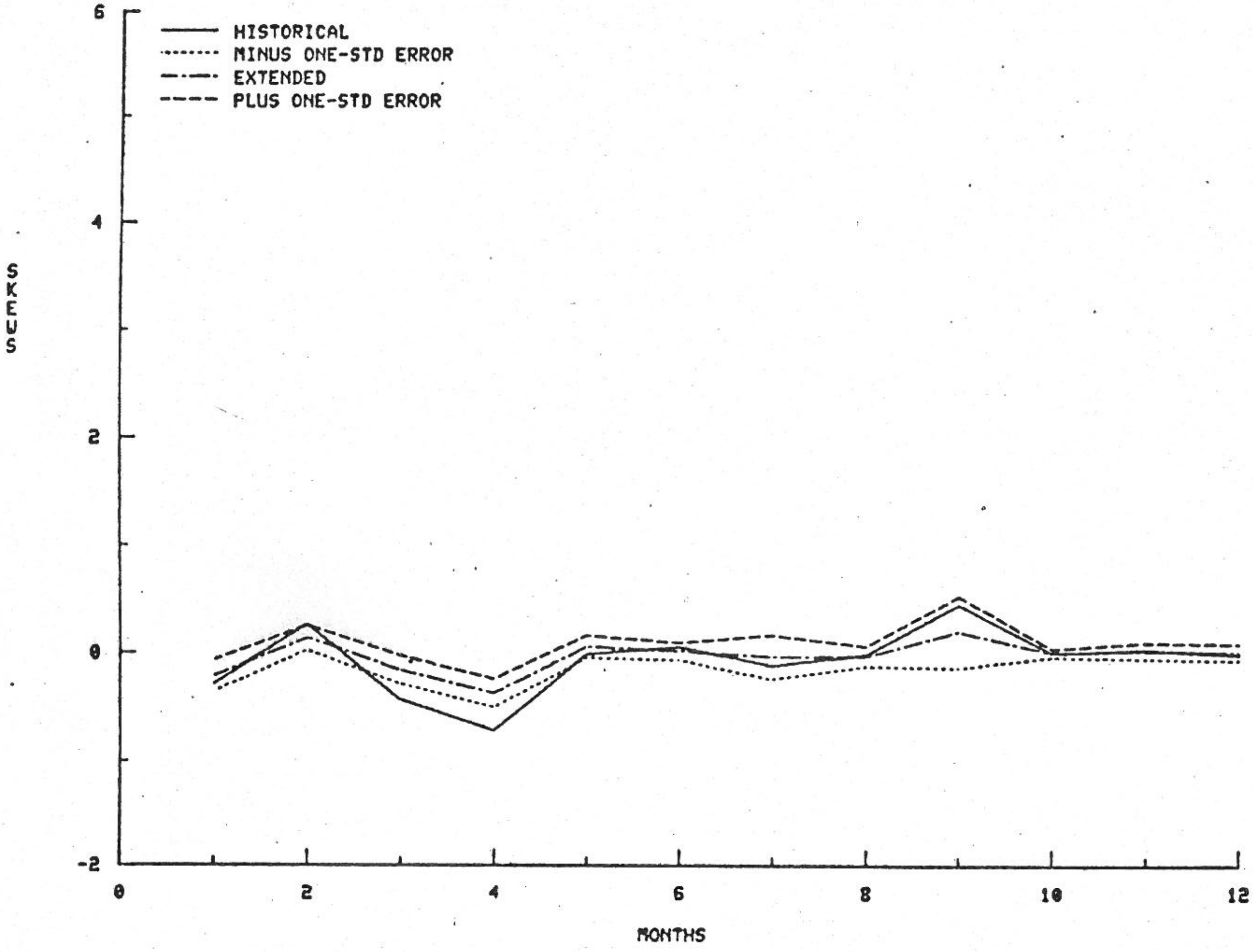


Figure 1.9.B.13. Historical and extended series monthly skewness coefficients of Paso del Ermitaño in log-Wilson-Hilferty domain of flows.

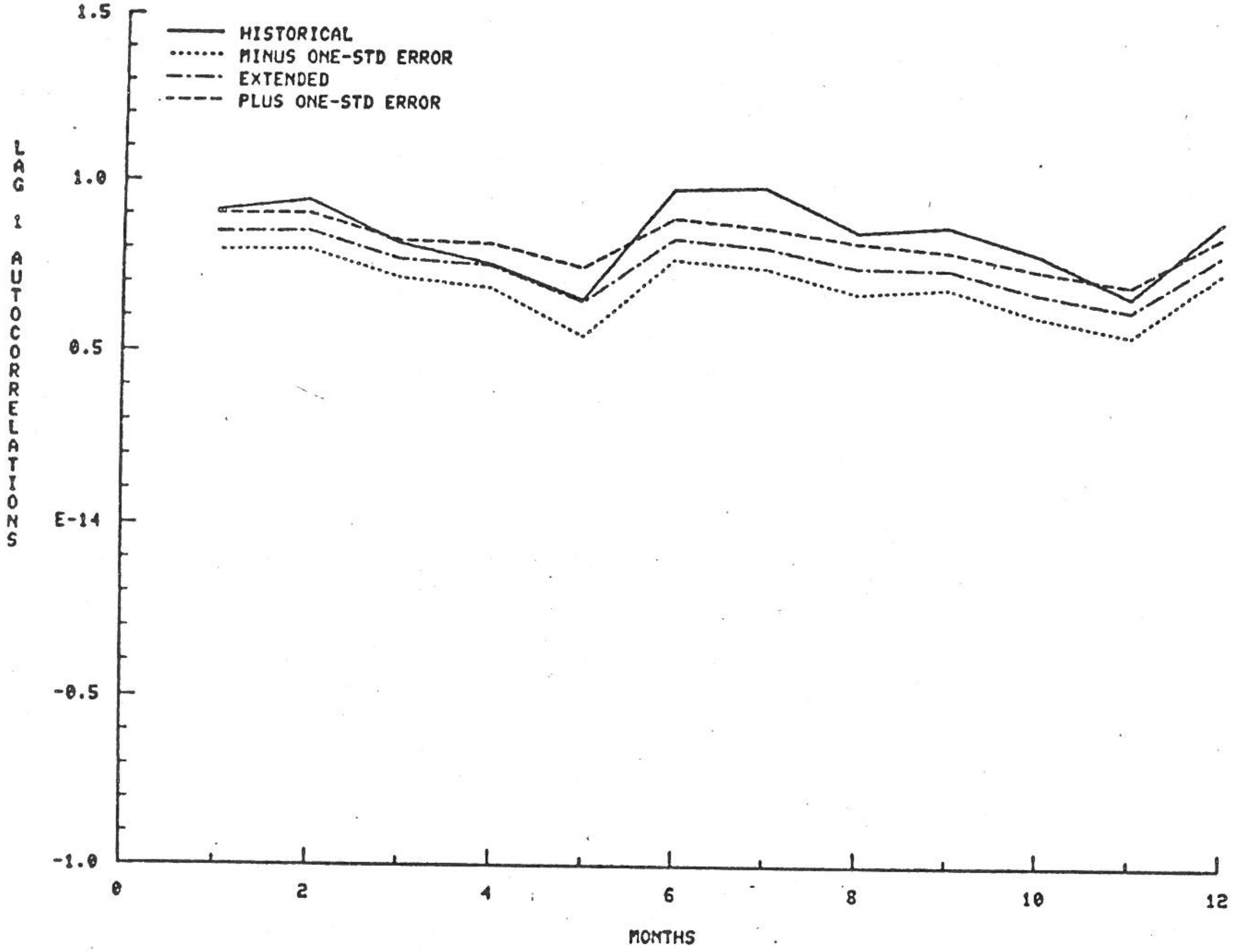


Figure 1.9.B.14. Historical and extended series monthly lag-1 autocorrelation coefficients of Paso del Ermitaño in log-Wilson-Hilferty domain of flows.

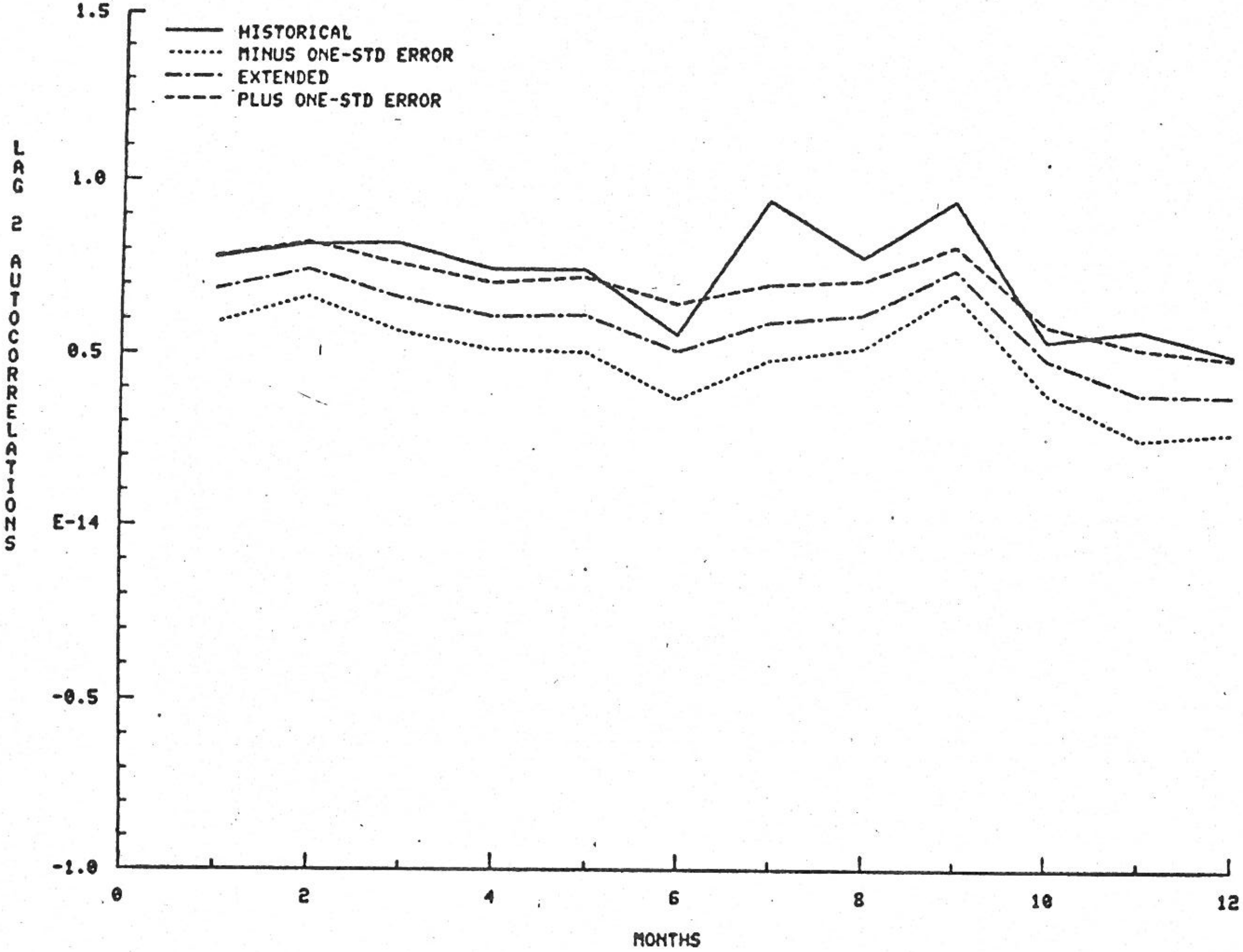


Figure 1.9.B.15. Historical and extended series monthly lag-2 autocorrelation coefficients of Paso del Ermitaño in log-Wilson-Hilferty domain of flows.

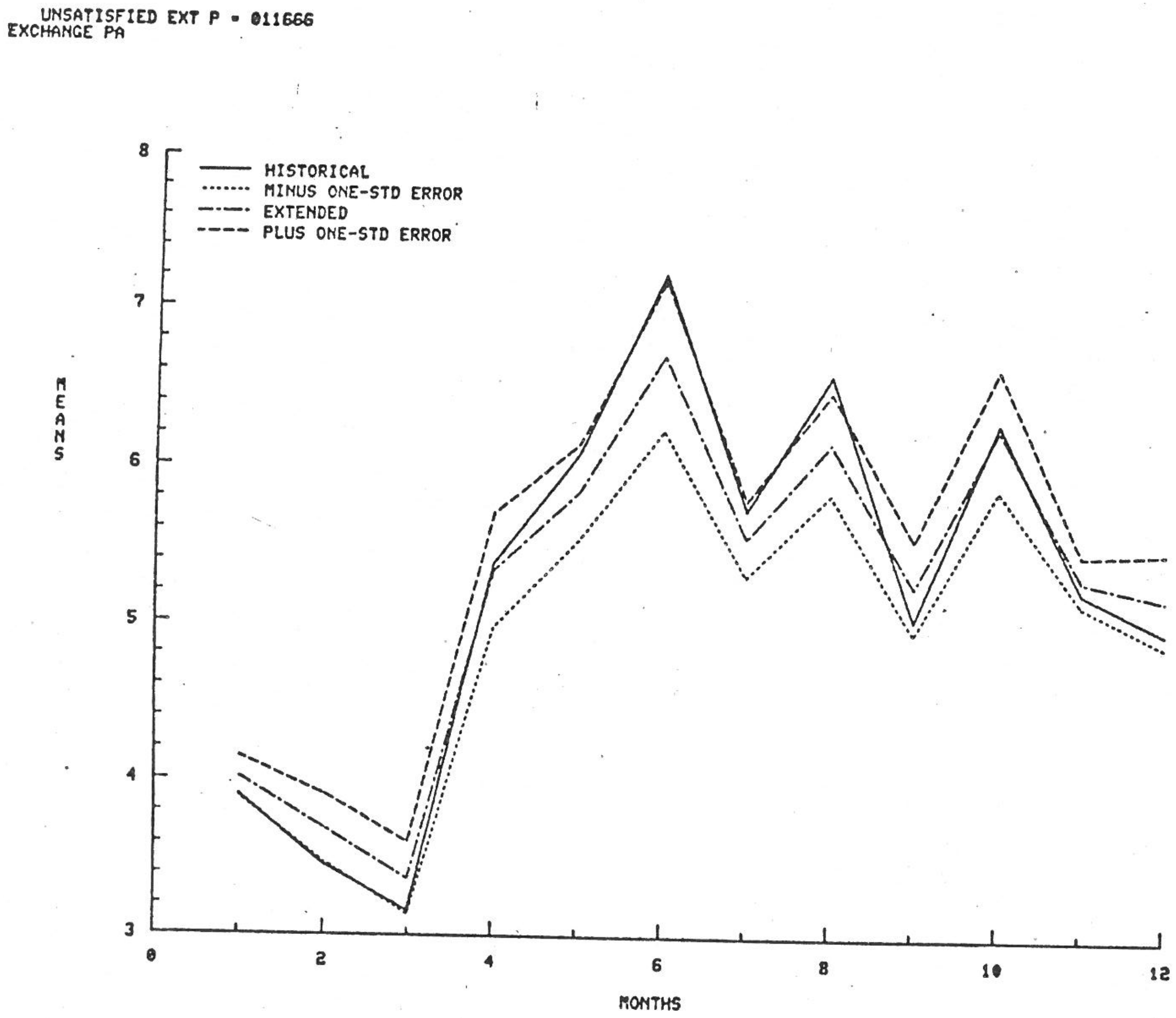


Figure 1.9.B.16. Historical and extended series monthly means of Rancho Arriba in original domain of flows.

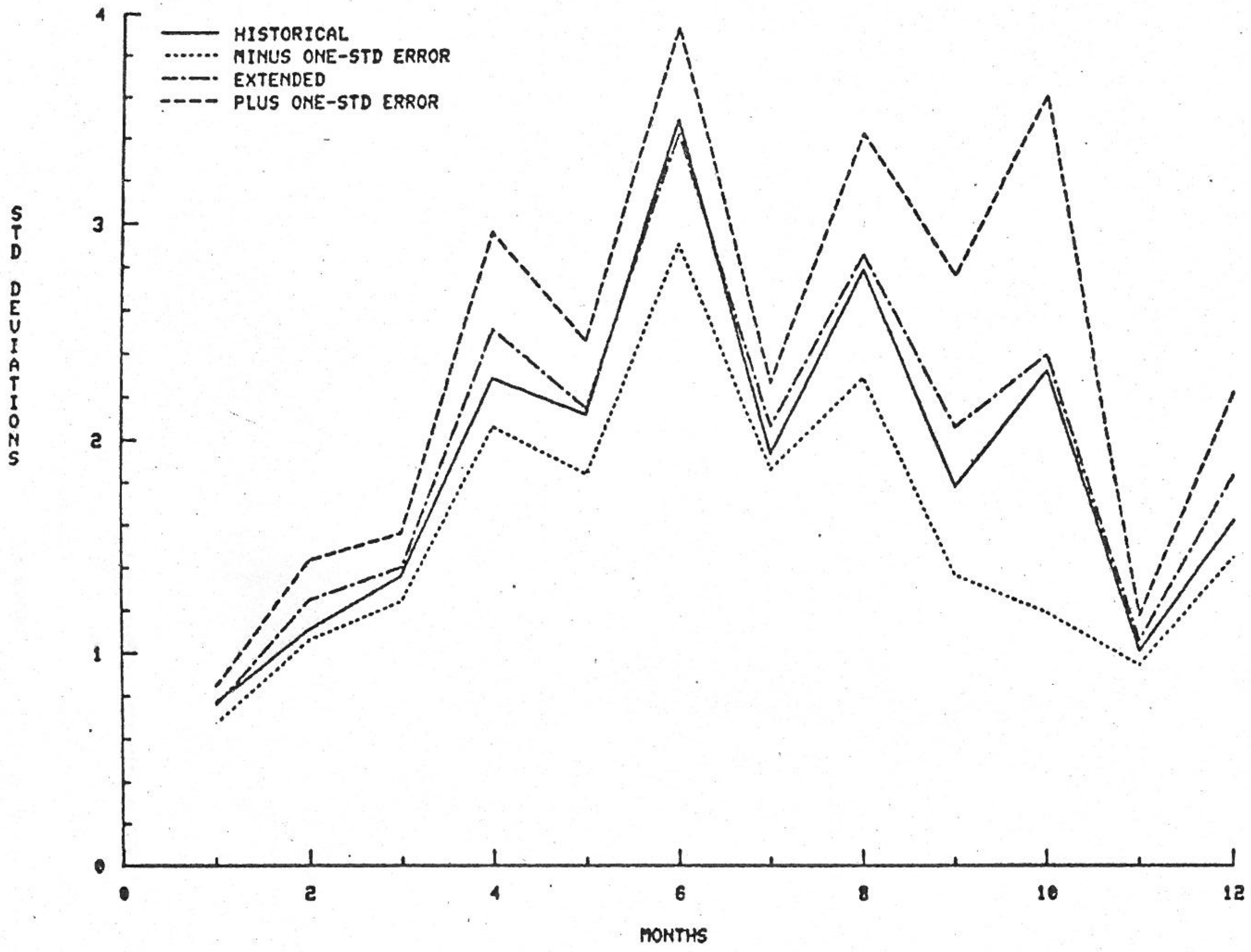


Figure 1.9.B.17. Historical and extended series monthly standard deviations of Rancho Arribain original domain of flows.

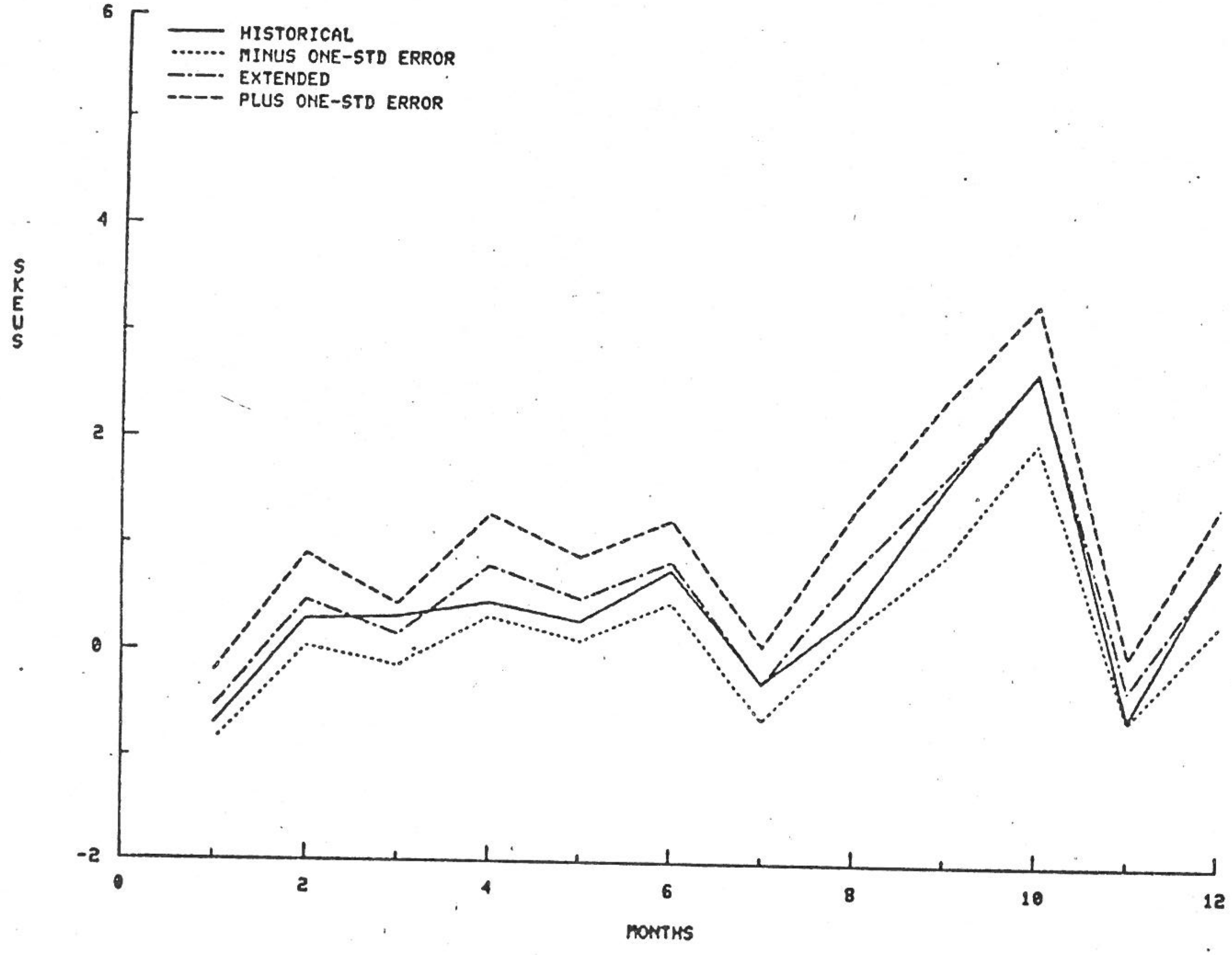


Figure 1.9.B.18. Historical and extended series monthly skewness coefficients of Rancho Arriba in original domain of flows.

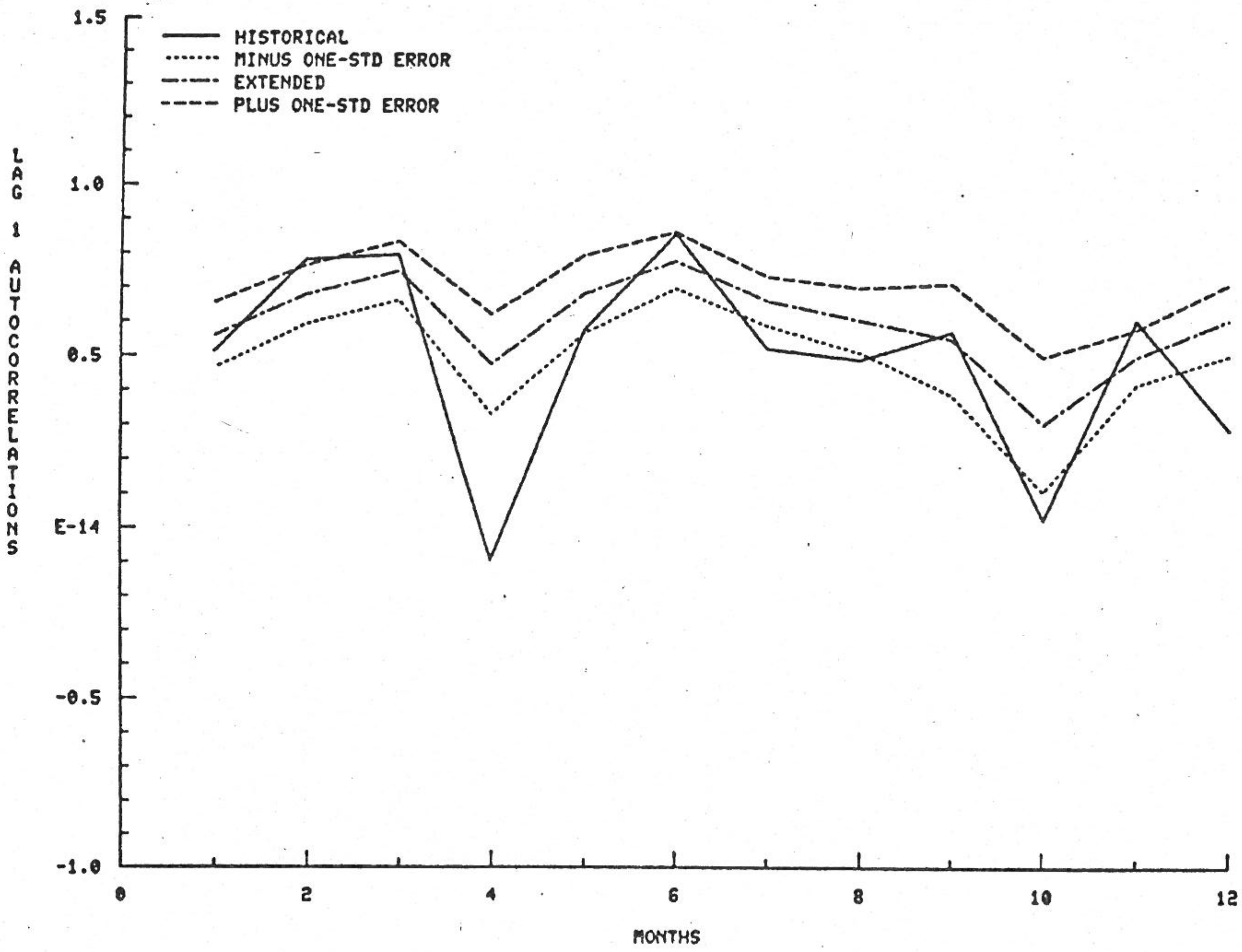


Figure 1.9.B.19. Historical and extended series monthly lag-1 autocorrelation coefficients of Rancho Arriba in original domain of flows.

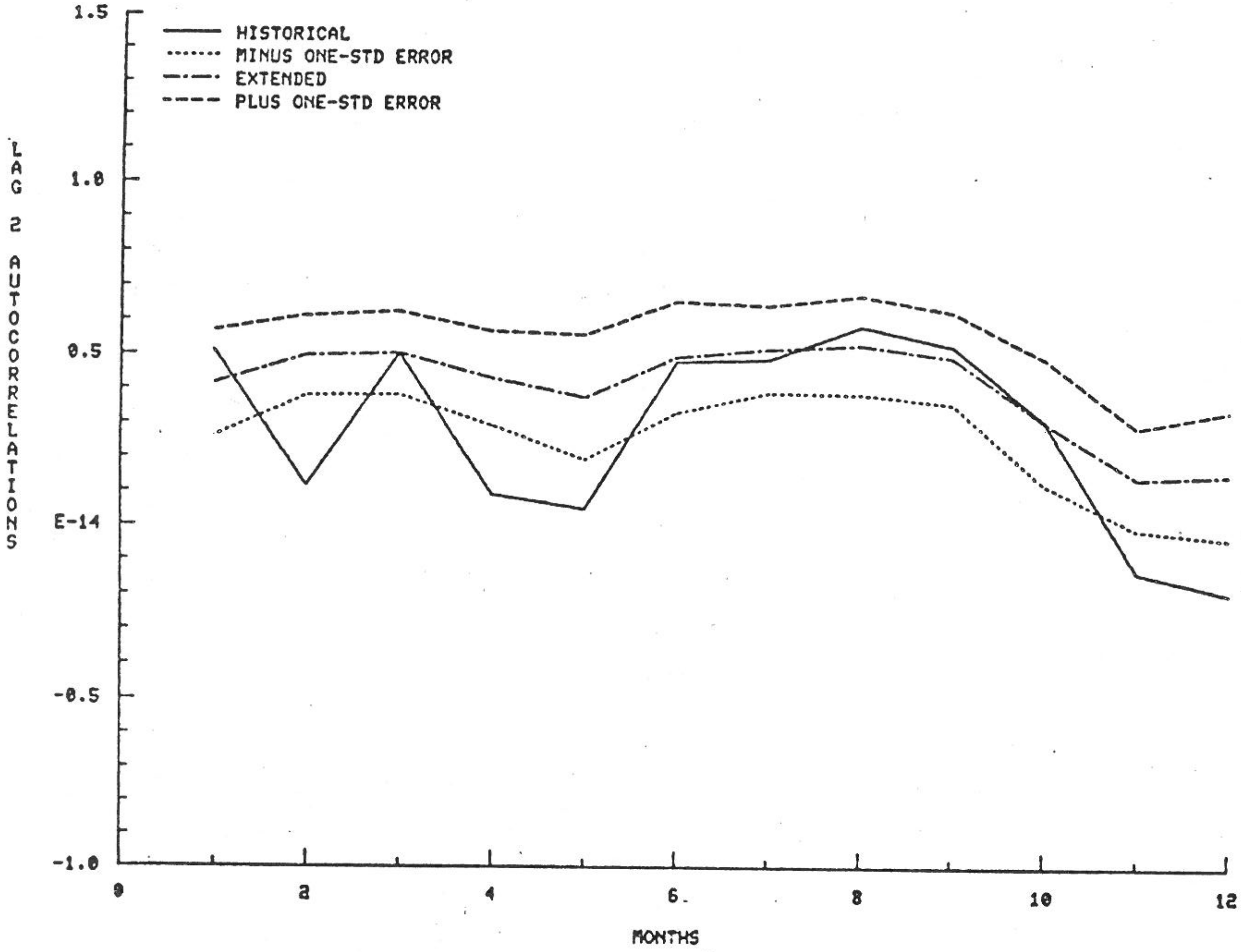


Figure 1.9.B.20. Historical and extended series monthly lag-2 autocorrelation coefficients of Rancho Arriba in original domain of flows.

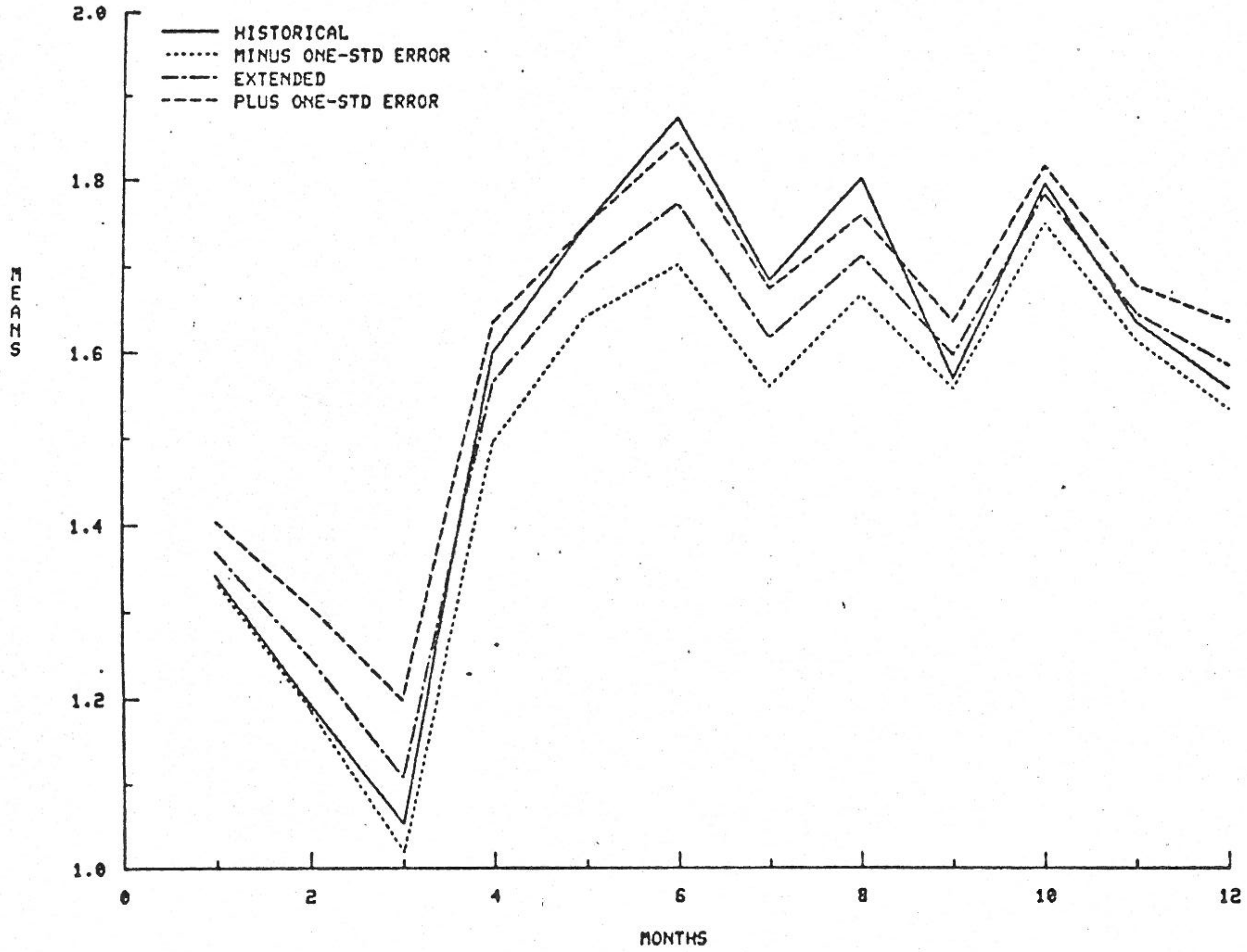


Figure 1.9.B.21. Historical and extended series monthly means of Rancho Arriba in logarithmic domain of flows.

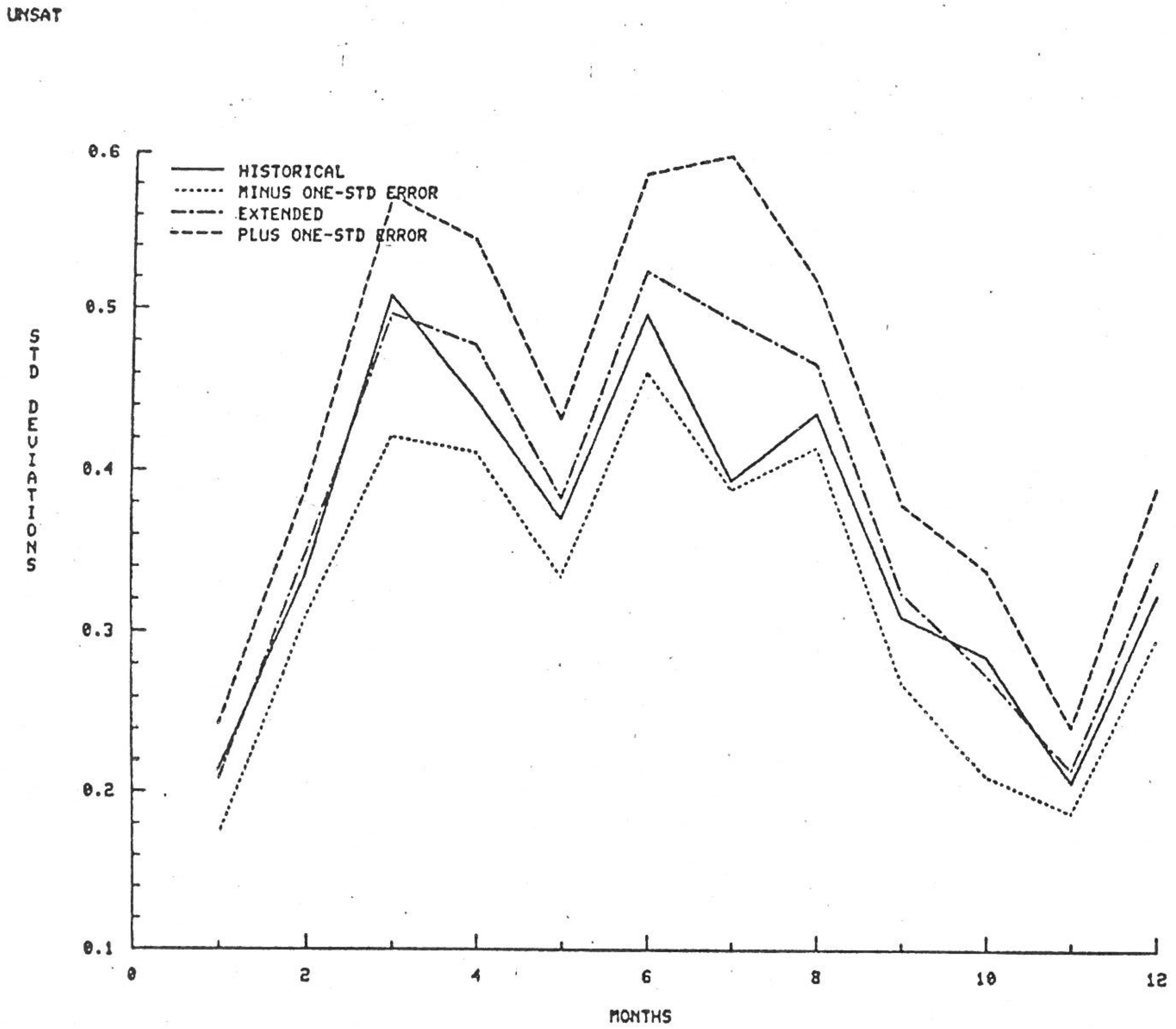


Figure 1.9.B.22. Historical and extended series monthly standard deviations of Rancho Arriba in logarithmic domain of flows.

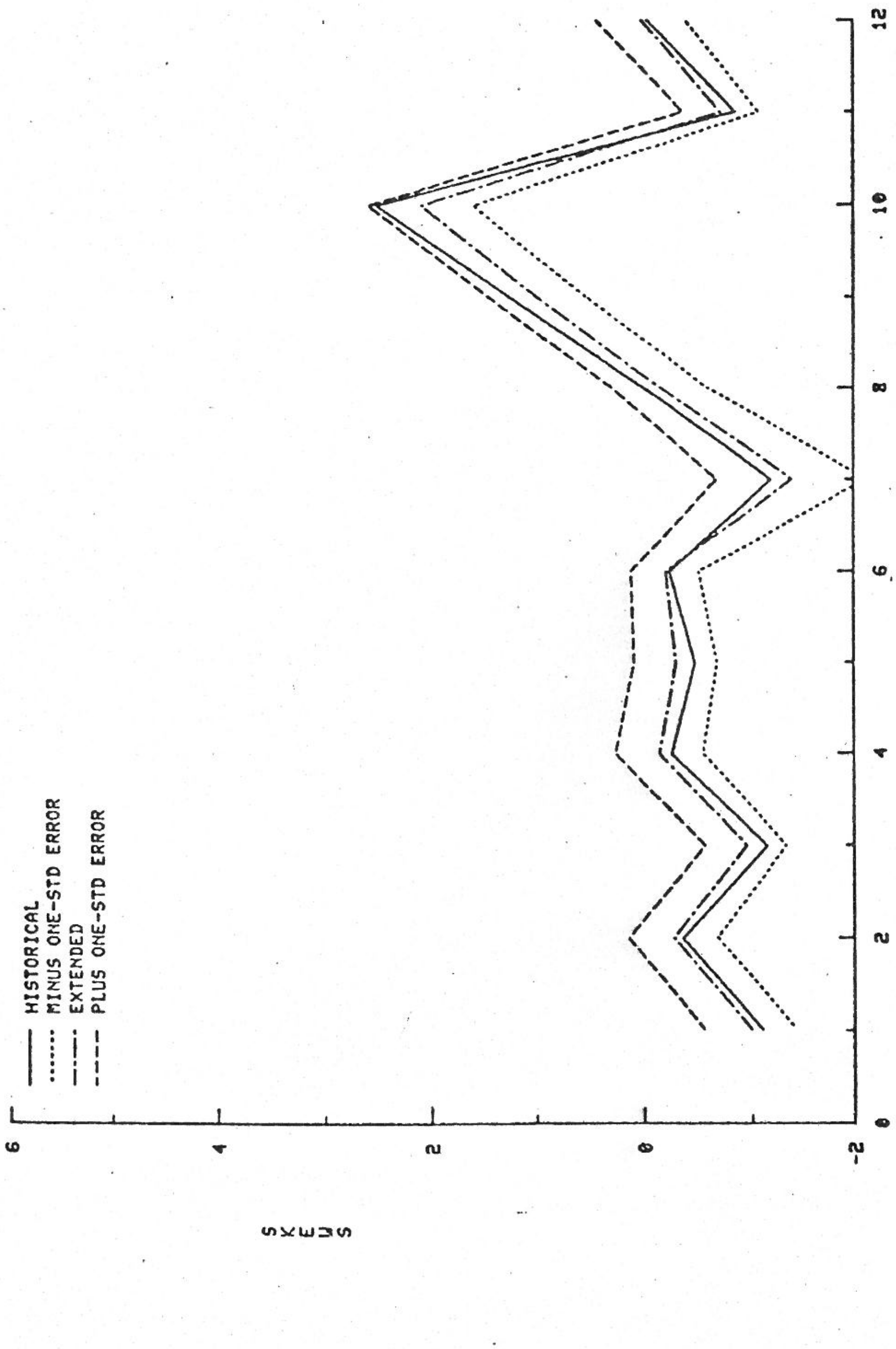


Figure 1.9.B.23. Historical and extended series monthly skewness coefficients of Rancho Arriba in logarithmic domain of flows.

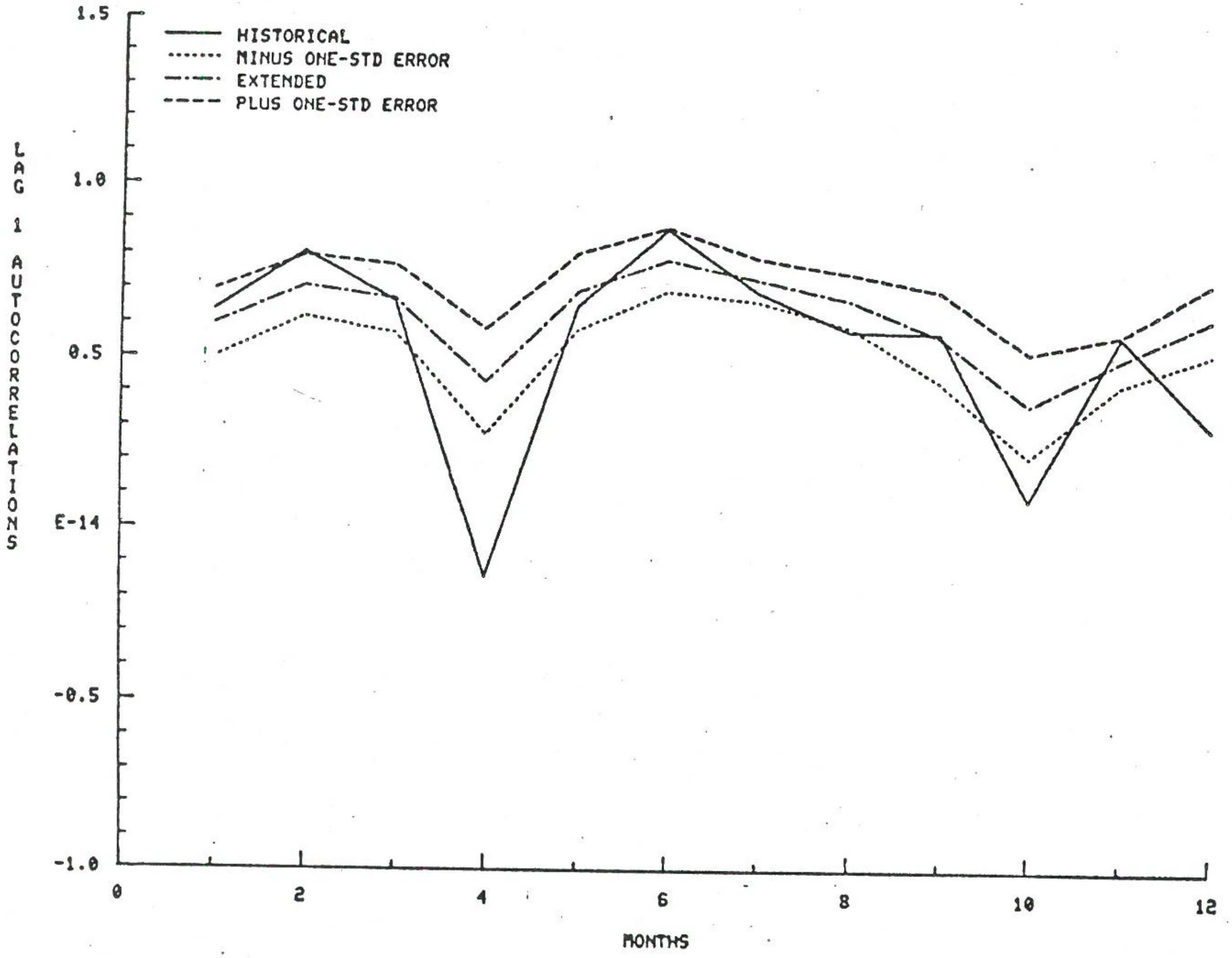


Figure 1.9.B.24. Historical and extended series monthly lag-1 autocorrelation coefficients of Rancho Arriba in logarithmic domain of flows.

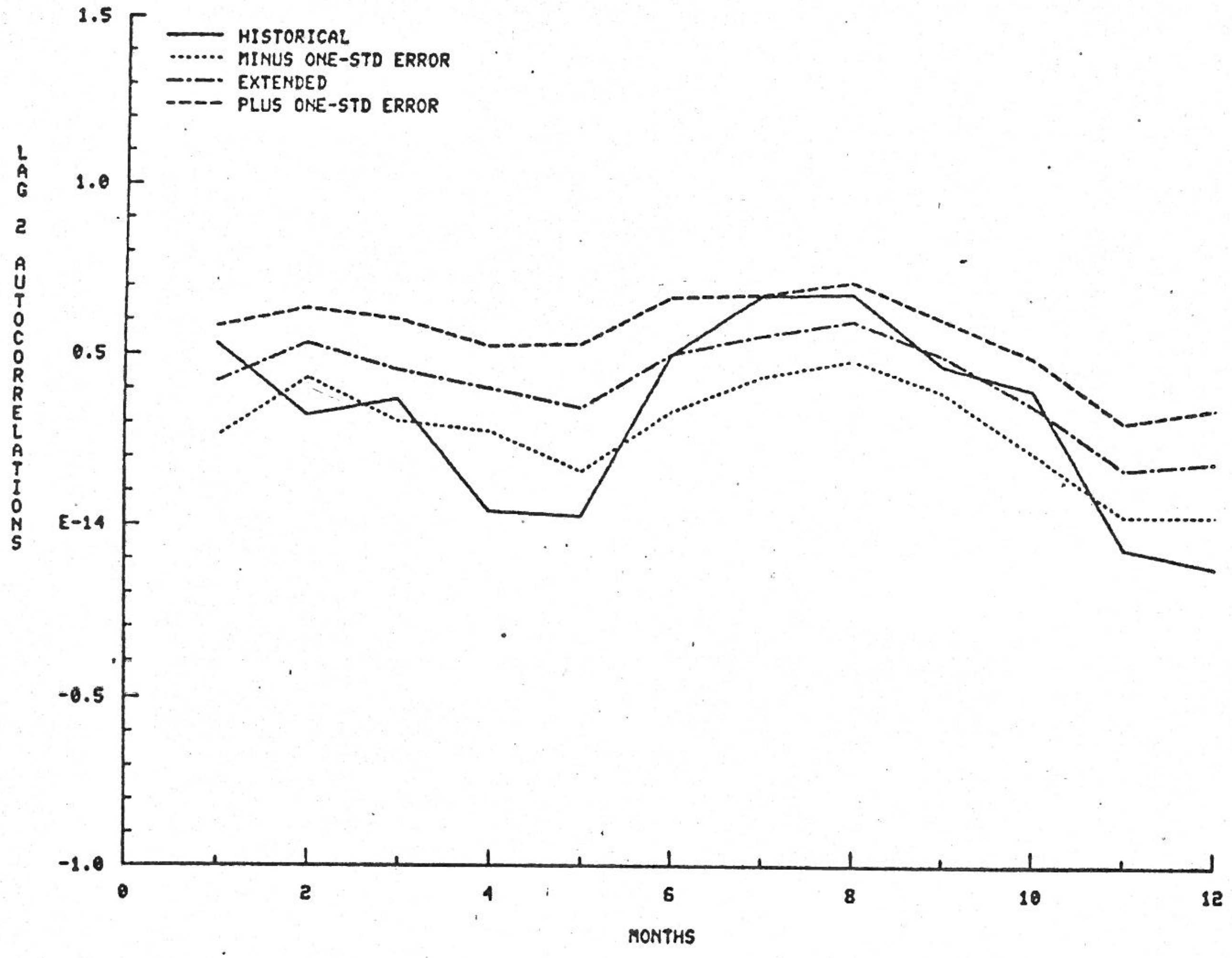


Figure 1.9.B.25. Historical and extended series monthly lag-2 autocorrelation coefficients of Rancho Arriba in logarithmic domain of flows.

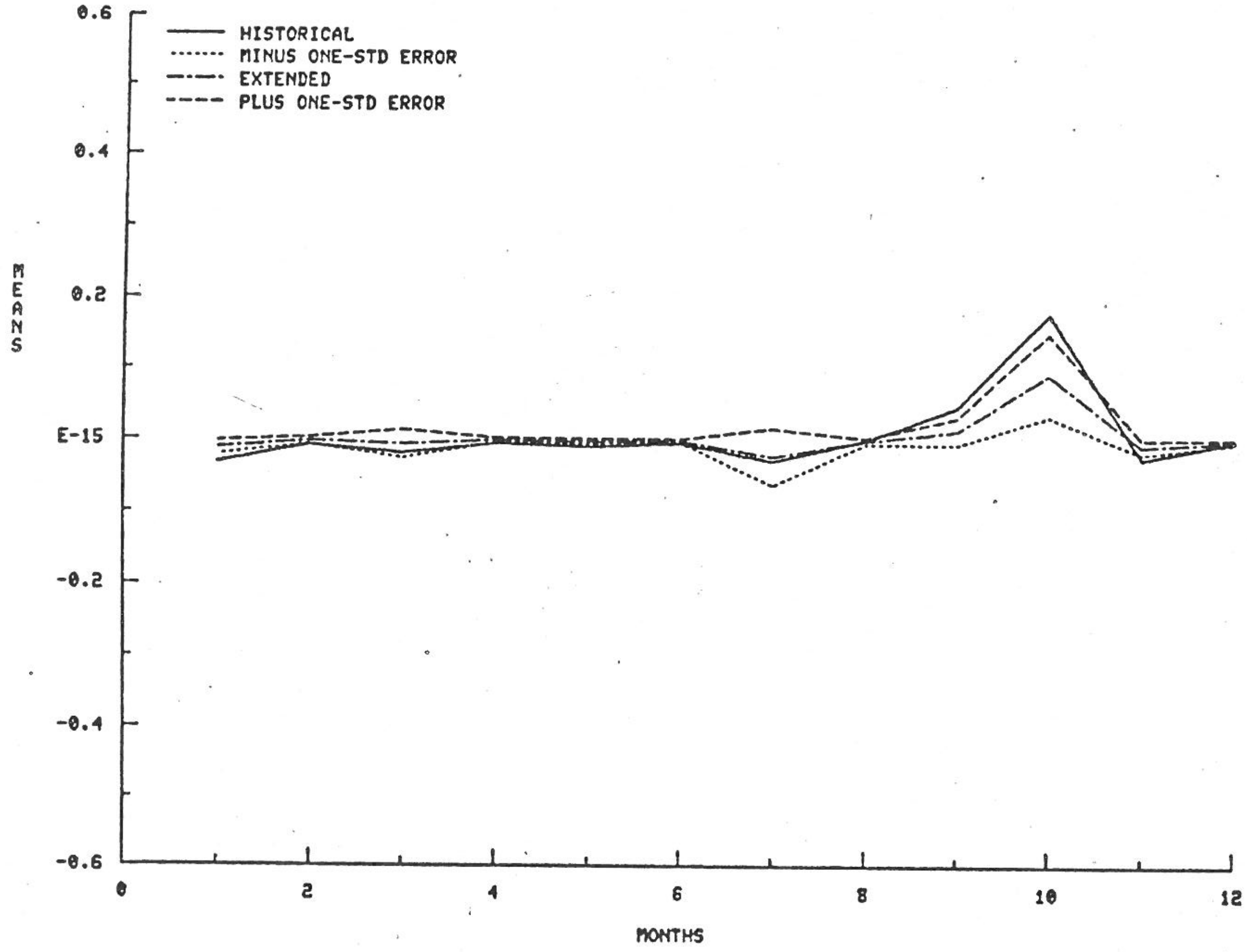


Figure 1.9.B.26. Historical and extended series monthly means of Rancho Arriba in log-Wilson-Hilferty domain of flows.

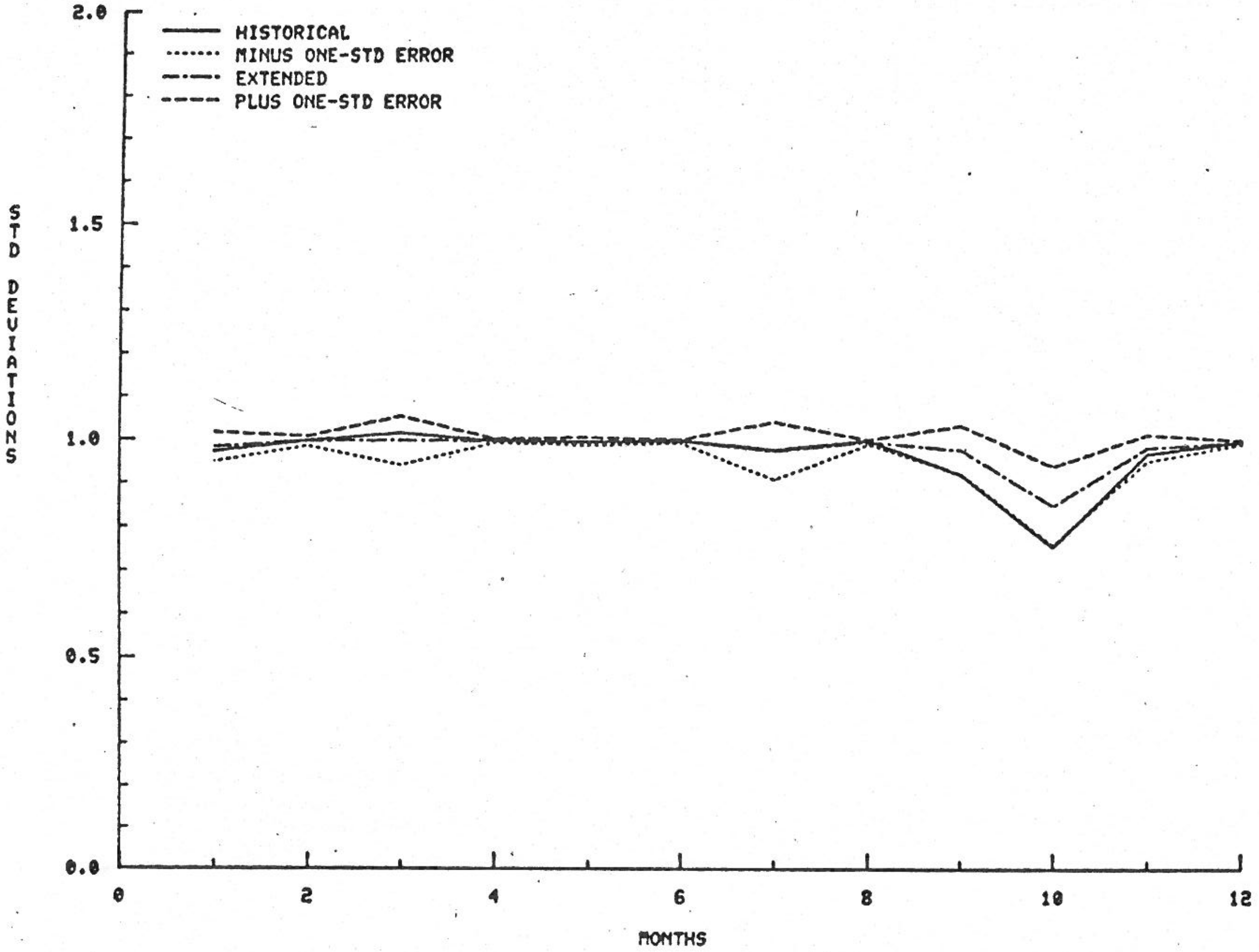


Figure 1.9.B.27. Historical and extended series monthly standard deviations of Rancho Arriba in log-Wilson-Hilferty domain of flows.

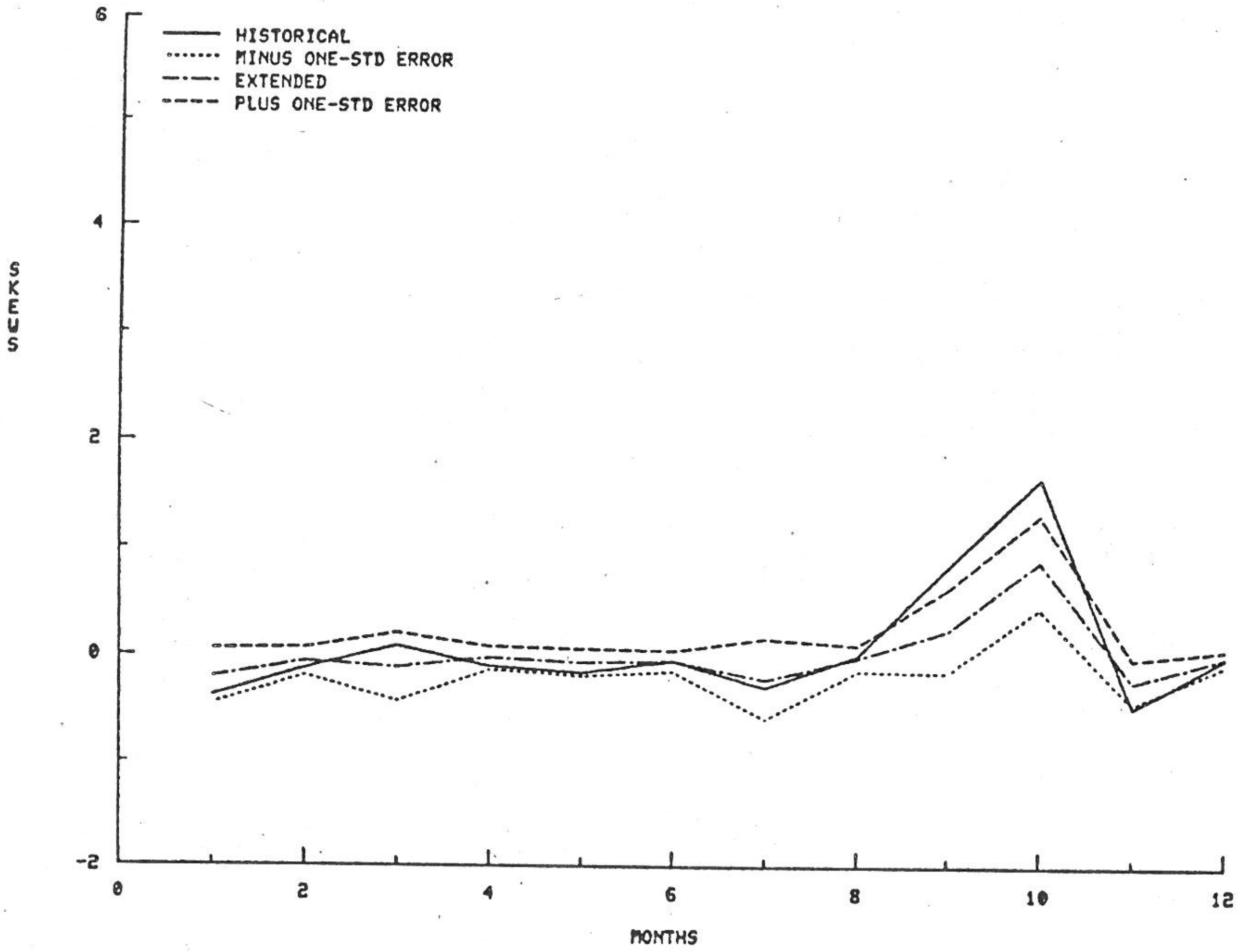


Figure 1.9.B.28. Historical and extended series monthly skewness coefficients of Rancho Arriba in log-Wilson-Hilferty domain of flows.

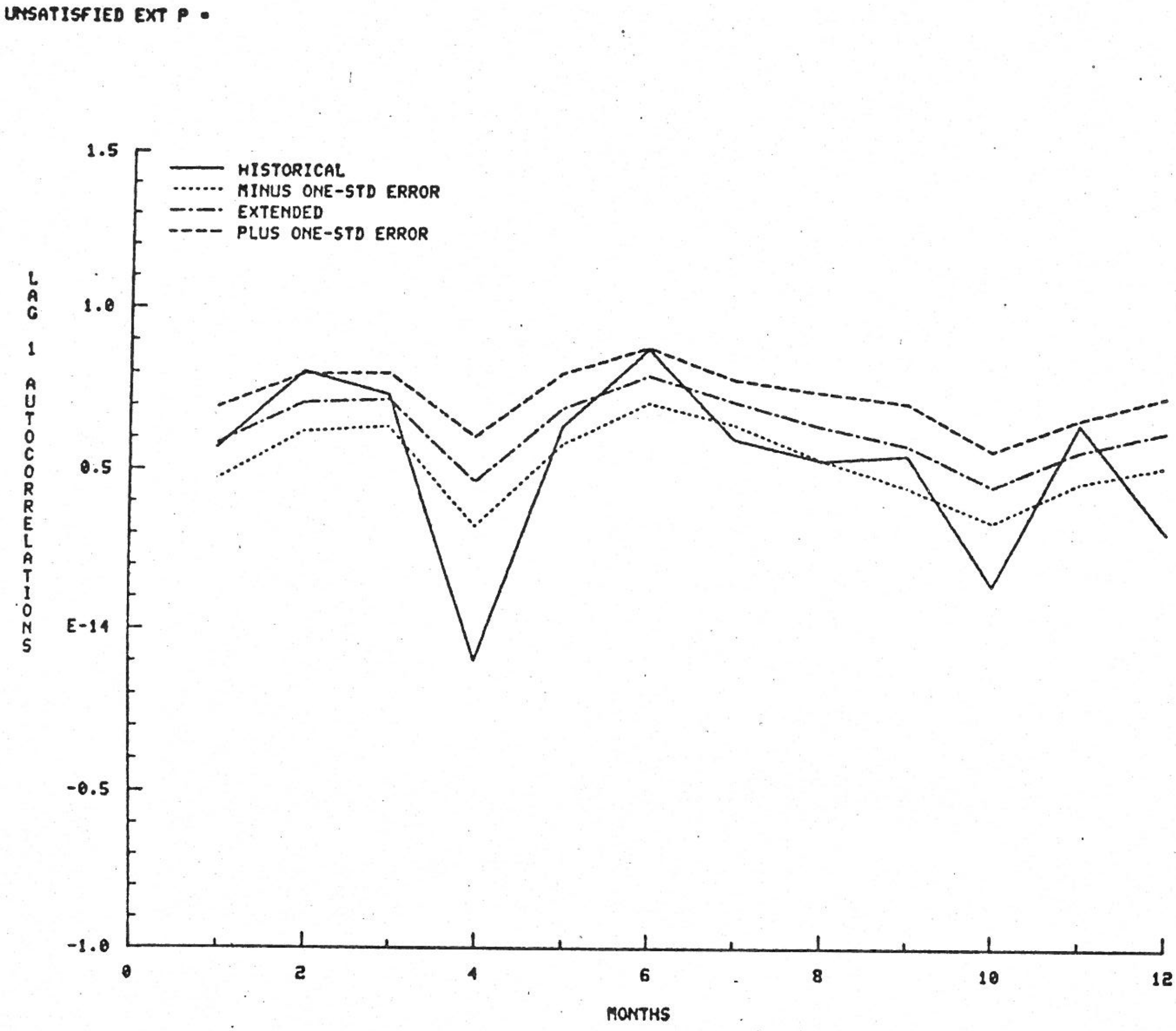


Figure 1.9.B.29. Historical and extended series monthly lag-1 autocorrelation coefficients of Rancho Arriba in log-Wilson-Hilferty domain of flows.

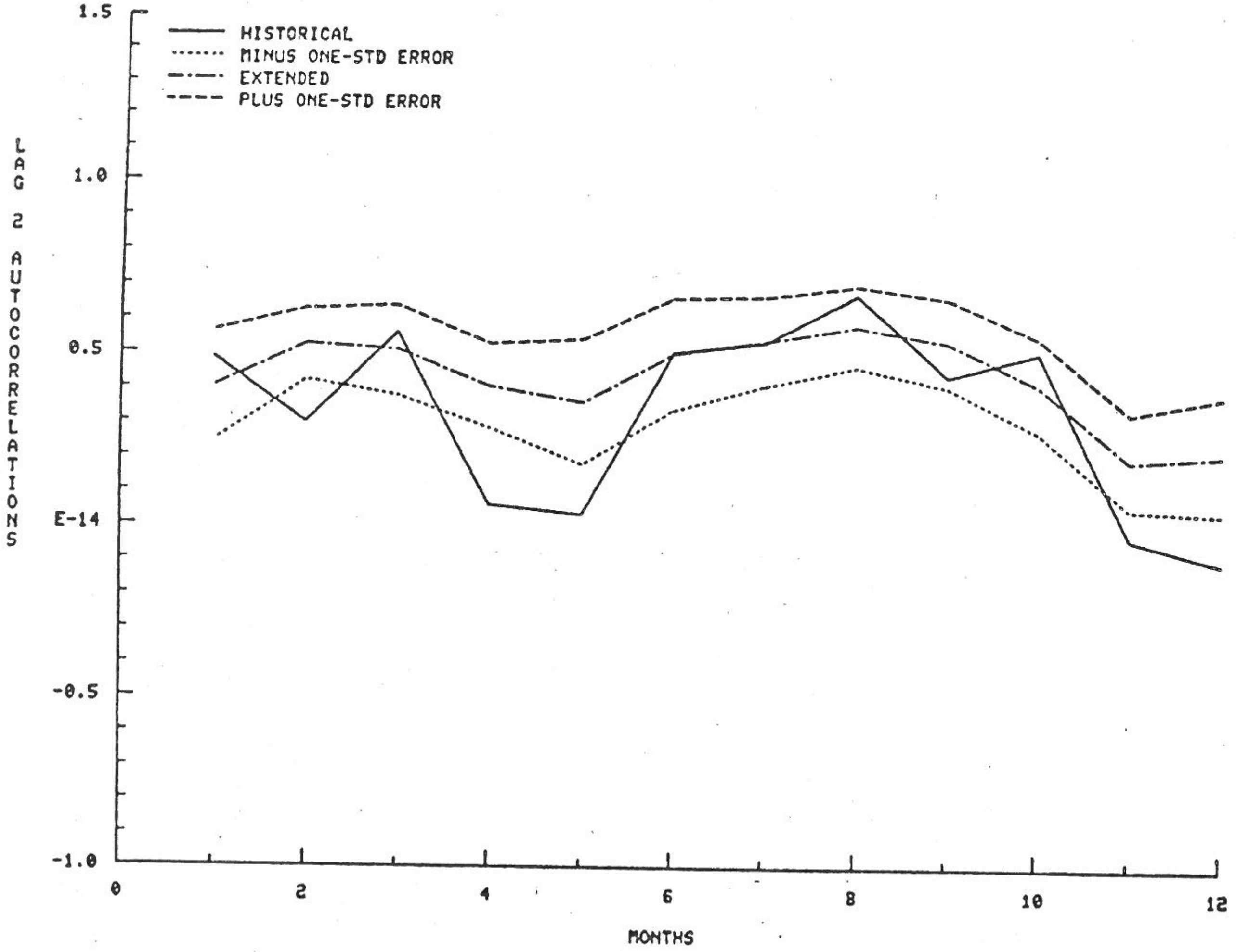


Figure 1.9.B.30. Historical and extended series monthly lag-2 autocorrelation coefficients of Rancho Arriba in log-Wilson-Hilferty domain of flows.

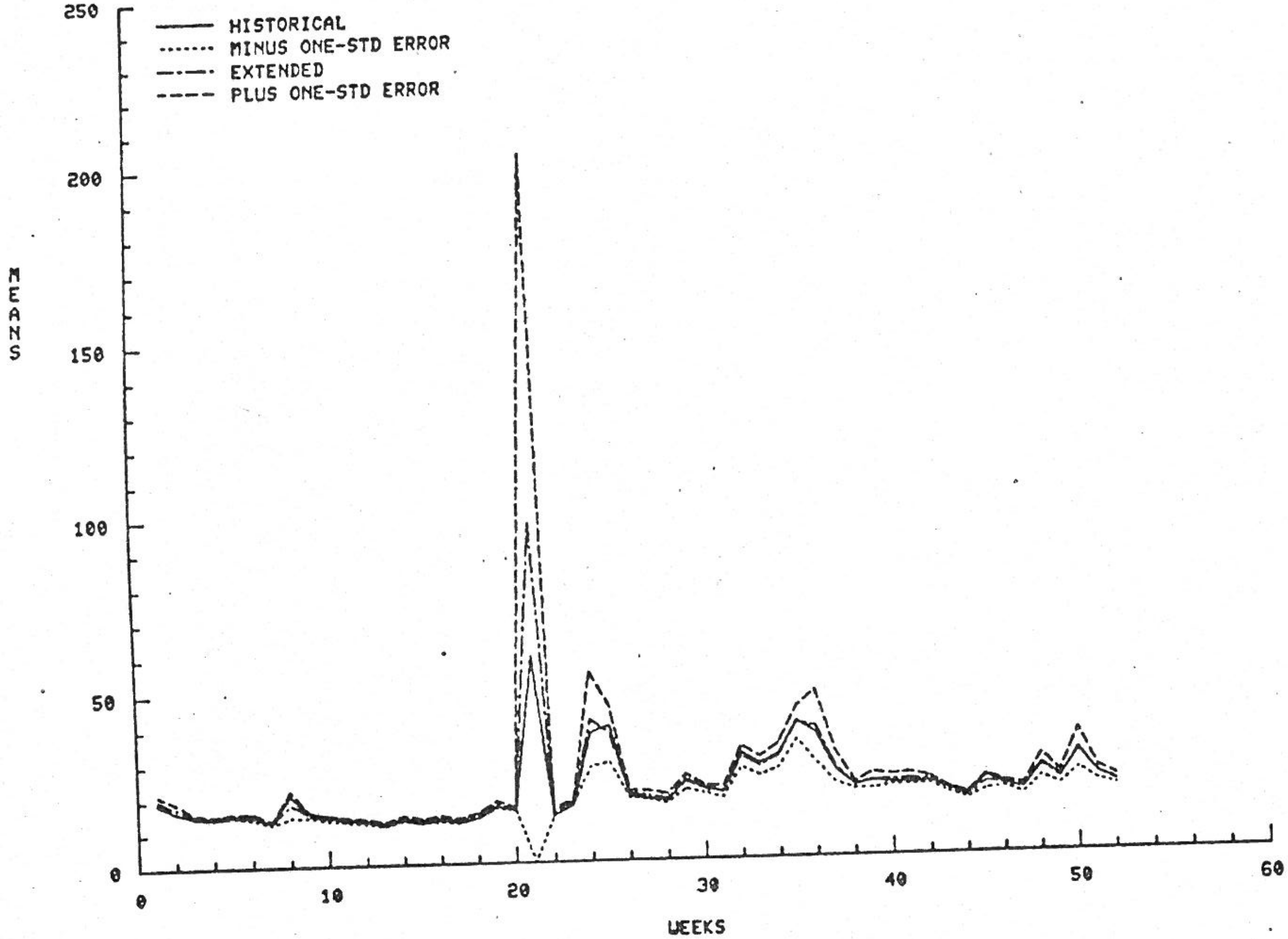


Figure 1.9.B.31. Historical and extended series weekly means of Paso del Ermitaño in original domain of flows.

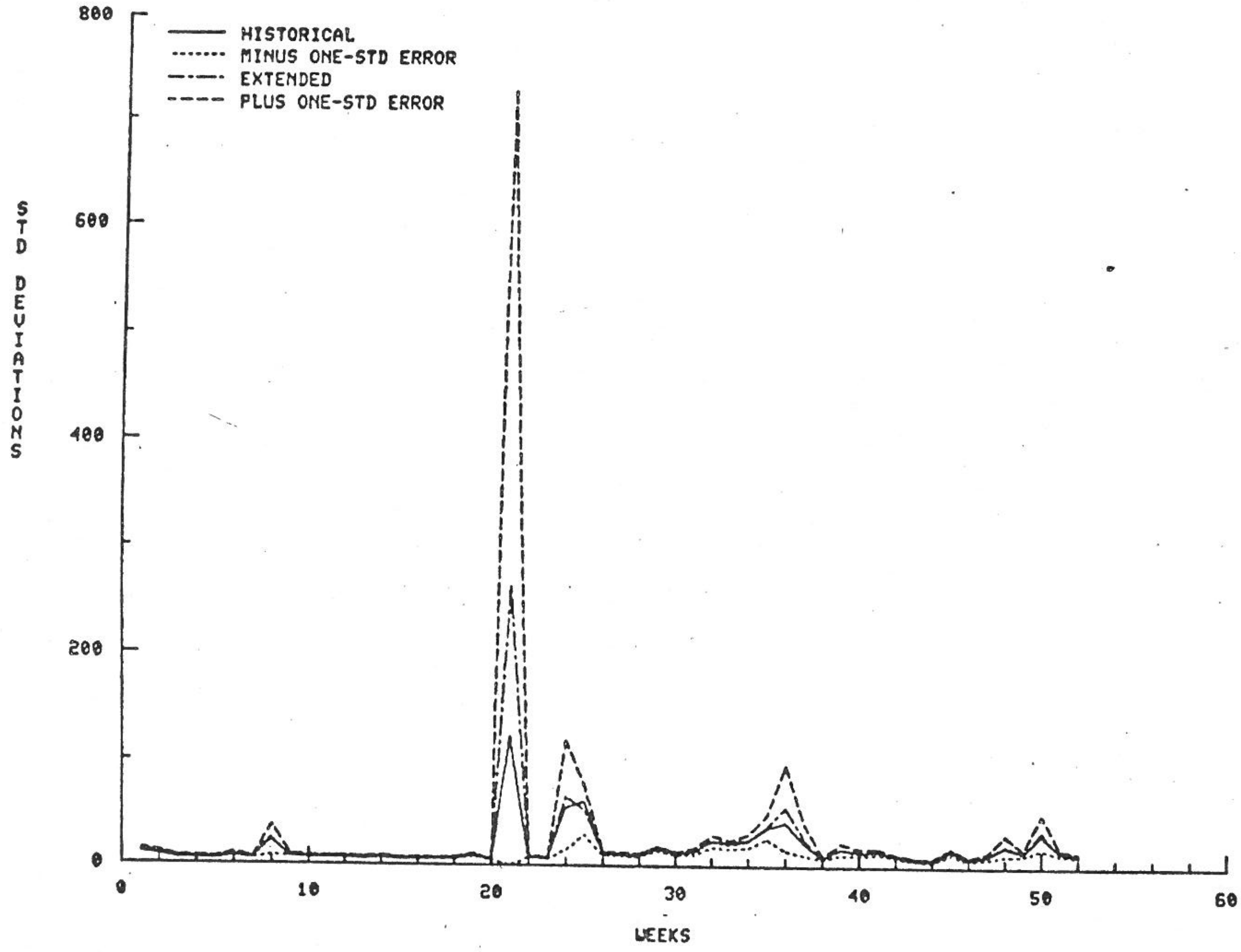


Figure 1.9.B.32. Historical and extended series weekly standard deviations of Paso del Ermitaño in original domain of flows.

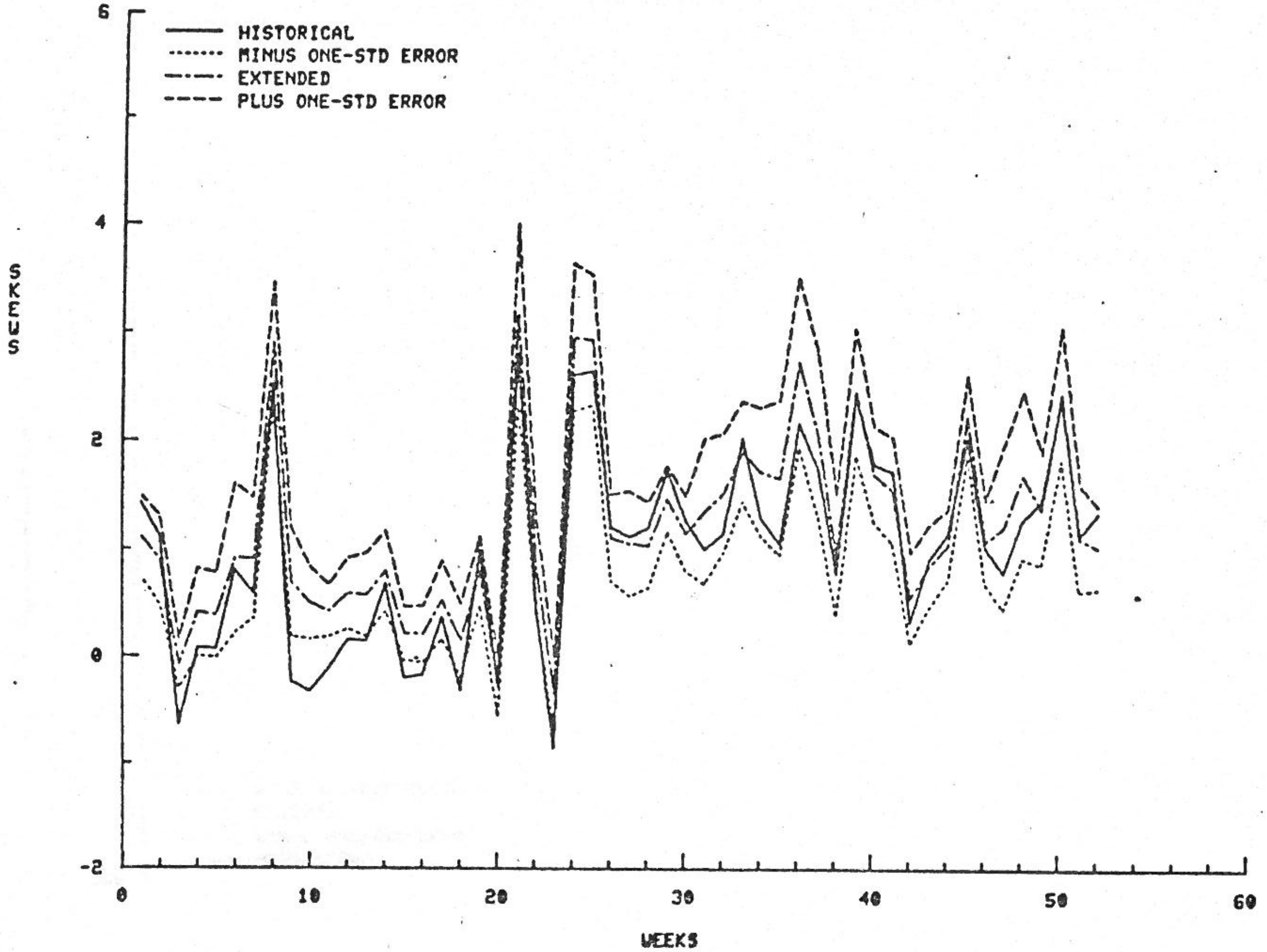


Figure 1.9.B.33. Historical and extended series weekly skewness coefficients of Paso del Ermitaño in original domain of flows.

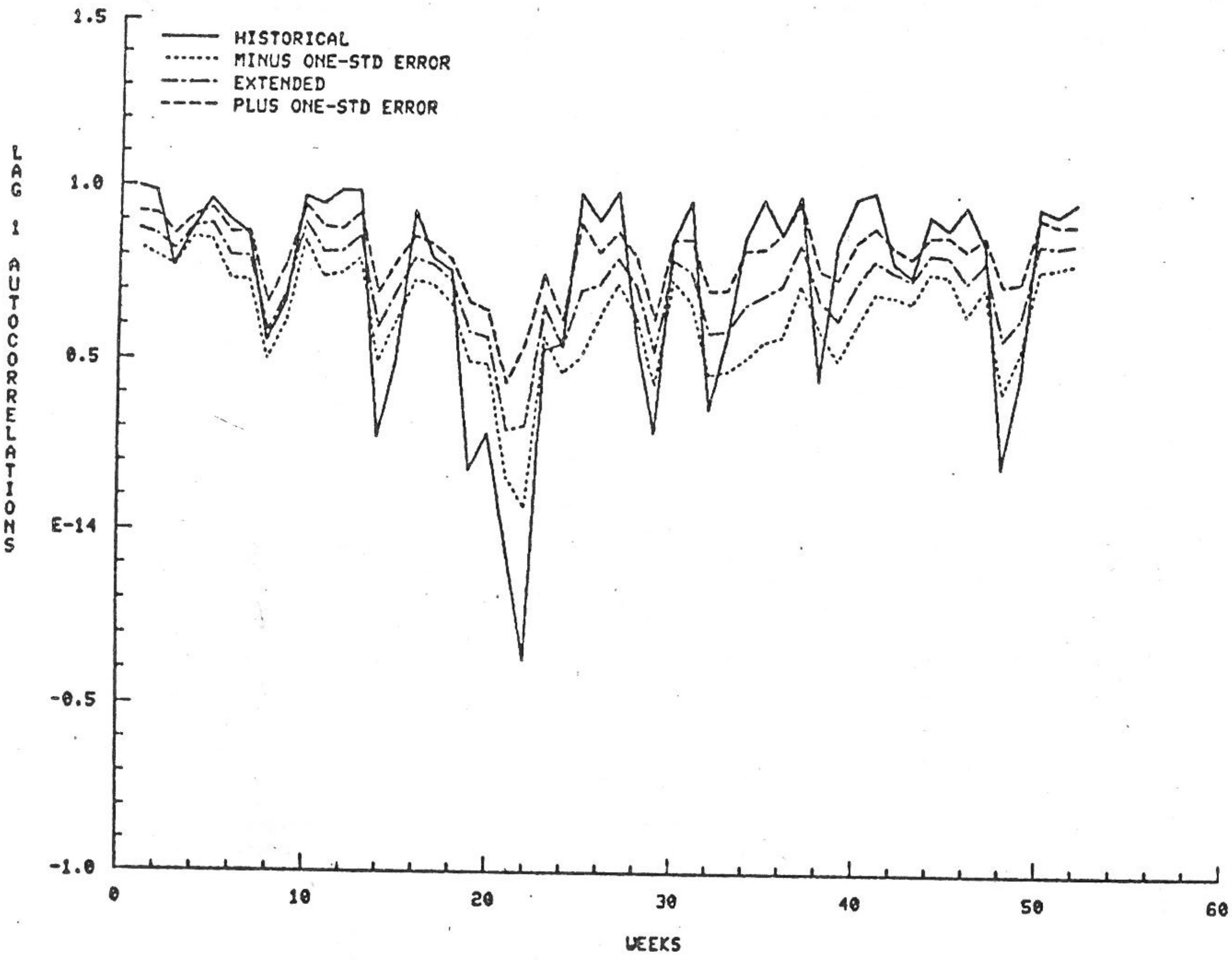


Figure 1.9.B.34. Historical and extended series weekly lag-1 autocorrelation coefficients of Paso del Ermitaño in original domain of flows.

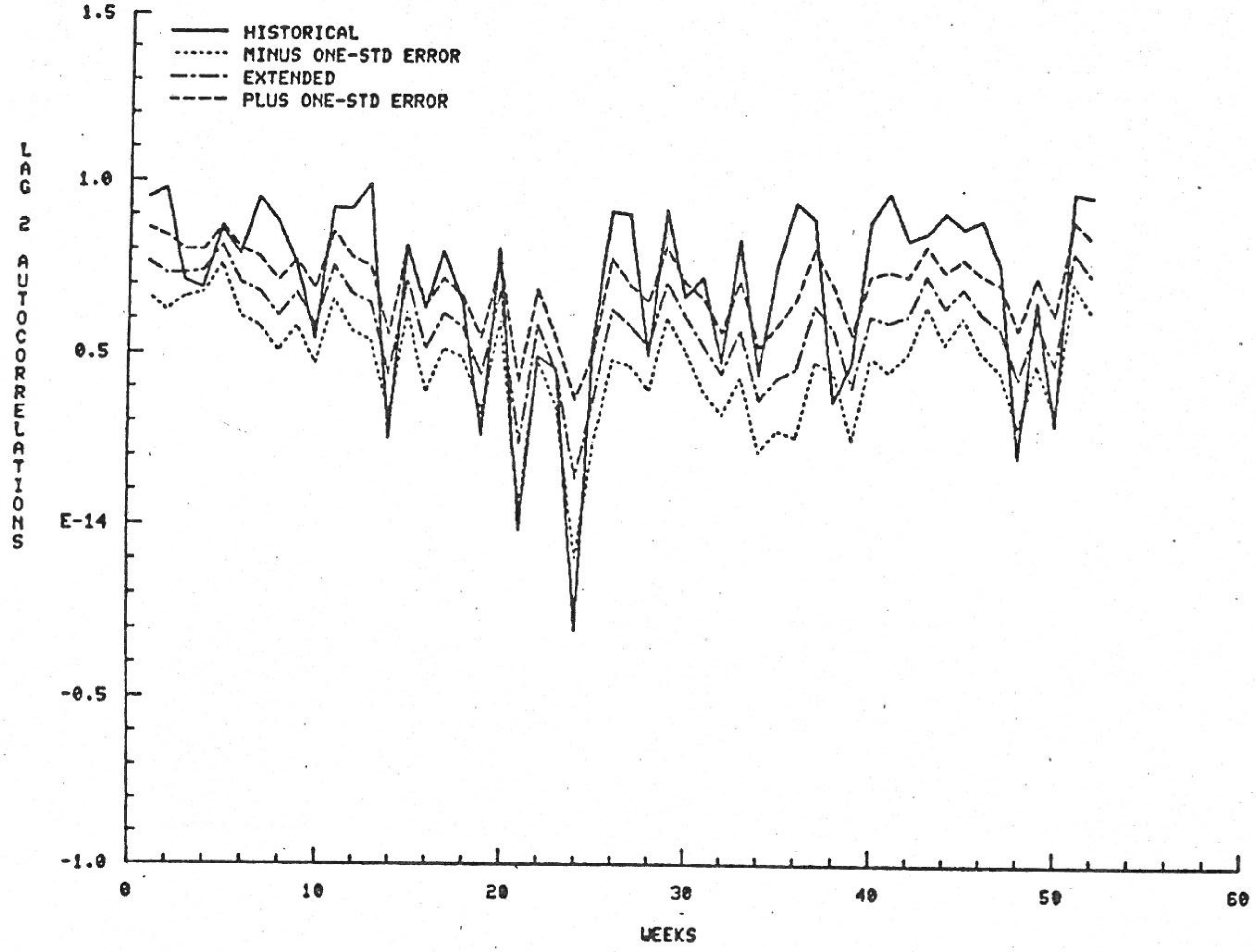


Figure 1.9.B.35. Historical and extended series weekly lag-2 autocorrelation coefficients of Paso del Ermitaño in original domain of flows.

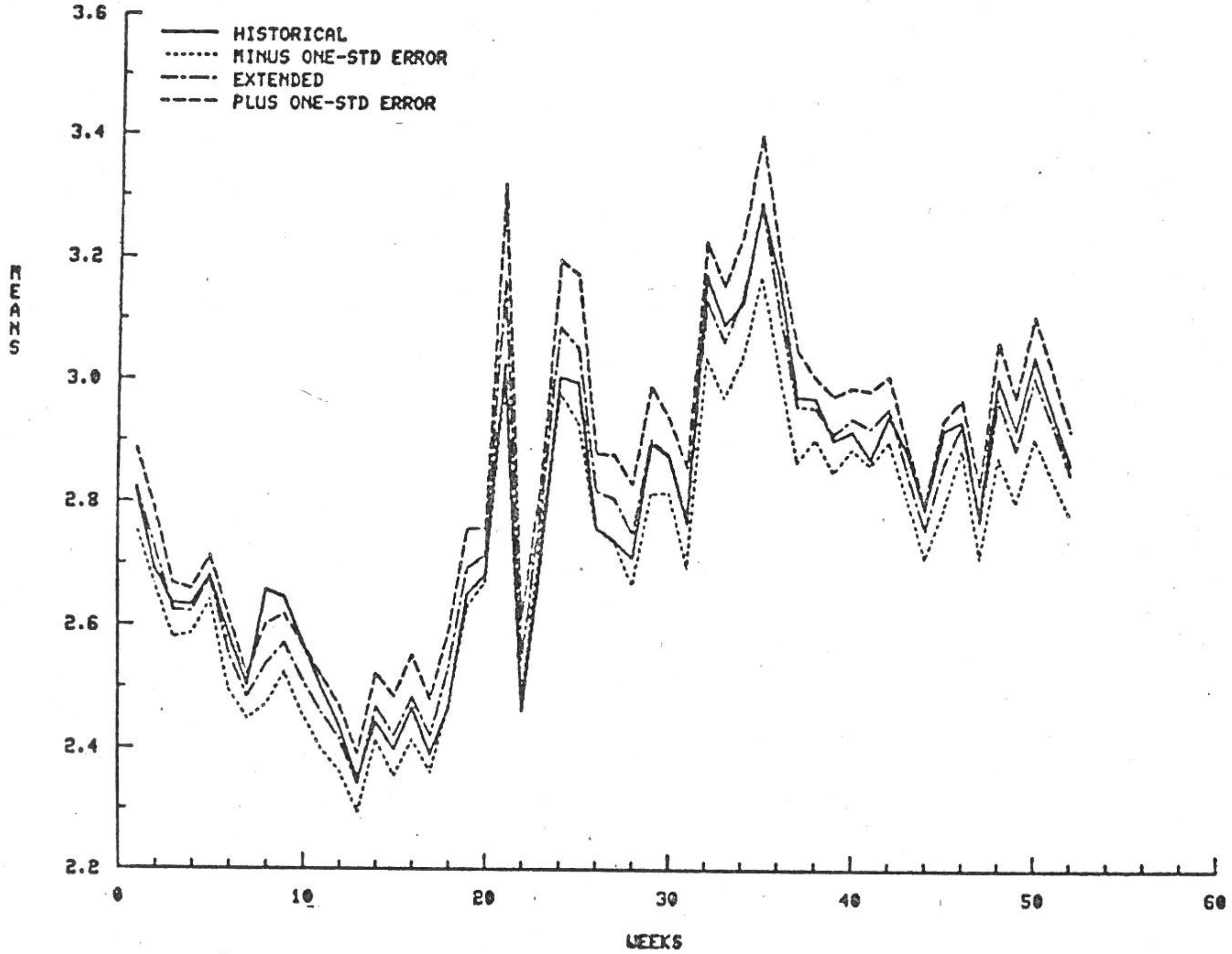


Figure 1.9.B.36. Historical and extended series weekly means of Paso del Ermitaño in logarithmic domain of flows.

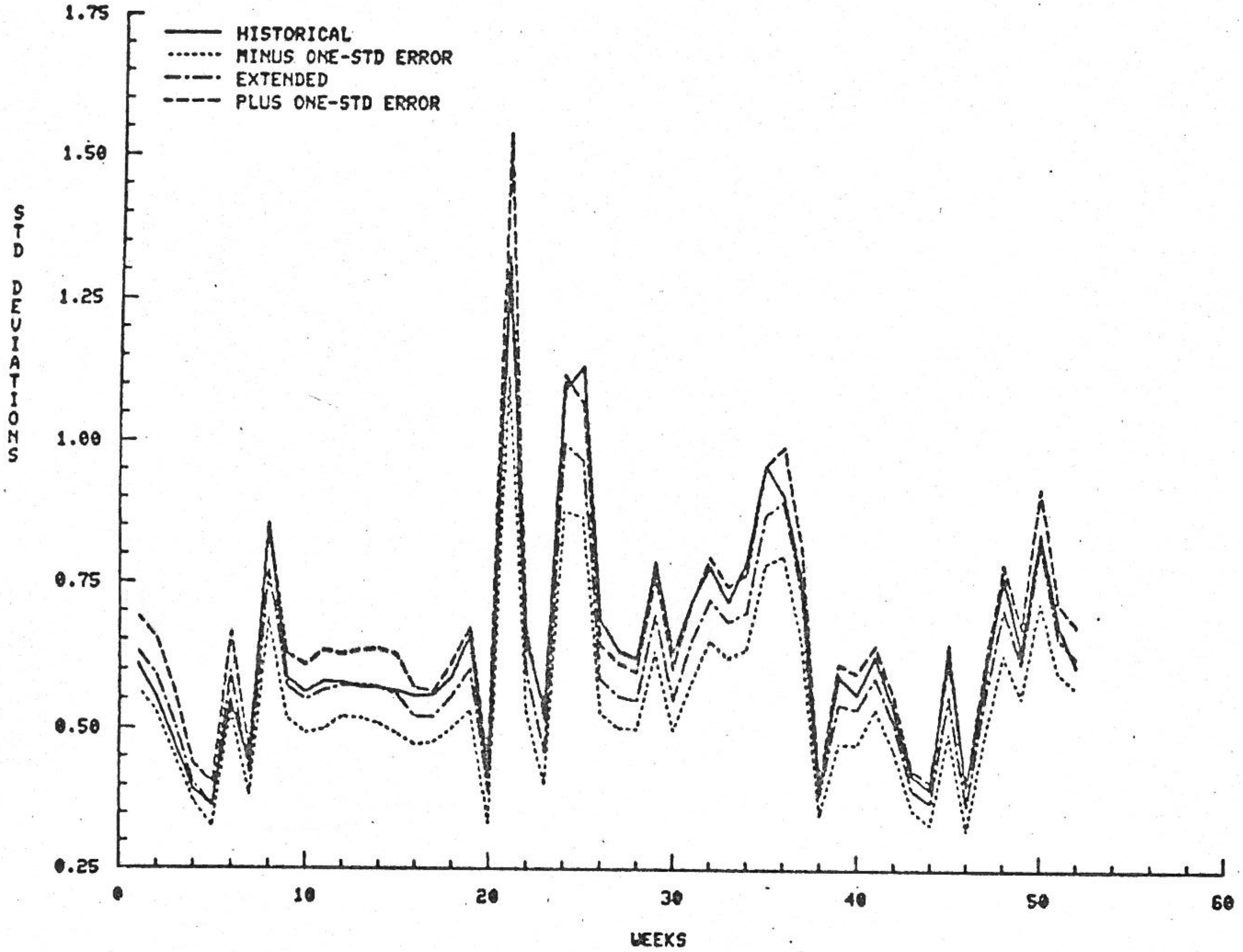


Figure 1.9.B.37. Historical and extended series weekly standard deviations of Paso del Ermitaño in logarithmic domain of flows.

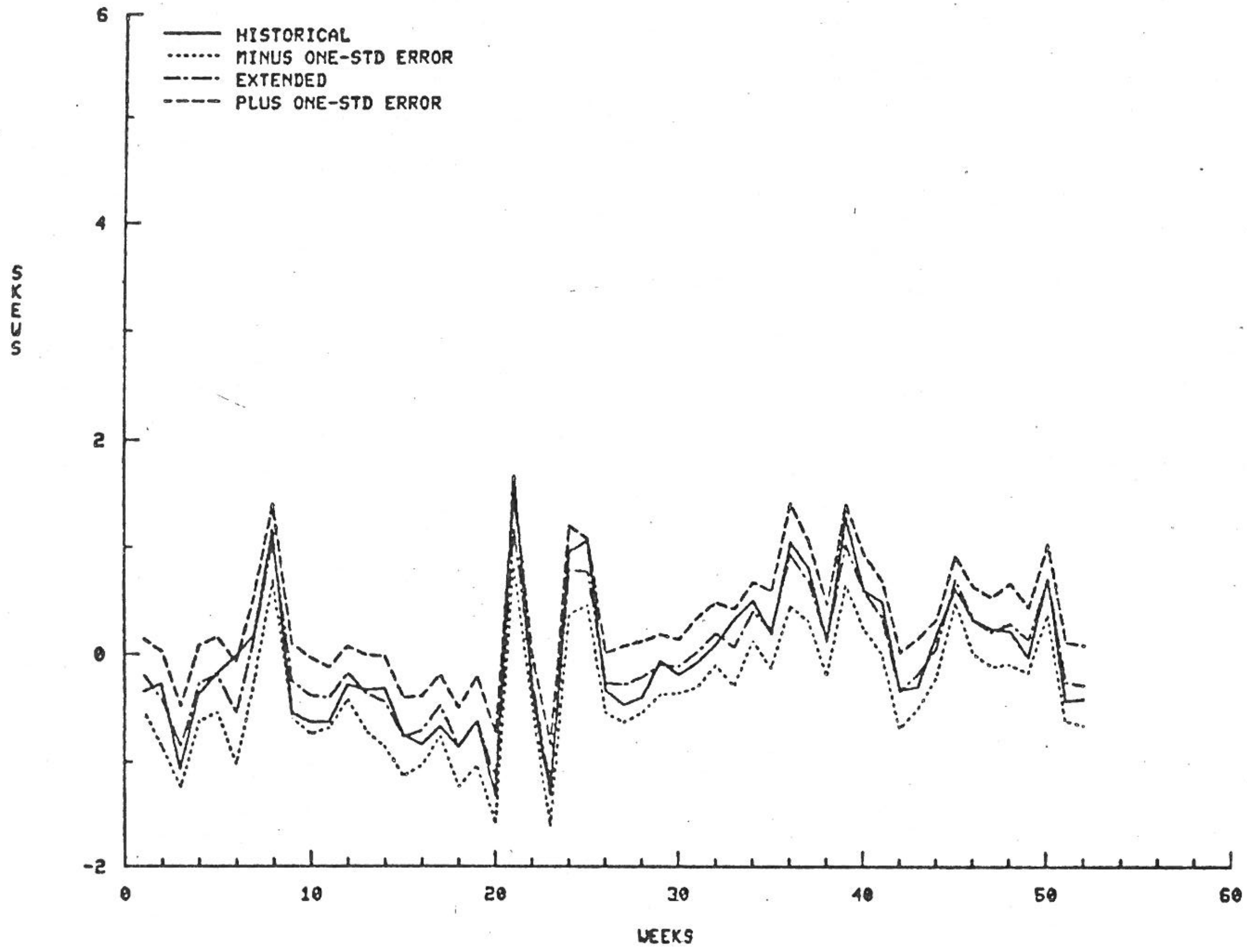


Figure 1.9.B.38. Historical and extended series weekly skewness coefficients of Paso del Ermitaño in logarithmic domain of flows.

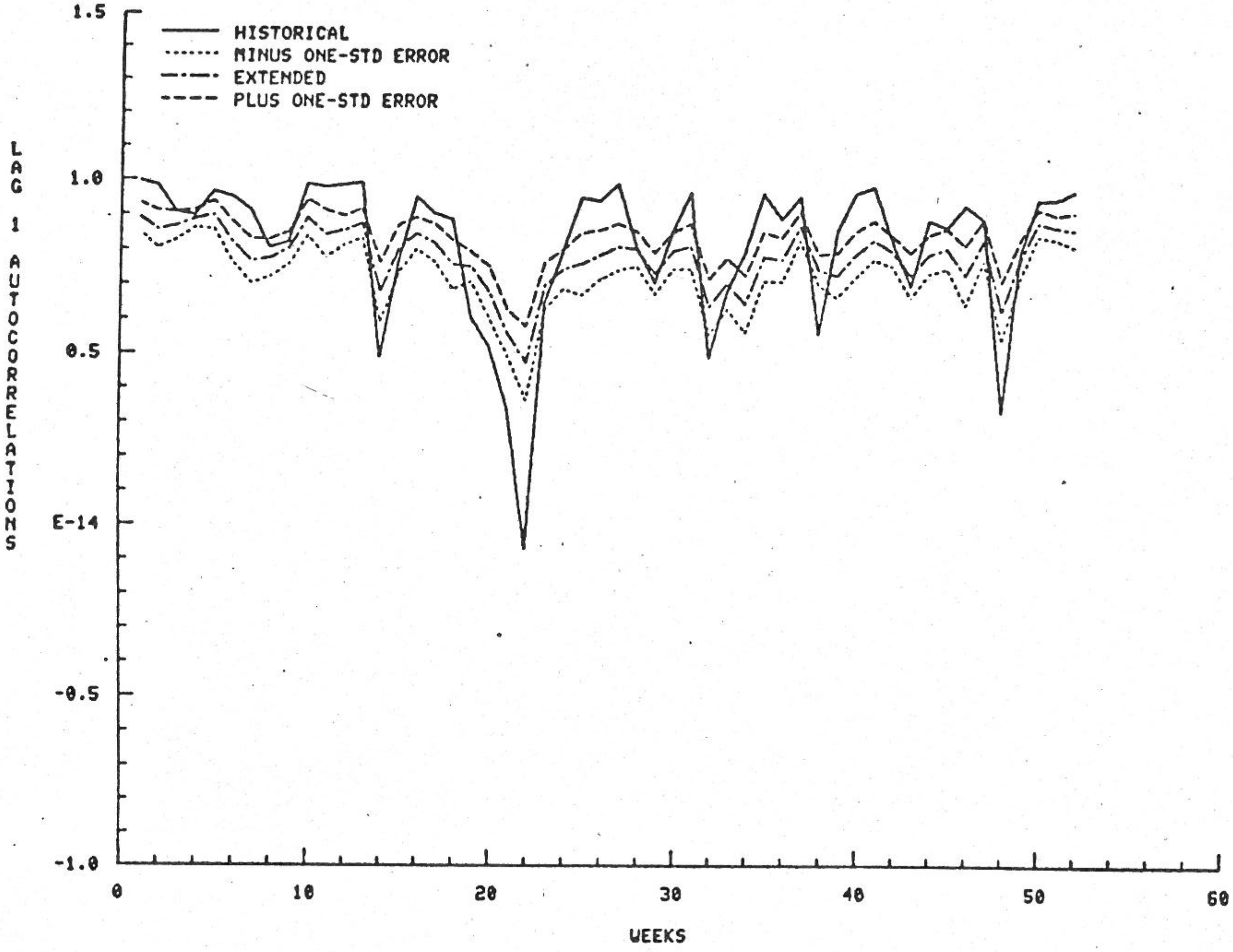


Figure 1.9.B.39. Historical and extended series weekly lag-1 autocorrelation coefficients of Paso del Ermitaño in logarithmic domain of flows.

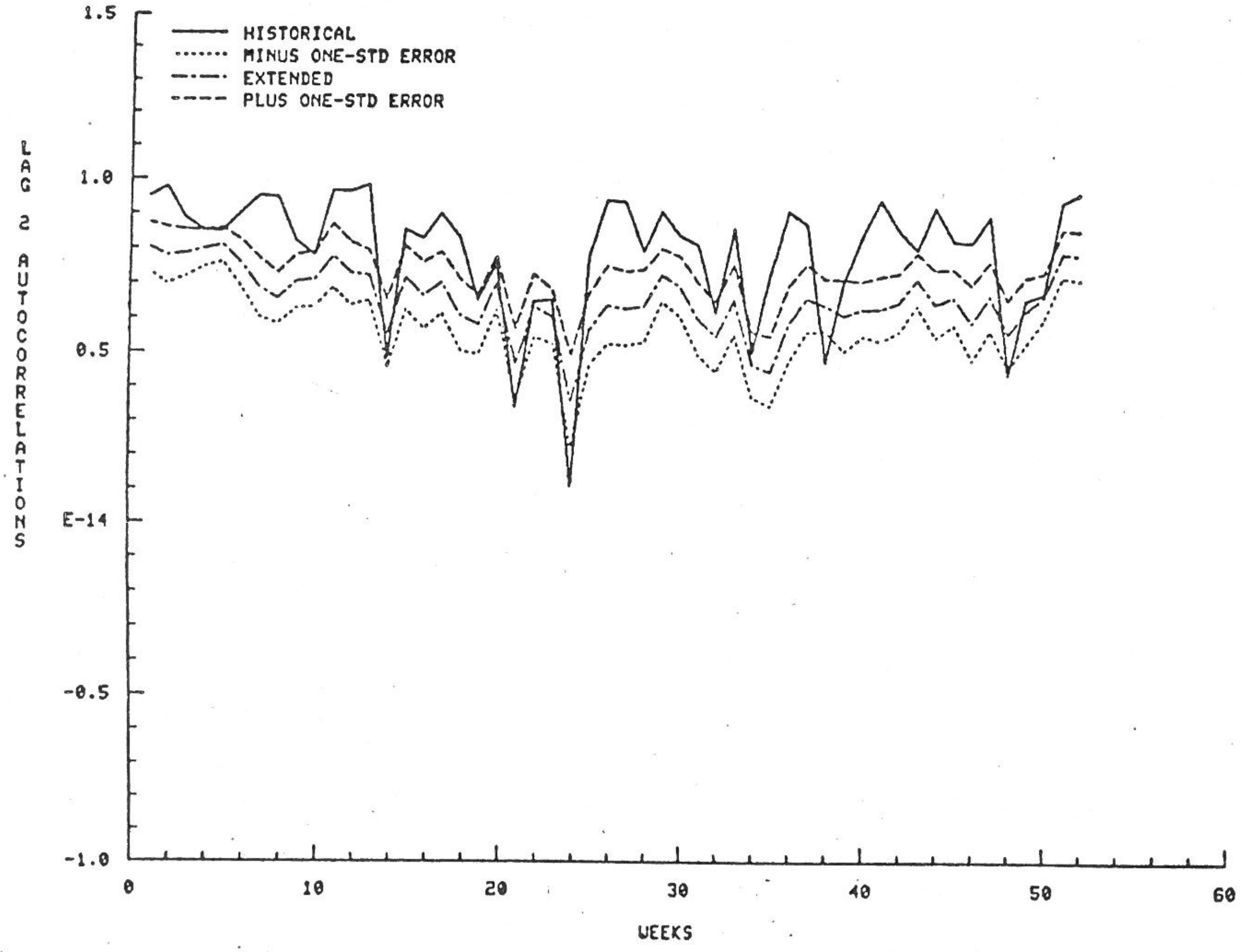


Figure 1.9.B.40. Historical and extended series weekly lag-2 autocorrelation coefficients of Paso del Ermitaño in logarithmic domain of flows.

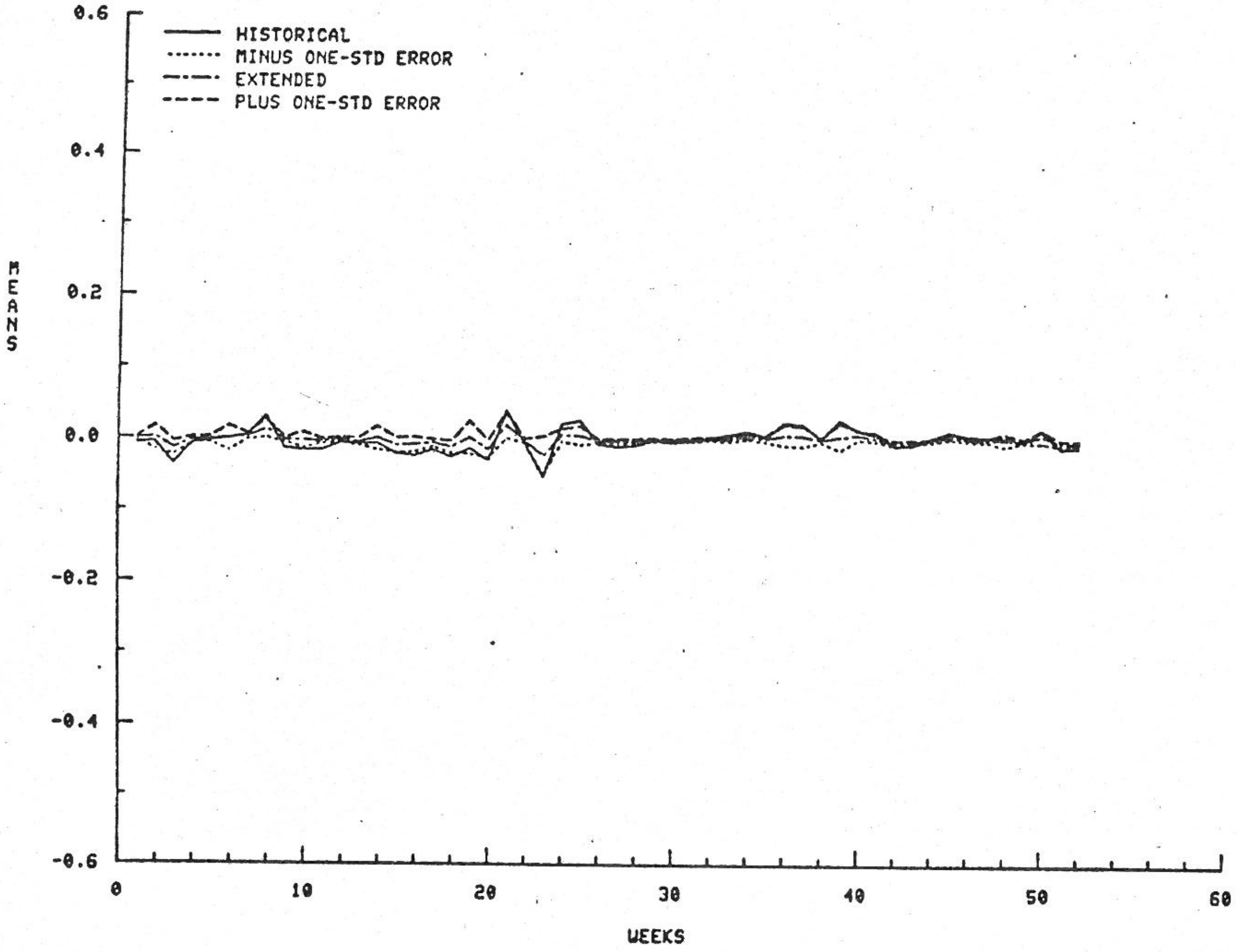


Figure 1.9.B.41. Historical and extended series weekly means of Paso del Ermitaño in log-Wilson-Hilferty domain of flows.

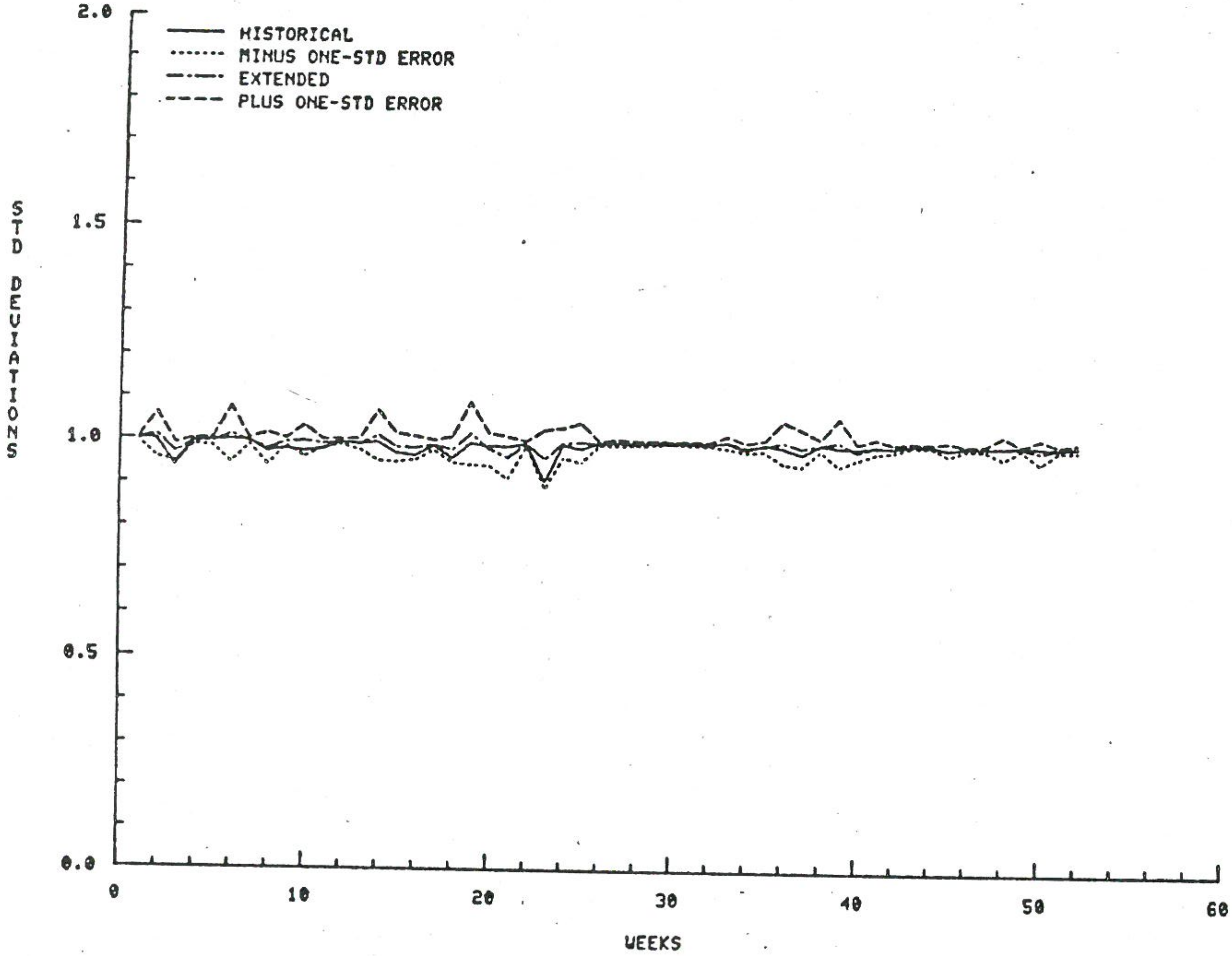


Figure 1.9.B.42. Historical and extended series weekly standard deviations of Paso del Ermitaño in log-Wilson-Hilferty domain of flows.

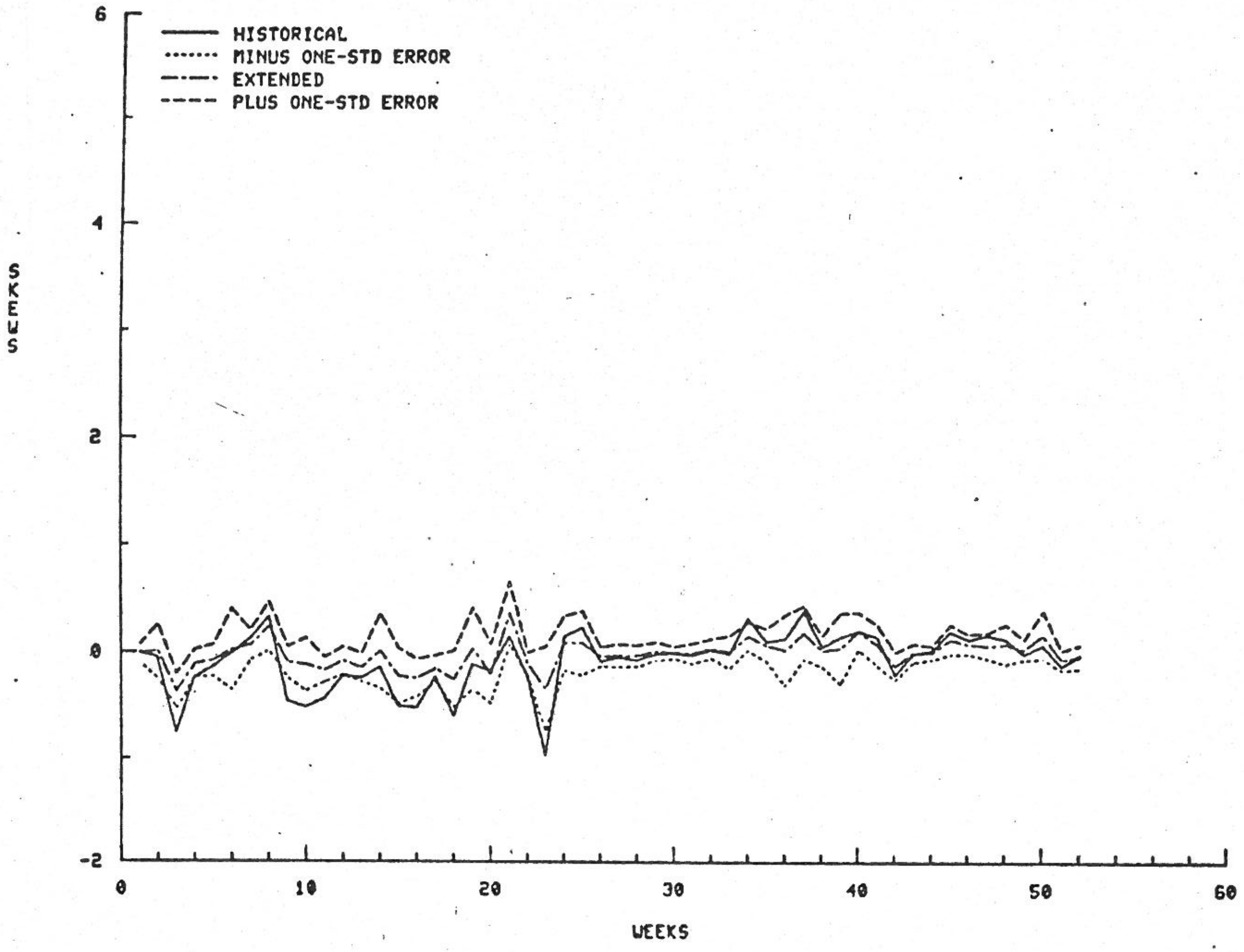


Figure 1.9.B.43. Historical and extended series weekly skewness coefficients of Paso del Ermitaño in log-Wilson-Hilferty domain of flows.

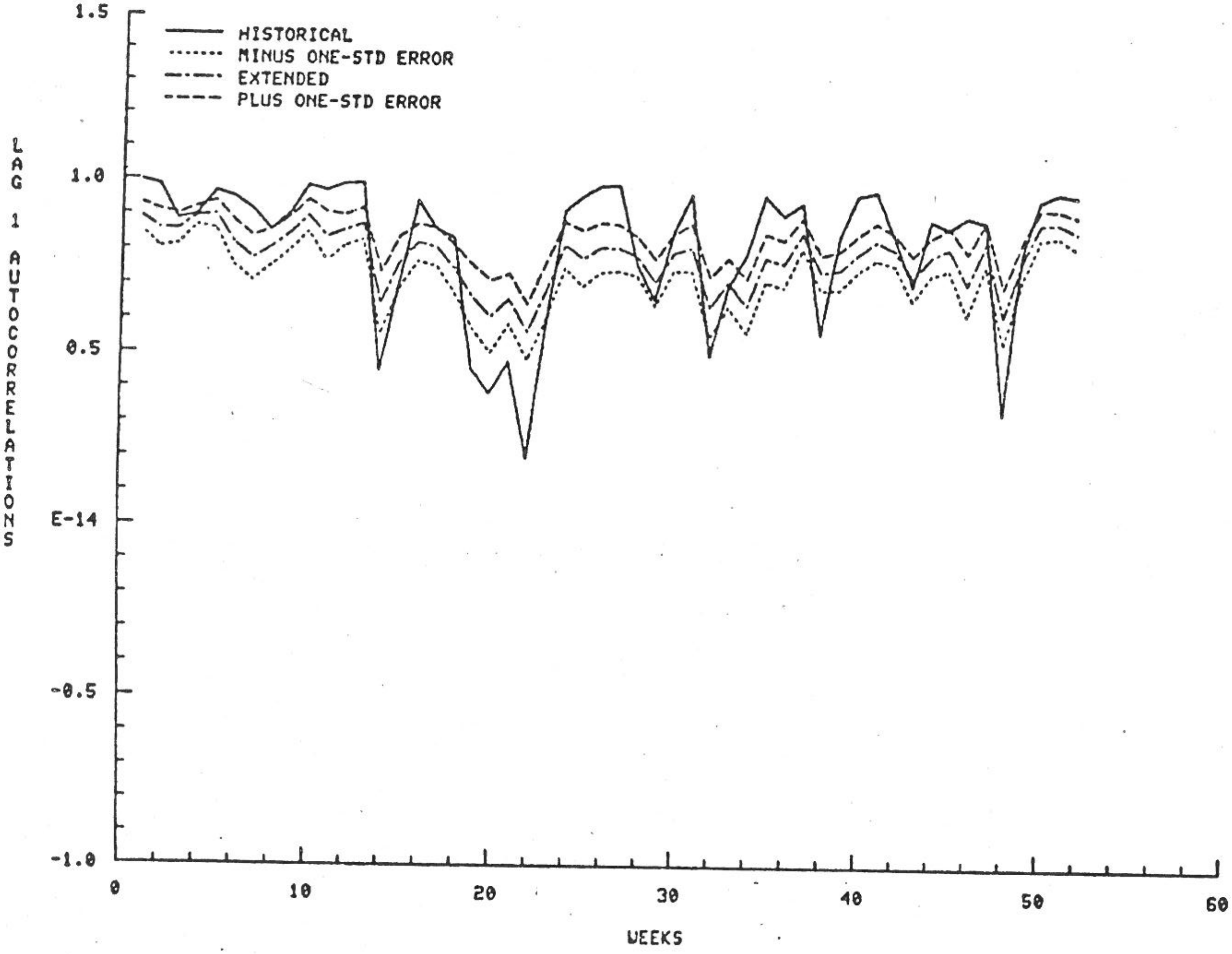


Figure 1.9.B.44. Historical and extended series weekly lag-1 autocorrelation coefficients of Paso del Ermitaño in log-Wilson-Hilferty domain of flows.

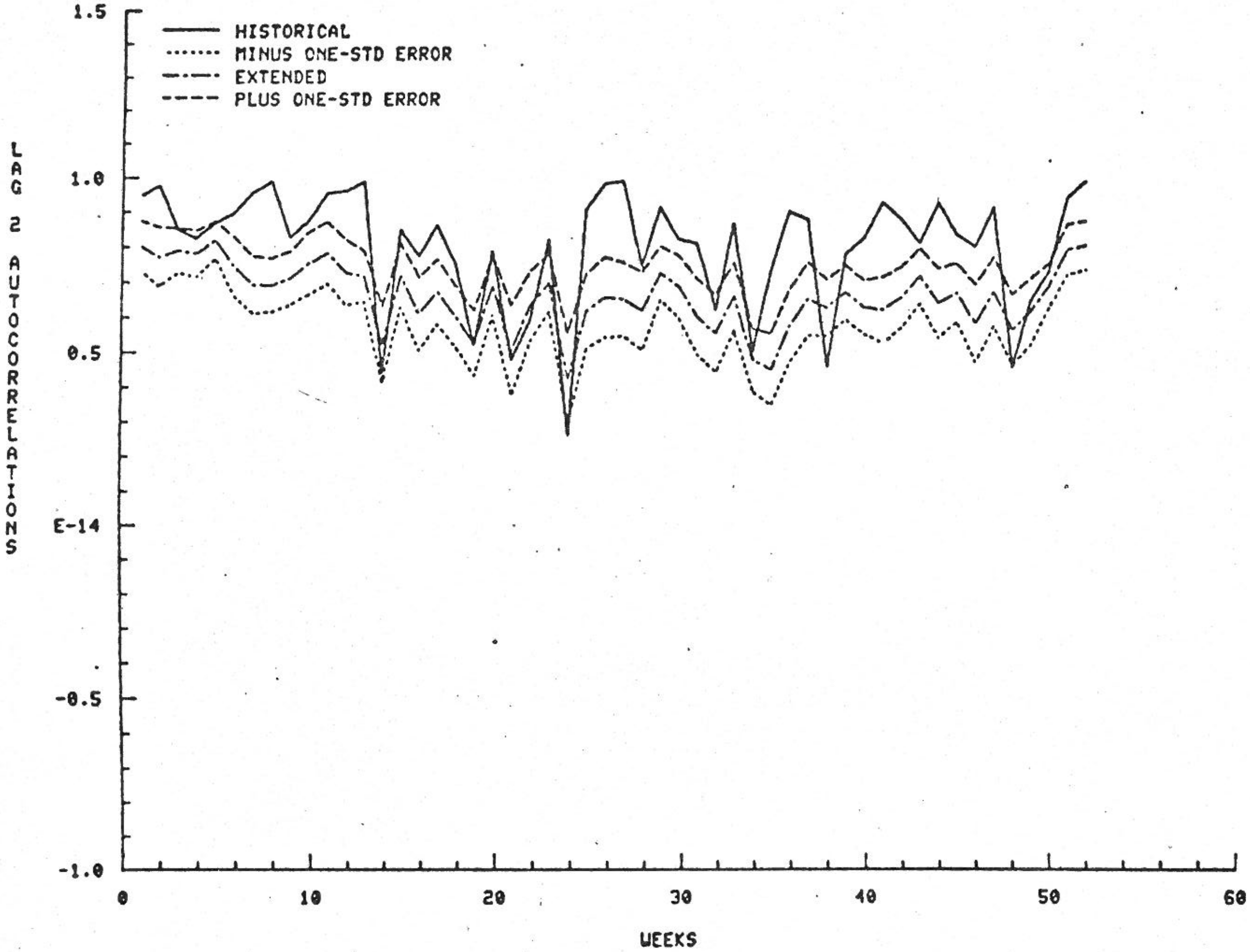


Figure 1.9.B.45. Historical and extended series weekly lag-2 autocorrelation coefficients of Paso del Ermitaño in log-Wilson-Hilferty domain of flows.

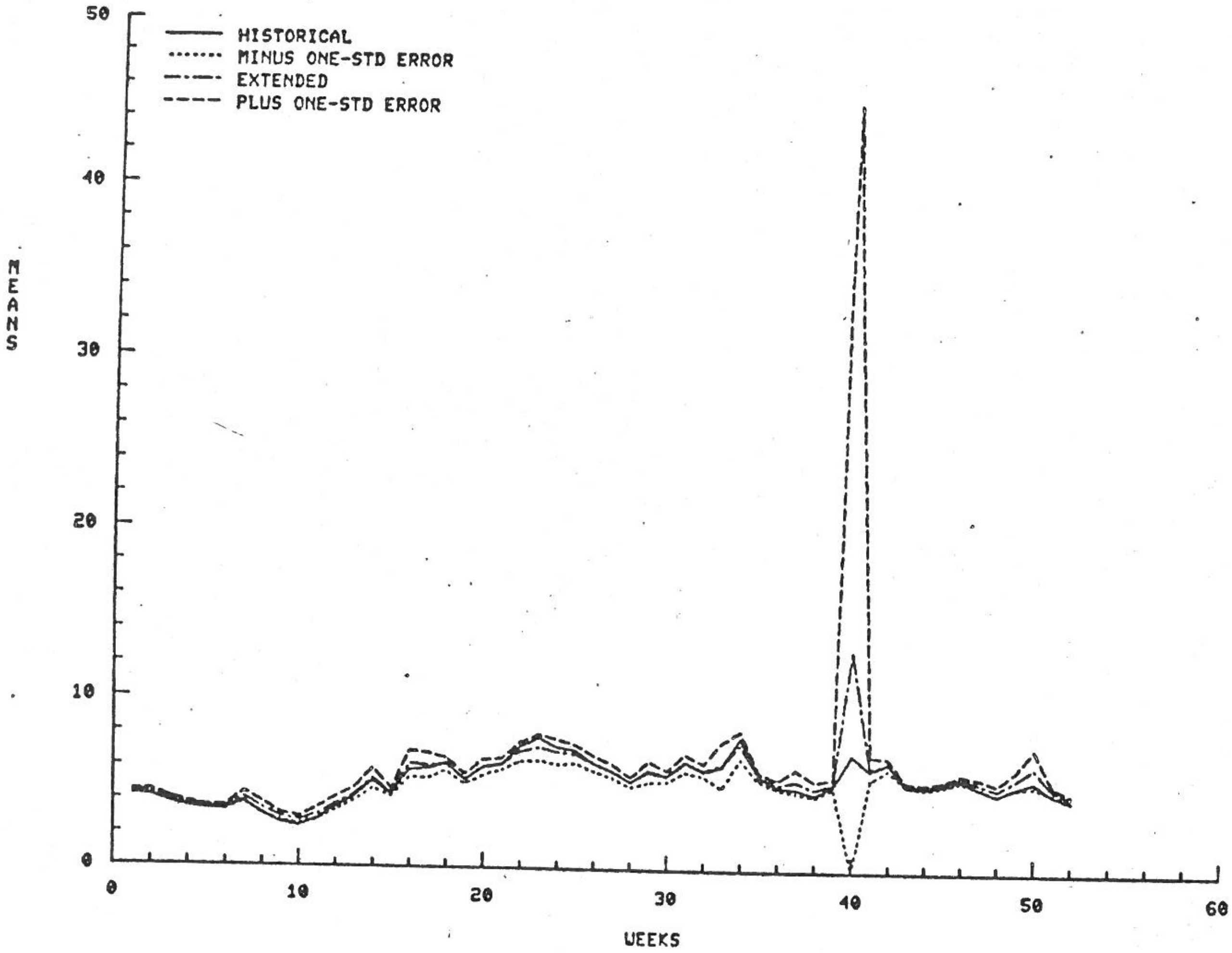


Figure 1.9.B.46. Historical and extended series weekly means of Rancho Arriba in original domain of flows.

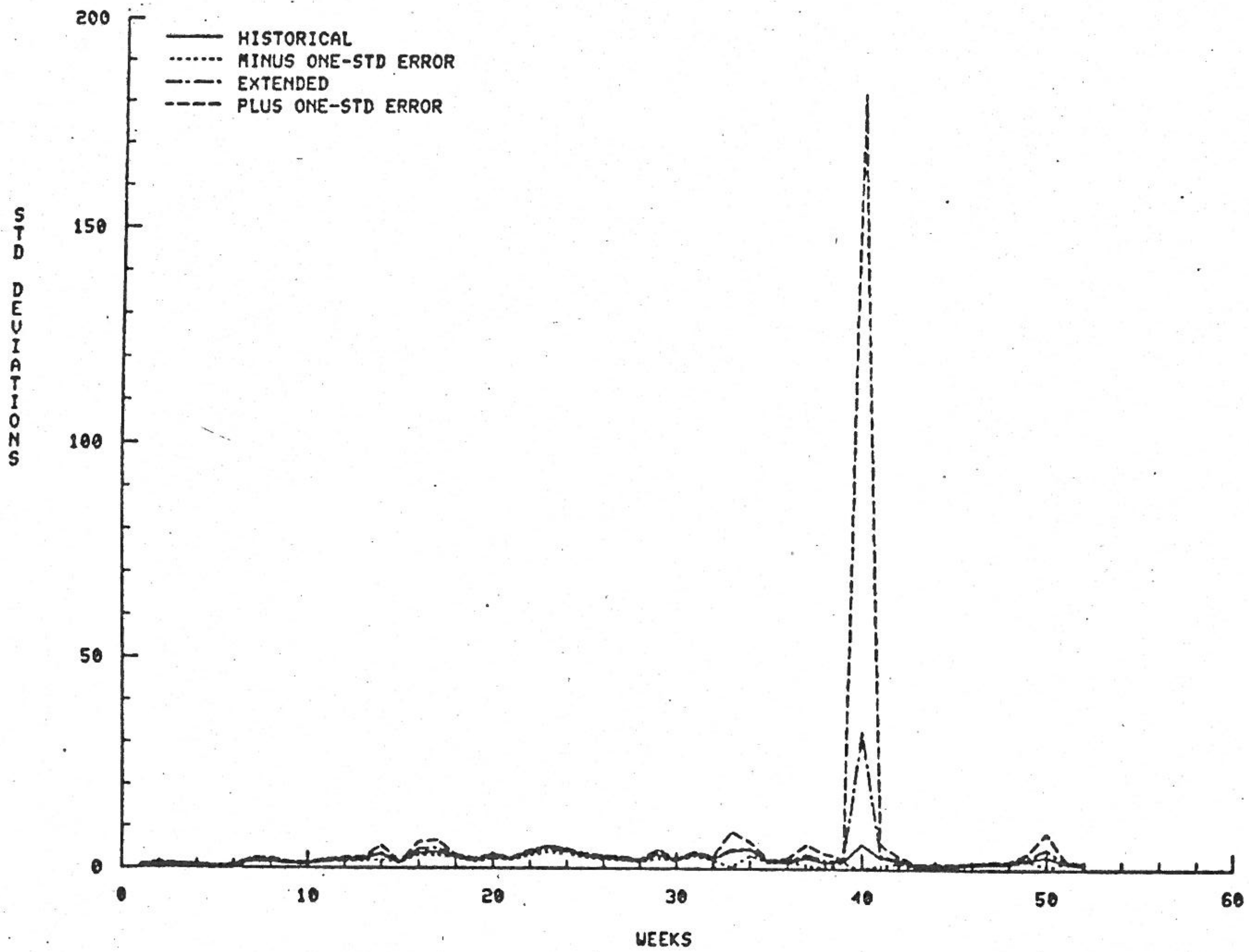


Figure 1.9.B.47. Historical and extended series weekly standard deviations of Rancho Arribain original domain of flows.

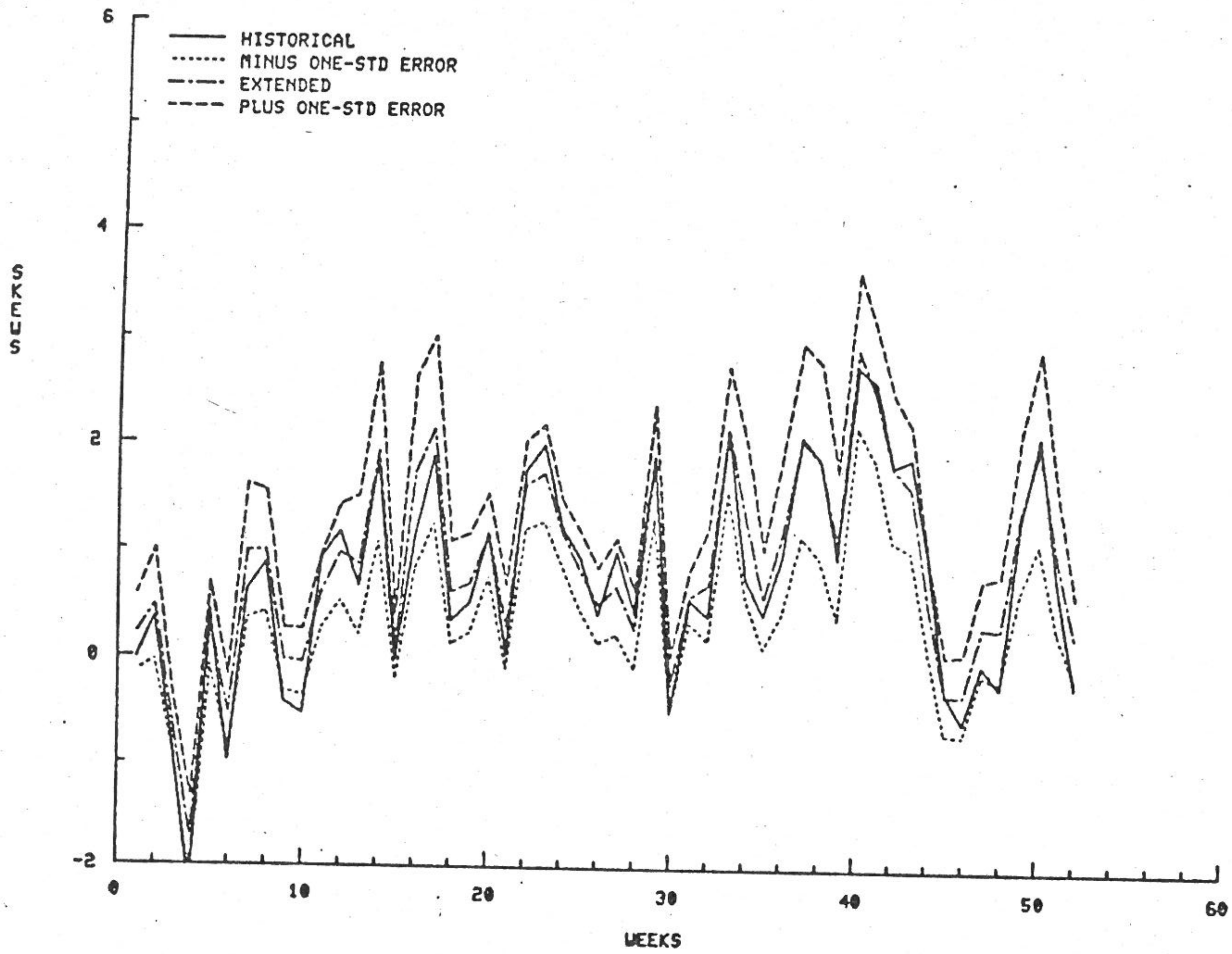


Figure 1.9.B.48. Historical and extended series weekly skewness coefficients of Rancho Arriba in original domain of flows.

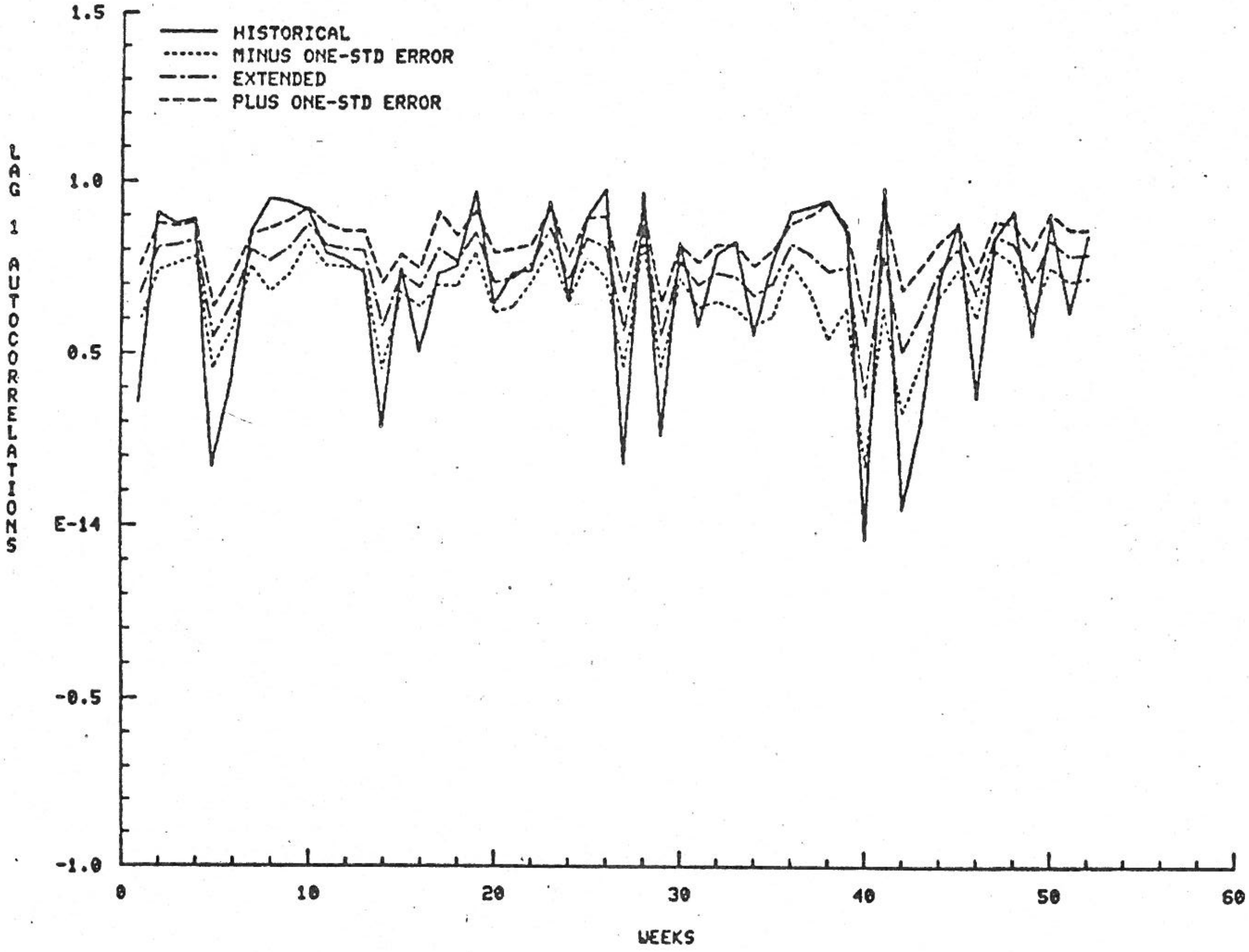


Figure 1.9.B.49. Historical and extended series weekly lag-1 autocorrelation coefficients of Rancho Arriba in original domain of flows.

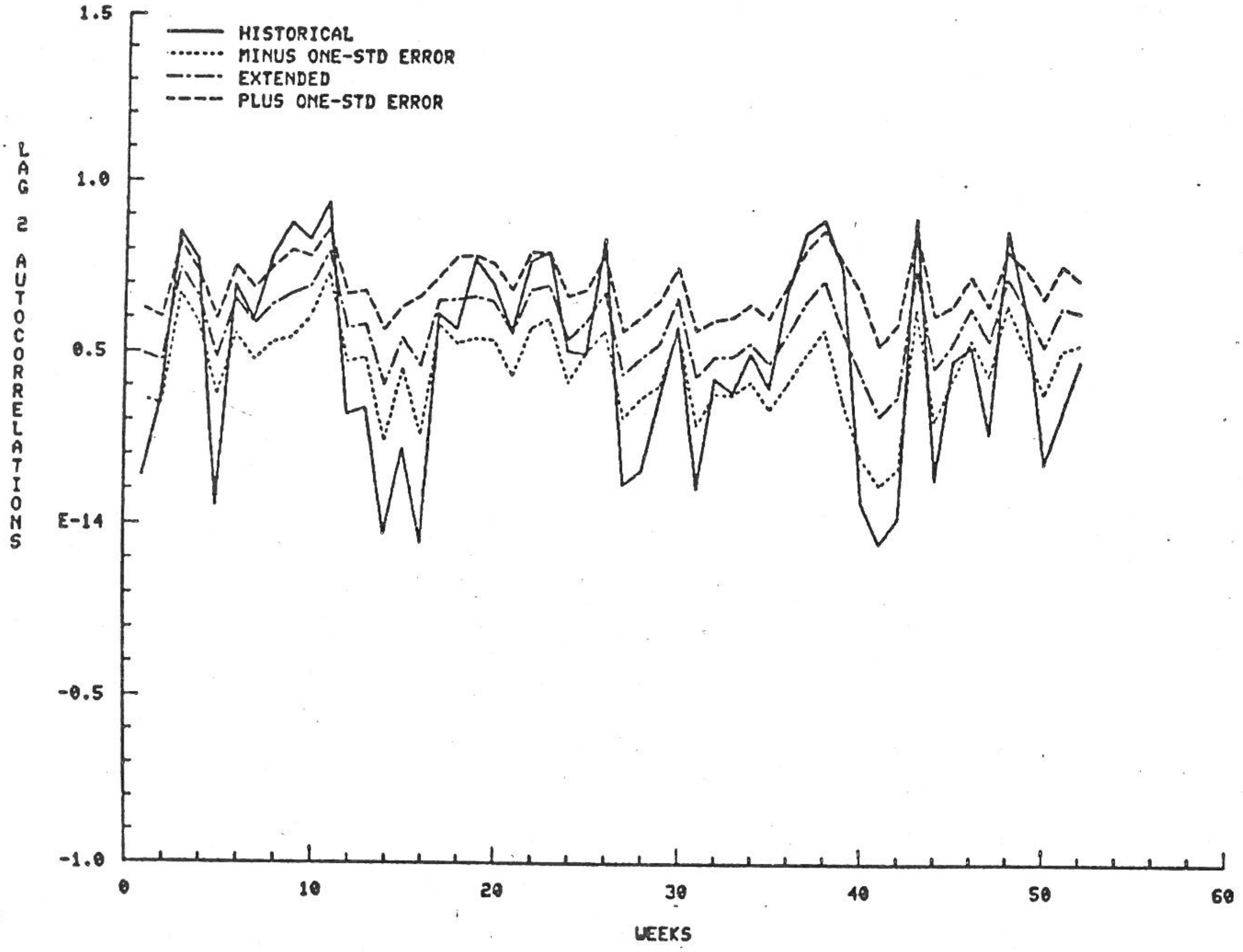


Figure 1.9.B.50. Historical and extended series weekly lag-2 autocorrelation coefficients of Rancho Arriba in original domain of flows.

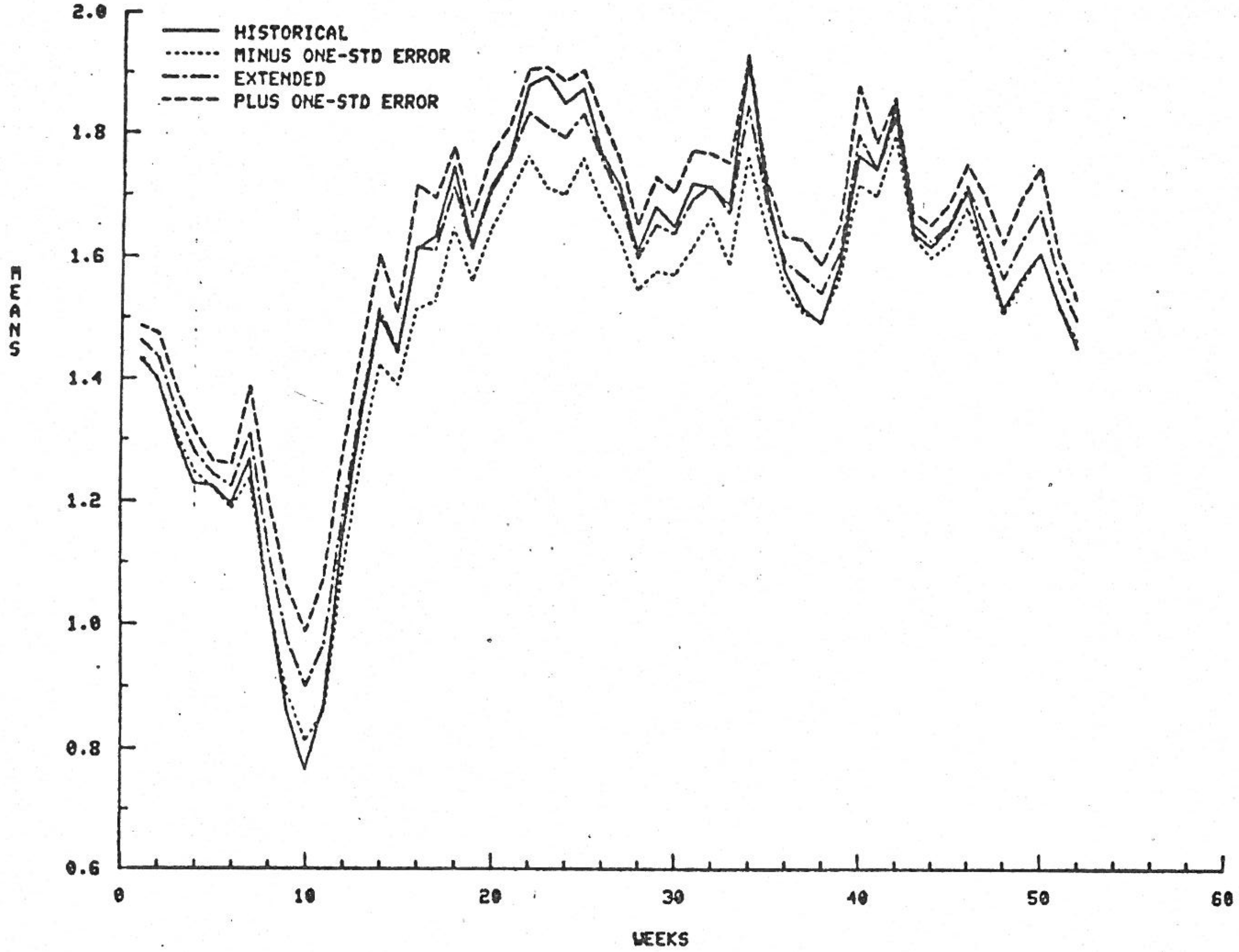


Figure 1.9.B.51. Historical and extended series weekly means of Rancho Arriba in logarithmic domain of flows.

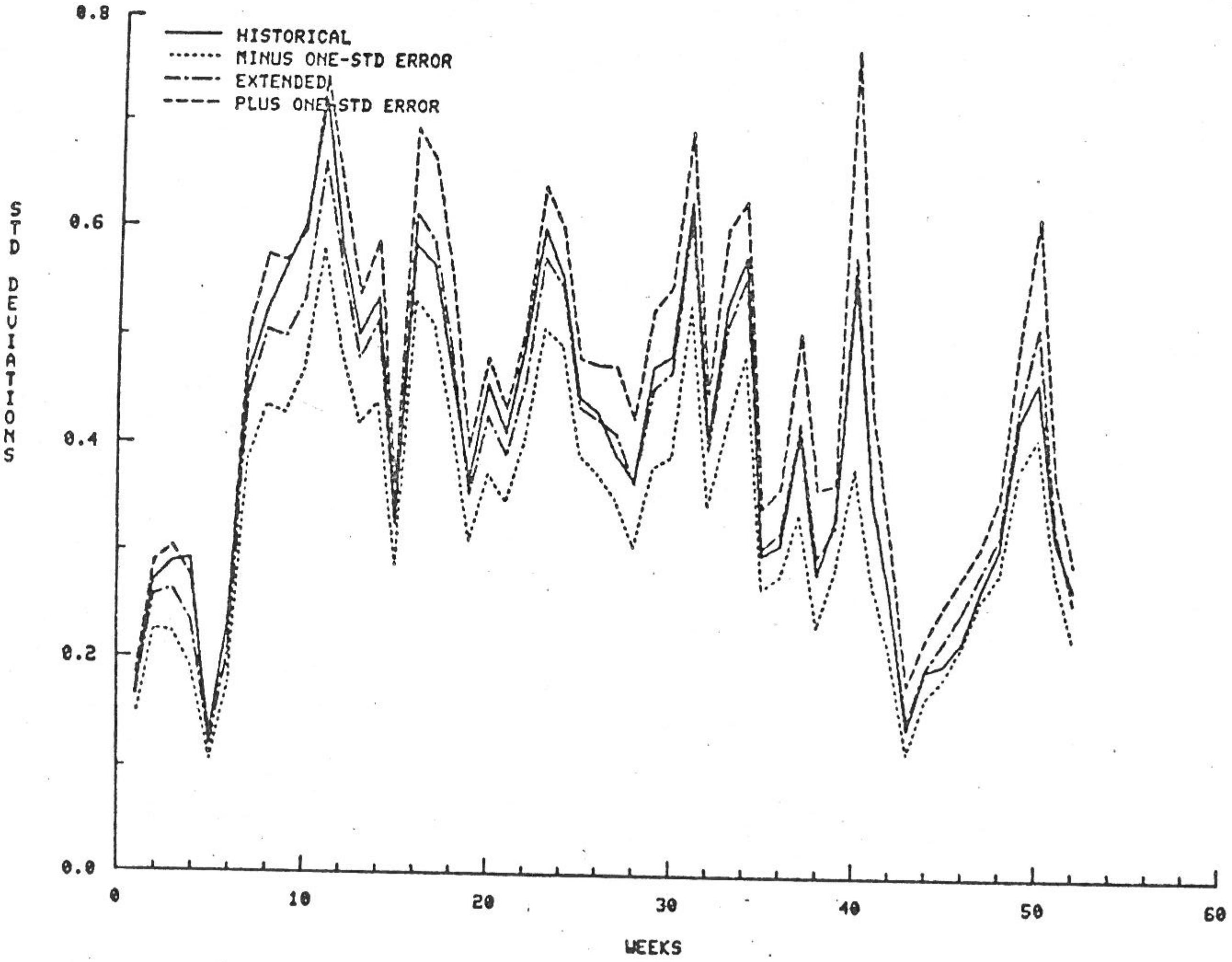


Figure 1.9.B.52. Historical and extended series weekly standard deviations of Rancho Arriba in logarithmic domain of flows.

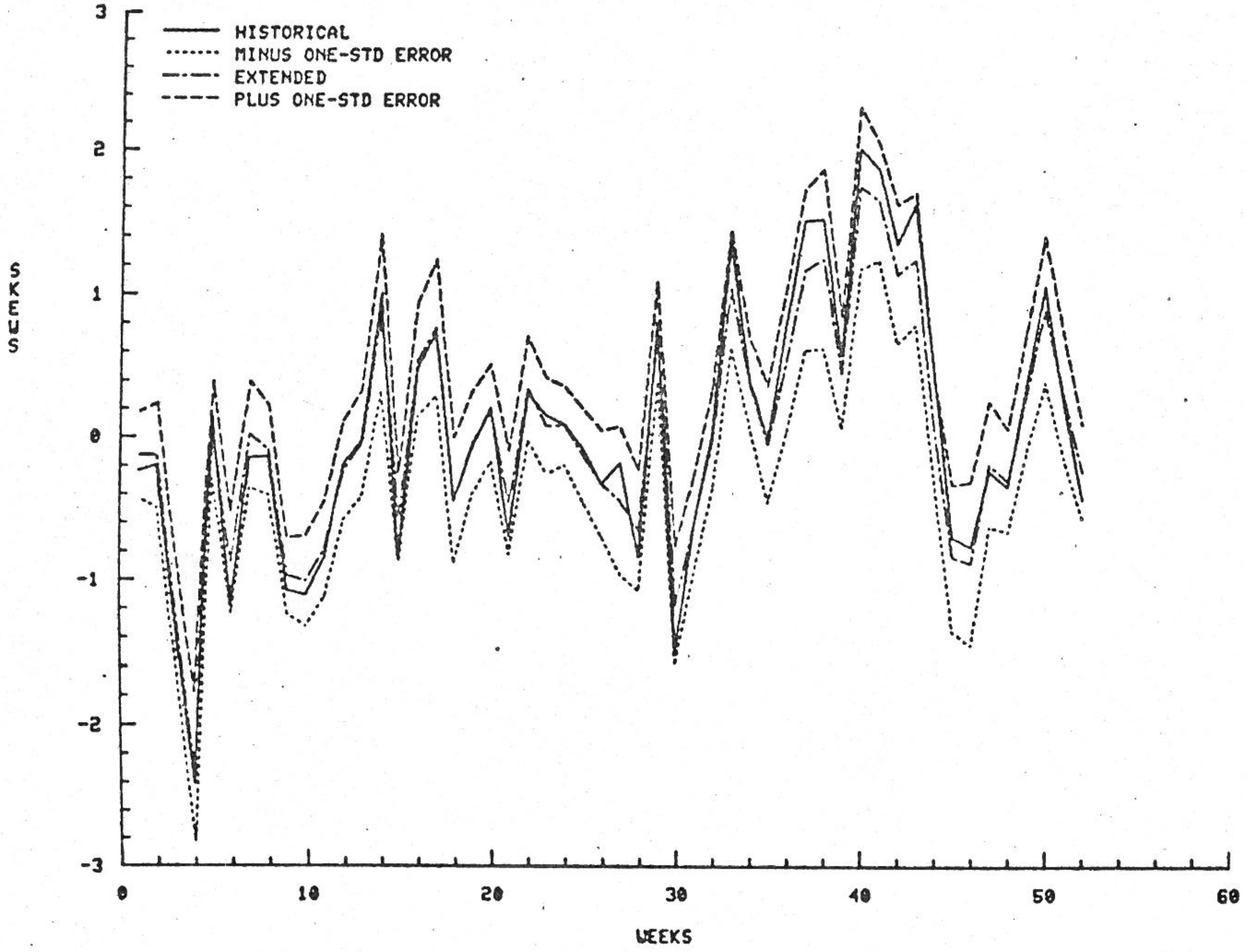


Figure 1.9.B.53. Historical and extended series weekly skewness coefficients of Rancho Arriba in logarithmic domain of flows.

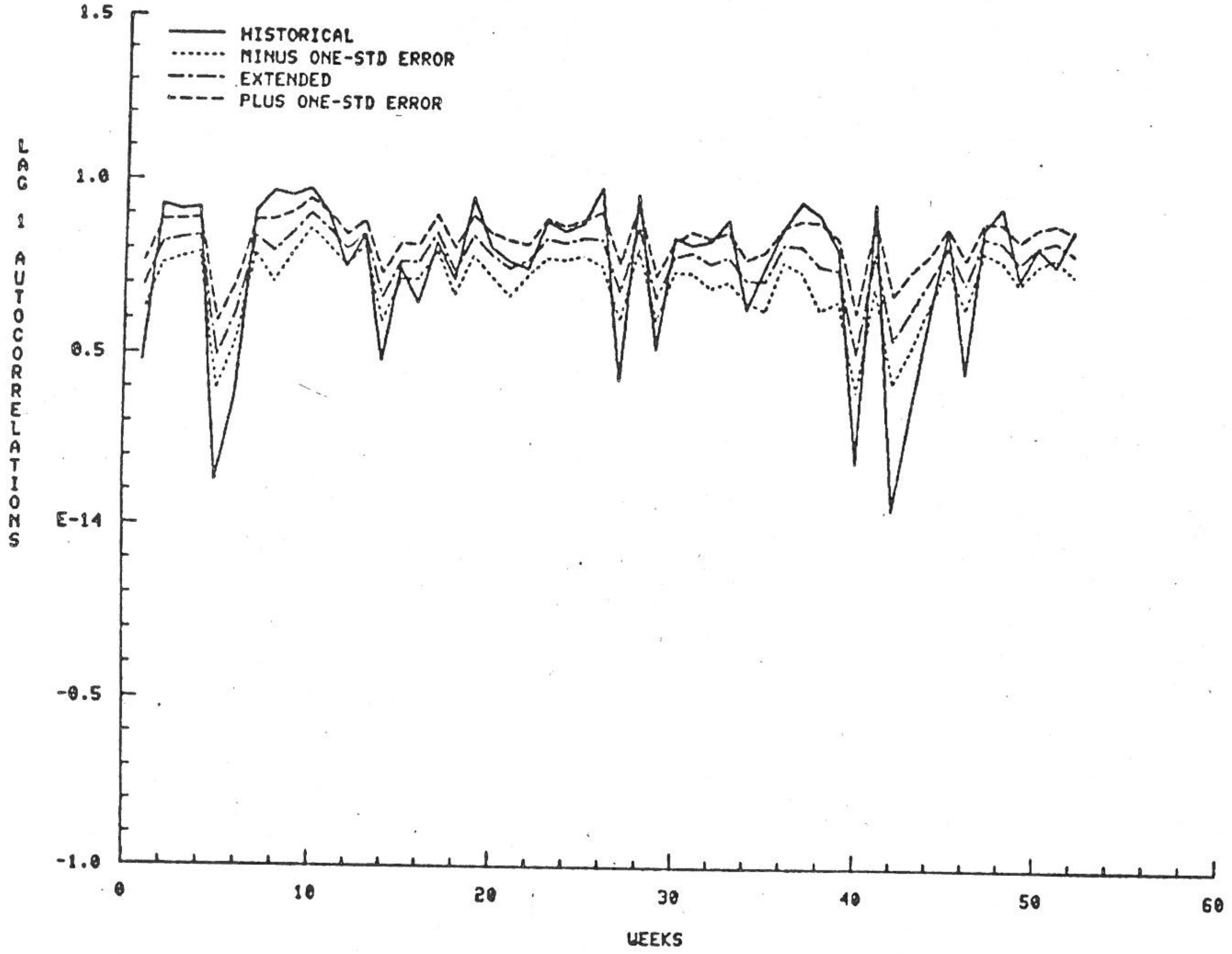


Figure 1.9.B.54. Historical and extended series weekly lag-1 autocorrelation coefficients of Rancho Arriba in logarithmic domain of flows.

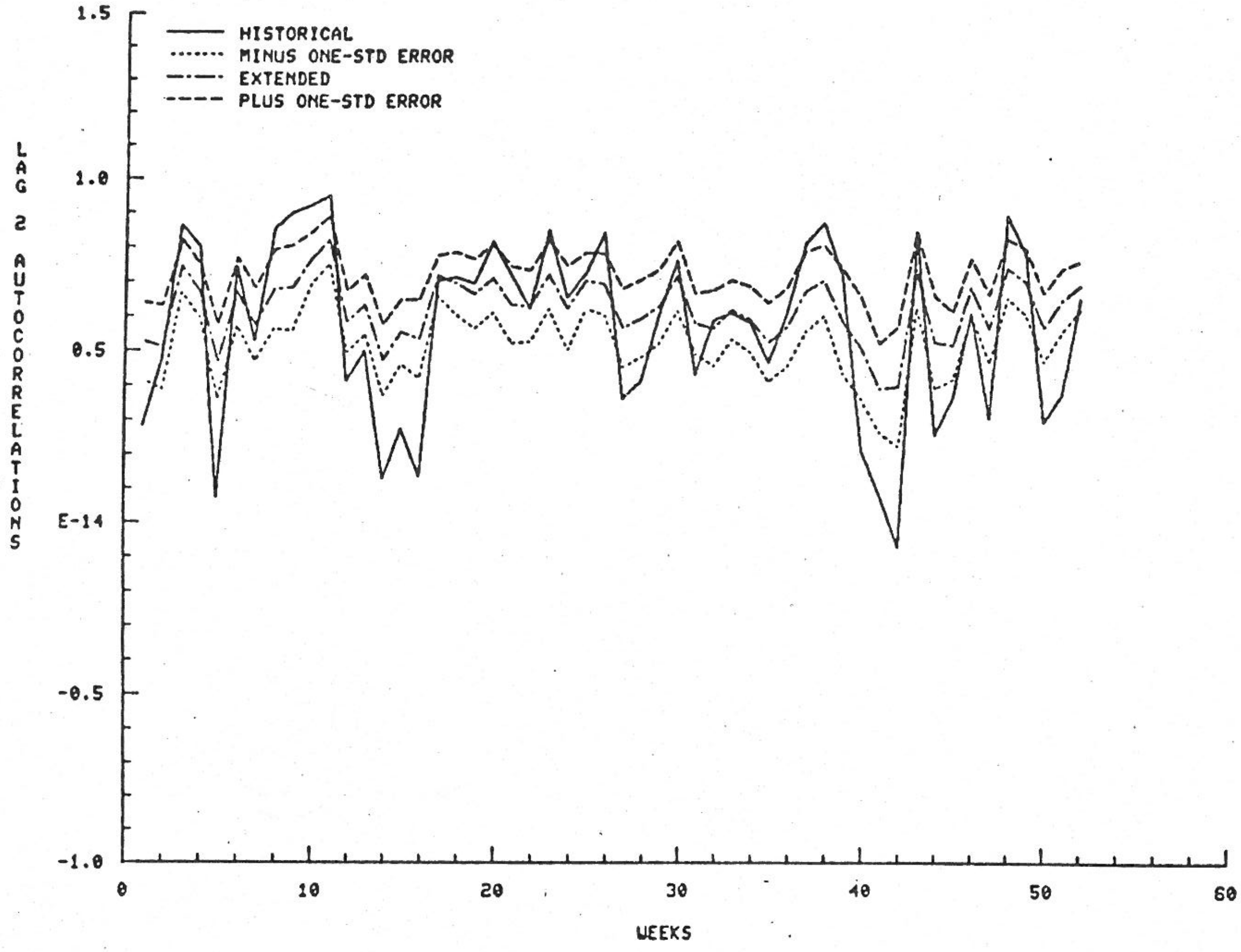


Figure 1.9.B.55. Historical and extended series weekly lag-2 autocorrelation coefficients of Rancho Arriba in logarithmic domain of flows.

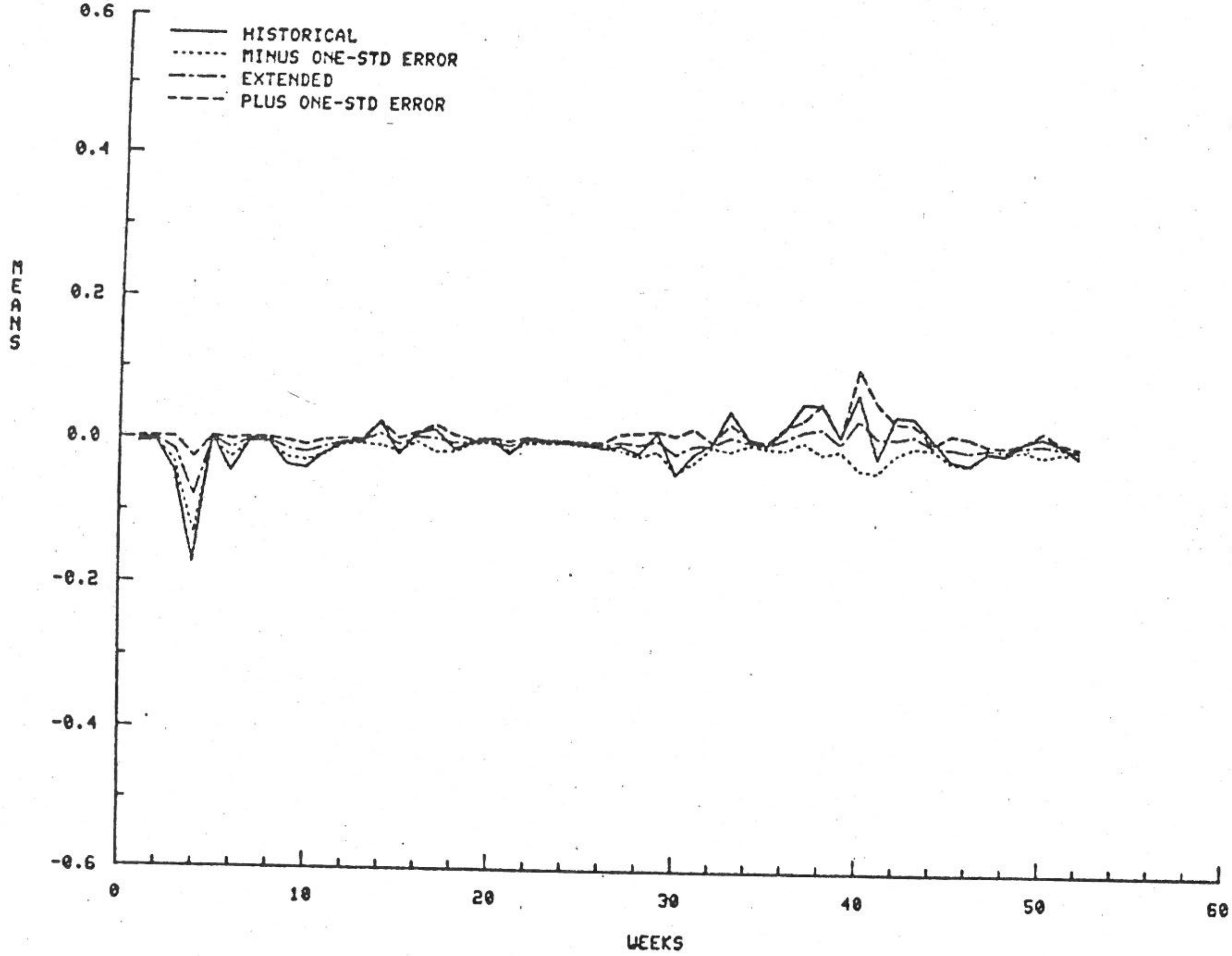


Figure 1.9.B.56. Historical and extended series weekly means of Rancho Arriba in log-Wilson-Hilferty domain of flows.

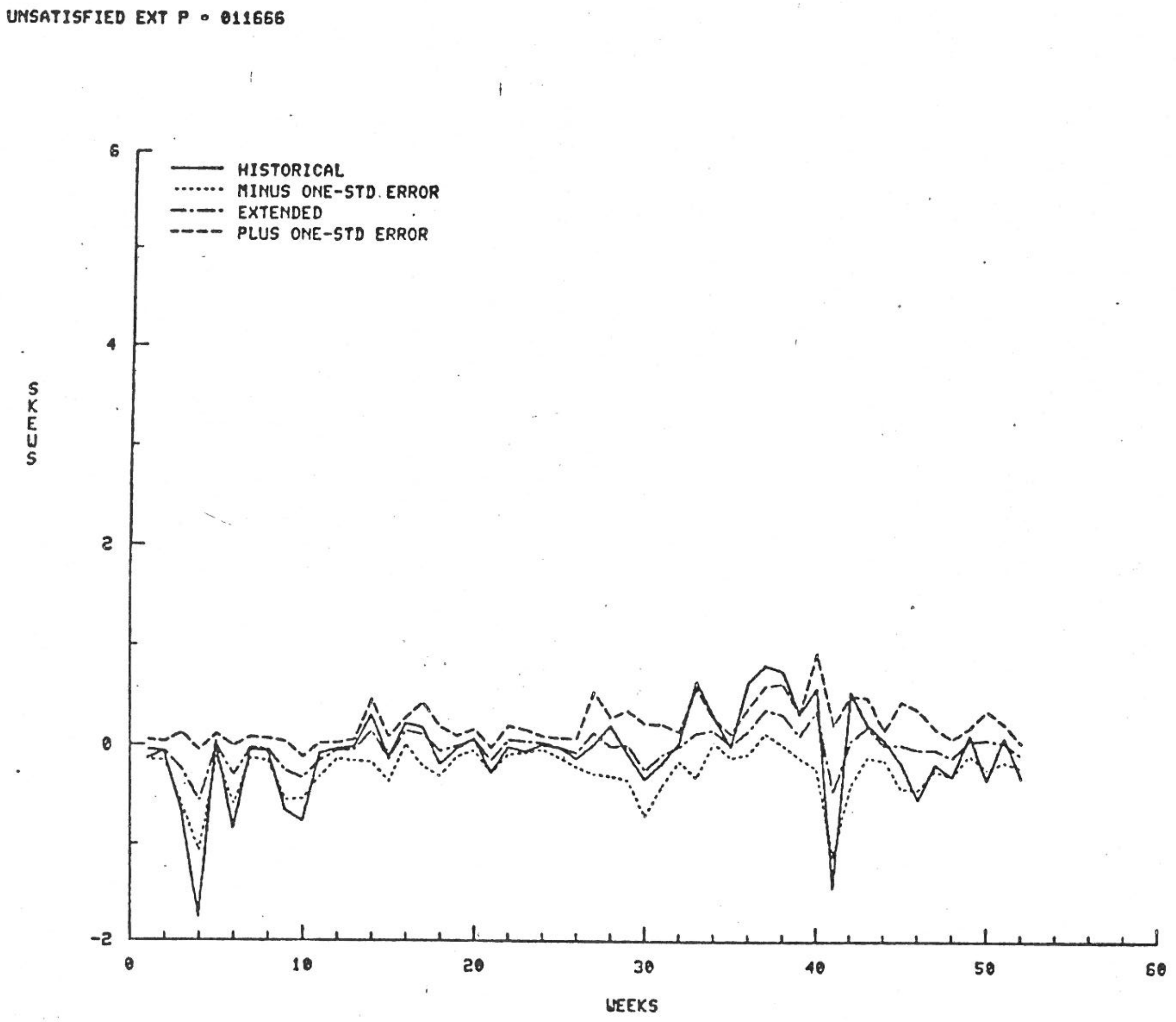


Figure 1.9.B.58. Historical and extended series weekly skewness coefficients of Rancho Arriba in log-Wilson-Hilferty domain of flows.

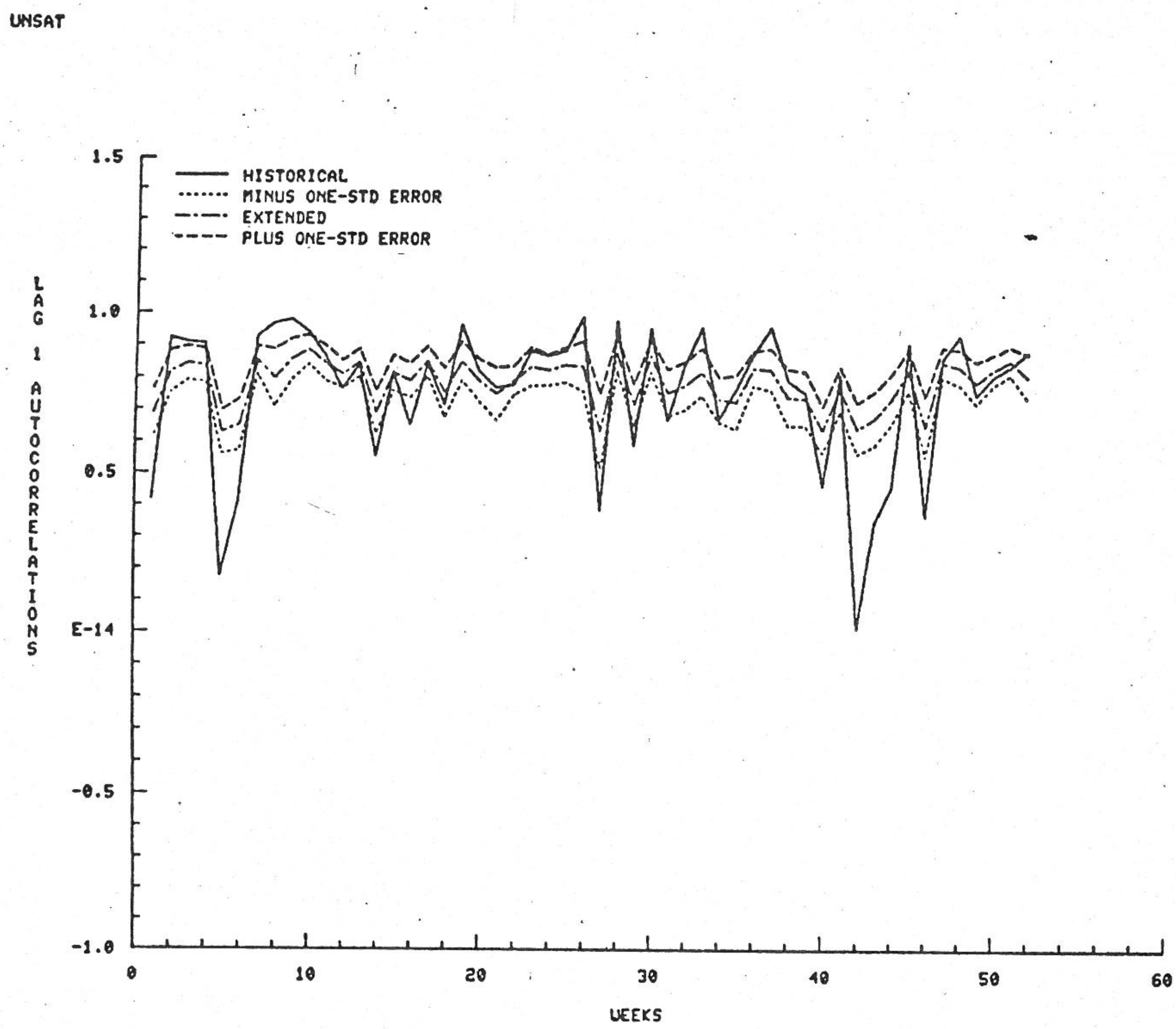


Figure 1.9.B.59. Historical and extended series weekly lag-1 autocorrelation coefficients of Rancho Arriba in log-Wilson-Hilferty domain of flows.

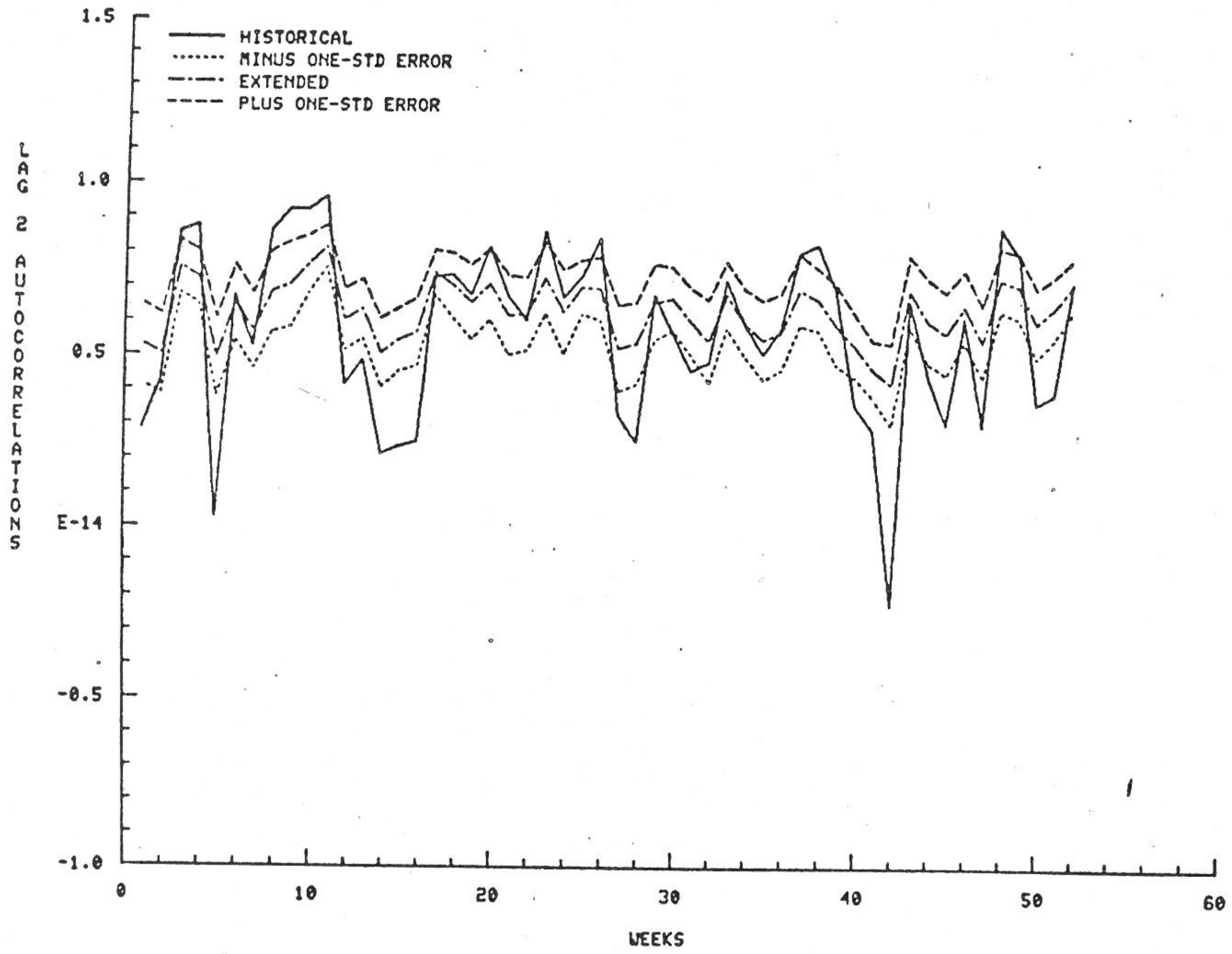


Figure 1.9.B.60. Historical and extended series weekly lag-2 autocorrelation coefficients of Rancho Arriba in log-Wilson-Hilferty domain of flows.

APPENDIX 1.9.C

FOURIER SERIES FITTING OF PERIODIC STATISTICAL PARAMETERS

Consider that U_τ represents the periodic statistical parameter such as skewness G_τ or the autocorrelation coefficient $R_\tau(k)$. The Fourier series representation of U_τ denoted by U^*_τ is obtained from (Salas, et al., 1980):

$$U^*_\tau = \bar{U} + \sum_{j=1}^{h} [A_j \cos(2\pi j\tau/\omega) + B_j \sin(2\pi j\tau/\omega)] \qquad (1.9.C.1)$$

for $\tau = 1,\ldots,\omega$ semi-months. The mean $\bar{U}$ and Fourier coefficients A_j and B_j are determined by

$$\bar{U} = \frac{1}{\omega} \sum_{t=1}^{\omega} U_\tau \qquad (1.9.C.2a)$$

$$A_j = \frac{2}{\omega} \sum_{\tau=1}^{\omega} U_\tau \cos\left(\frac{2\pi j\tau}{\omega}\right) \; ; \quad j = 1,\ldots,h \qquad (1.9.C.2b)$$

and

$$B_j = \frac{2}{\omega} \sum_{\tau=1}^{\omega} U_\tau \sin\left(\frac{2\pi j\tau}{\omega}\right) \; ; \quad j = 1,\ldots,h \qquad (1.9.C.2c)$$

The total number of harmonics h is theoretically equal to $\omega/2$ for ω an even number or equal to $(\omega-1)/2$ for ω an odd number. However, for purposes of removing sampling variabilities in the sample series U_τ, only a few harmonics are necessary. The selection of harmonics may be decided based on the significance of explained variance of each harmonic component. The so-called explained variance for each harmonic is computed from

$$EV_j = \frac{(A_j^2 + B_j^2)}{S^2(u)} \times 100 \text{ percent} \tag{1.9.C.3}$$

where EV_j is the explained variance in percent and $S^2(u)$ is the variance of the series $\{U_\tau\}$. Further details of selection of significant harmonics are given by Salas, et al. (1980).

Results of the Fourier series fitting of the monthly and weekly skewness coefficients in the log-domain for Palo de Caja, Paso del Ermitaño and Rancho Arriba are given in Figures 1.9.C.1 through 1.9.C.6. For monthly skewness coefficients, the first 2, 3, and 4 harmonics were fitted while those for weekly, the first 4, 5, and 6 harmonics were fitted. In the figures, the skewness coefficients of the extended series are referred to as "historical" and has been corrected for bias prior to Fourier series fitting. The bias correction for the skewness is based on gamma distribution which implies that the extended series in the log-domain of flows are assumed to be gamma distributed. This assumption is made post-de-facto since the suitable normalizing transformation is found to be the Wilson-Hilferty transformation (which is a gamma-based transformation) which was performed after logarithmic transformation. In equation form, the skewness $(G_\tau)_c$ corrected for bias is given by (Yevjevich and Obeysekera, 1984):

$$(G_\tau)_c = G_\tau \left[\left(1 + \frac{6.51}{N} + \frac{20.20}{N^2}\right) + \left(\frac{1.48}{N} + \frac{6.77}{N^2}\right) G_\tau^2 \right]$$

where G_τ is the extended series, average skewness of season τ and N is the number of years of record. From results herein, it is decided that the Fourier fitted functions using the first two harmonics be used for monthly skews while the first four harmonics be used for weekly skews.

Figures 1.9.C.7 to 1.9.C.18 show the results of Fourier series fitting of lag-1 and lag-2, monthly and weekly autocorrelations for the three stations in the log-Wilson-Hilferty domain of flows. From results herein, it is likewise decided that the first two harmonic fitted functions be used for monthly autocorrelations while the first four harmonic functions be used for weekly autocorrelations.

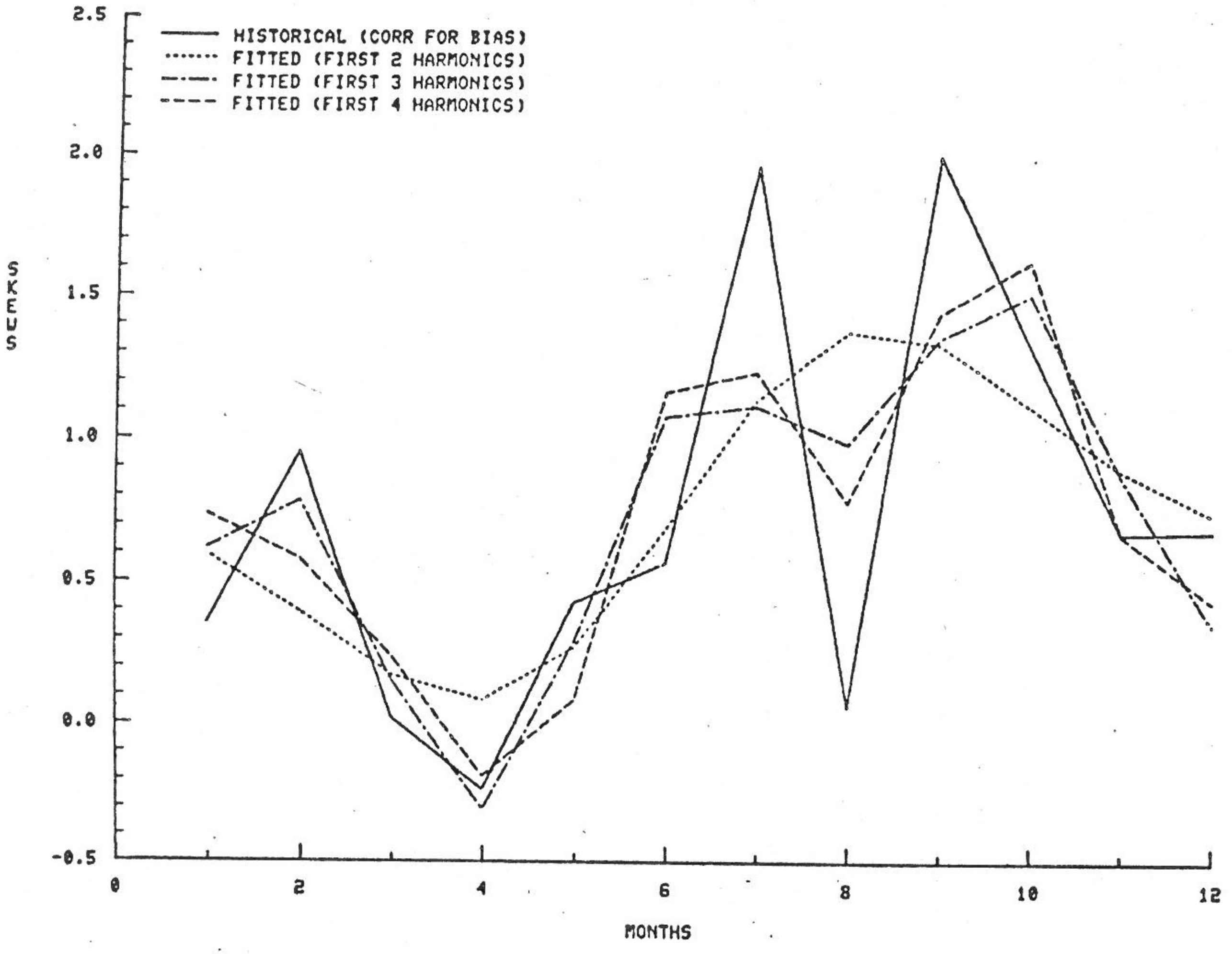


Figure 1.9.C.1 PALO DE CAJA - SKEWS IN LOG DOMAIN

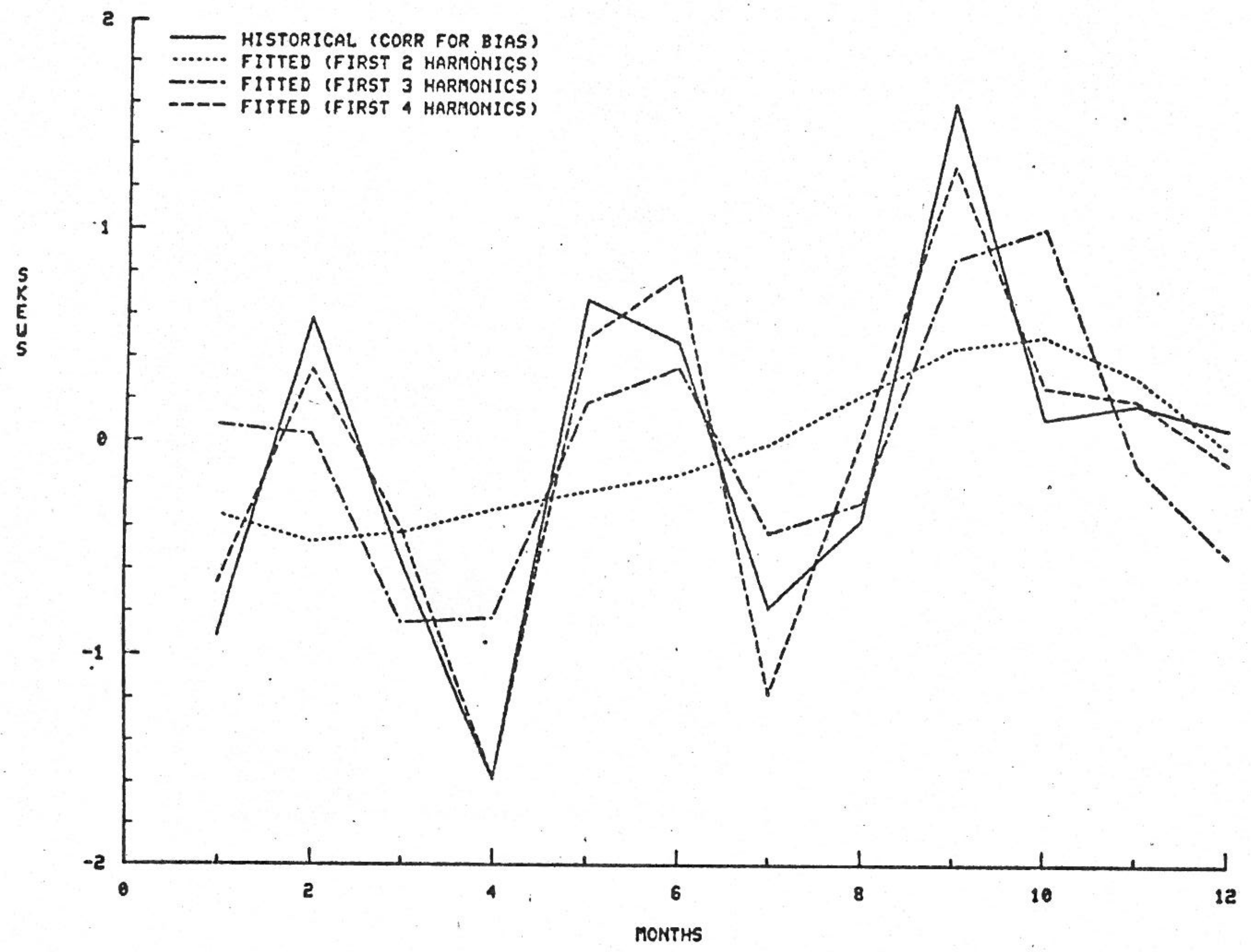


Figure 1.9.C.2 PASO DEL ERMITANO - SKEWS IN LOG DOMAIN

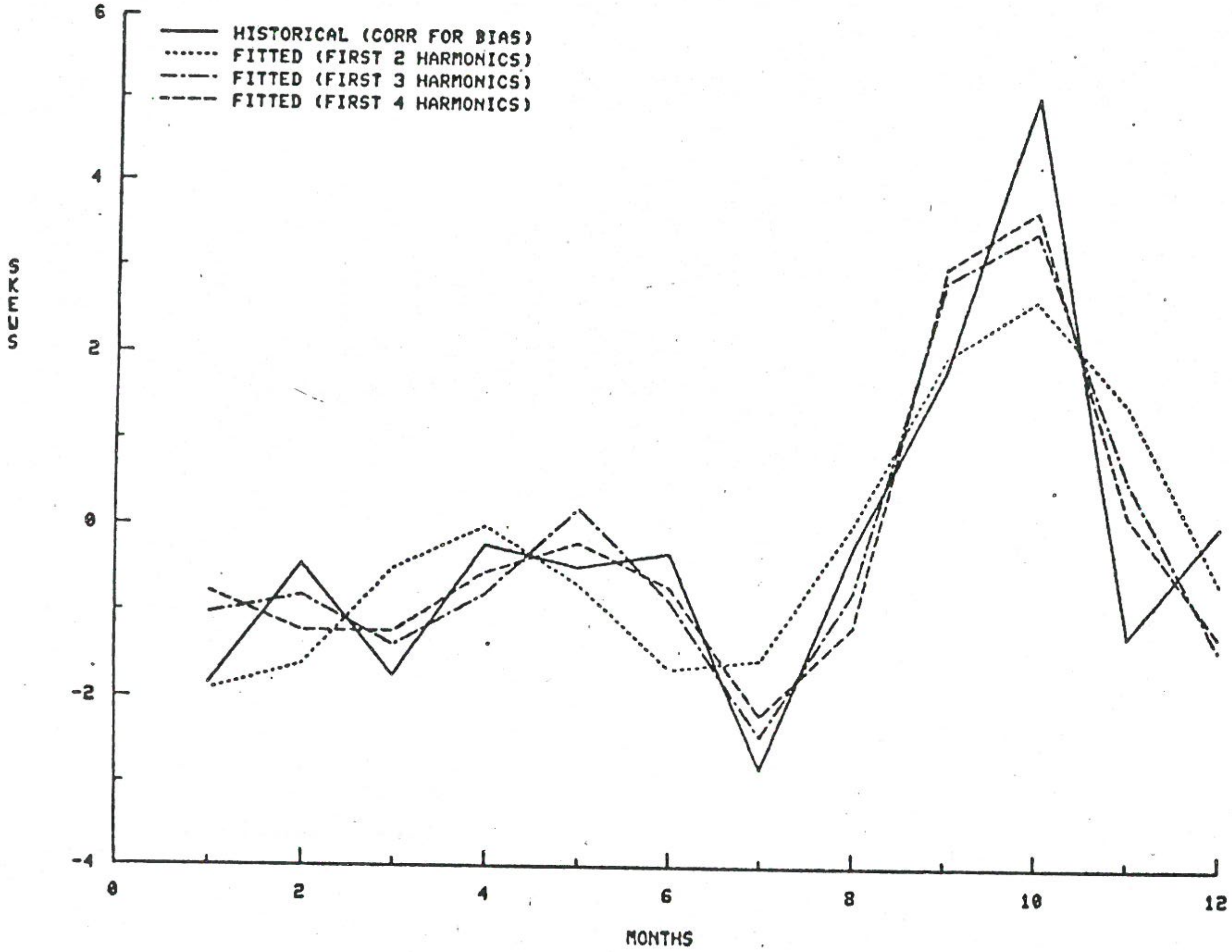


Figure 1.9.C.3 RANCHO ARRIBA - SKEWS IN LOG DOMAIN

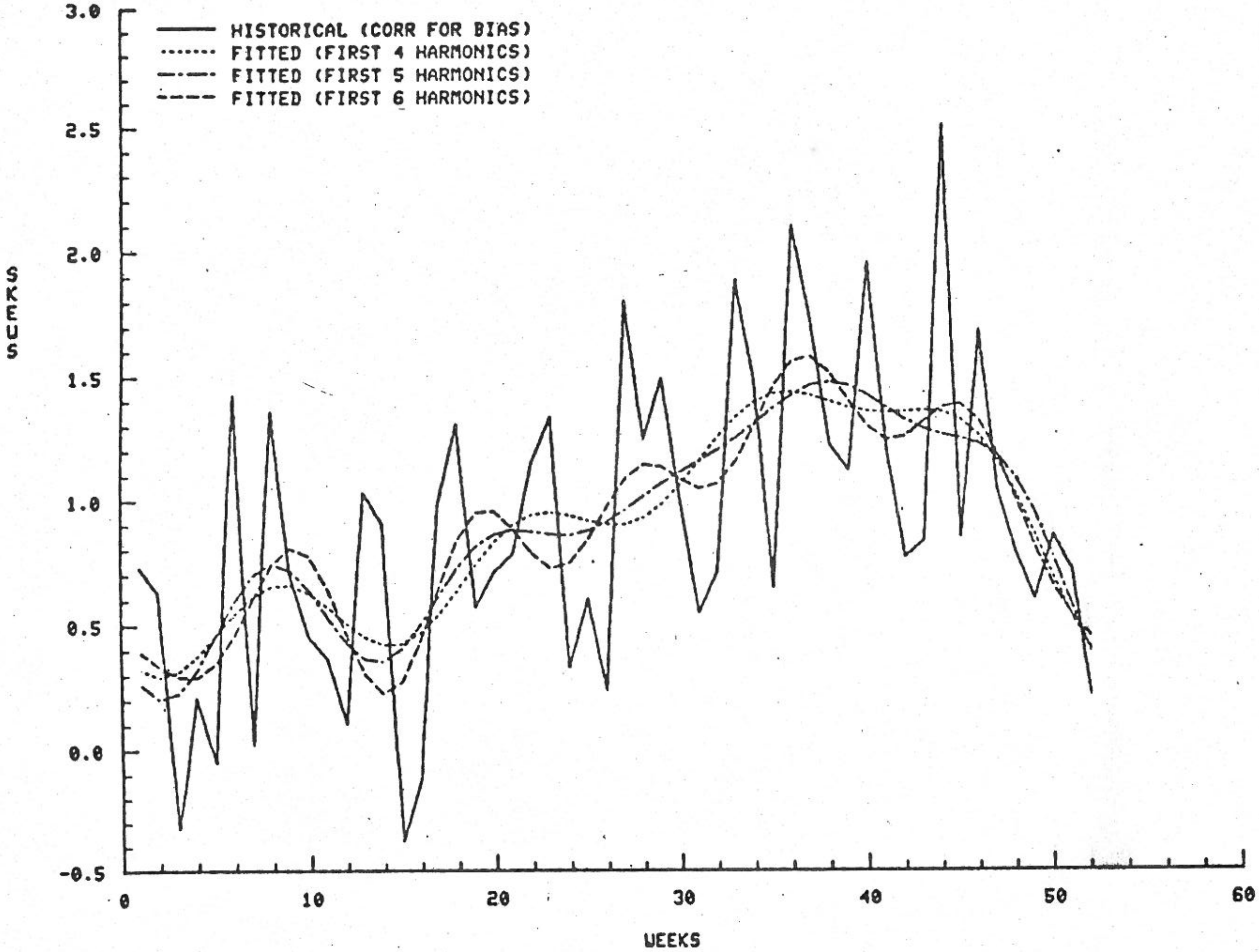


Figure 1.9.C.4 PALO DE CAJA - SKEWS IN LOG DOMAIN

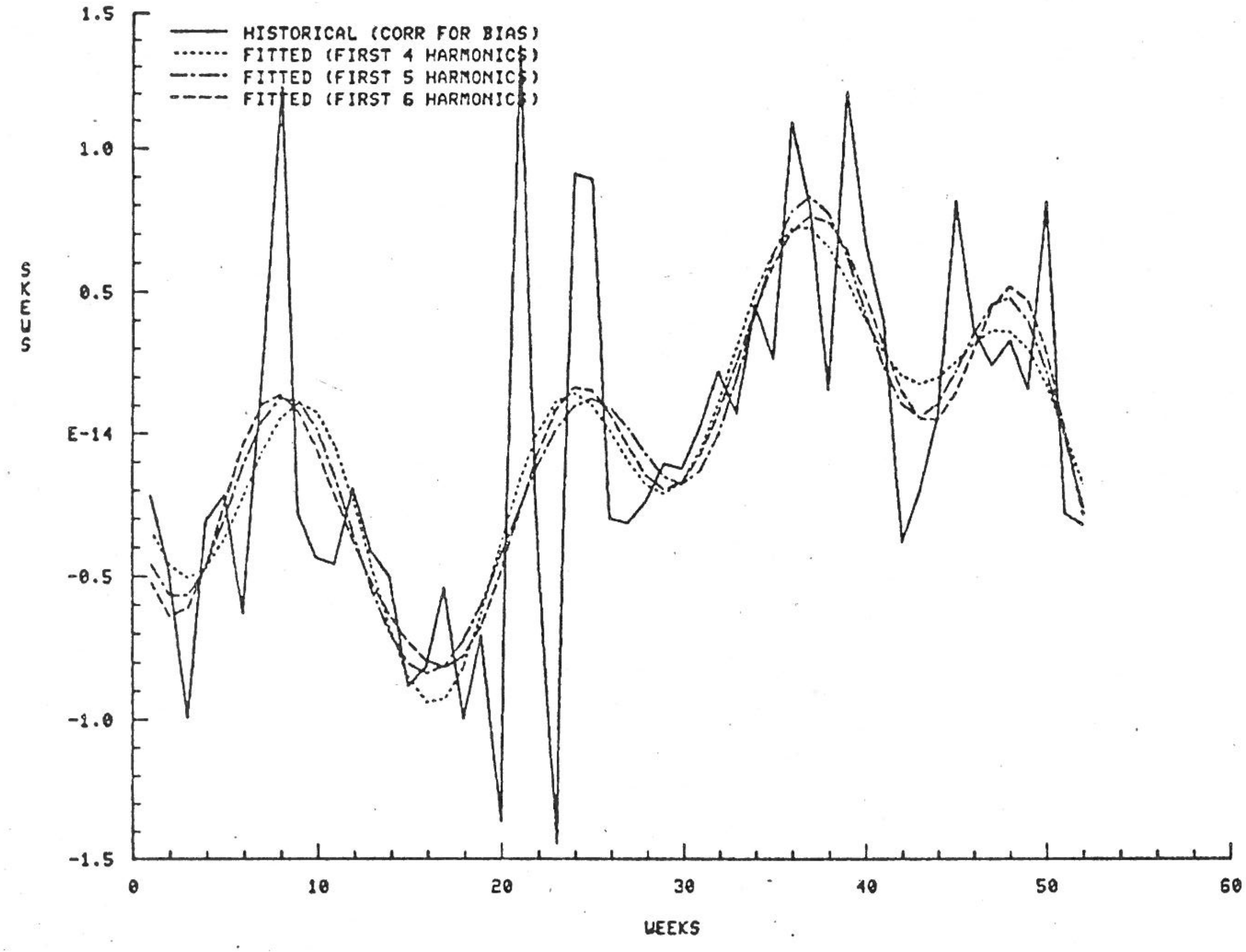


Figure 1.9.C.5 PASO DEL ERMITANO - SKEWS IN LOG DOMAIN

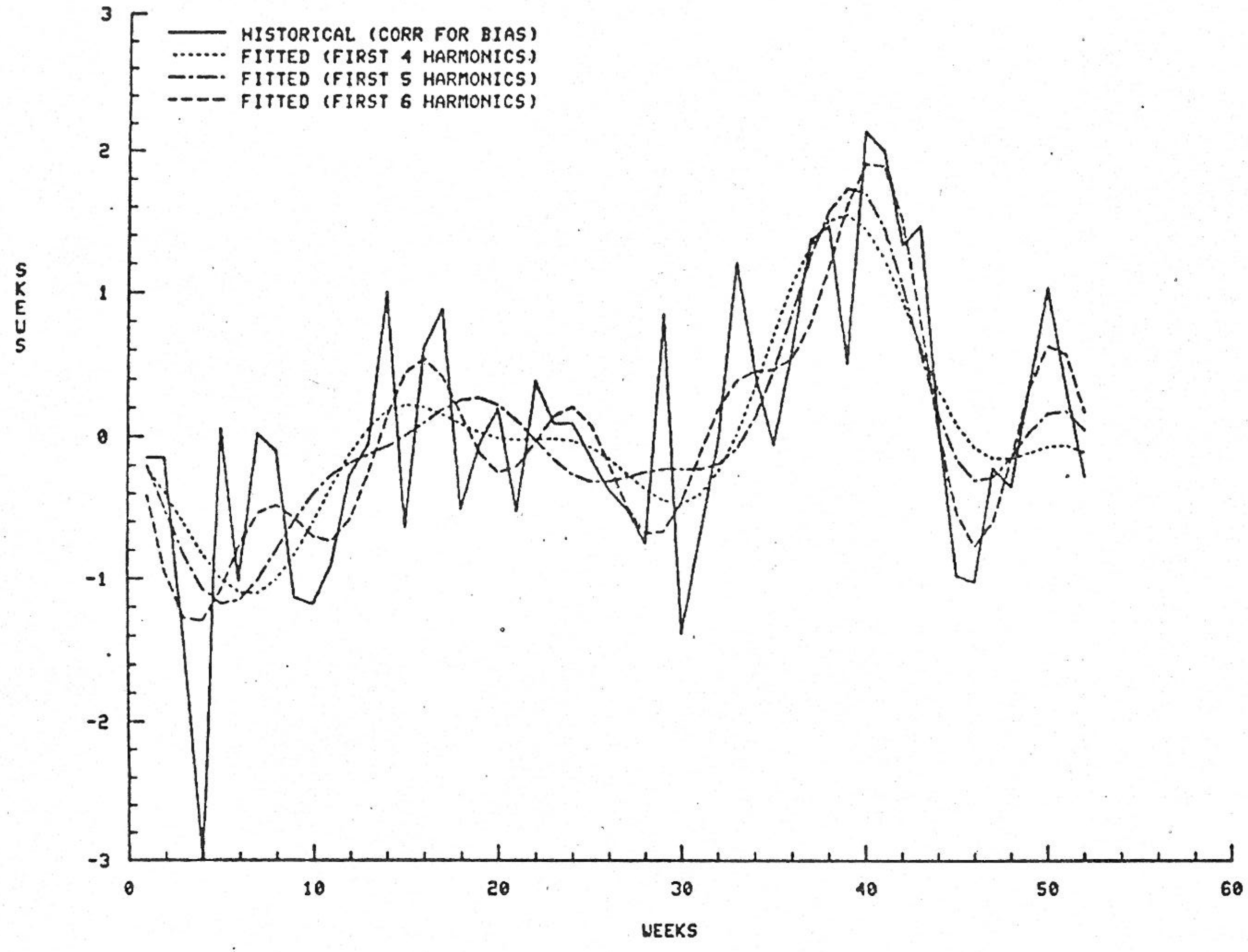


Figure 1.9.C.6 RANCHO ARRIBA - SKEWS IN LOG DOMAIN

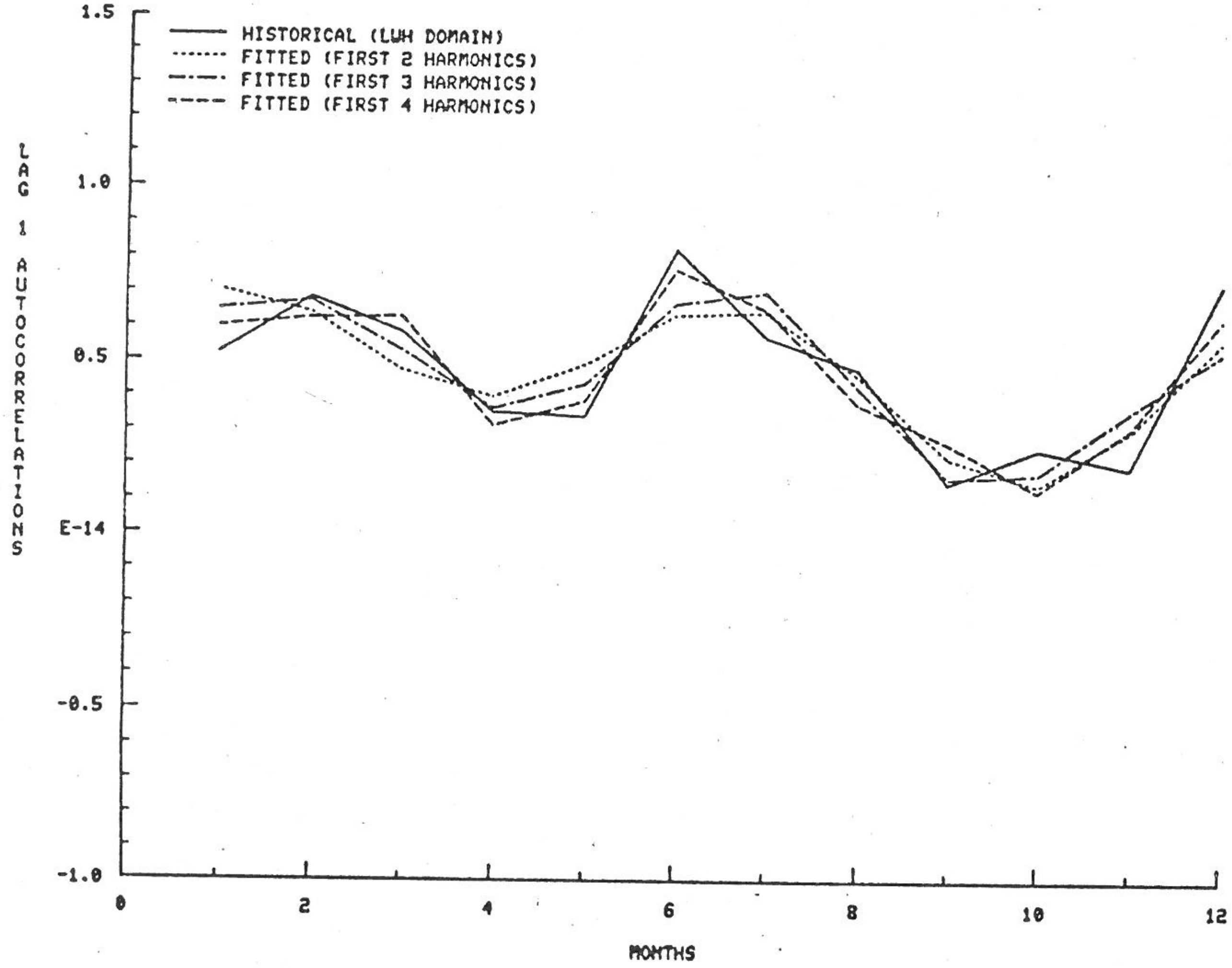


Figure 1.9.C.7 PALO DE CAJA - LAG 1 AUTOCORRELATIONS IN LWH DOMAIN

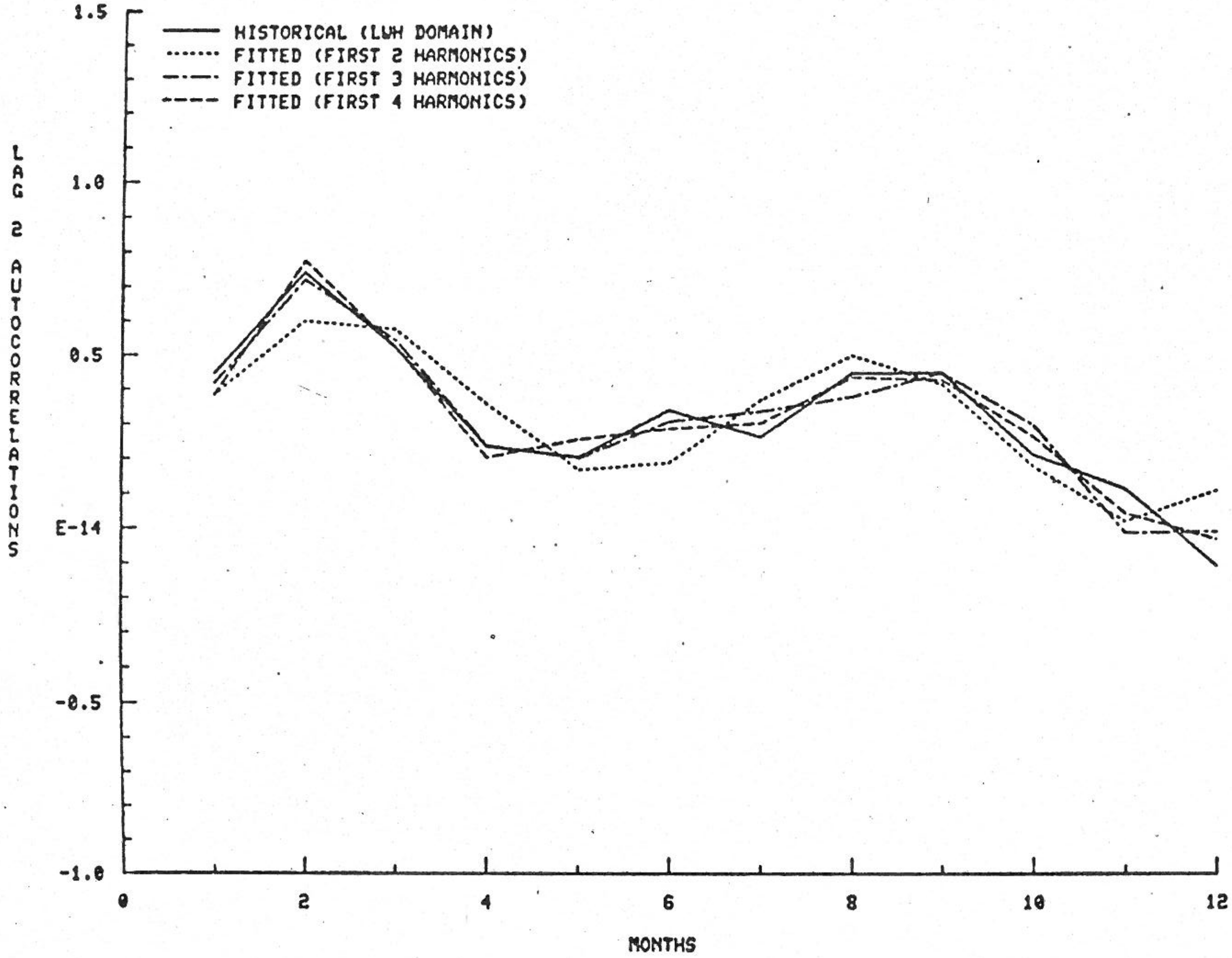


Figure 1.9.C.8 PALO DE CAJA - LAG 2 AUTOCORRELATIONS IN LWH DOMAIN

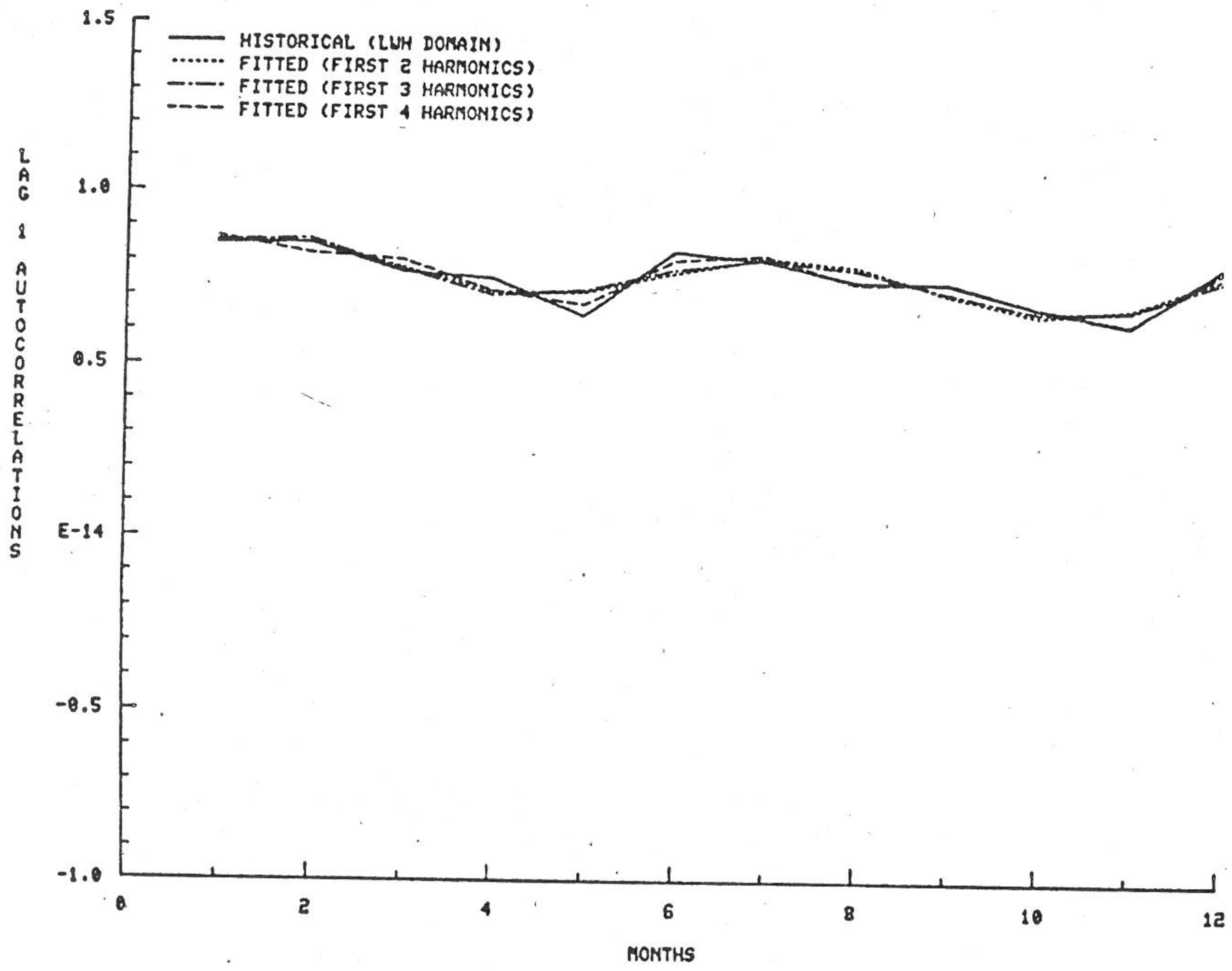


Figure 1.9.C.9 PASO DEL ERMITANO - LAG 1 AUTOCORRELATIONS IN LWH DOMAIN

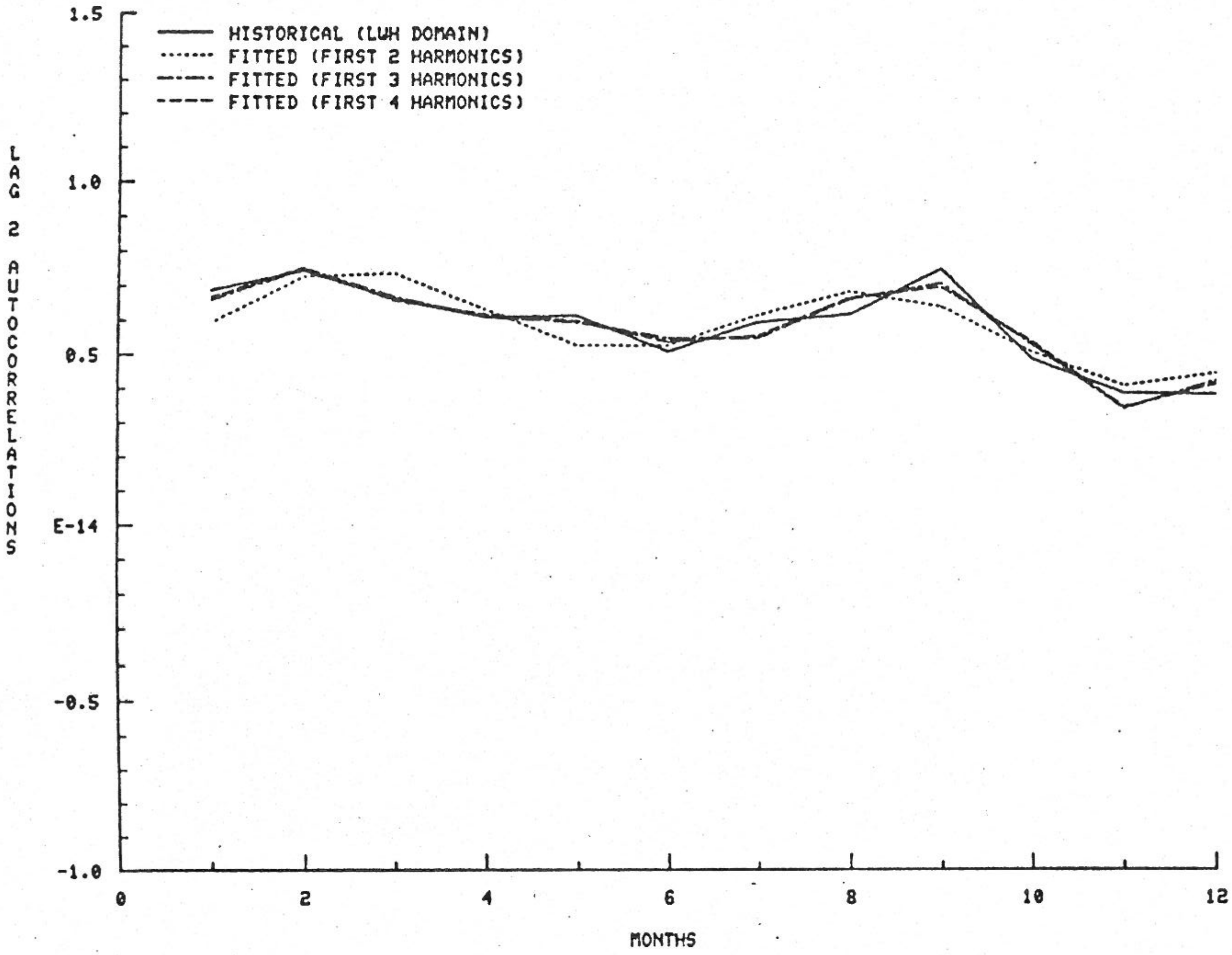


Figure 1.9.C.10 PASO DEL ERMITANO - LAG 2 AUTOCORRELATIONS IN LWH DOMAIN

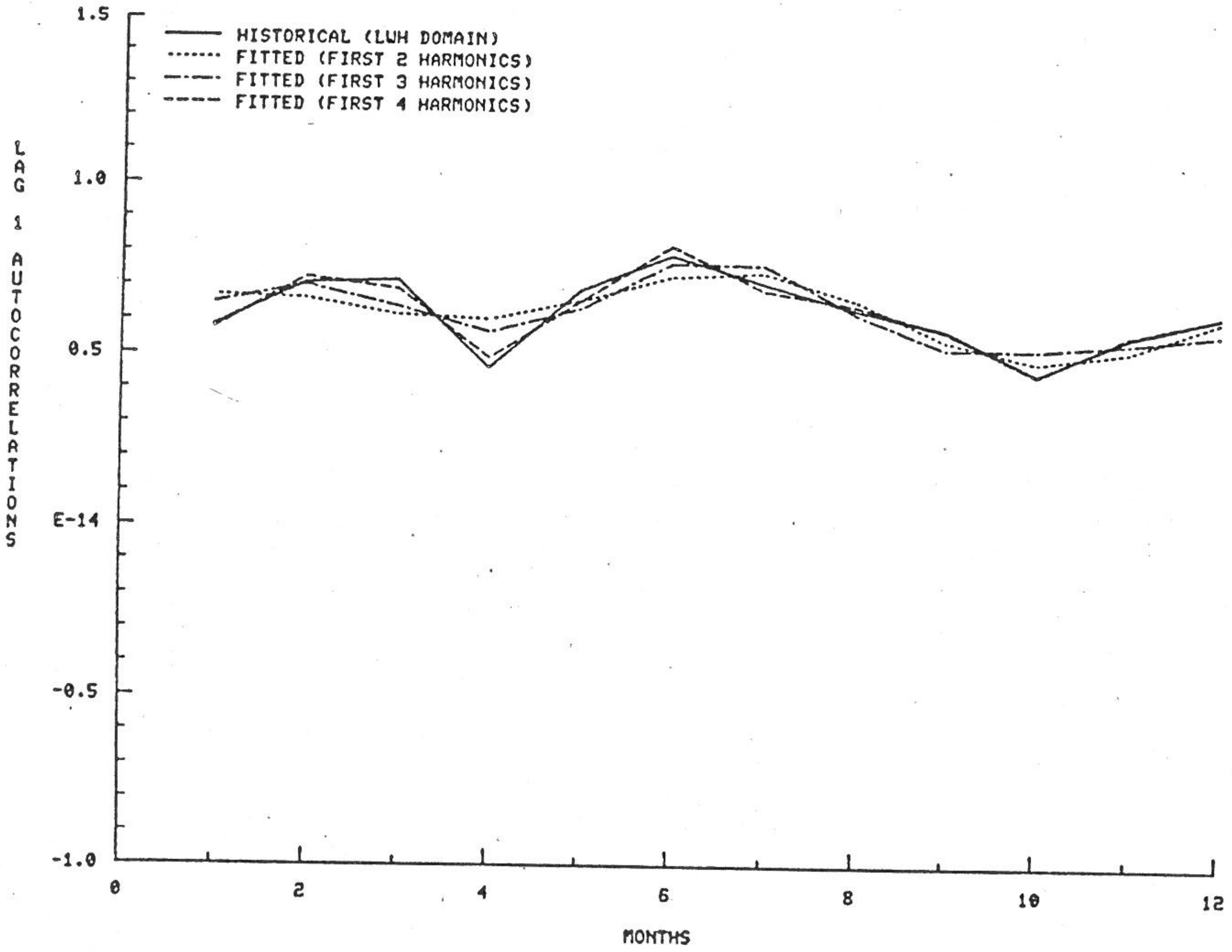


Figure 1.9.C.11 RANCHO ARRIBA - LAG 1 AUTOCORRELATIONS IN LWH DOMAIN

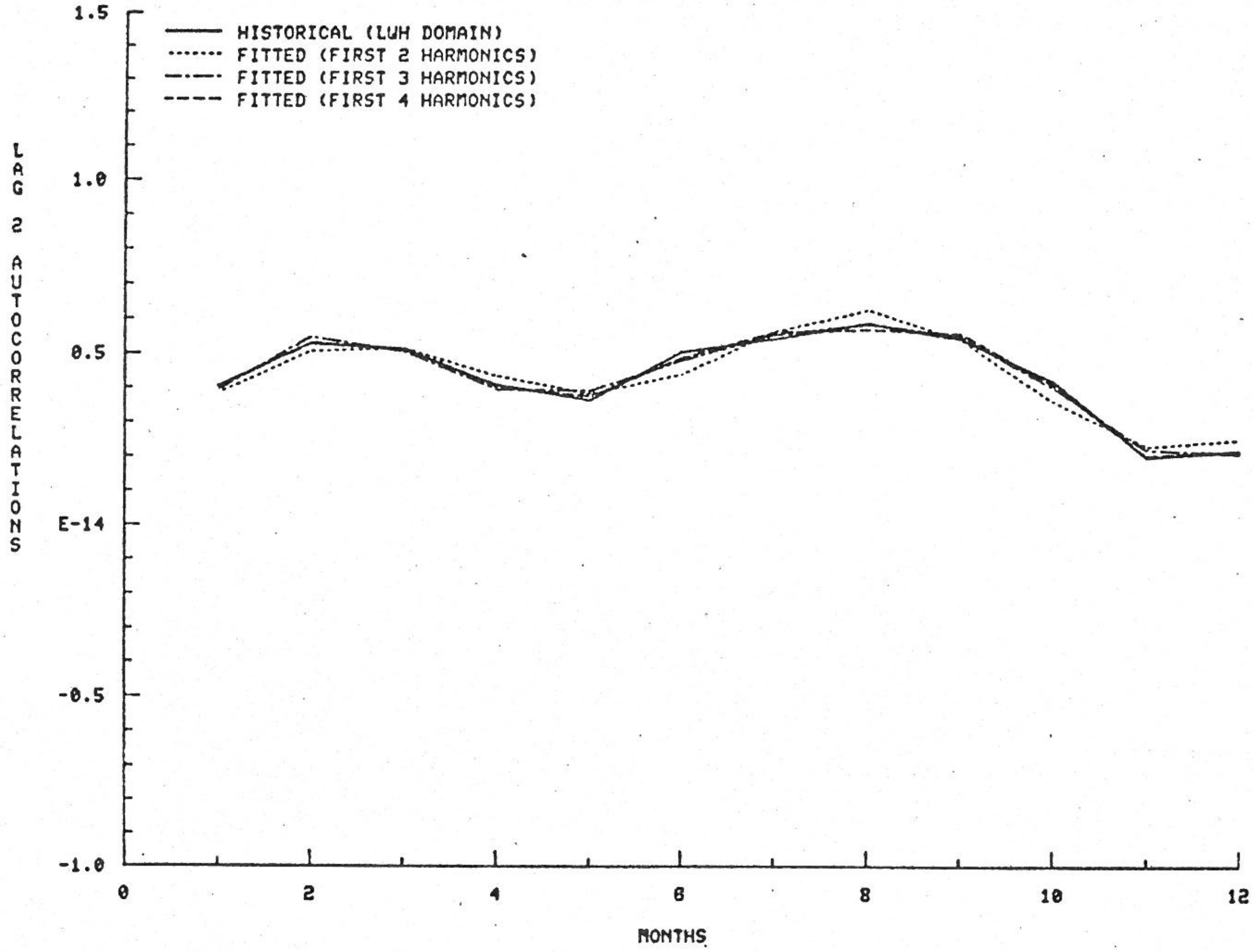


Figure 1.9.C.12 RANCHO ARRIBA - LAG 2 AUTOCORRELATIONS IN LWH DOMAIN

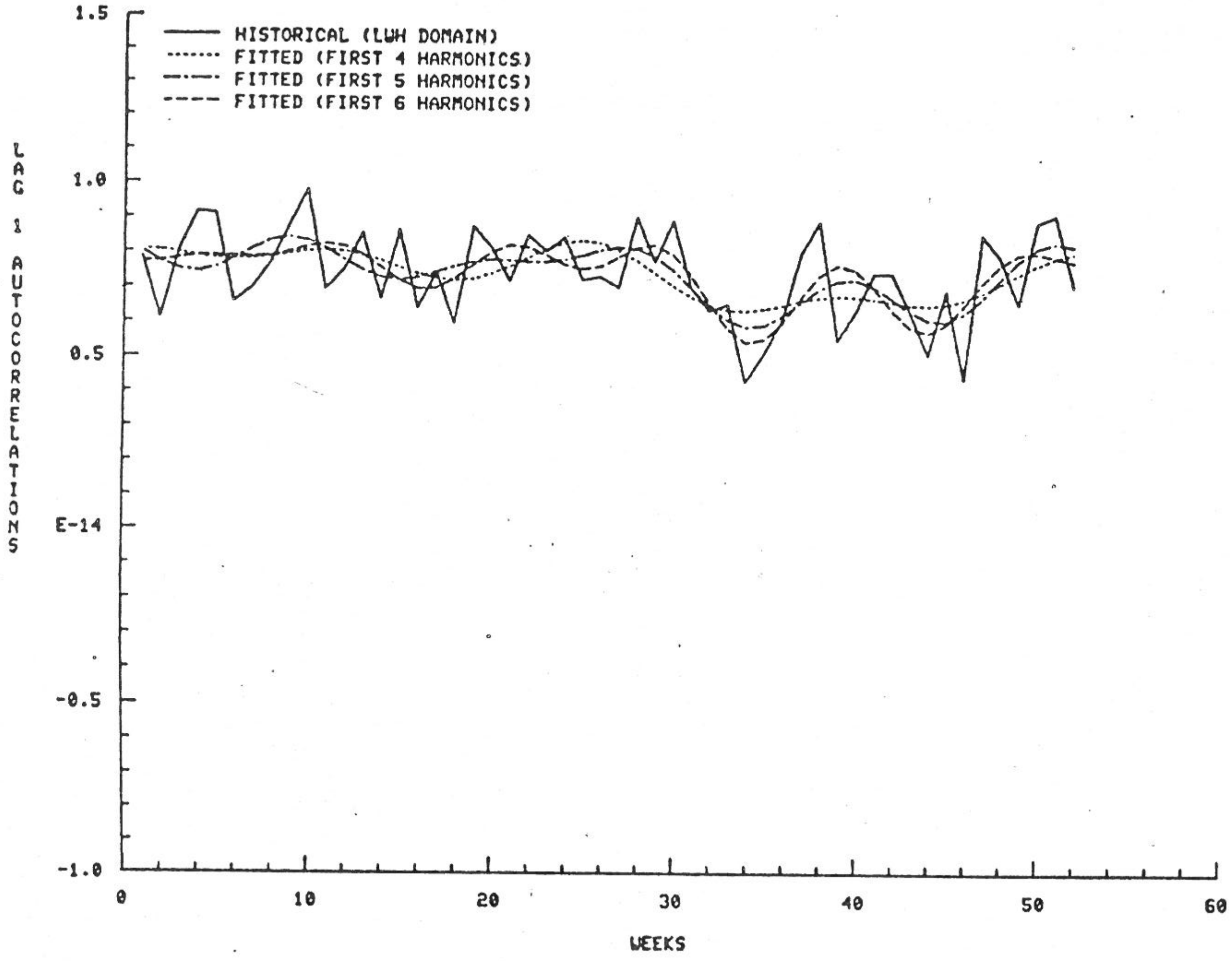


Figure 1.9.C.13 PALO DE CAJA - LAG 1 AUTOCORRELATIONS IN LWH DOMAIN

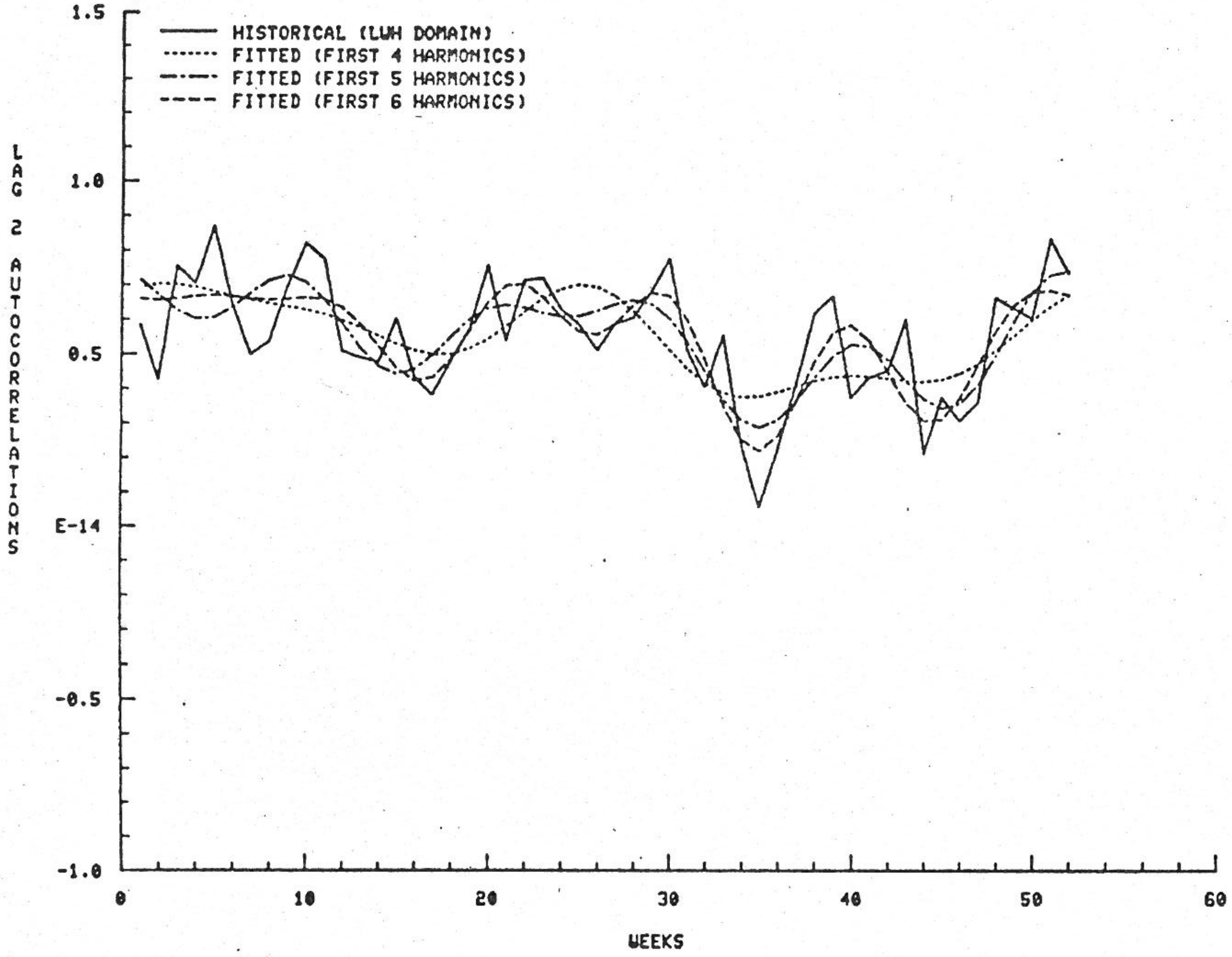


Figure 1.9.C.14 PALO DE CAJA - LAG 2 AUTOCORRELATIONS IN LWH DOMAIN

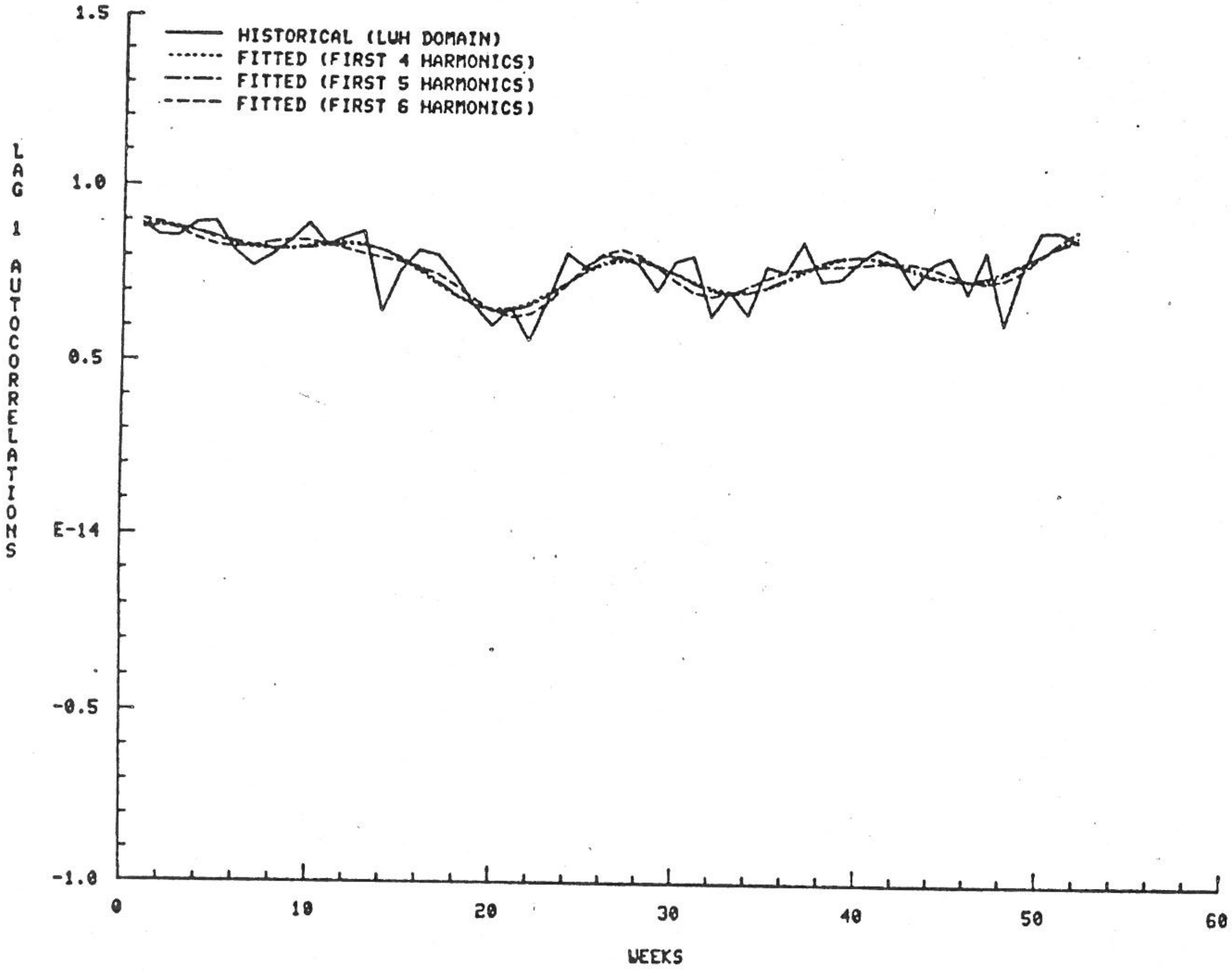


Figure 1.9.C.15 PASO DEL ERMITANO - LAG 1 AUTOCORRELATIONS IN LWH DOMAIN

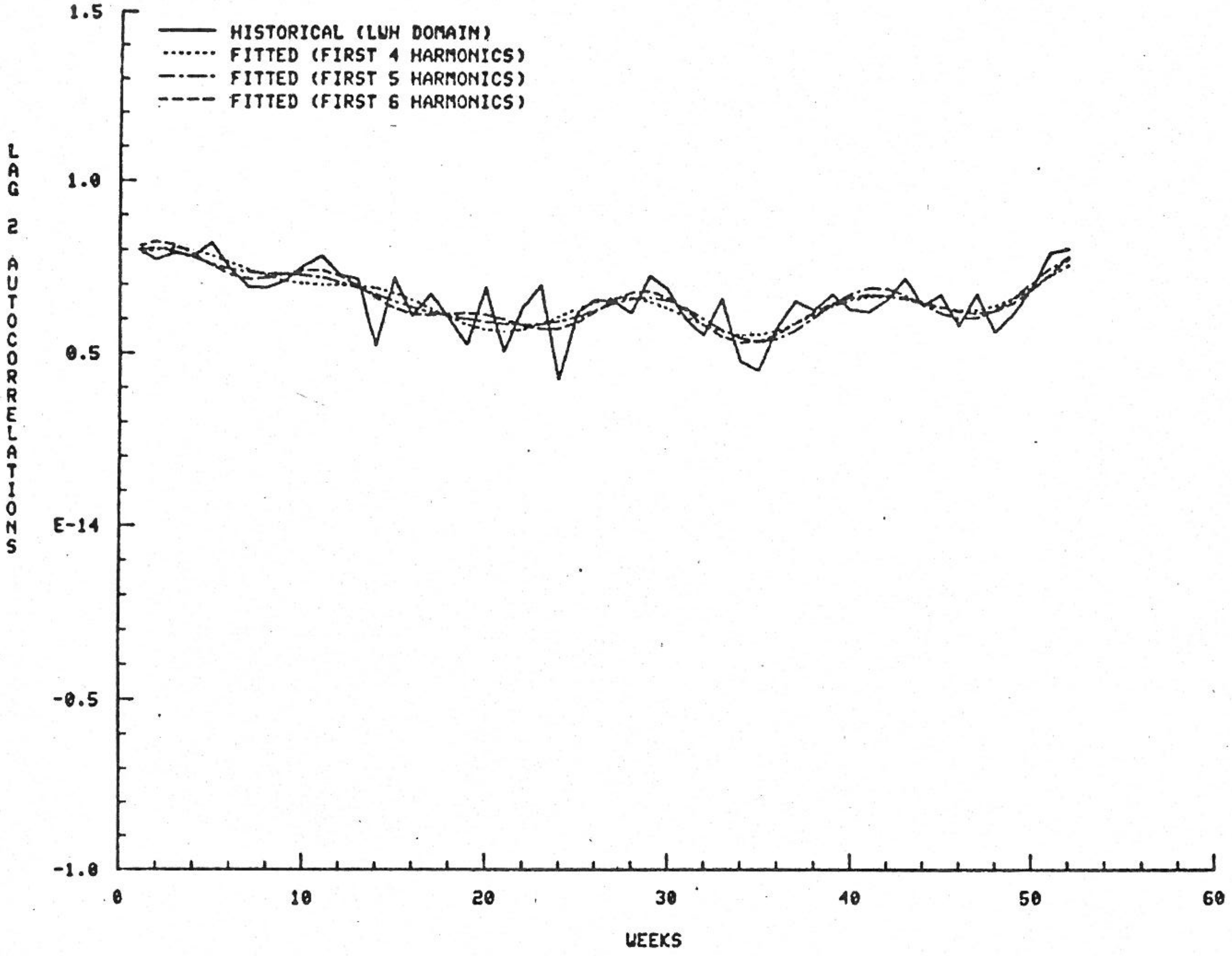


Figure 1.9.C.16 PASO DEL ERMITANO - LAG 2 AUTOCORRELATIONS IN LWH DOMAIN

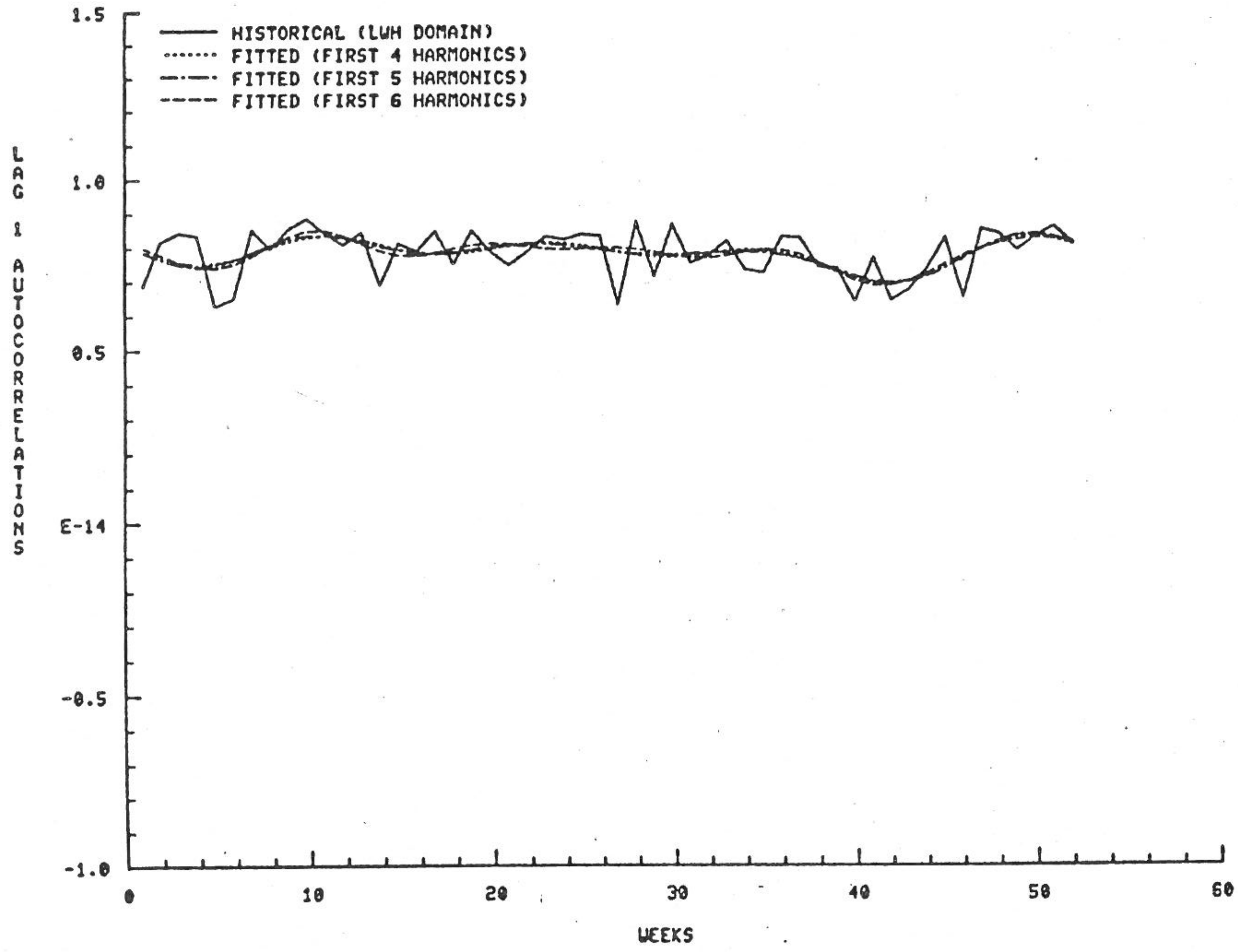


Figure 1.9.C.17 RANCHO ARRIBA - LAG 1 AUTOCORRELATIONS IN LWH DOMAIN

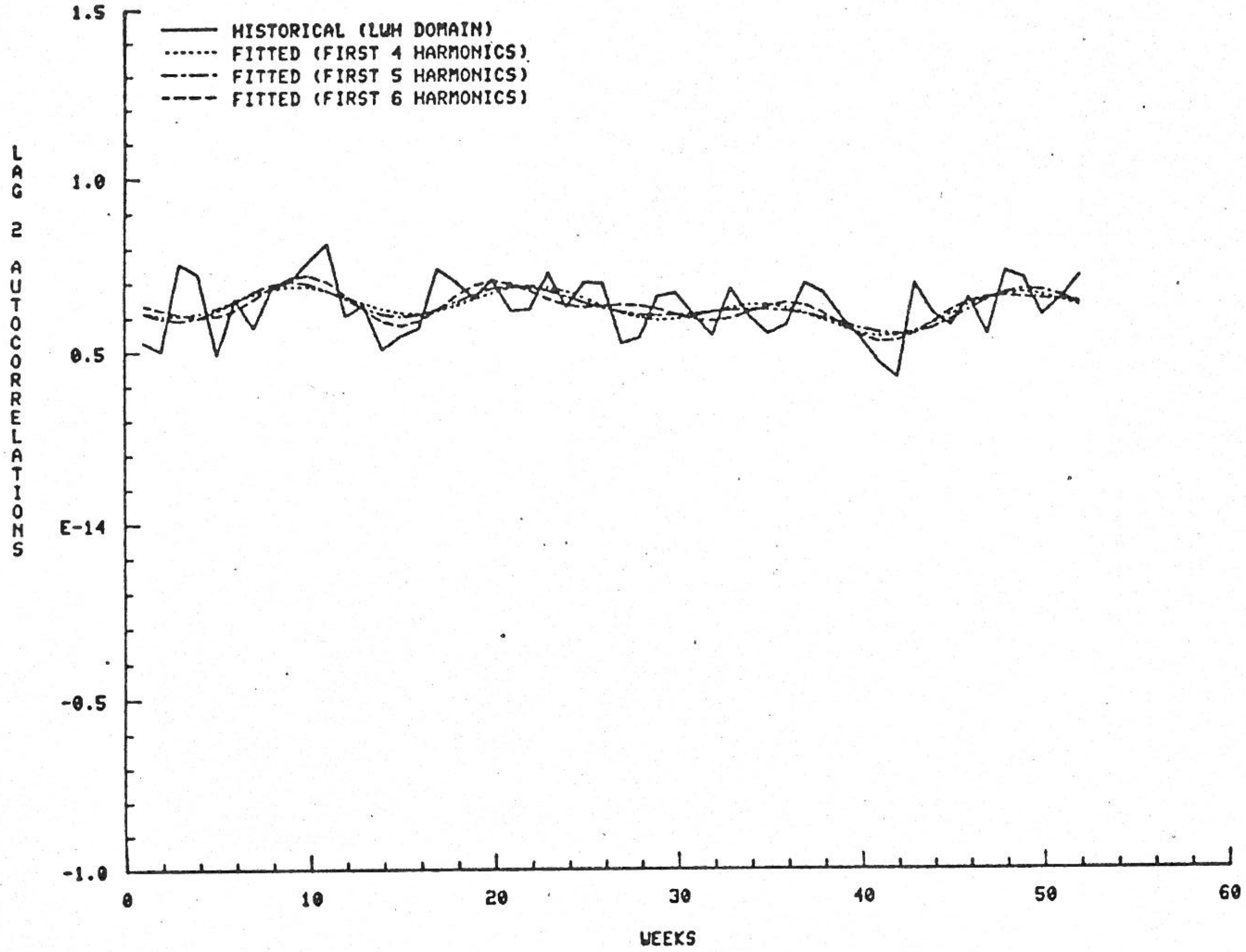


Figure 1.9.C.18 RANCHO ARRIBA - LAG 2 AUTOCORRELATIONS IN LWH DOMAIN

APPENDIX 1.9.D

HISTORICAL (EXTENDED SERIES) AND GENERATED MONTHLY AND WEEKLY STATISTICS FOR PALO DE CAJA (PALODE), PASO DEL ERMITAÑO (PASODE) AND RANCHO ARRIBA (RANCHO) USING MODELS A, B AND C IN THE ORIGINAL DOMAIN OF FLOWS

Note: See Appendix 1.9.E for details of computing generated statistics.

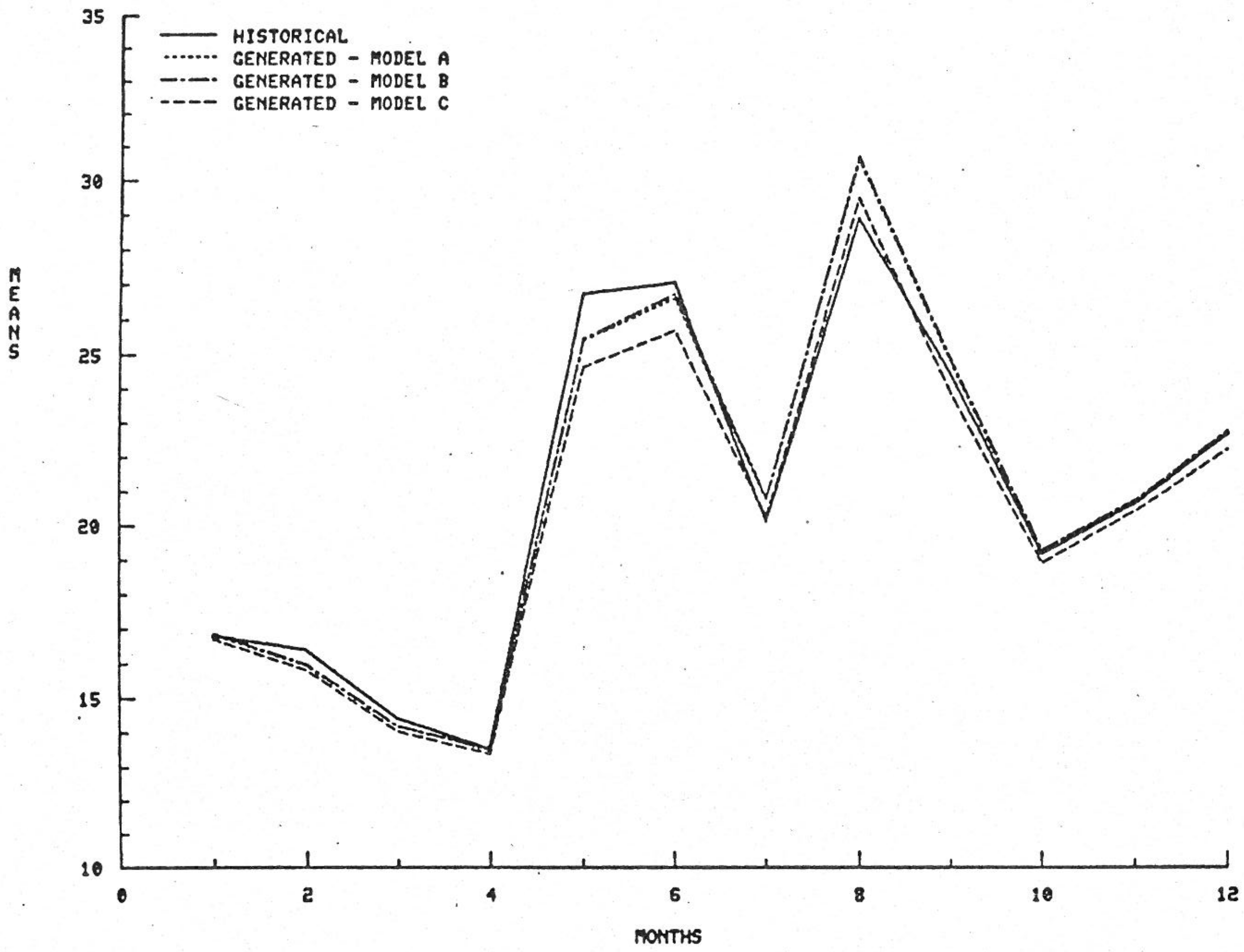


Figure 1.9.D.1 PASODE - MEANS (ORIGINAL DOMAIN)

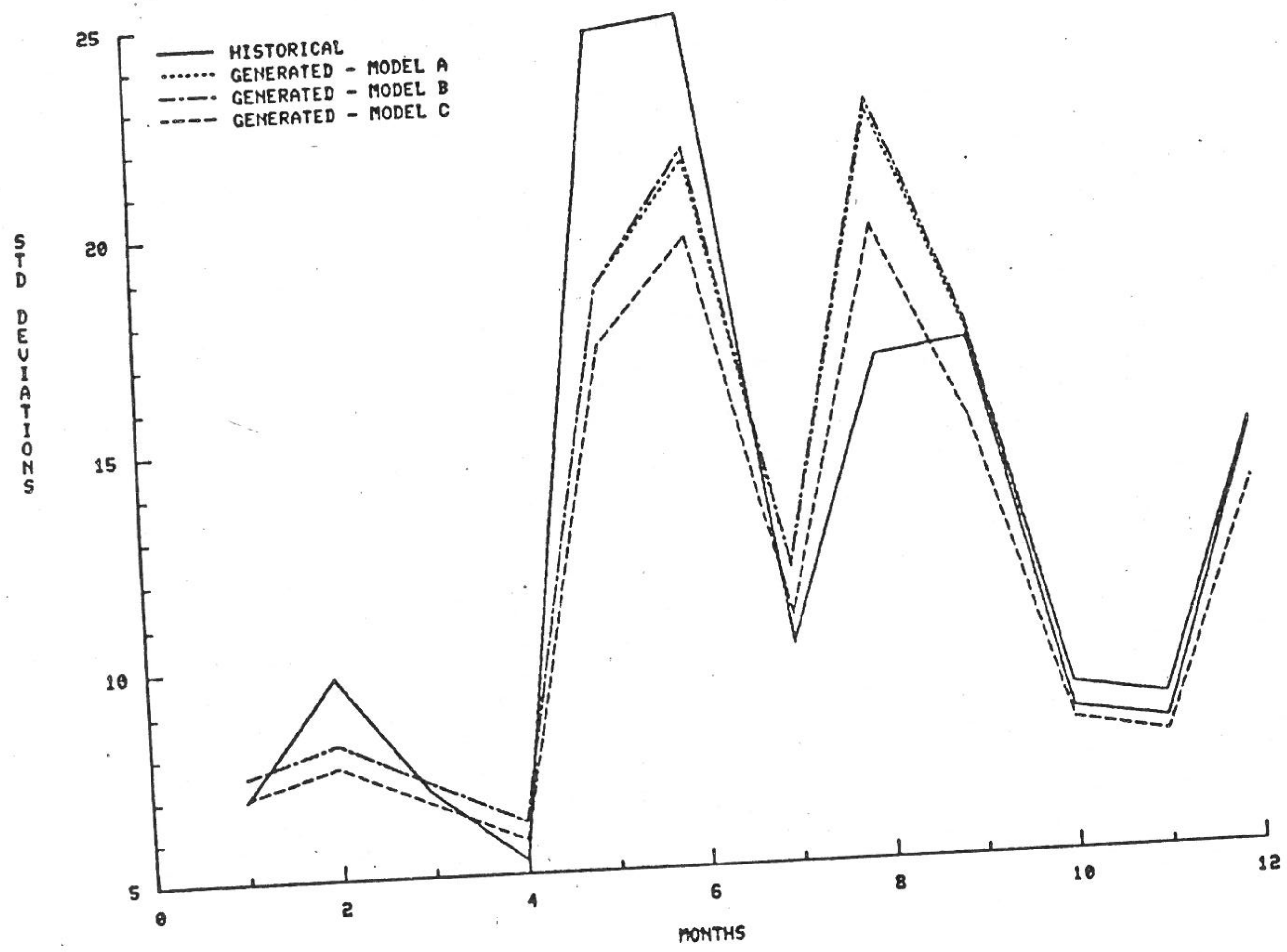


Figure 1.9.D.2 PASODE - STD DEVIATIONS (ORIGINAL DOMAIN)

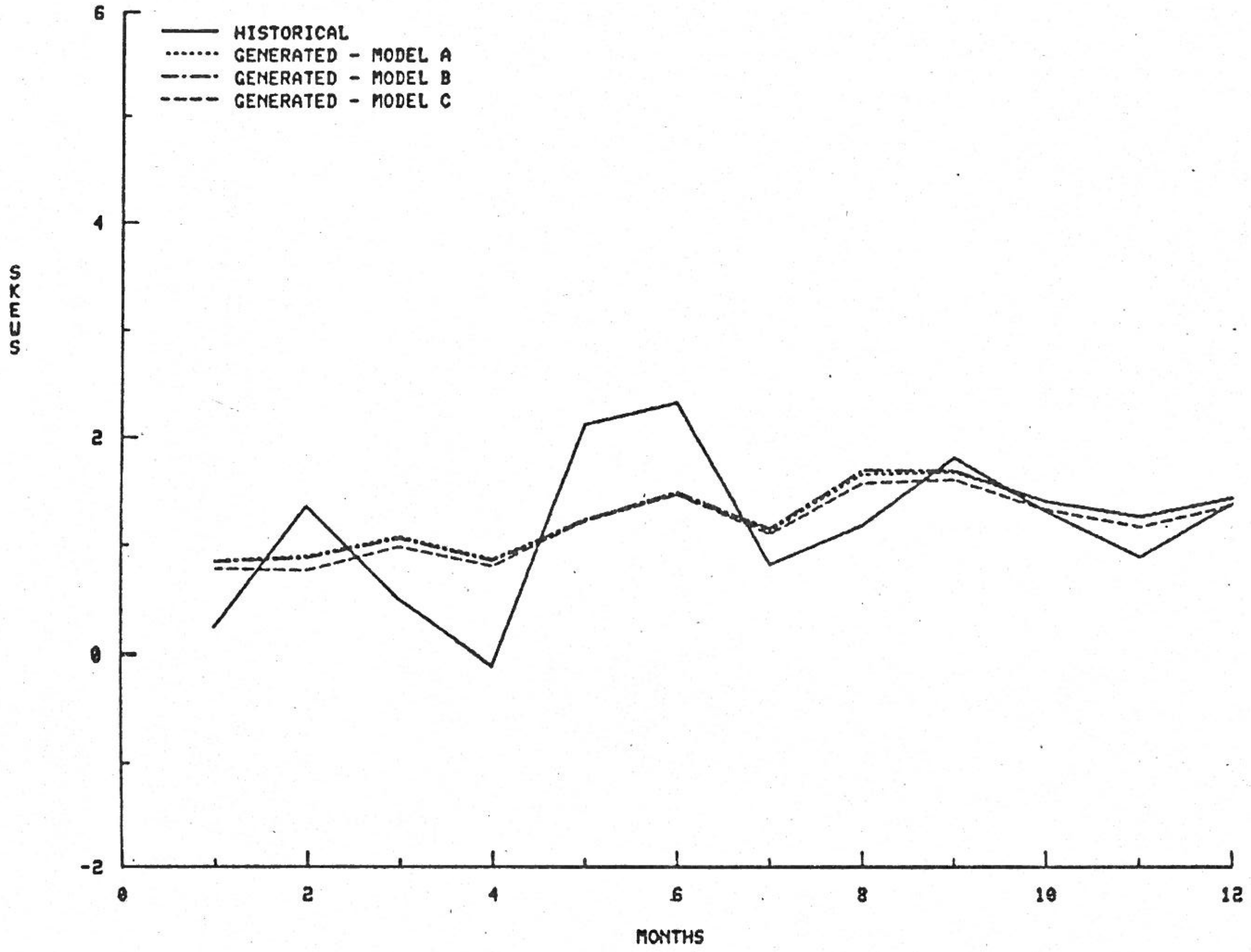


Figure 1.9.D.3 PASODE - SKEWS (ORIGINAL DOMAIN)

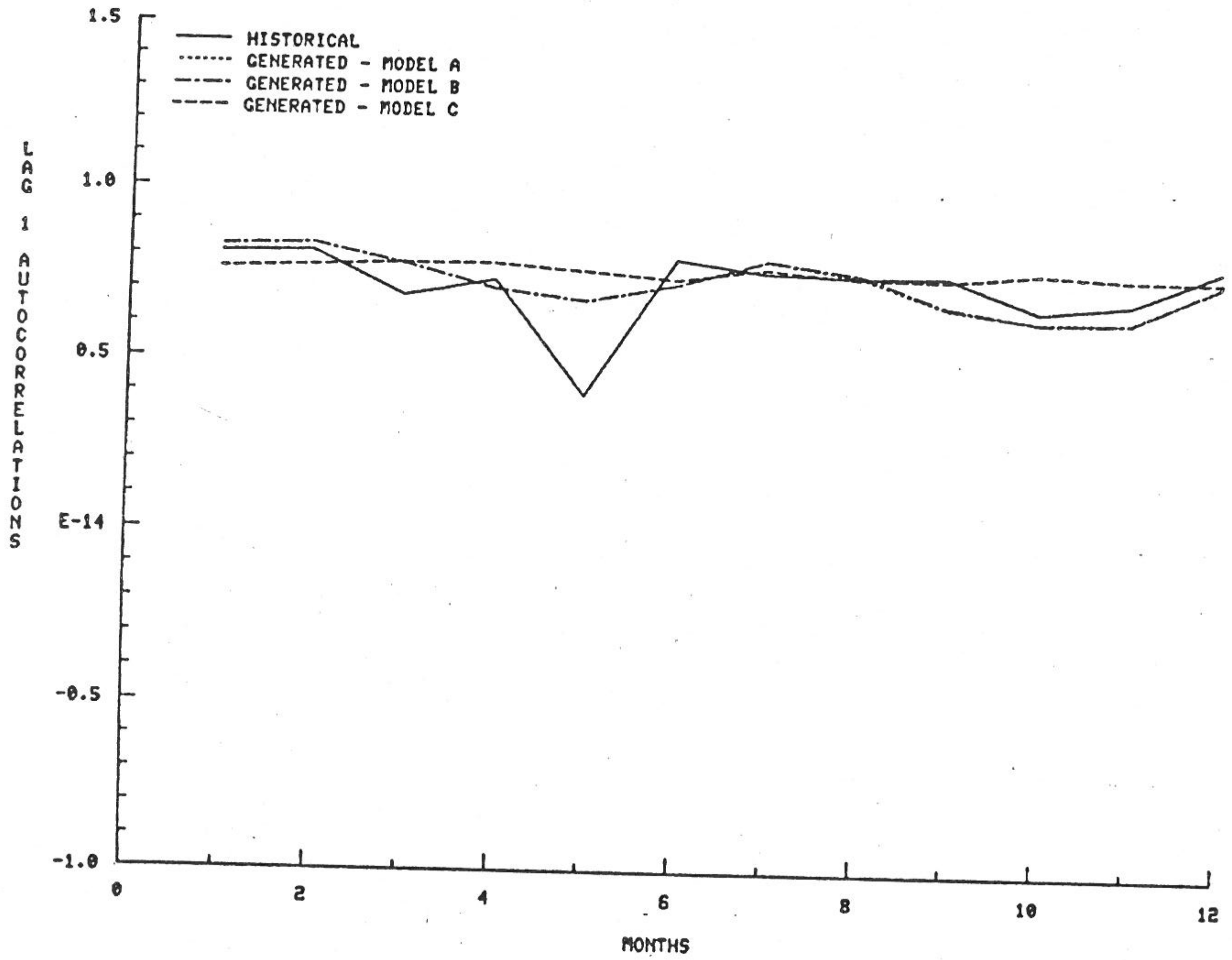
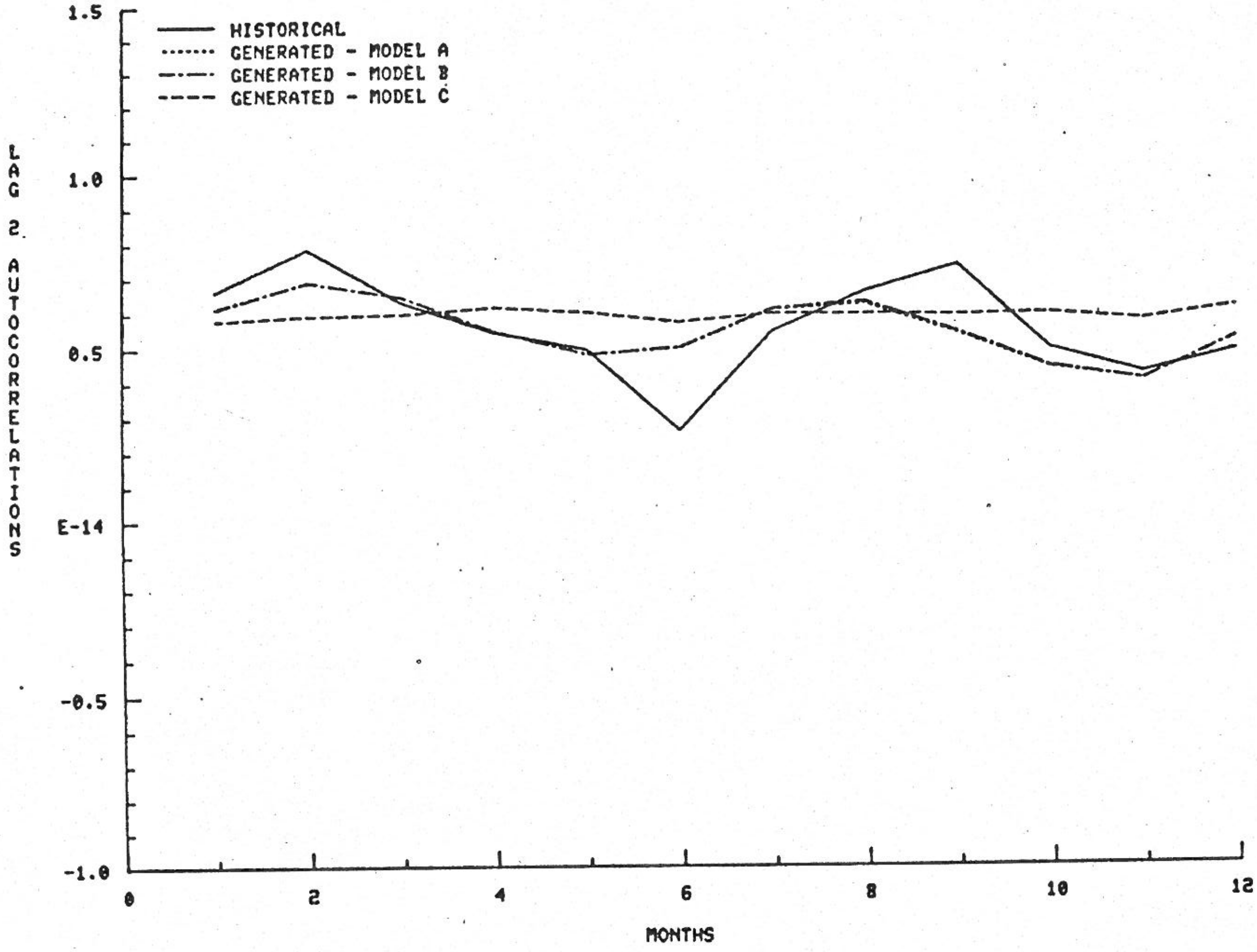


Figure 1.9.D.4 PASODE - LAG 1 AUTOCORRELATIONS (ORIGINAL DOMAIN)



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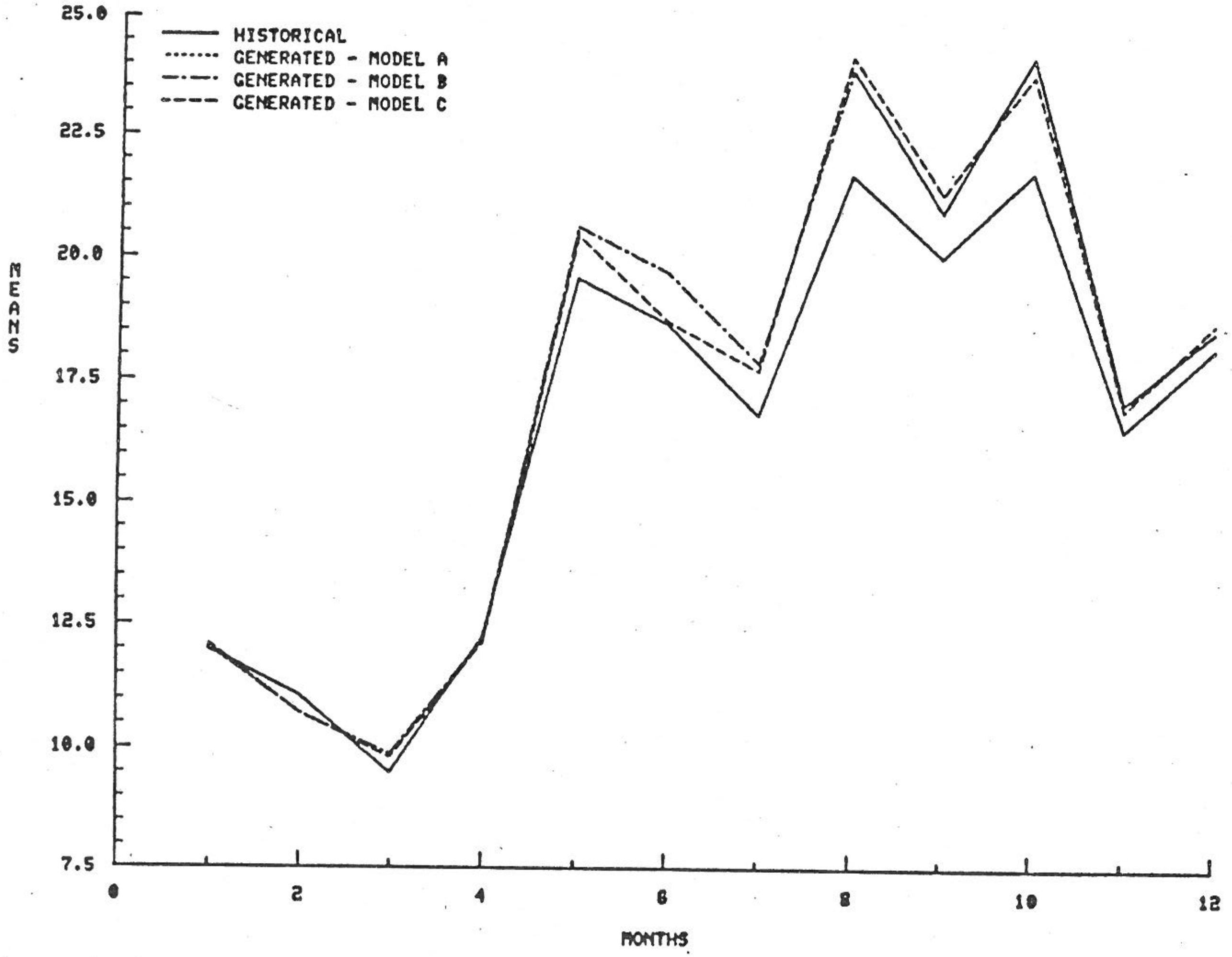
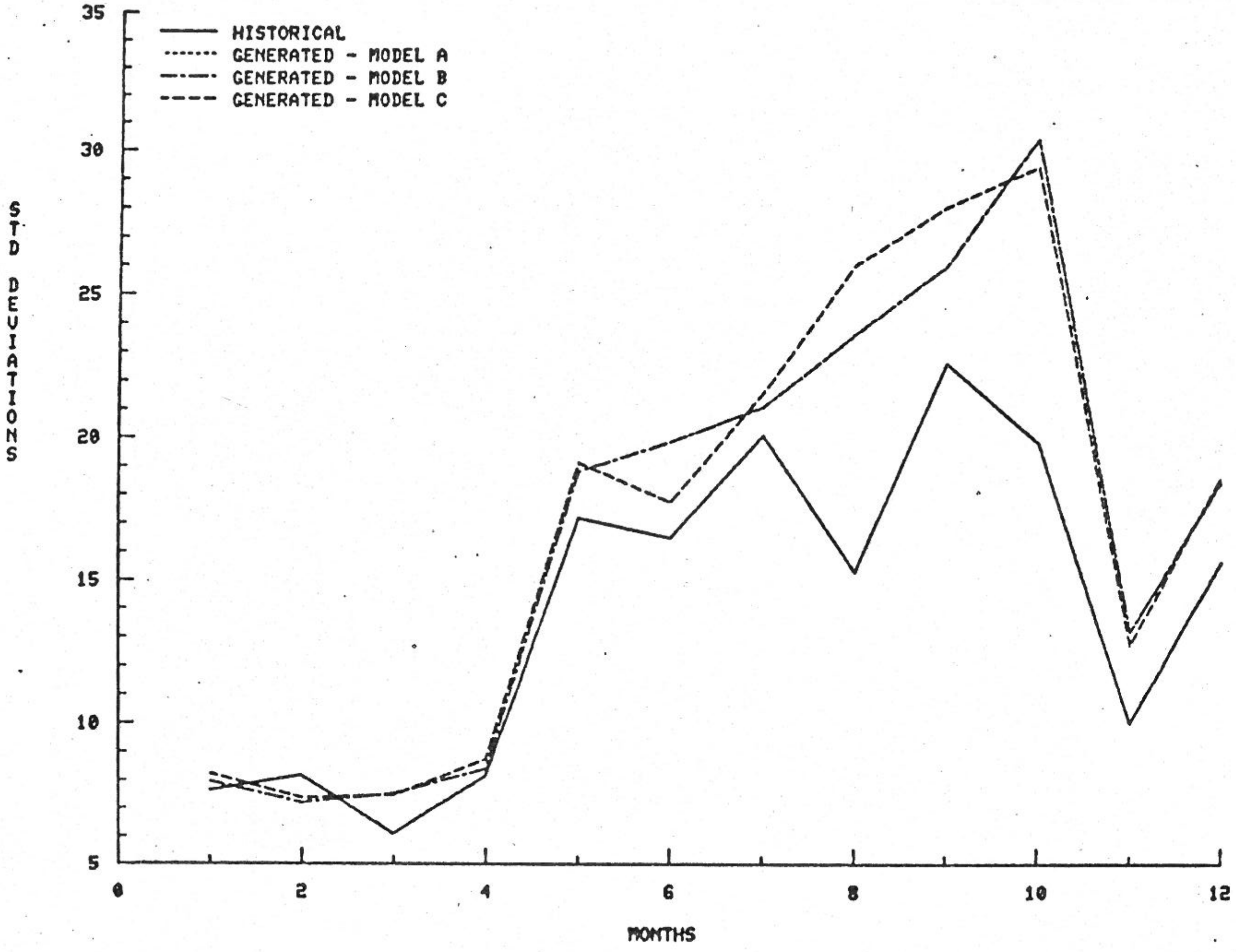


Figure 1.9.D.6 PALODE - MEANS (ORIGINAL DOMAIN)



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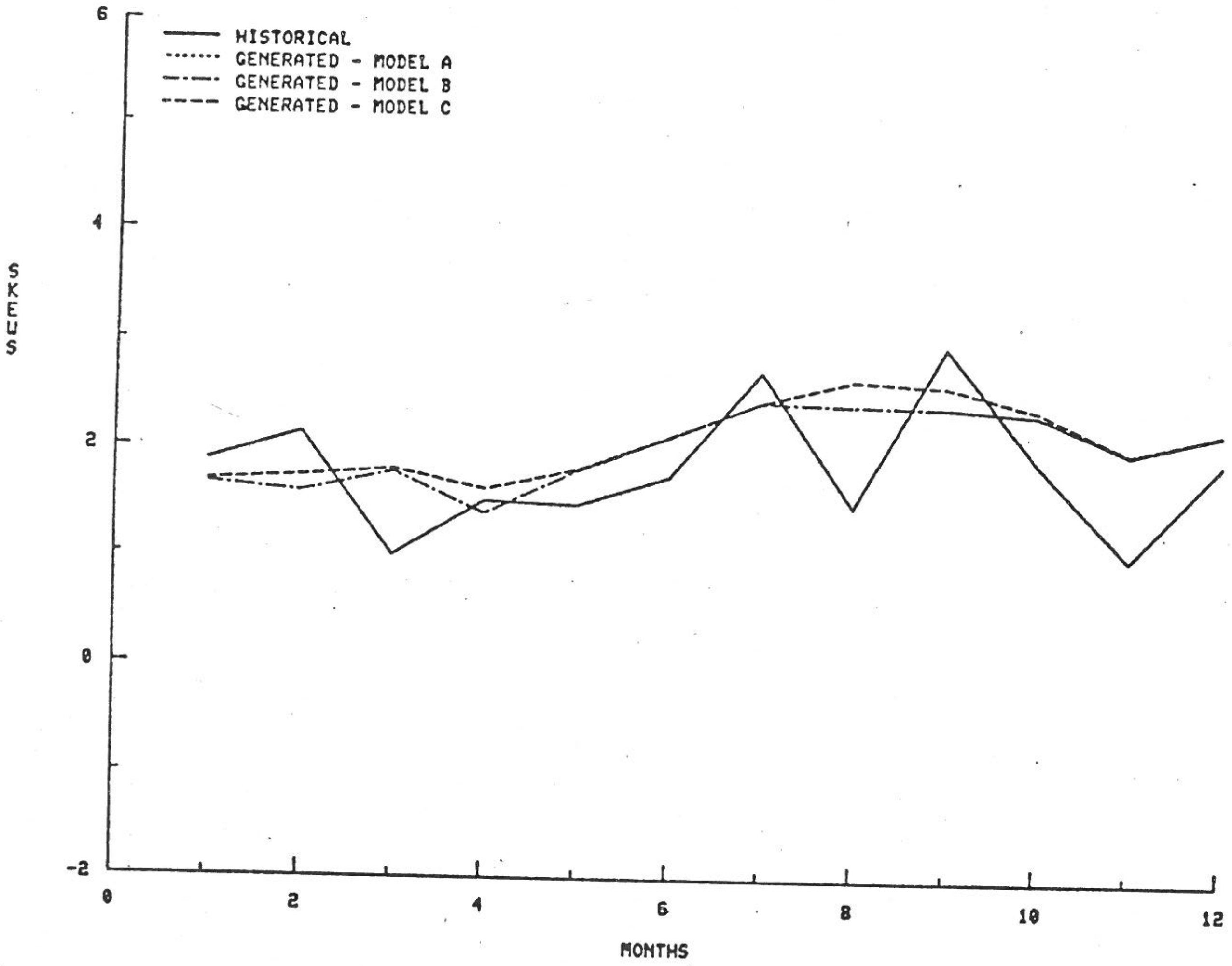


Figure 1.9.D.8 PALODE - SKEWS (ORIGINAL DOMAIN)

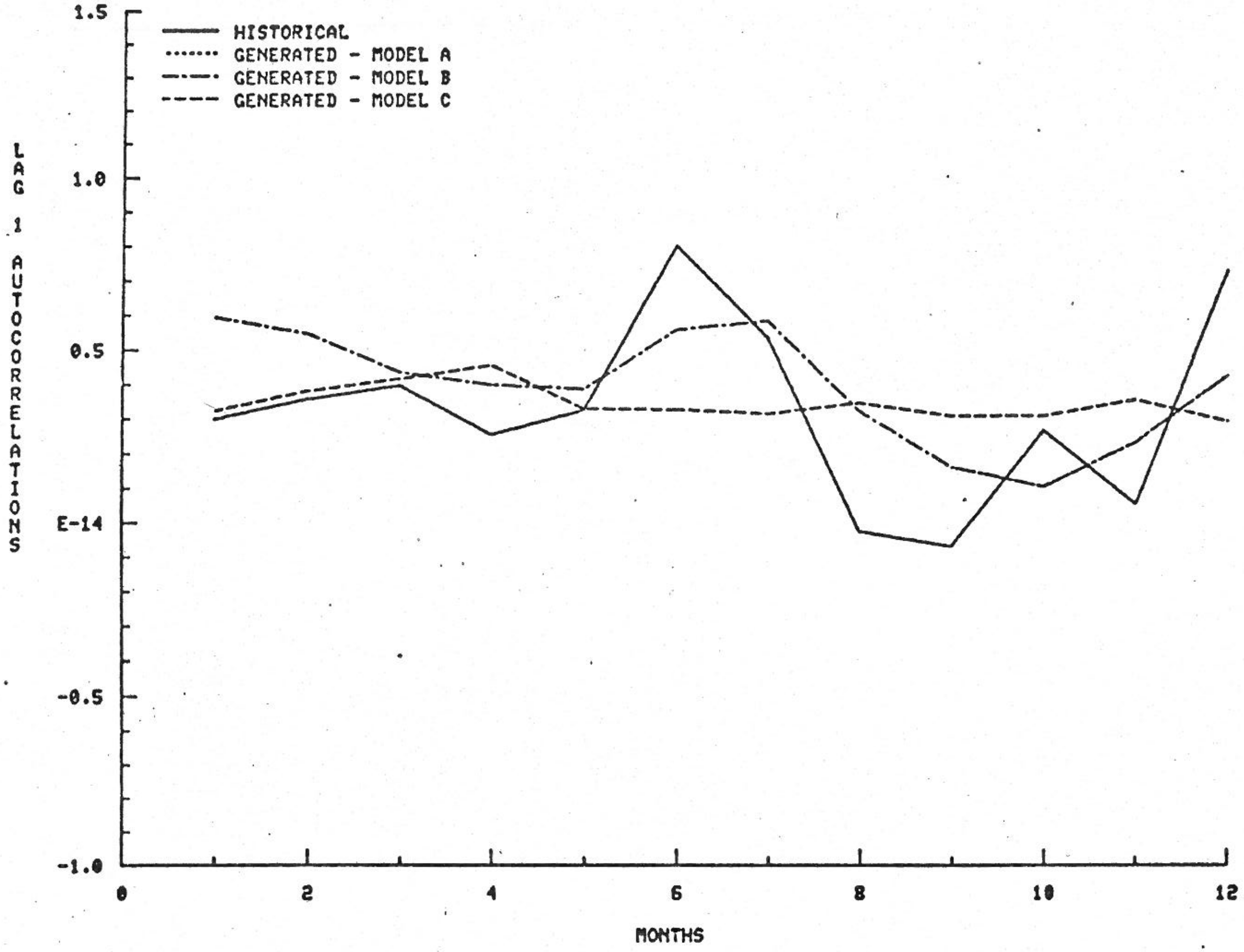


Figure 1.9.D.9 PALODE - LAG 1 AUTOCORRELATIONS (ORIGINAL DOMAIN)

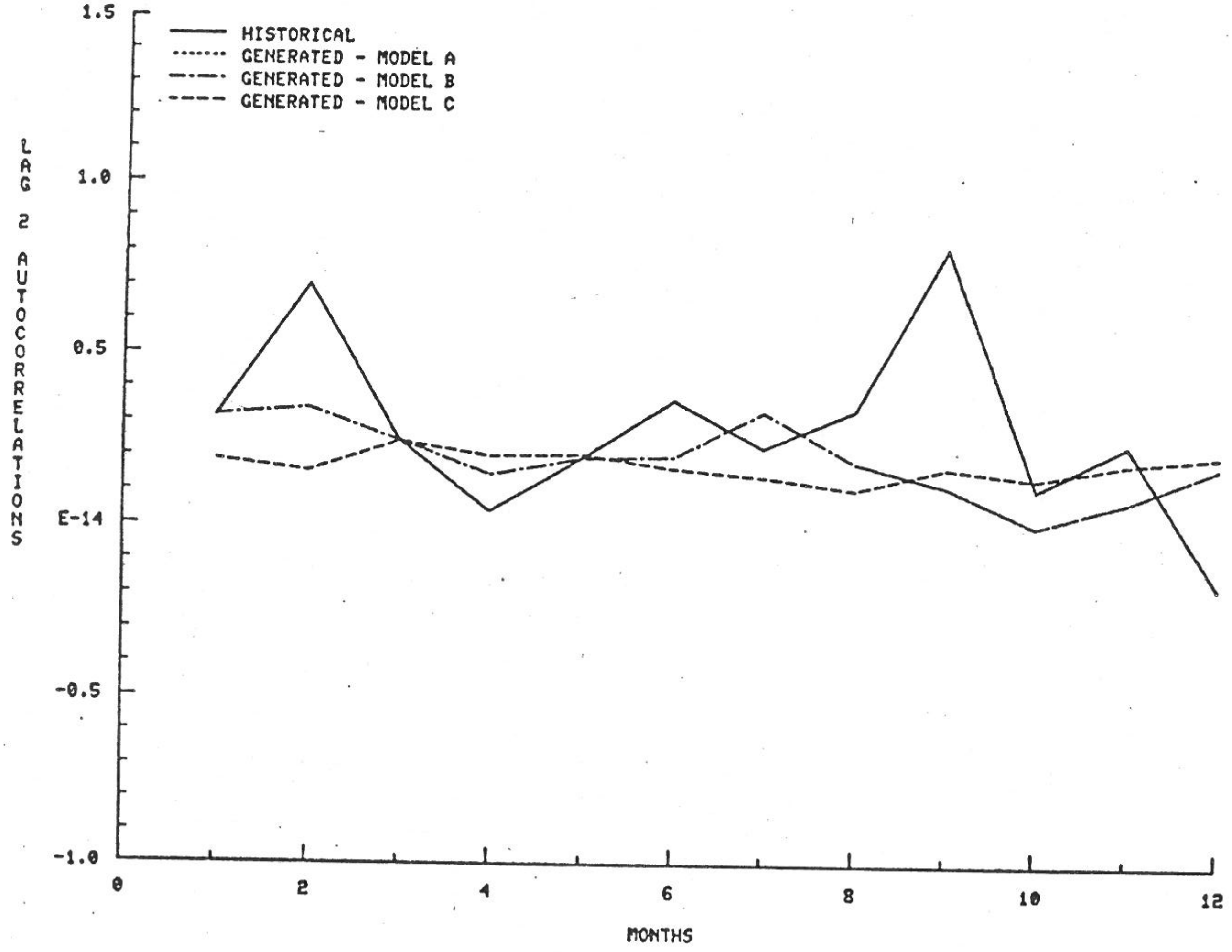


Figure 1.9.D.10 PALODE - LAG 2 AUTOCORRELATIONS (ORIGINAL DOMAIN)

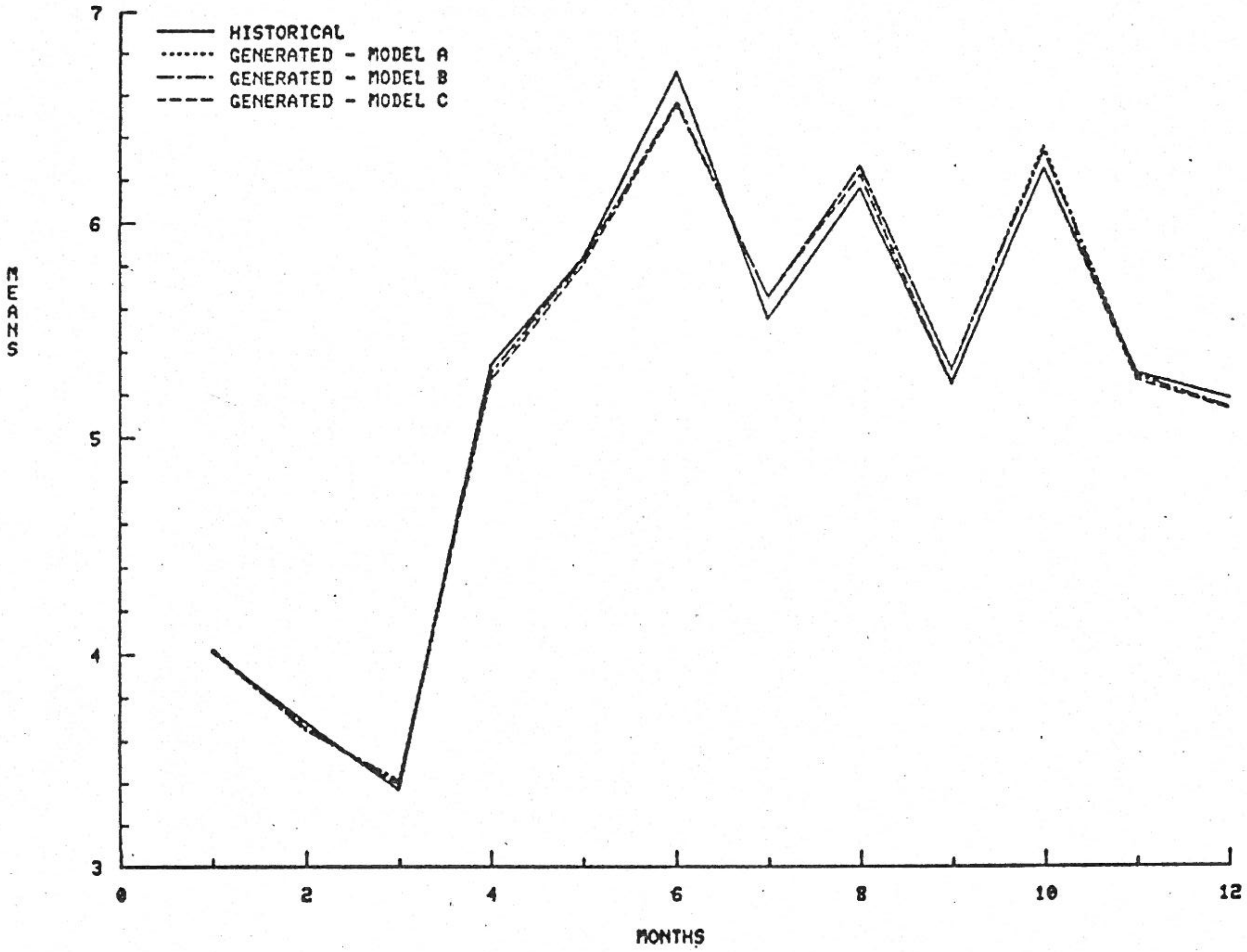
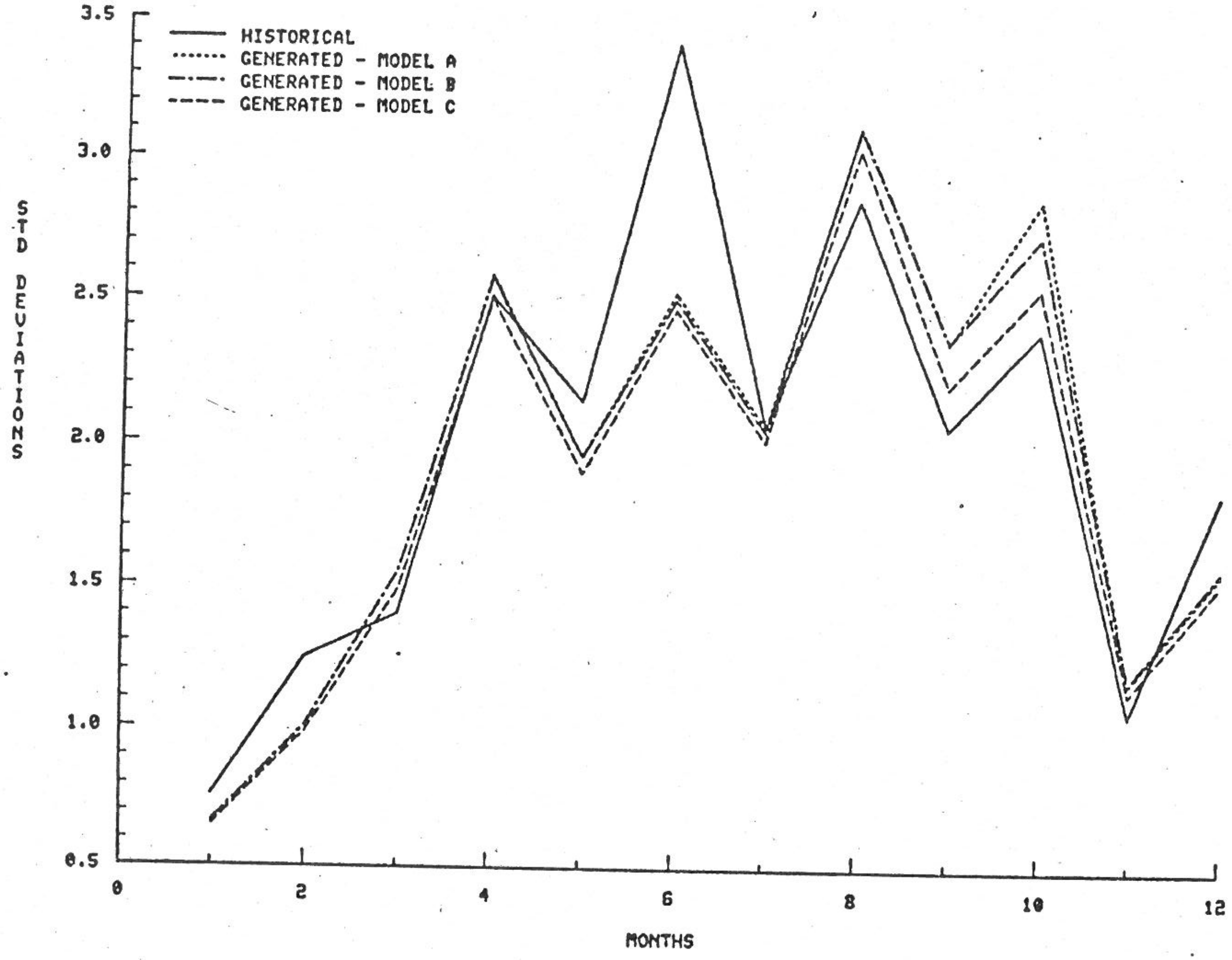


Figure 1.9.D.11 RANCHO - MEANS (ORIGINAL DOMAIN)



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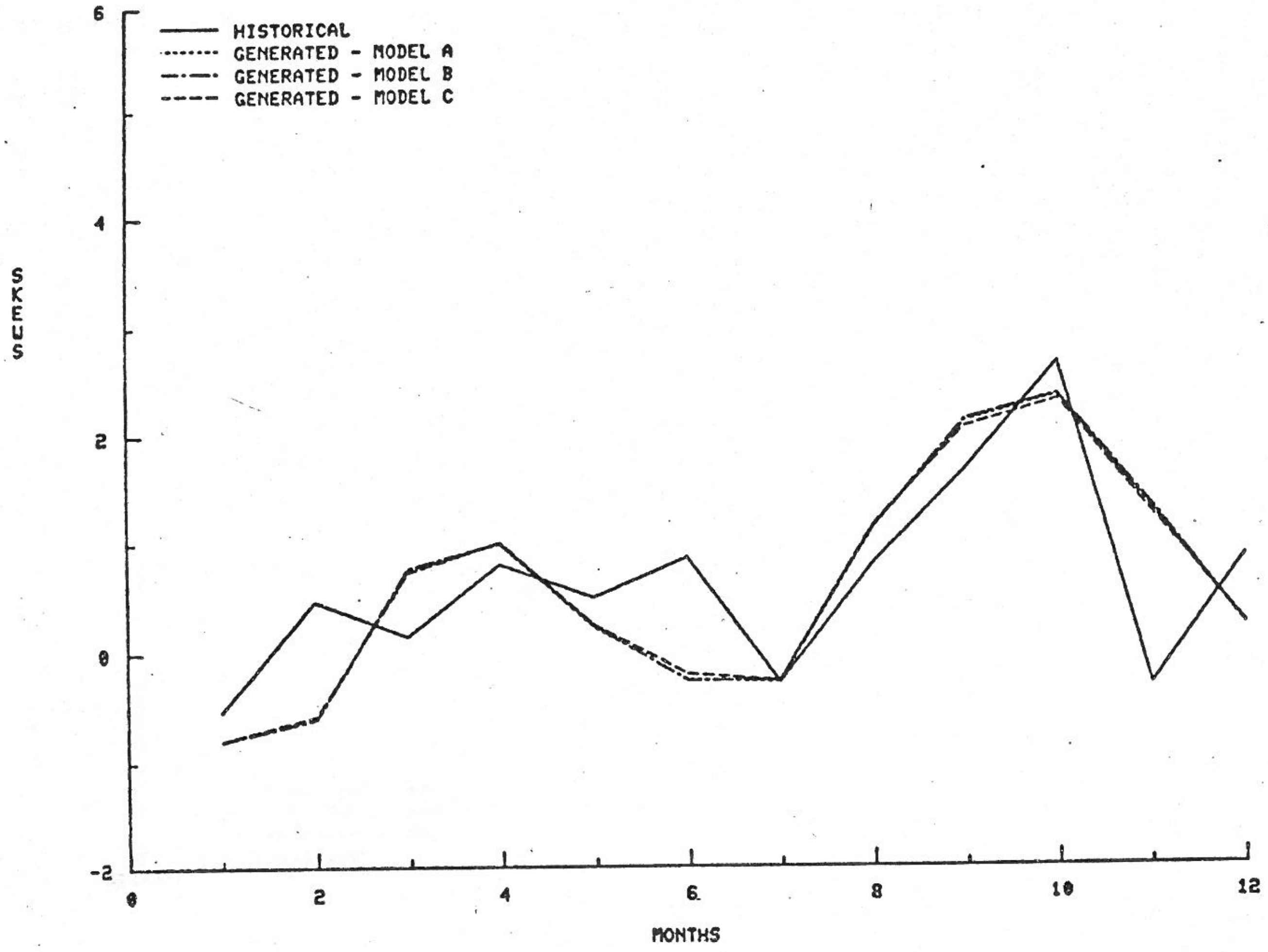


Figure 1.9.D.13 RANCHO - SKEWS (ORIGINAL DOMAIN)

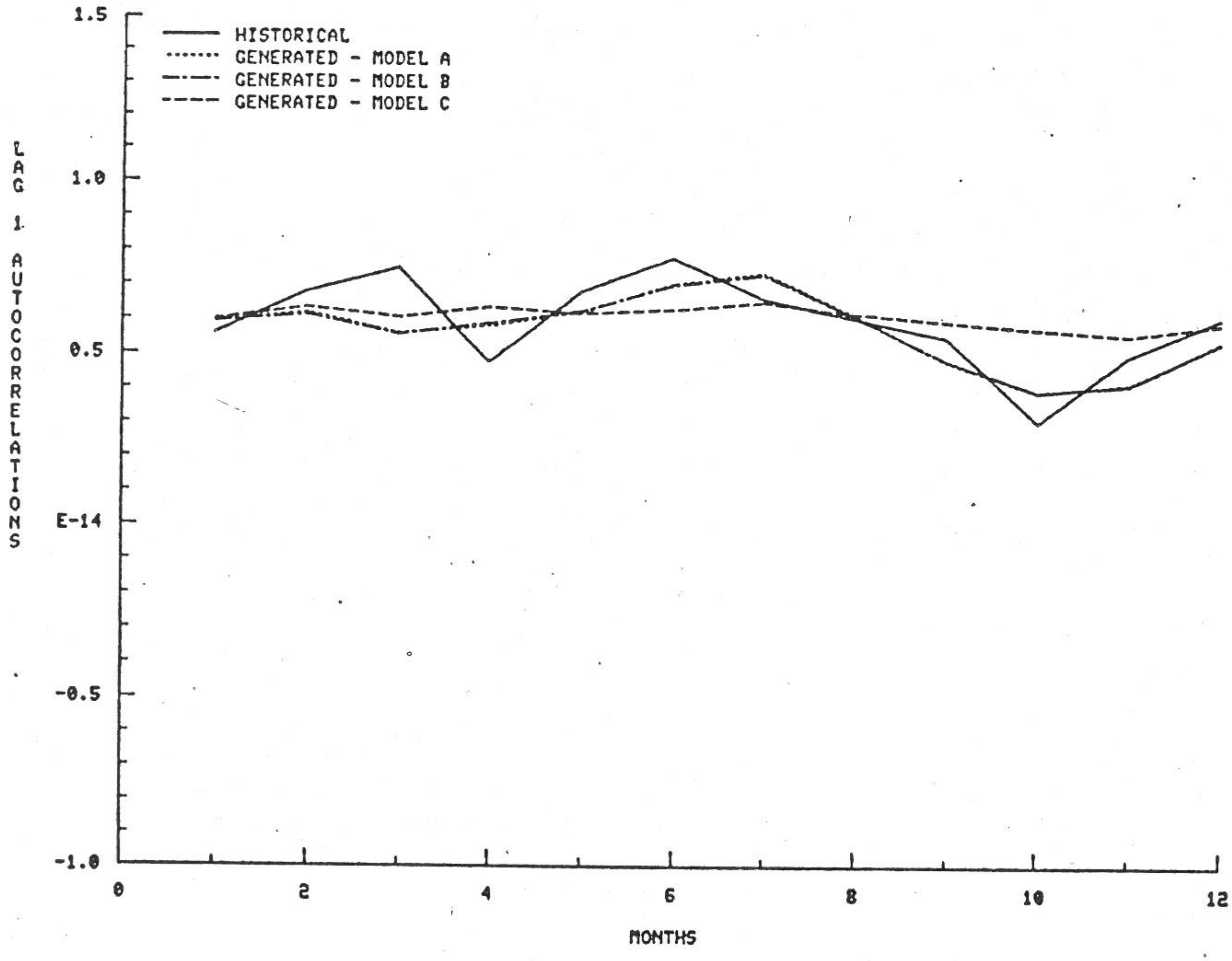


Figure 1.9.D.14 RANCHO - LAG 1 AUTOCORRELATIONS (ORIGINAL DOMAIN)

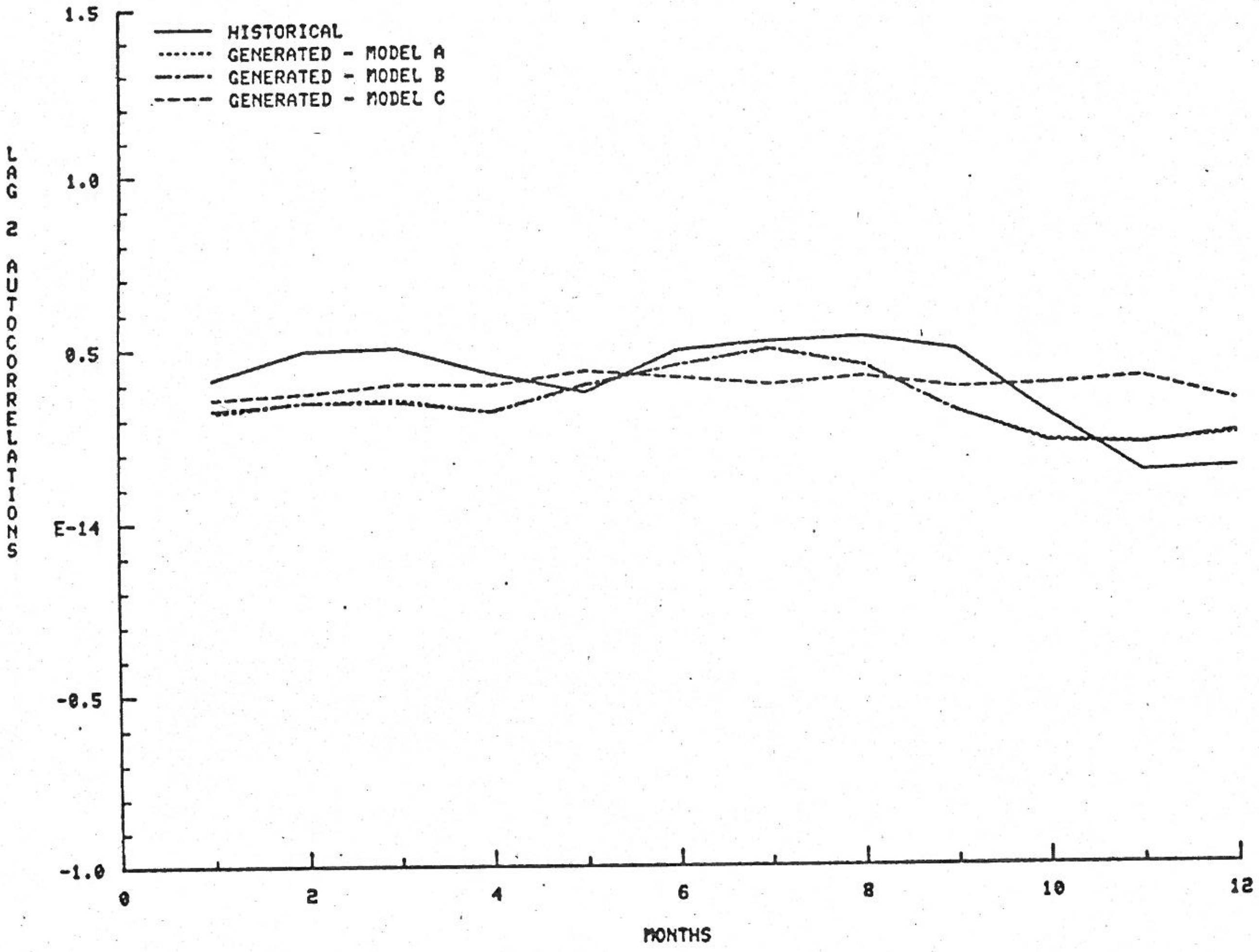


Figure 1.9.D.15 RANCHO - LAG 2 AUTOCORRELATIONS (ORIGINAL DOMAIN)

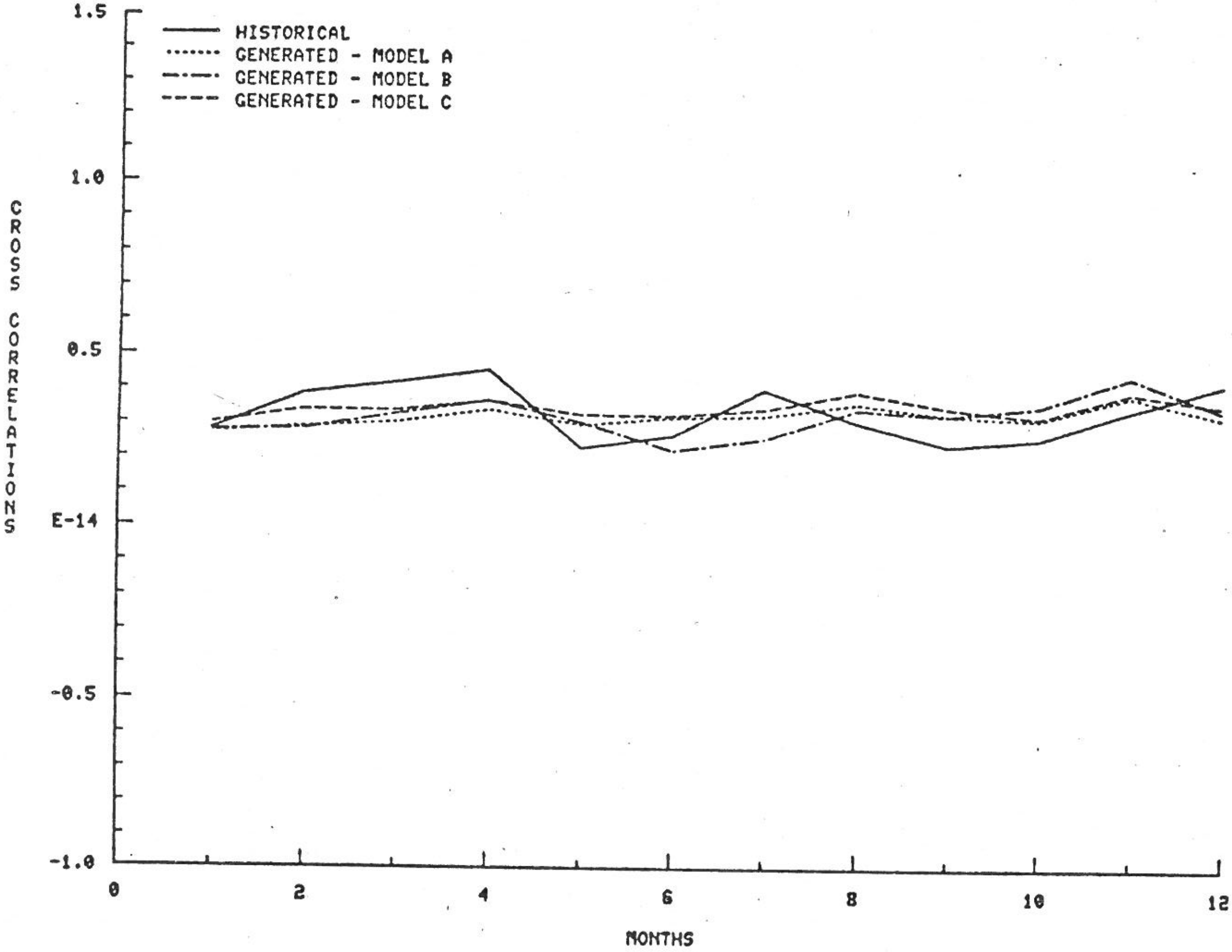


Figure I.9.D.16 CROSS-CORR PASODE AND RANCHO (ORIGINAL DOMAIN)

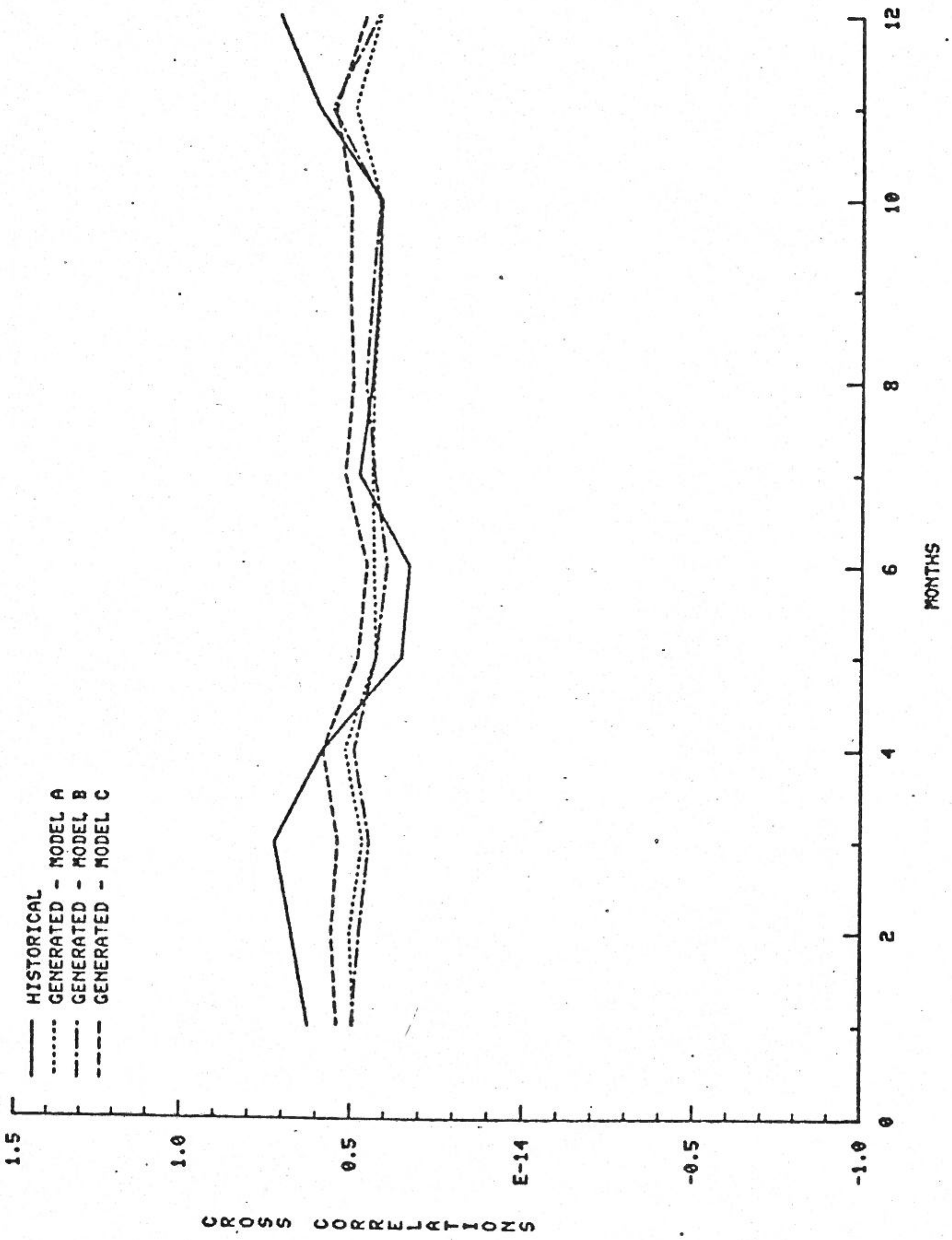
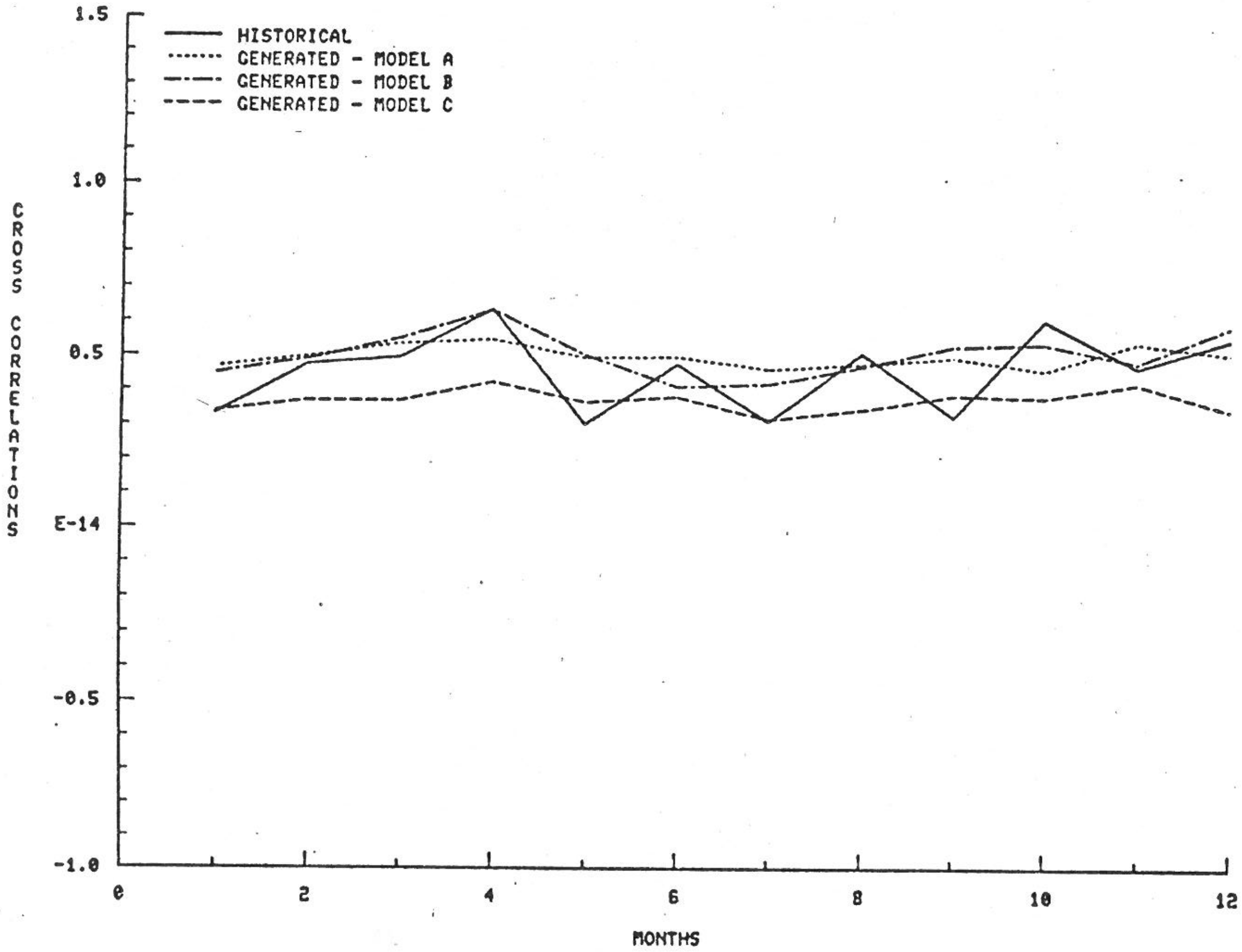


Figure 1.9.D.17 CROSS-CORR PALODE AND PASODE (ORIGINAL DOMAIN)



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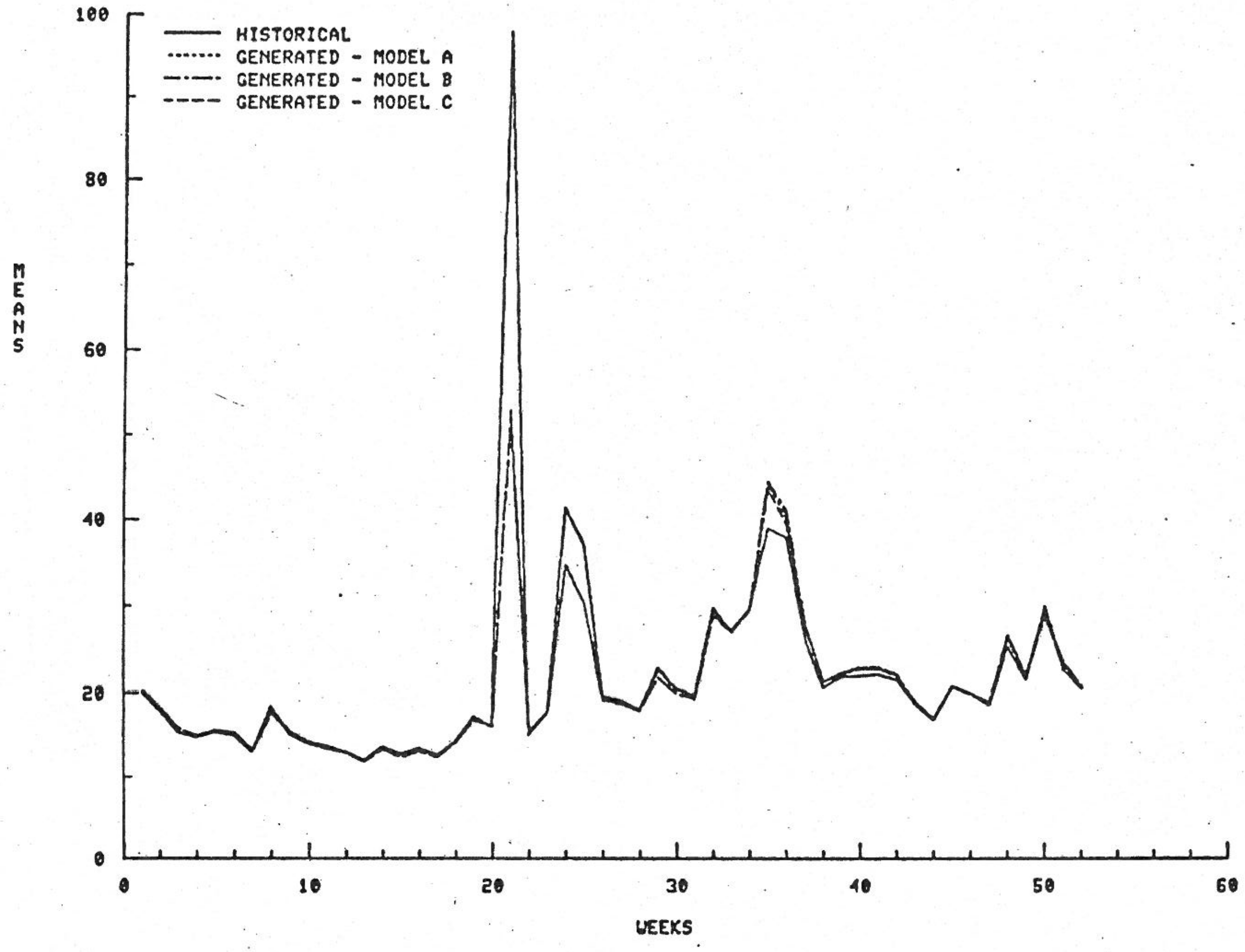


Figure 1.9.D.19 PASODE - MEANS (ORIGINAL DOMAIN)

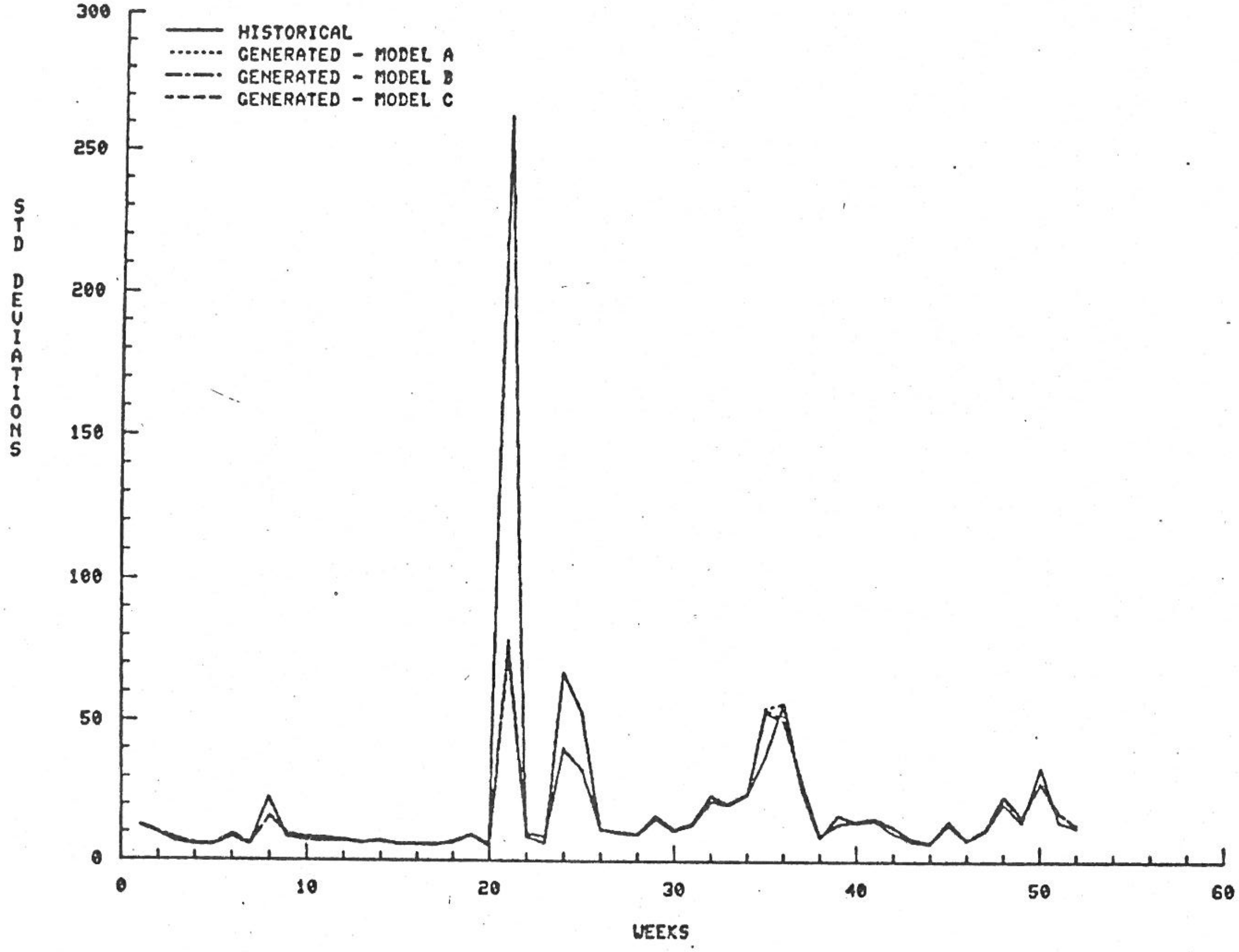


Figure 1.9.D.20 PASODE - STD DEVIATIONS (ORIGINAL DOMAIN)

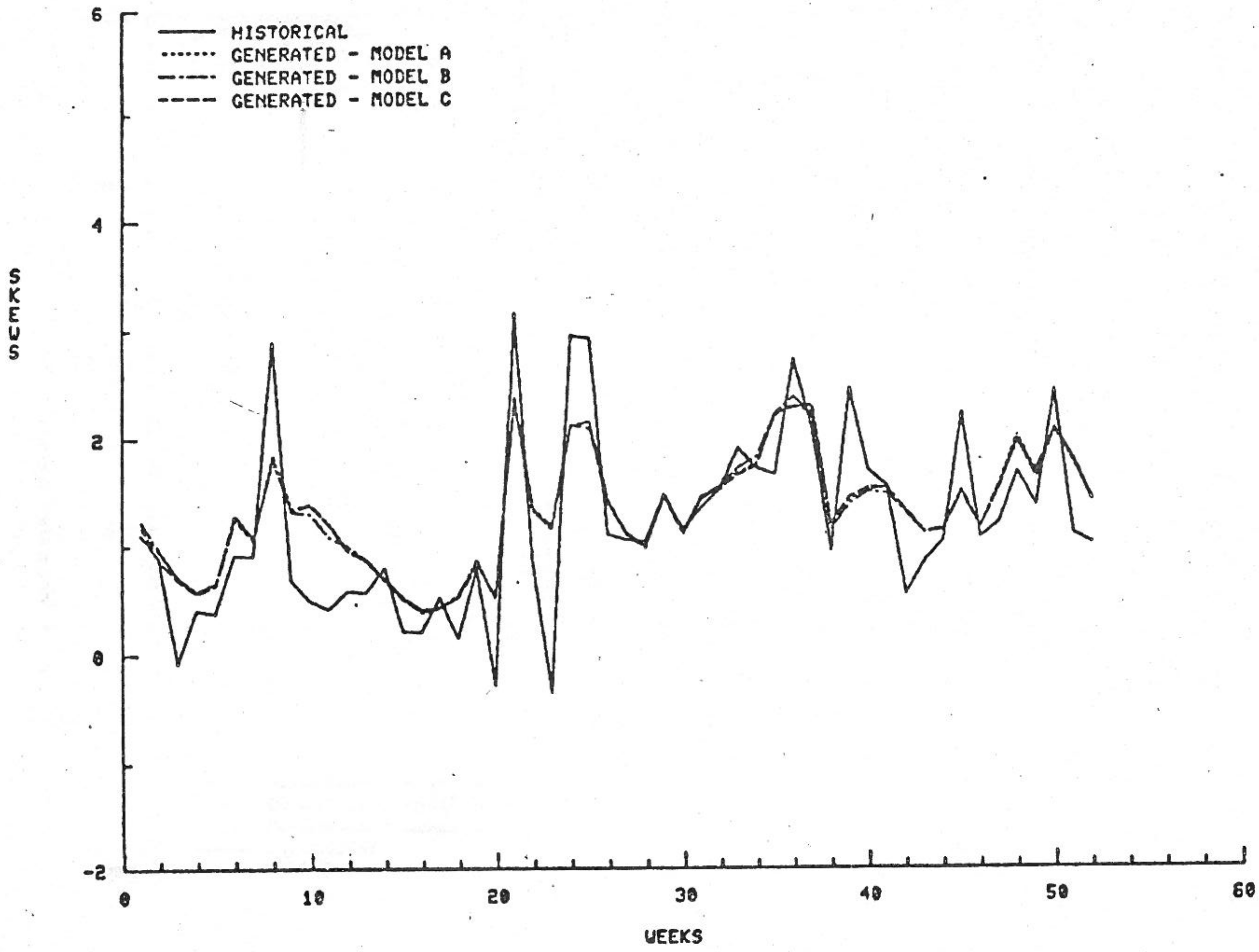
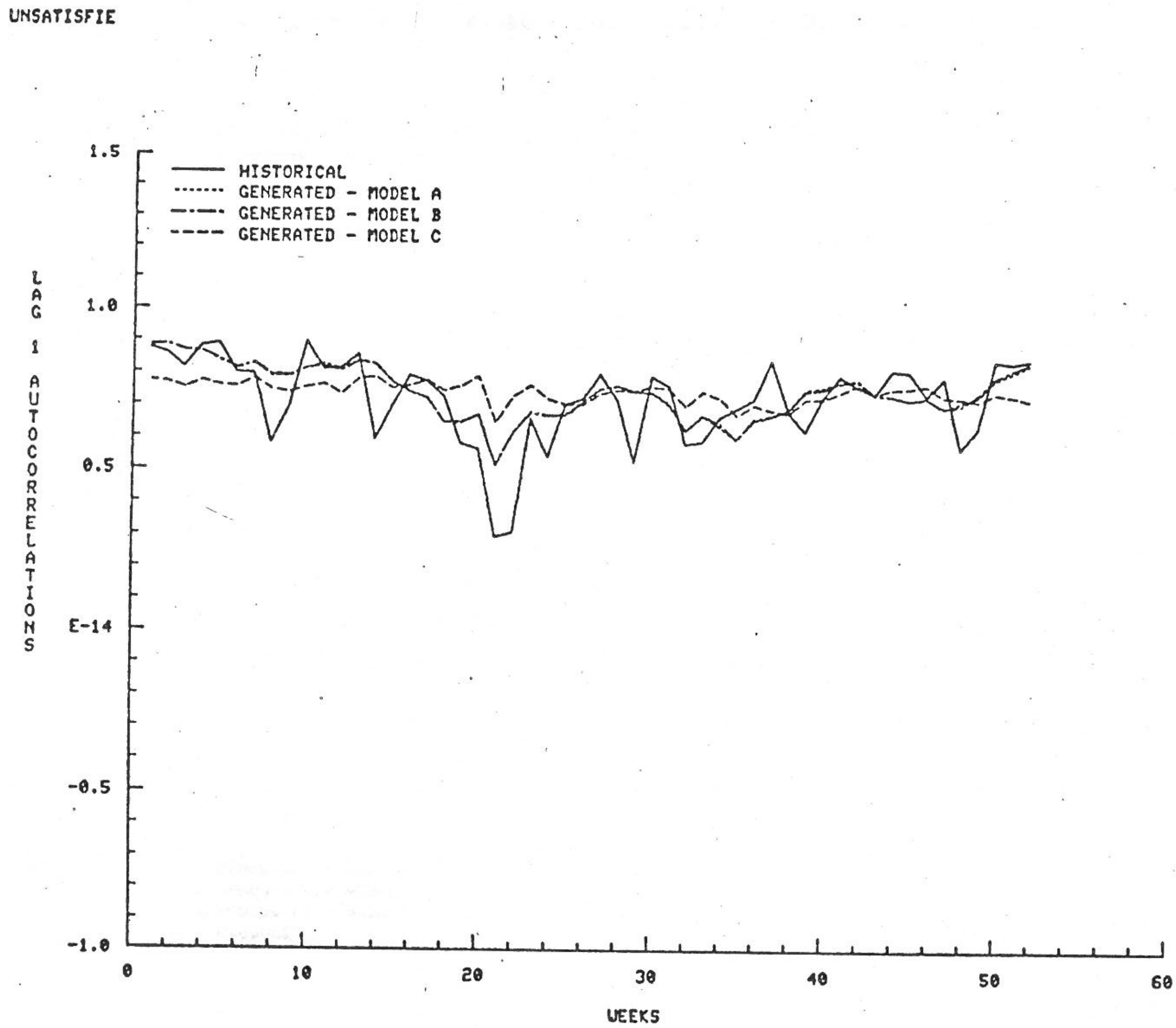


Figure 1.9.D.21 PASODE - SKEWS (ORIGINAL DOMAIN)



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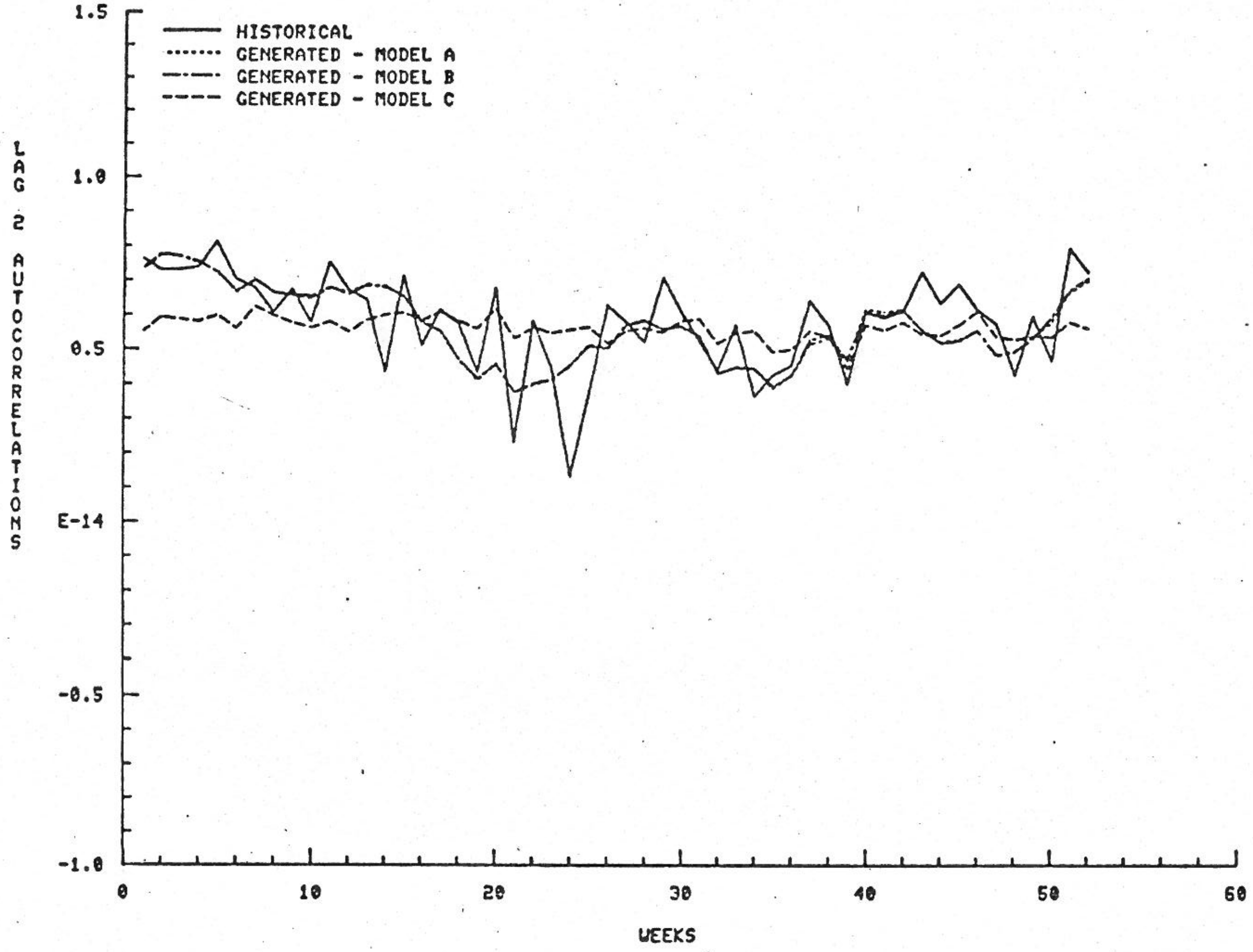

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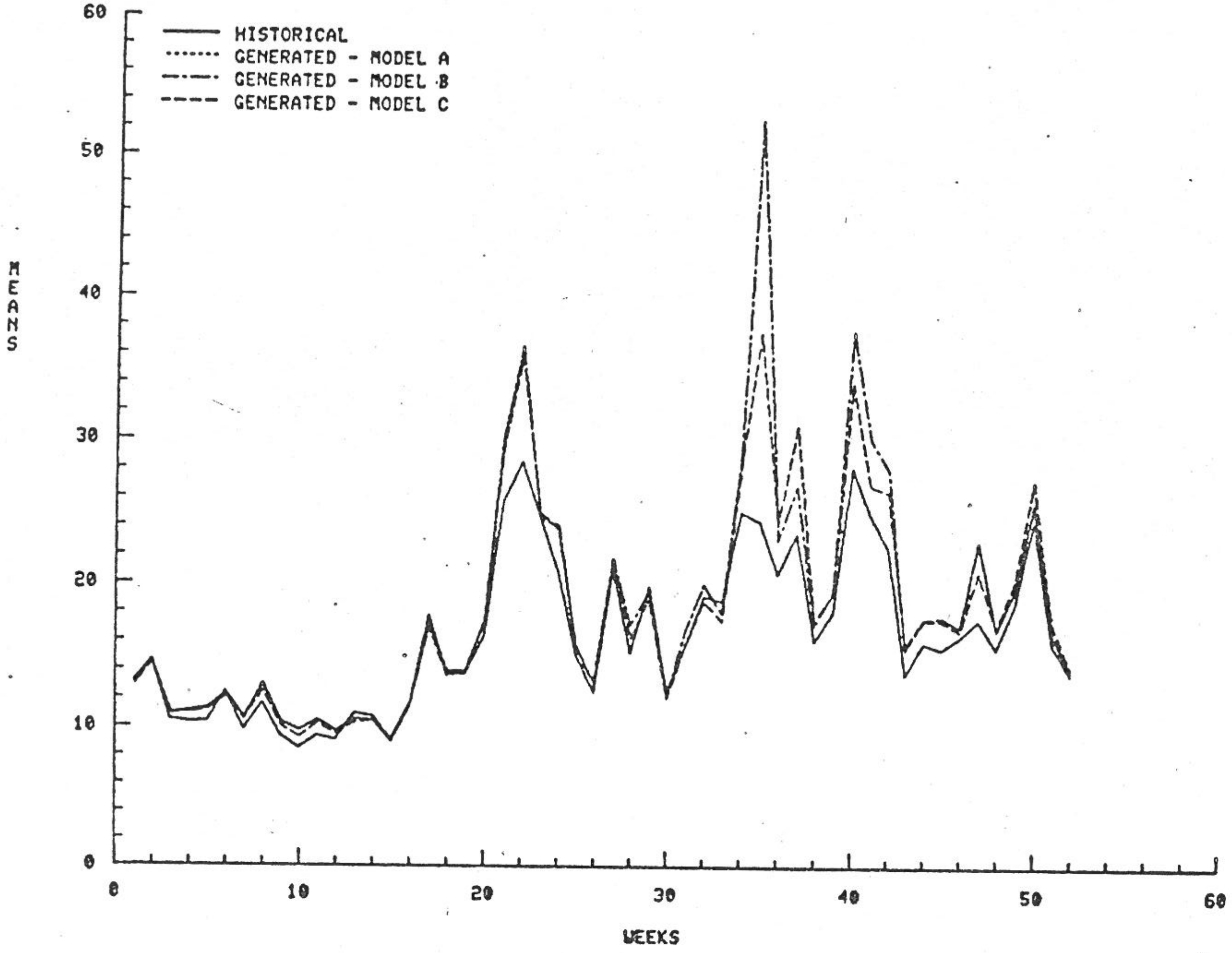


Figure 1.9.D.24 PALODE - MEANS (ORIGINAL DOMAIN)

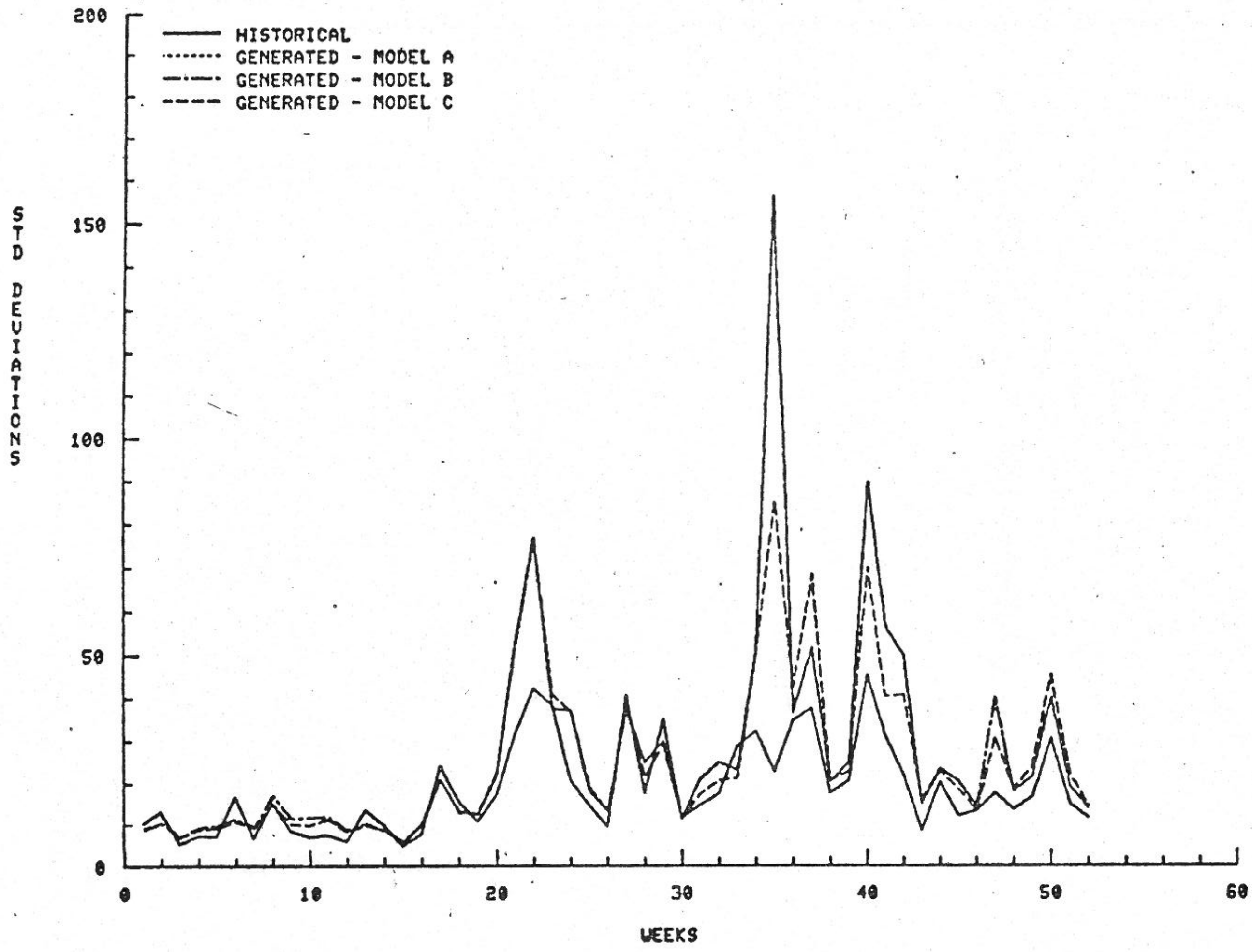


Figure 1.9.D.25 PALODE - STD DEVIATIONS (ORIGINAL DOMAIN)

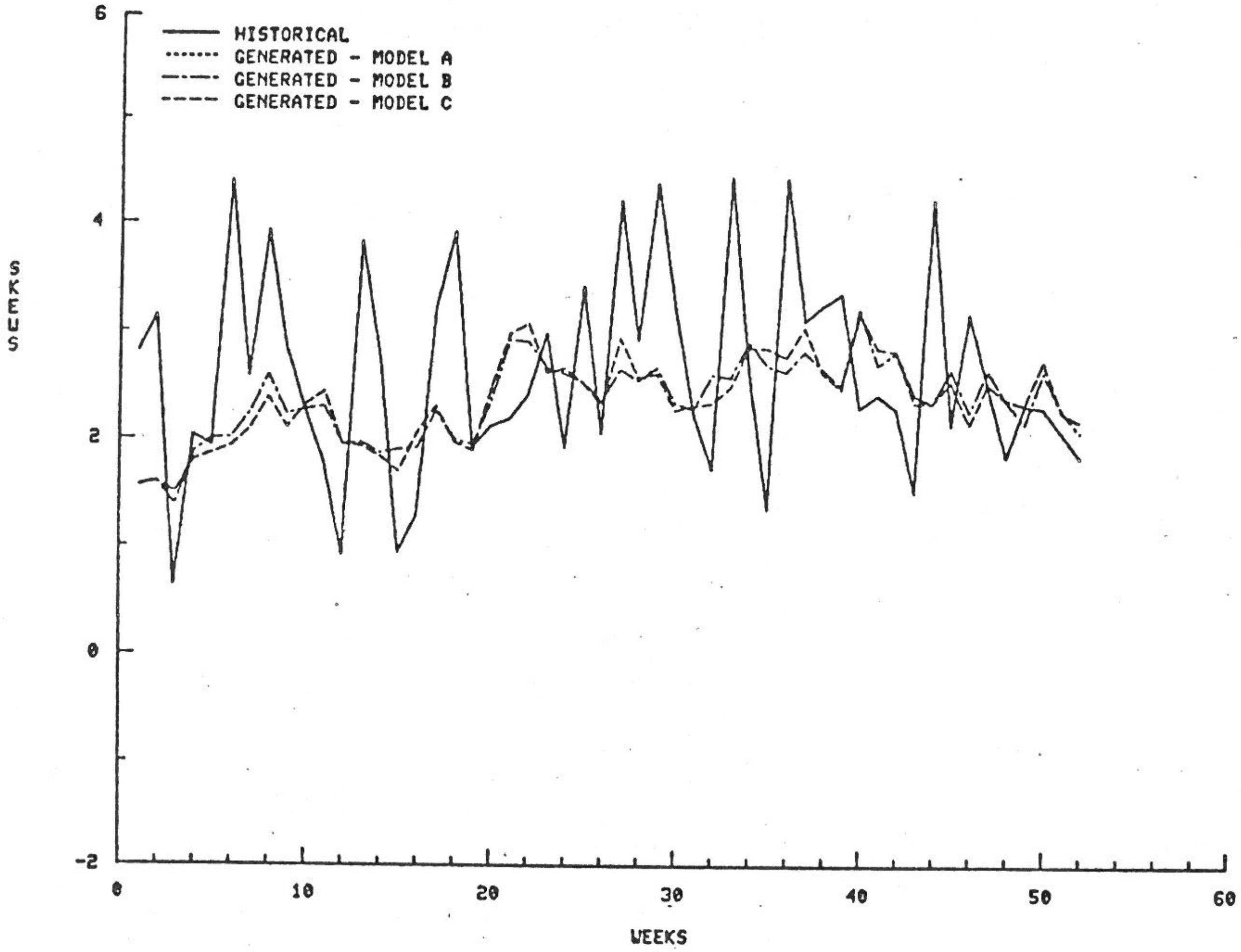
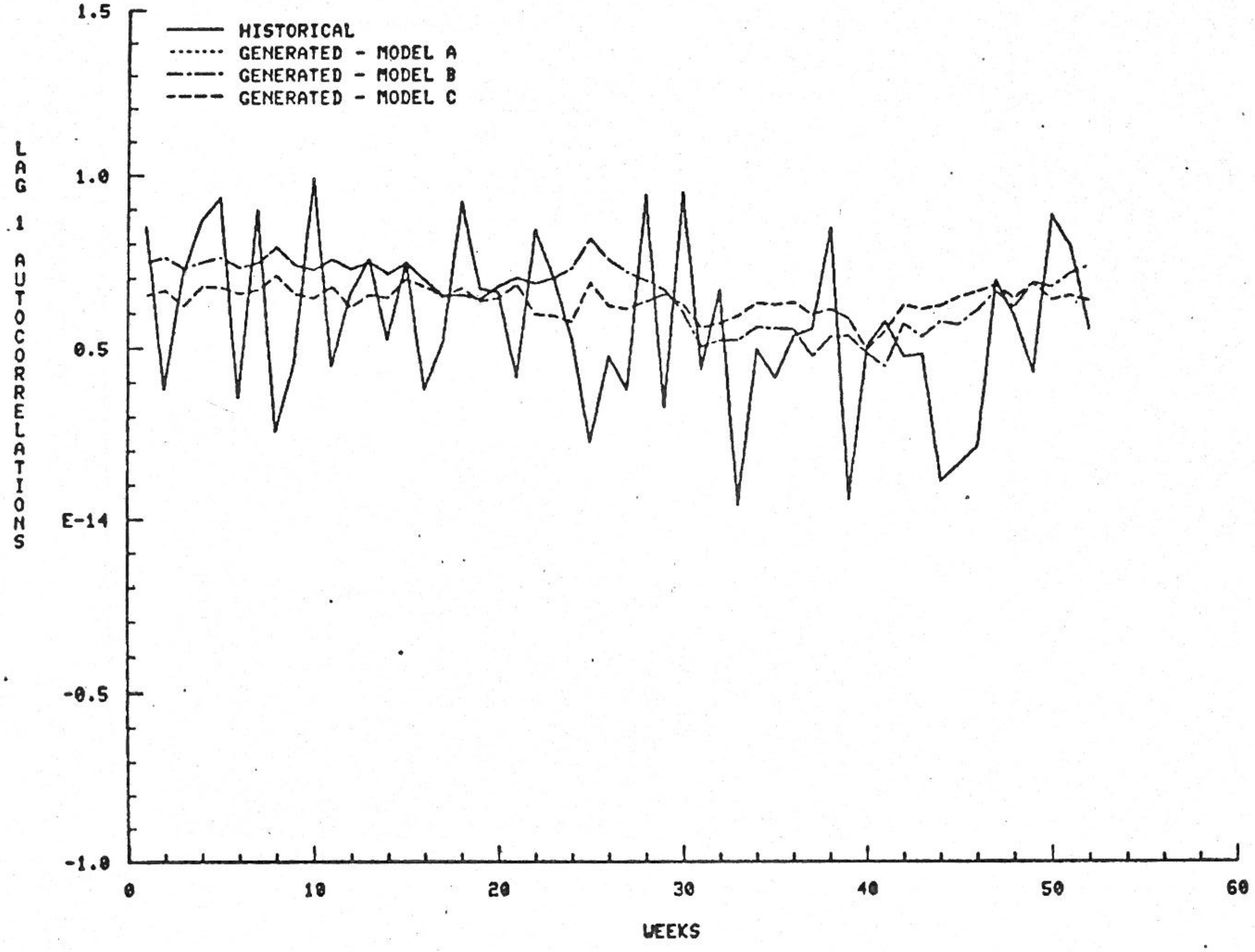


Figure 1.9.D.26 PALODE - SKEWS (ORIGINAL DOMAIN)



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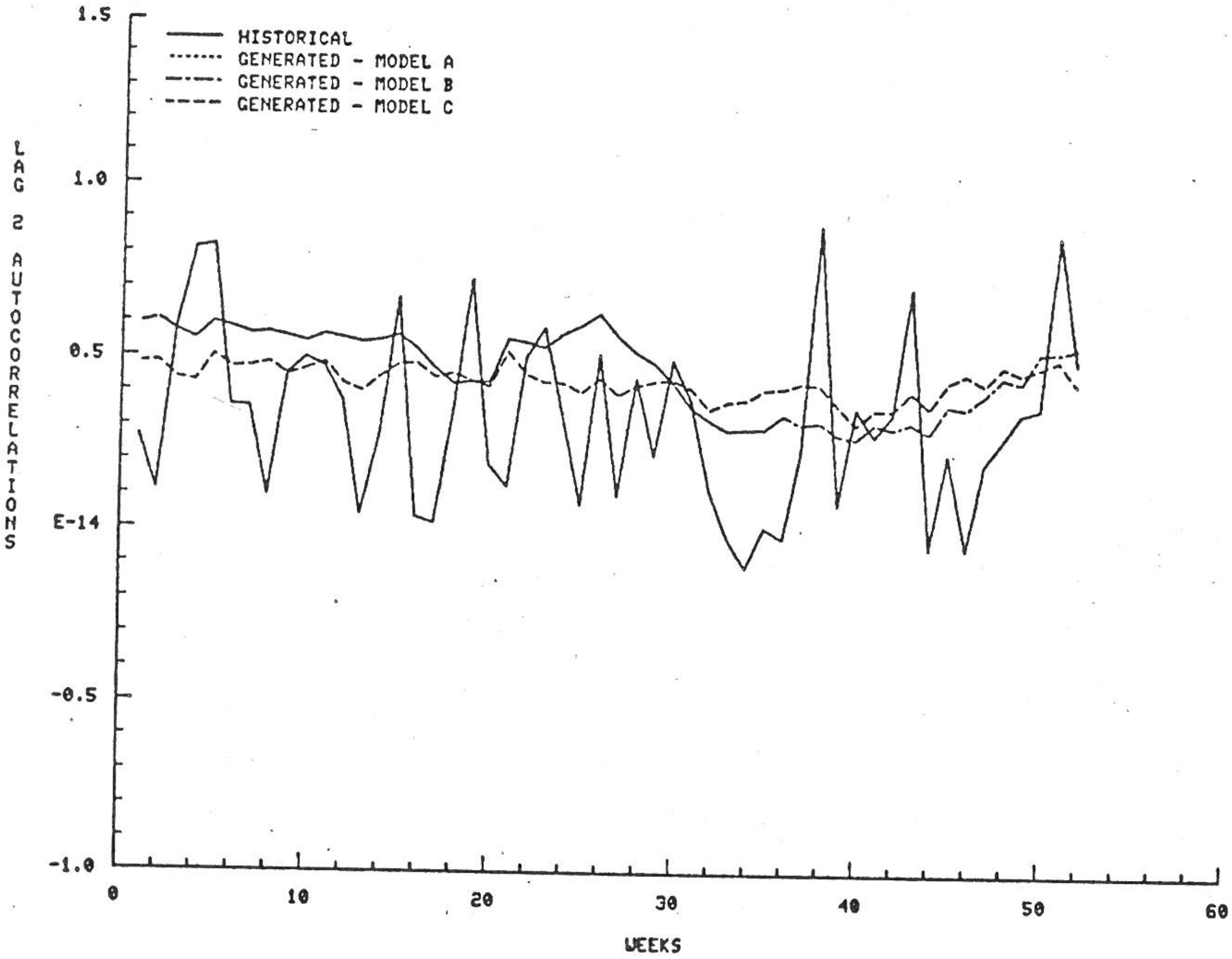

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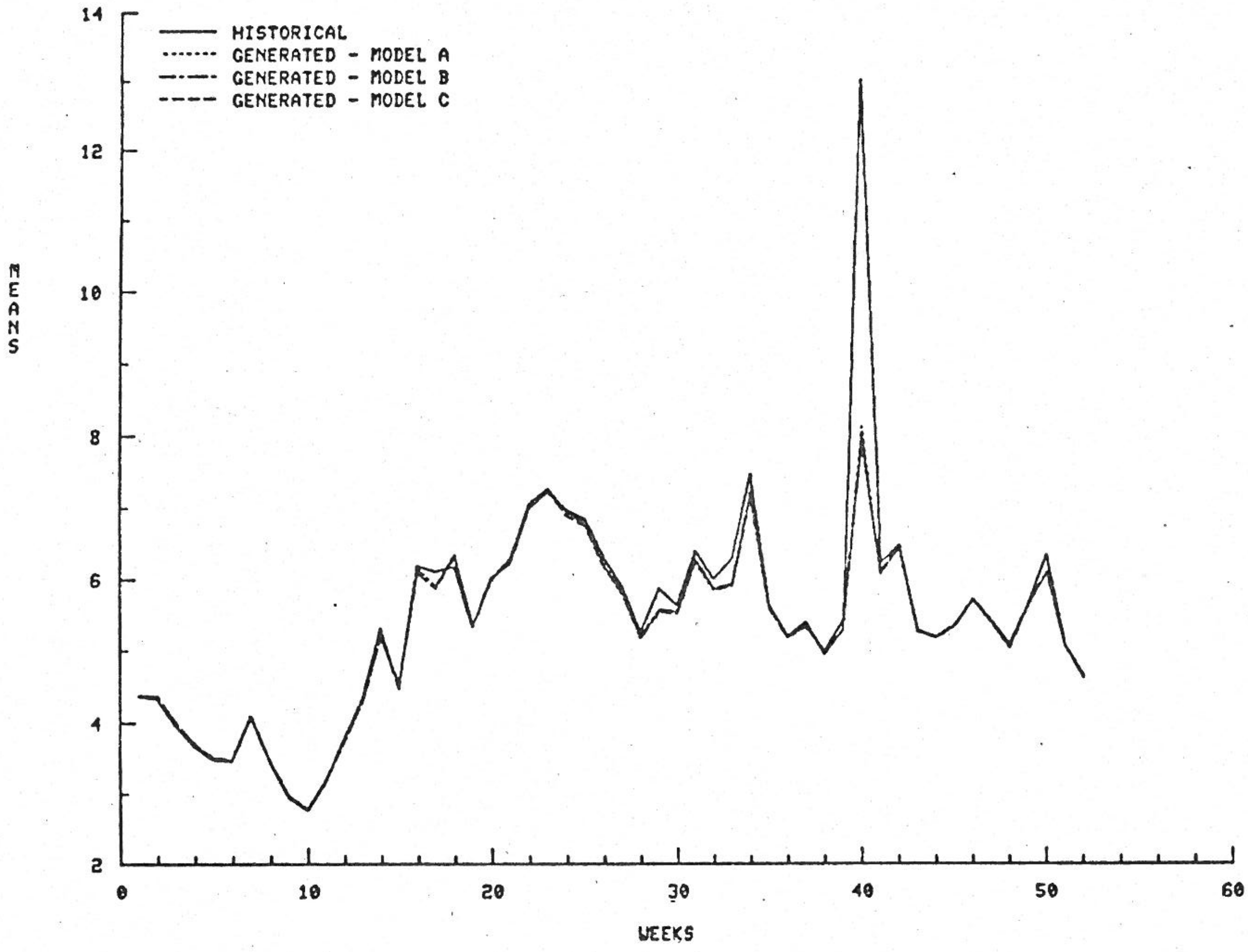

Figure 1.9.D.29 RANCHO - MEANS (ORIGINAL DOMAIN)

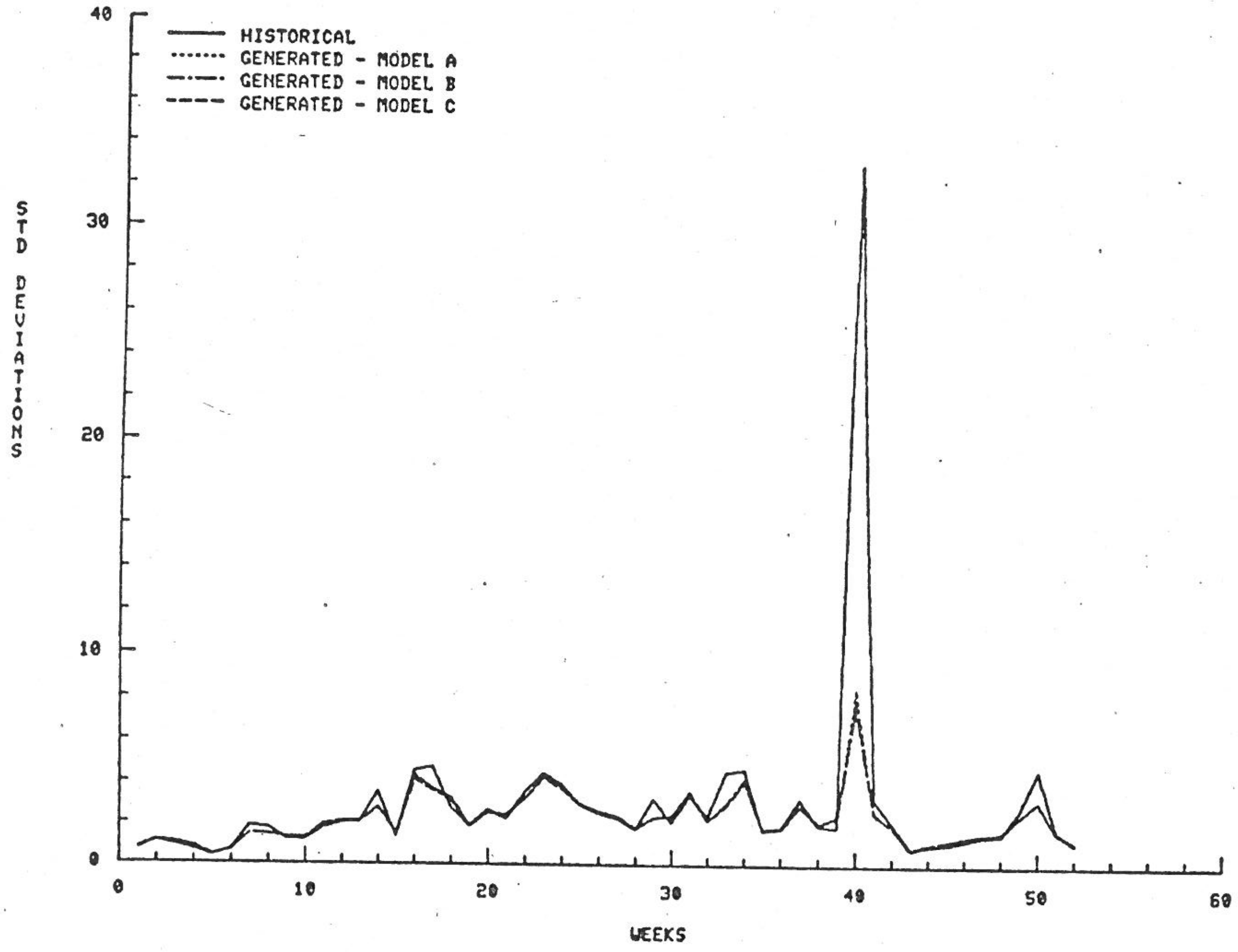

Figure 1.9.D.30 RANCHO - STD DEVIATIONS (ORIGINAL DOMAIN)

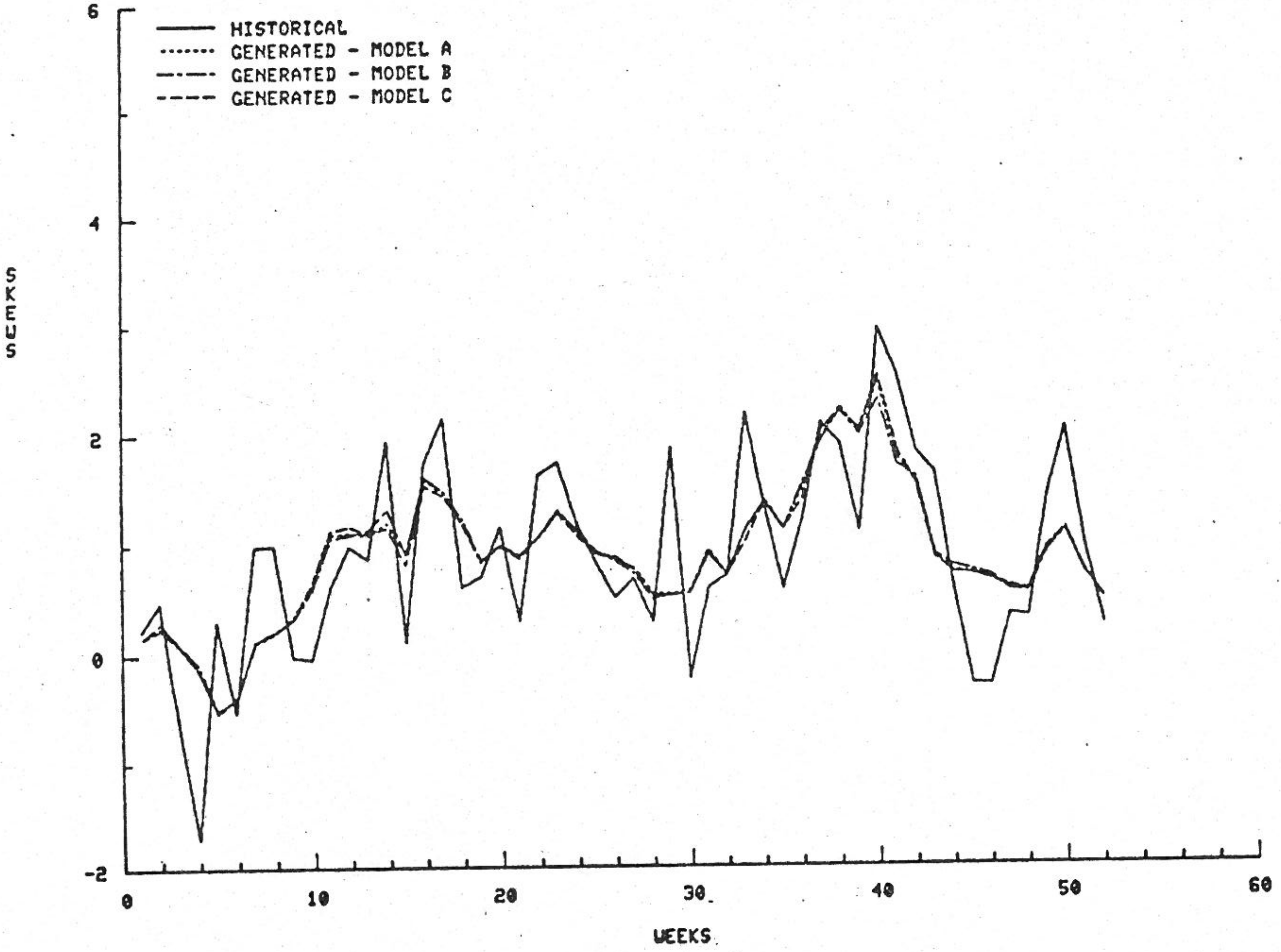

Figure 1.9.D.31 RANCHO - SKEWS (ORIGINAL DOMAIN)

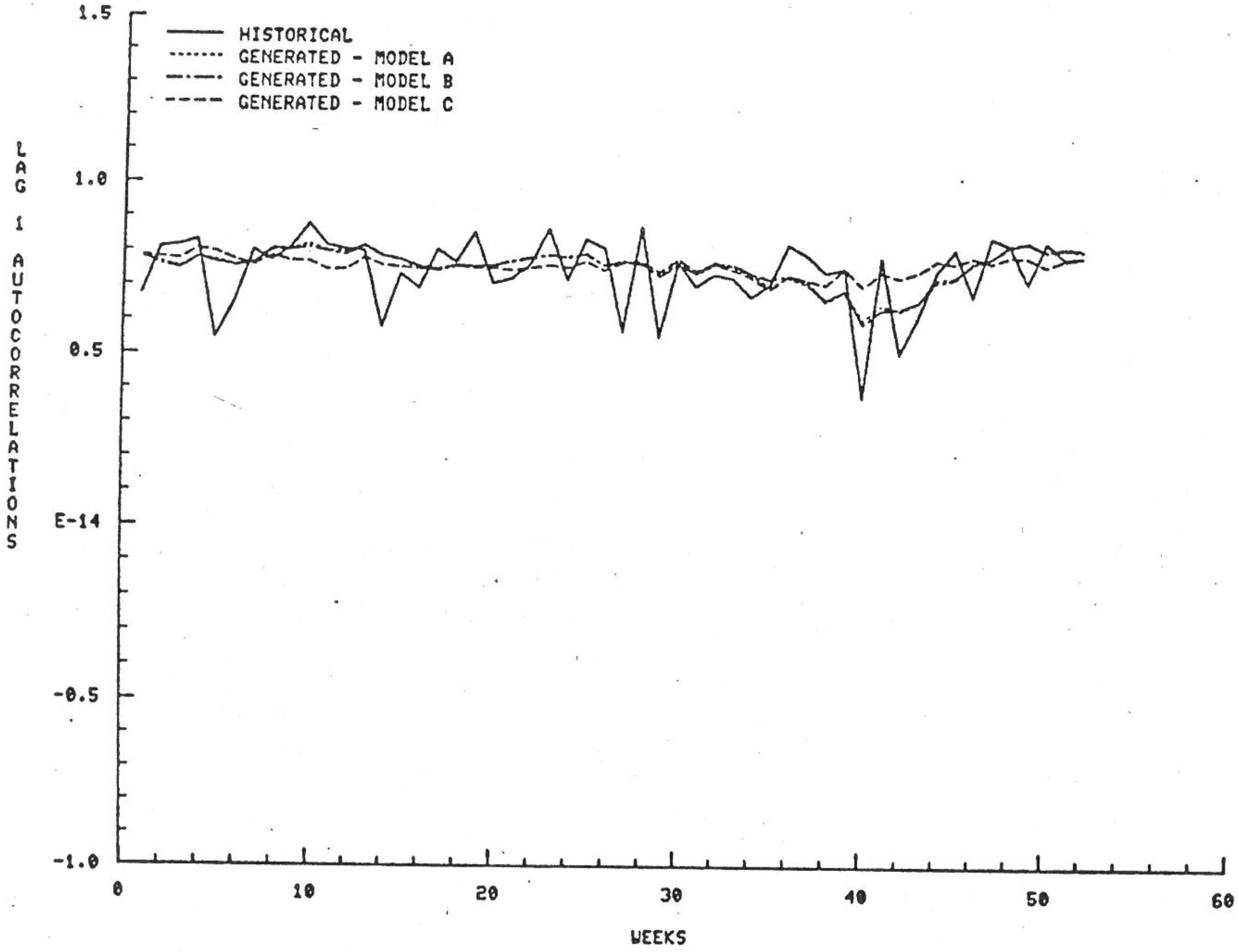

Figure 1.9.D.32 RANCHO - LAG 1 AUTOCORRELATIONS (ORIGINAL DOMAIN)

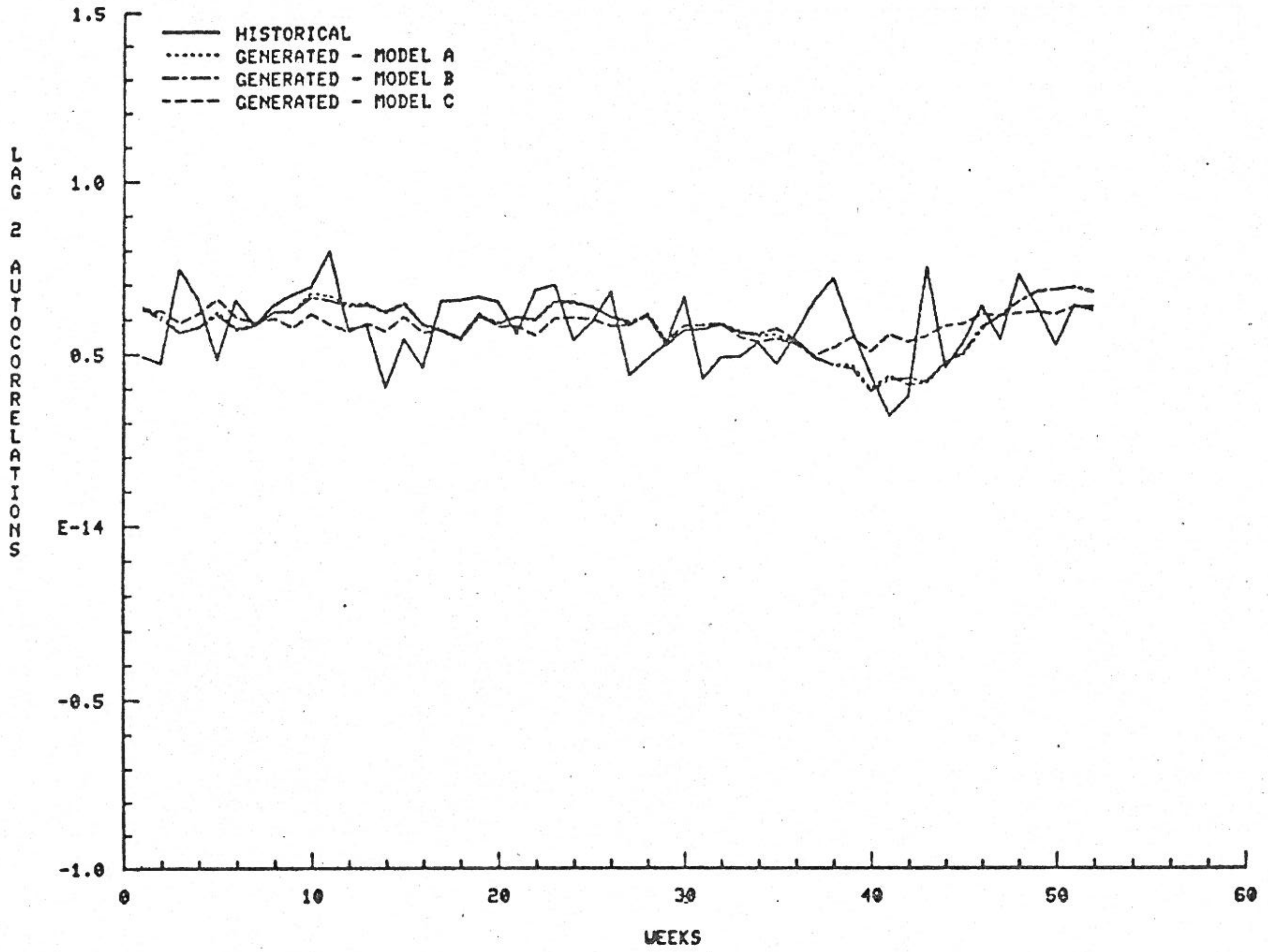

Figure 1.9.D.33 RANCHO - LAG 2 AUTOCORRELATIONS (ORIGINAL DOMAIN)

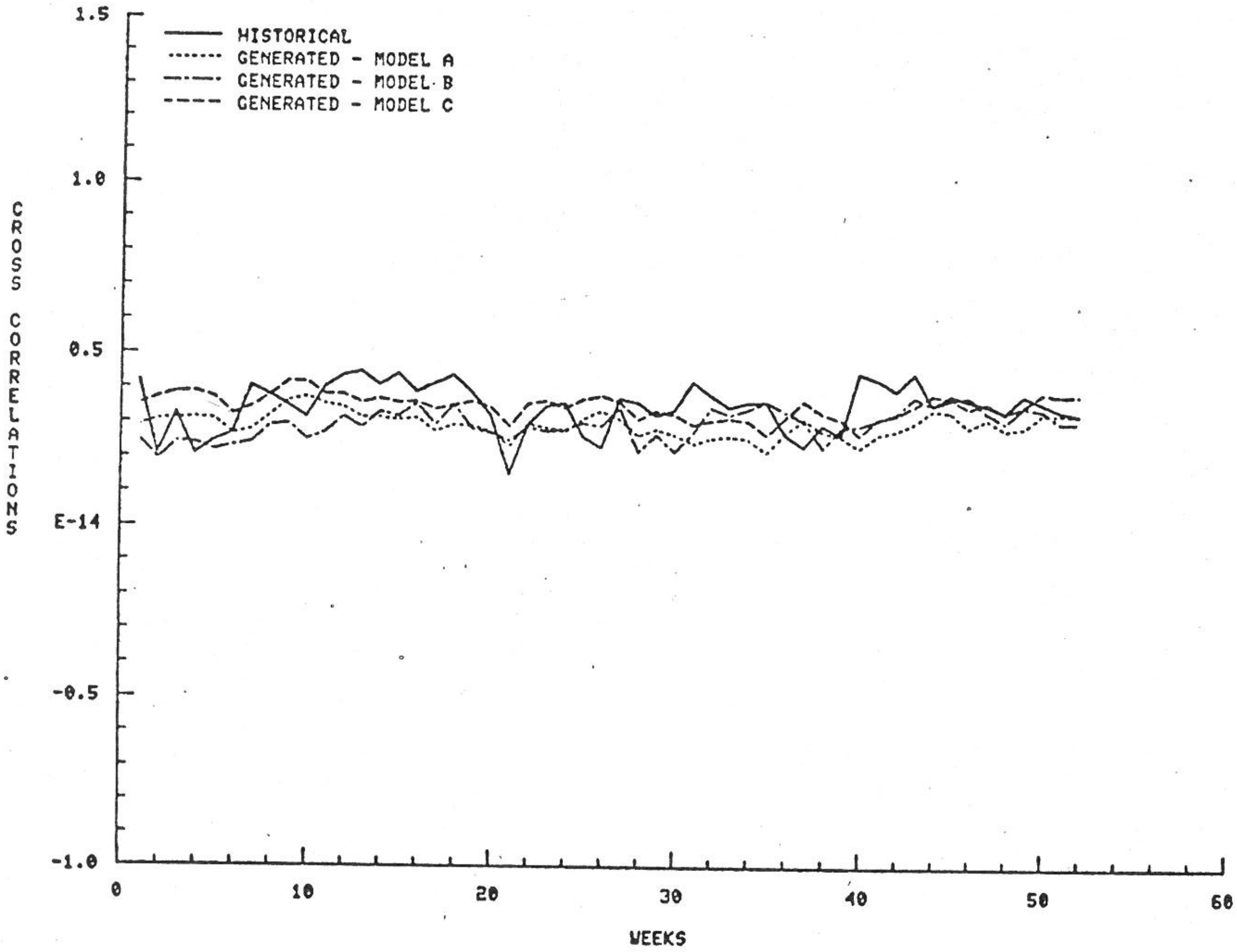

Figure 1.9.D.34 CROSS-CORR PASODE AND RANCHO (ORIGINAL DOMAIN)

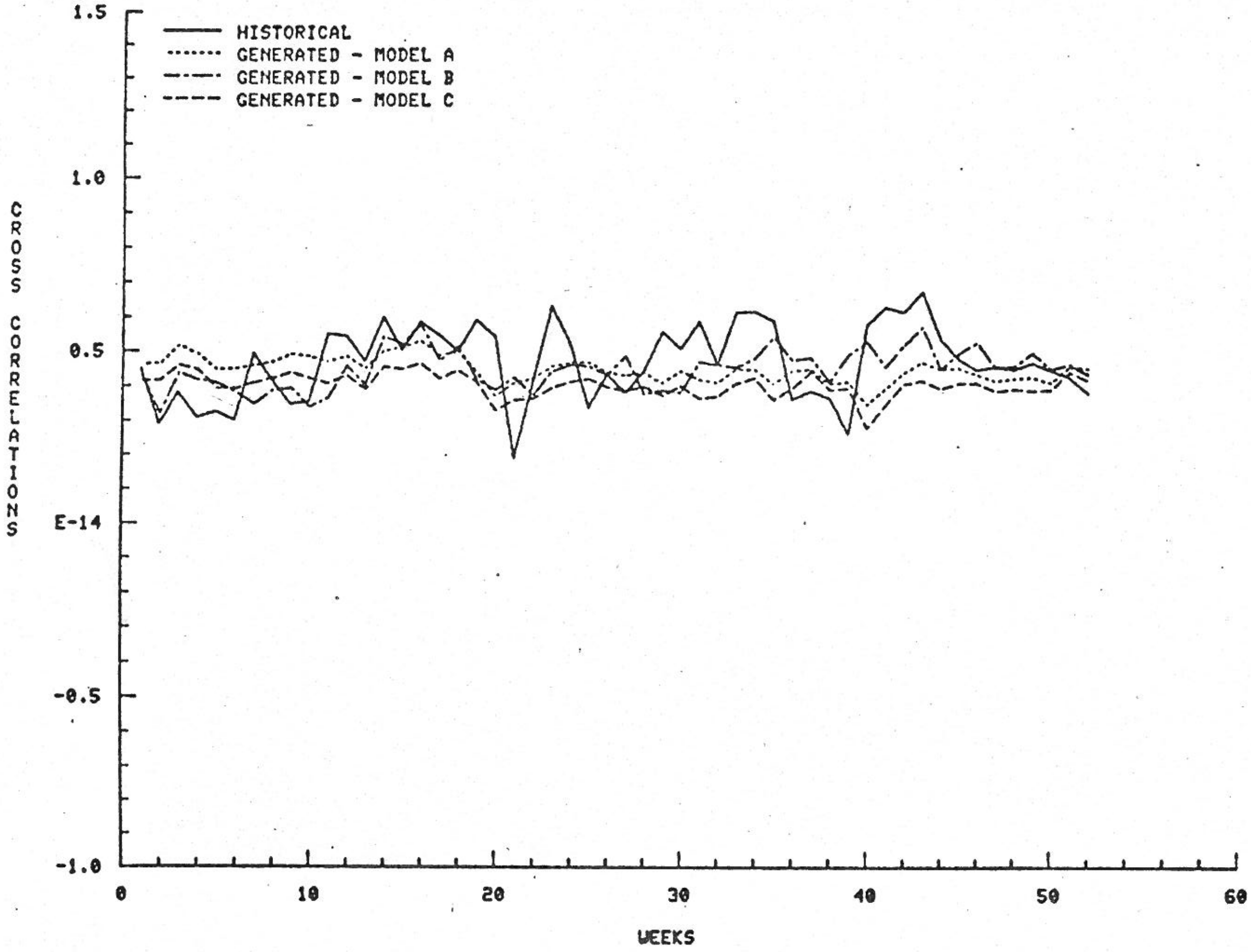

Figure 1.9.D.35 CROSS-CORR PALODE AND RANCHO (ORIGINAL DOMAIN)

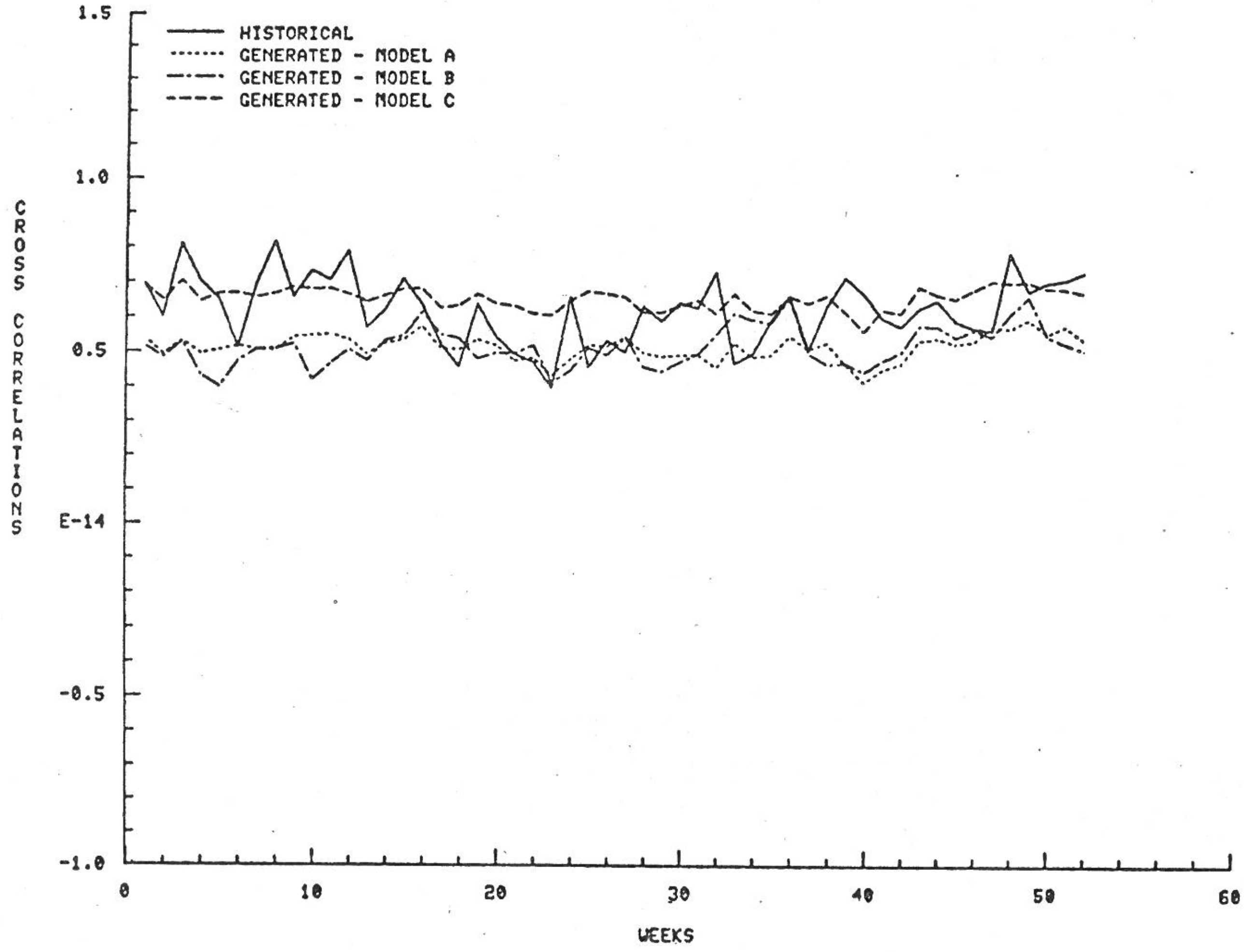

Figure 1.9.D.36 CROSS-CORR PALODE AND PASODE (ORIGINAL DOMAIN)

APPENDIX 1.9.E

HISTORICAL (EXTENDED SERIES) AND GENERATED MONTHLY AND WEEKLY STATISTICS OF PALO DE CAJA, PASO DEL ERMITAÑO AND RANCHO ARRIBA FOR MODEL B IN THE ORIGINAL, LOGARITHMIC AND LOG-WILSON-HILFERTY DOMAIN OF FLOWS

In computing the generated statistics of each sample, Stedinger and Taylor (1982) suggested using the "theoretical" means and standard deviations (i.e., means and standard deviations of the extended data) for computing the generated statistics. This is done in order to reduce any statistical biases introduced from small-sample estimates of the standard deviations, skew coefficients and autocorrelations when computed based on the means and standard deviations of the generated flows. Thus, the unbiased estimates of the generated statistics are:

$$\overline{Y}_\tau = \frac{1}{n} \sum_{\nu=1}^{n} Y_{\nu,\tau} \qquad (1.9.E.1)$$

$$S_\tau(Y) = \left\{ \frac{1}{n} \sum_{\nu=1}^{n} [Y_{\nu,\tau} - \hat{\mu}_\tau(Y)]^2 \right\}^{1/2} \qquad (1.9.E.2)$$

$$G_\tau(Y) = \frac{1}{n\hat{\sigma}_\tau^3(Y)} \sum_{\nu=1}^{n} [Y_{\nu,\tau} - \hat{\mu}_\tau(Y)]^3 \qquad (1.9.E.3)$$

$$R_\tau(k) = \frac{1}{n\hat{\sigma}_\tau(Y)\hat{\sigma}_{\tau-k}(Y)} \sum_{\nu=1}^{n} [Y_{\nu,\tau} - \hat{\mu}_\tau(Y)][Y_{\nu,\tau-k} - \hat{\mu}_{\tau-k}(Y)] \qquad (1.9.E.4)$$

where $\hat{\mu}_\tau(Y)$ and $\hat{\sigma}_\tau(Y)$ are the seasonal means and standard deviations, n is the sample size, and τ is the seasonal index where $\tau = 1,\ldots,\omega$ seasons. Equations (1.9.E.1) through (1.9.E.4) are used to compute the generated statistics of each sample not only for the original domain of flows (represented by Y) but for the other domain of flows by replacing the notation Y by Z for the log-Wilson-Hilferty domain, and by X for the log-domain (see Appendix 1.9.A).

After computing the generated statistics for each sample (a total of 50 for each statistic), the average and standard error are determined. Denoting the mth sample generated statistic by $V_\tau(m)$, the average $\bar{V}_\tau$ and standard error $S_\tau(V)$ are computed from

$$\bar{V}_\tau = \frac{1}{M} \sum_{m=1}^{M} V_\tau(m) \qquad (1.9.E.5)$$

and

$$S_\tau(V) = \left\{ \frac{1}{M} \sum_{m=1}^{M} [V_\tau(m) - \bar{V}_\tau]^2 \right\}^{1/2} \qquad (1.9.E.6)$$

where M is equal to 50 samples.

The computed averages and standard errors of the monthly and weekly generated statistics are given in the figures below for the three stations in the log-Wilson-Hilferty domain, logarithmic domain, and original domain. Also plotted in these figures are the historical statistics and the upper and lower confidence bands of the generated statistics. The confidence band B_τ is computed as positive and negative one-standard error relative to the average as

$$B_\tau = \bar{V}_\tau \pm S_\tau(V) \qquad (1.9.E.7)$$

where $\overline{V}_\tau$ and $S_\tau(V)$ are as defined above. Note that for the plots of historical lag-1 autocorrelation coefficients in the log-Wilson-Hilferty domain, and the historical skew coefficients in the log-domain are the fitted Fourier functions (since, these are the parameters used in data generation).

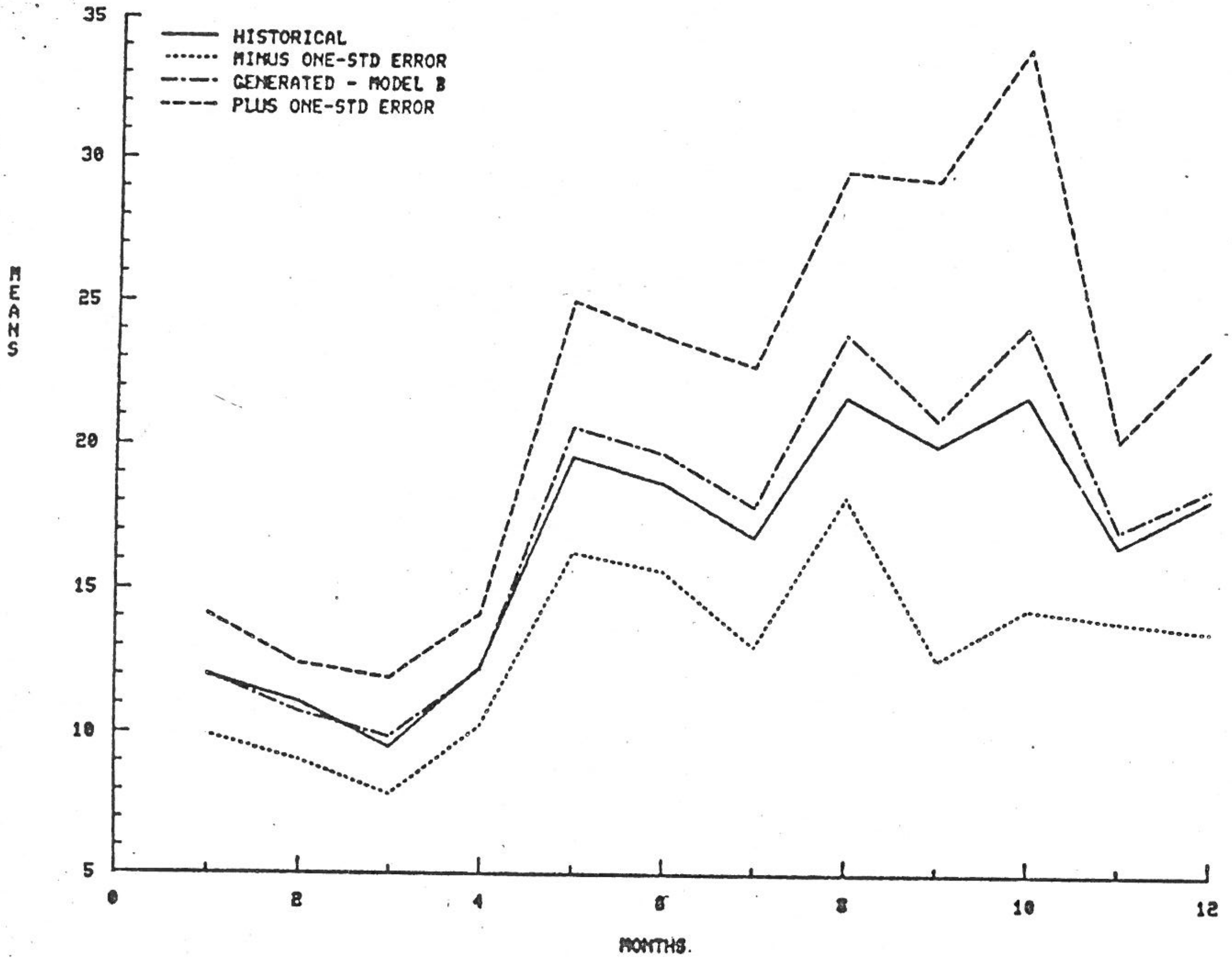

Figure 1.9.E.1. PALODE - MEANS (ORIGINAL DOMAIN)

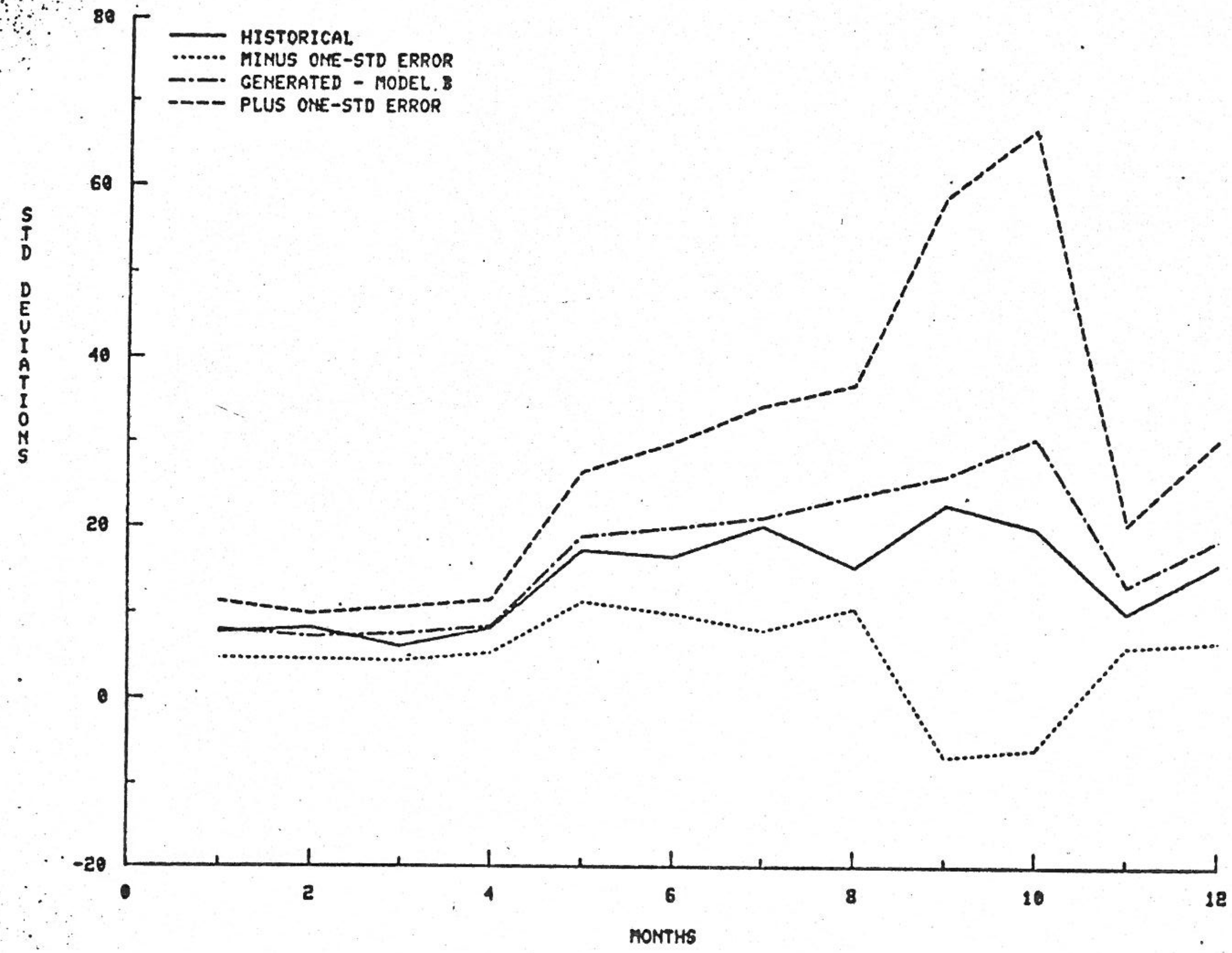

Figure 1.9.E.2. PALODE - STD DEVIATIONS (ORIGINAL DOMAIN)

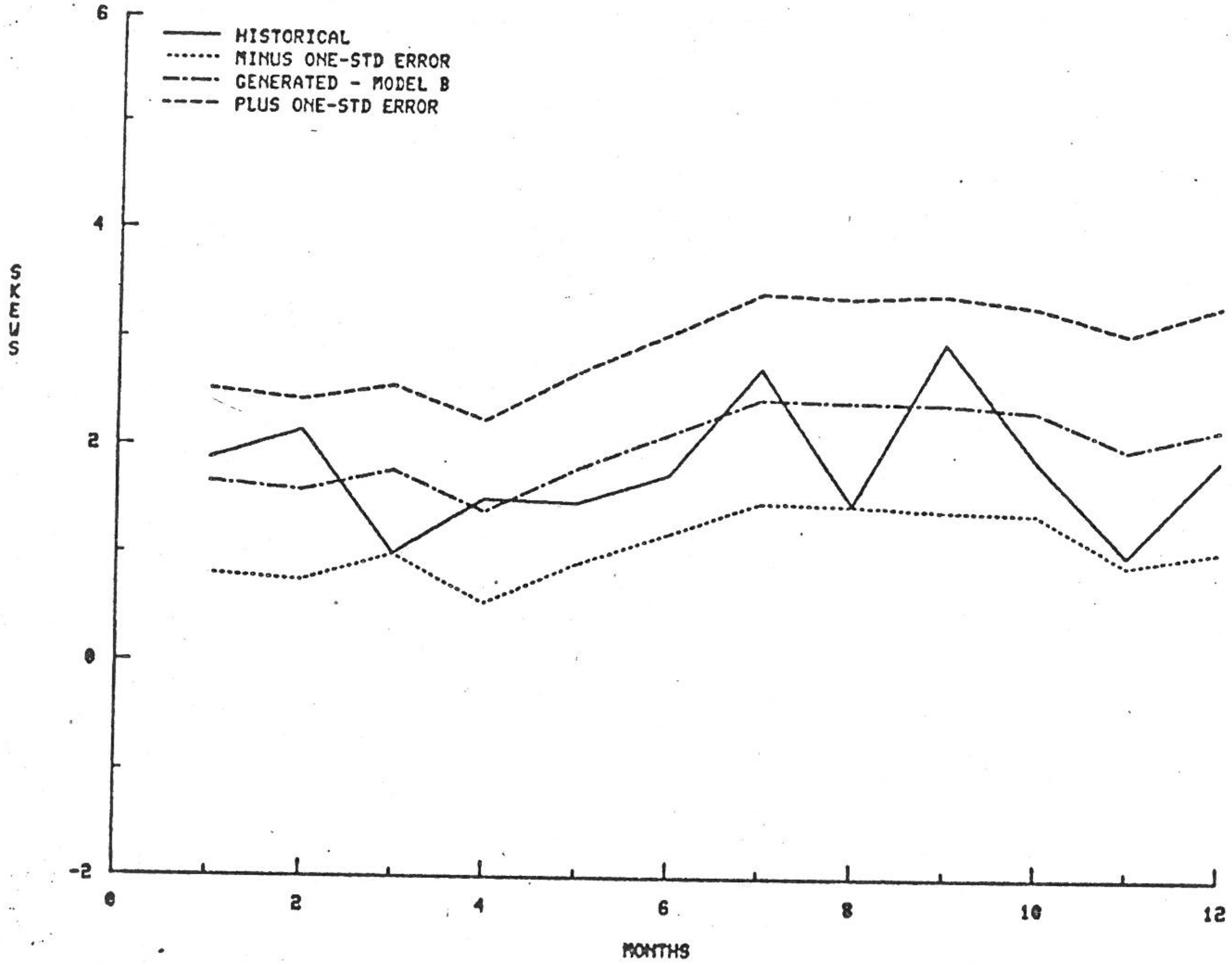

Figure 1.9.E.3. PALODE - SKEWS (ORIGINAL DOMAIN)

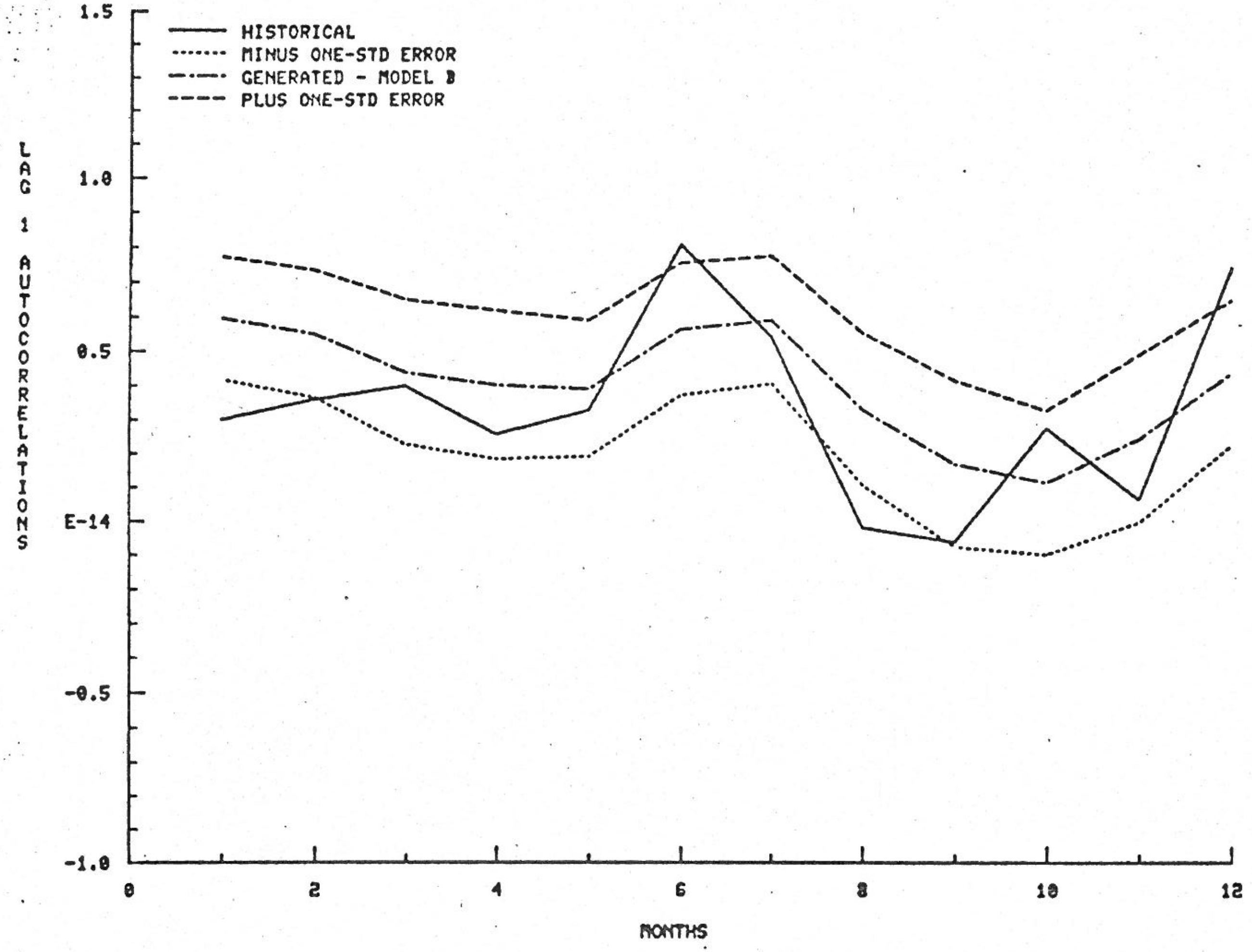

Figure 1:9.E.4. PALODE - LAG 1 AUTOCORRELATIONS (ORIGINAL DOMAIN)

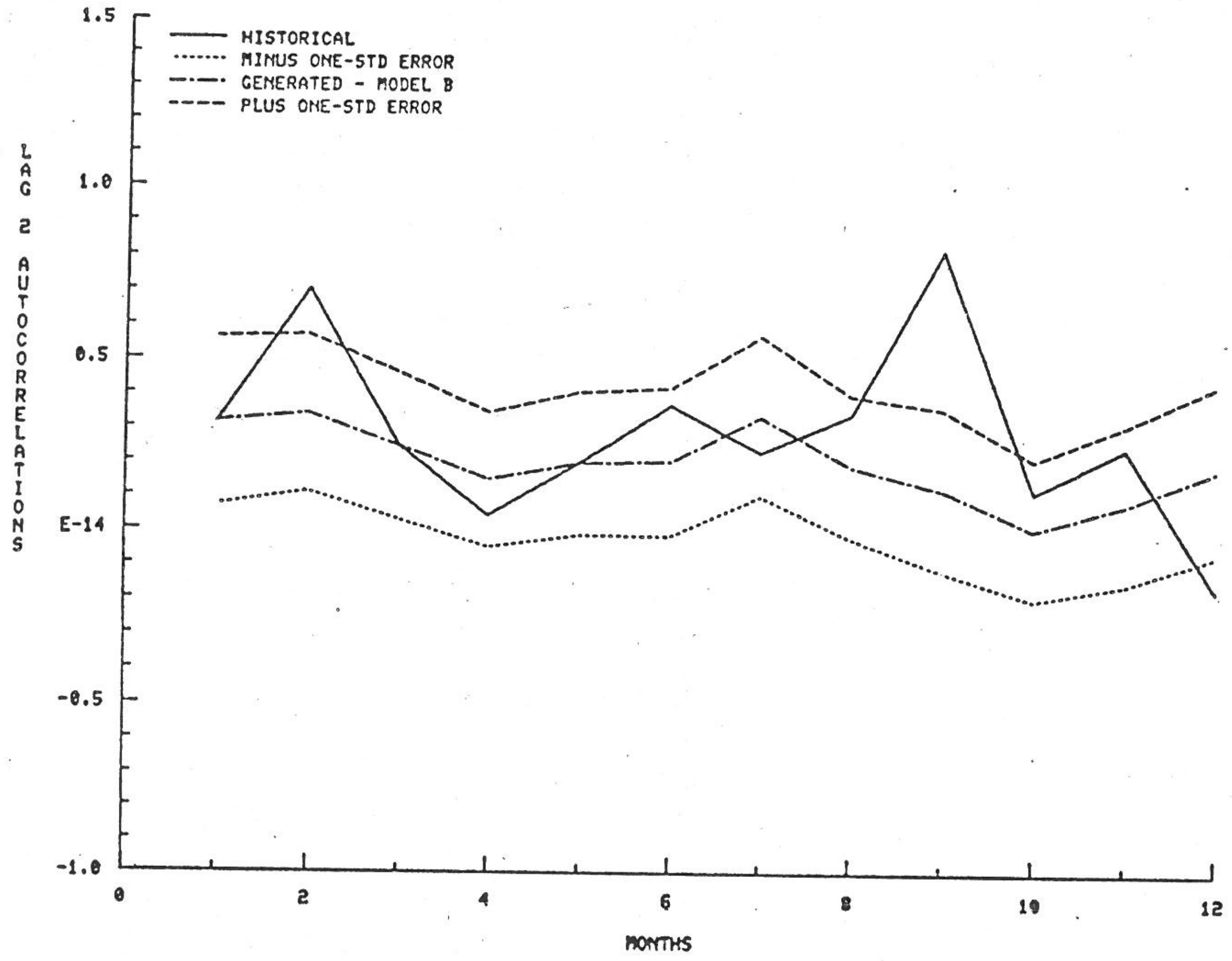

Figure 1.9.E.5. PALODE - LAG 2 AUTOCORRELATIONS (ORIGINAL DOMAIN)

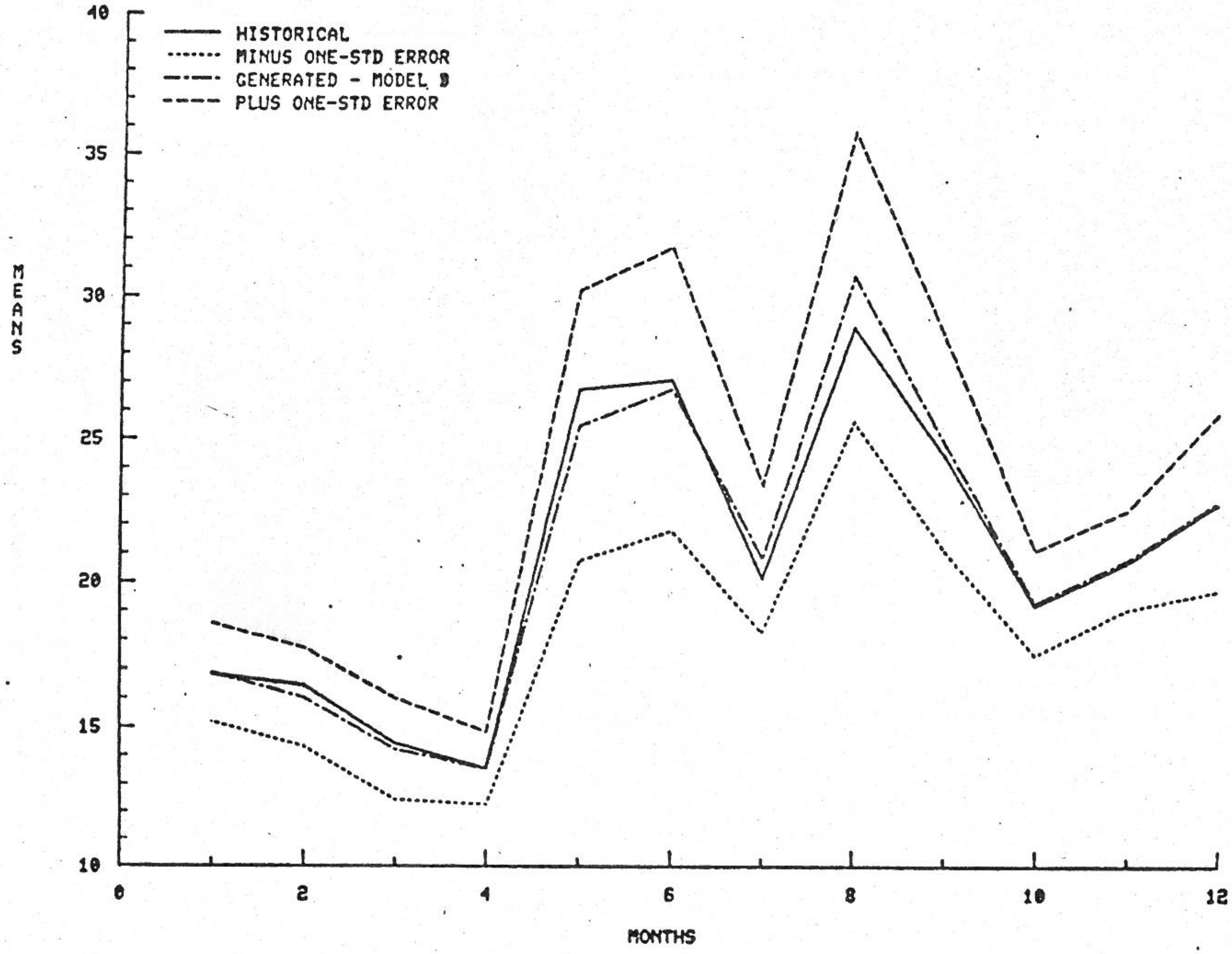

Figure 1.9.E.6. PASODE - MEANS (ORIGINAL DOMAIN)

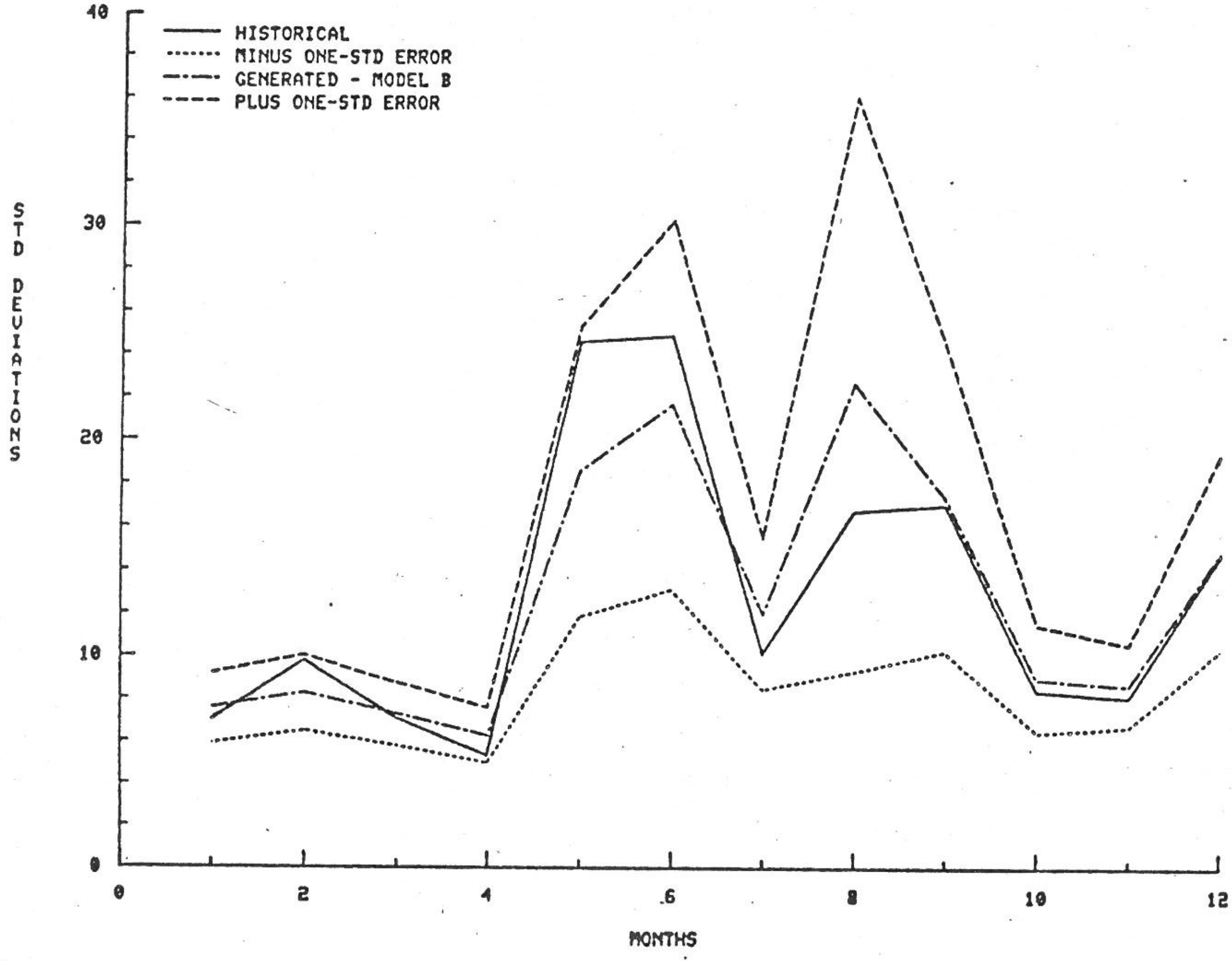

Figure 1.9.E.7. PASODE - STD DEVIATIONS (ORIGINAL DOMAIN)

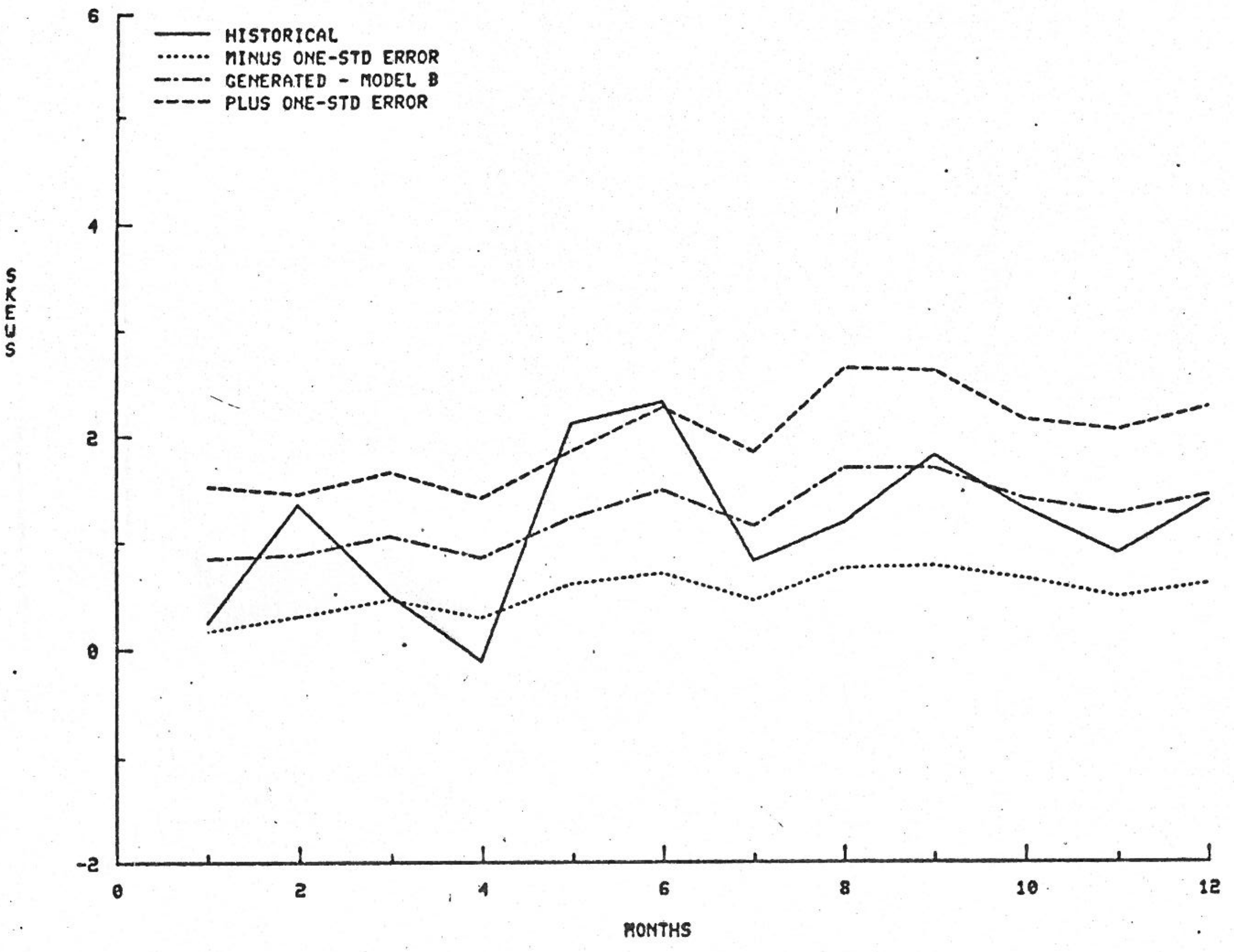

Figure 1.9.E.8. PASODE - SKEWS (ORIGINAL DOMAIN)

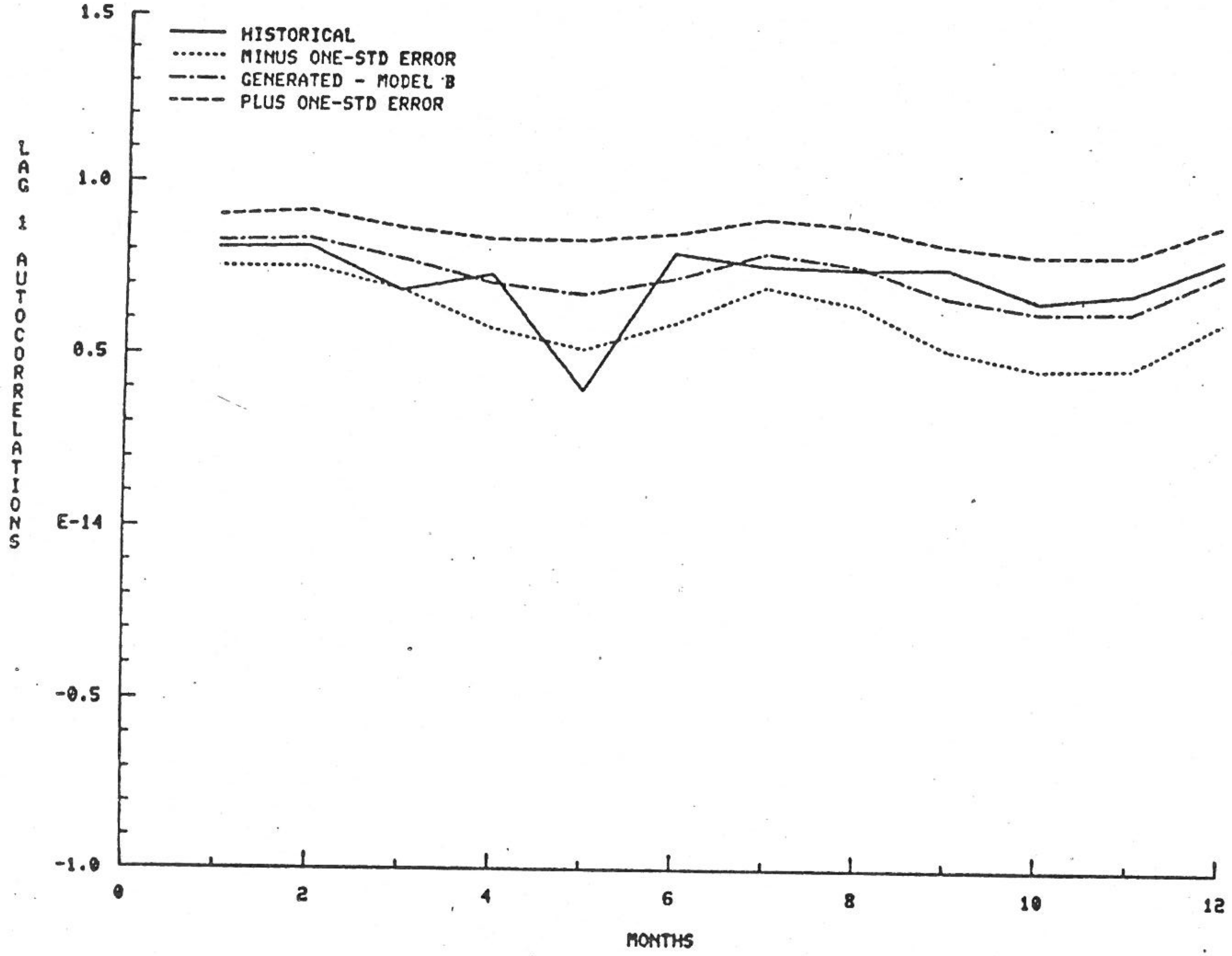

Figure 1.9.E.9. PASODE - LAG 1 AUTOCORRELATIONS (ORIGINAL DOMAIN)

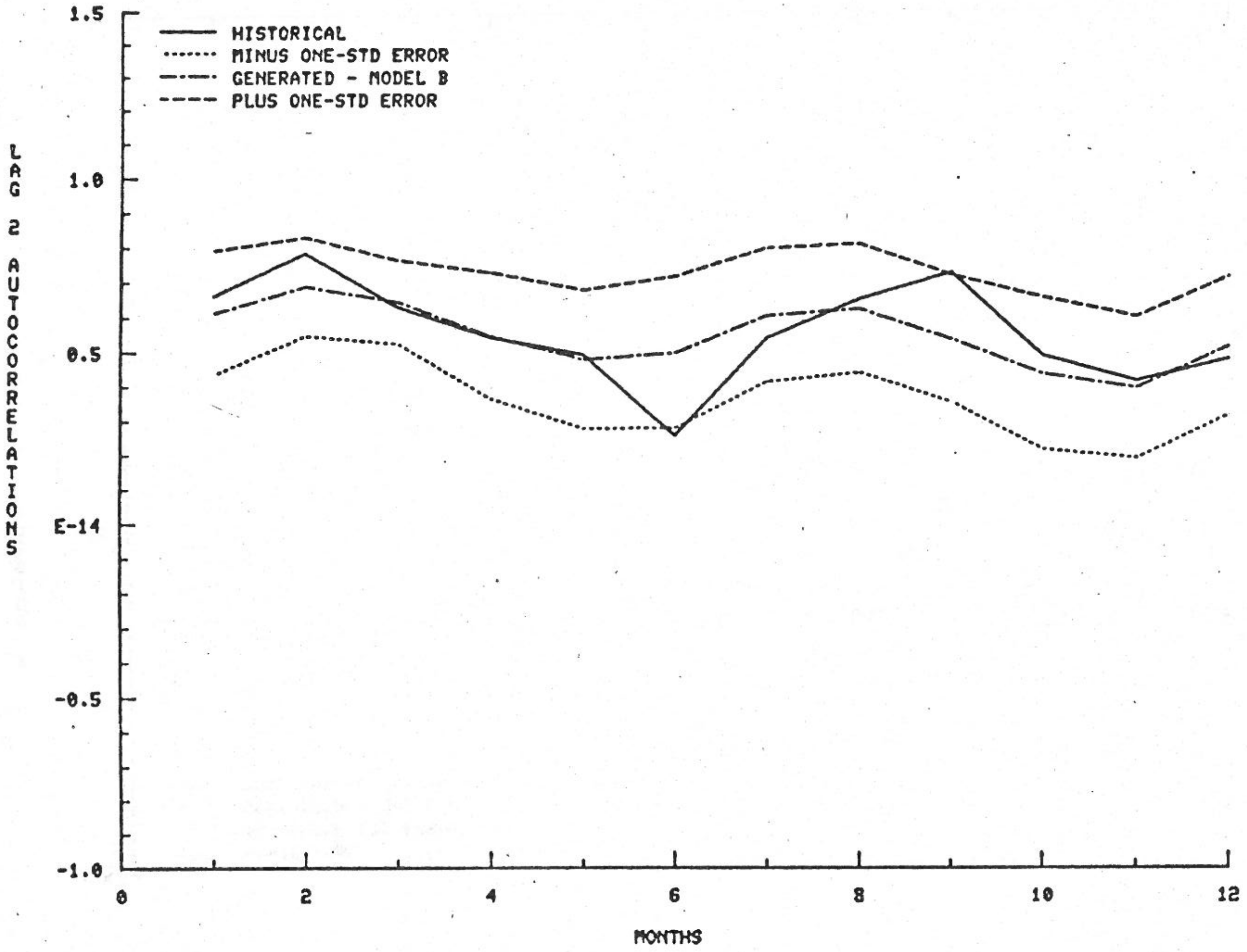

Figure 1.9.E.10. PASODE - LAG 2 AUTOCORRELATIONS (ORIGINAL DOMAIN)

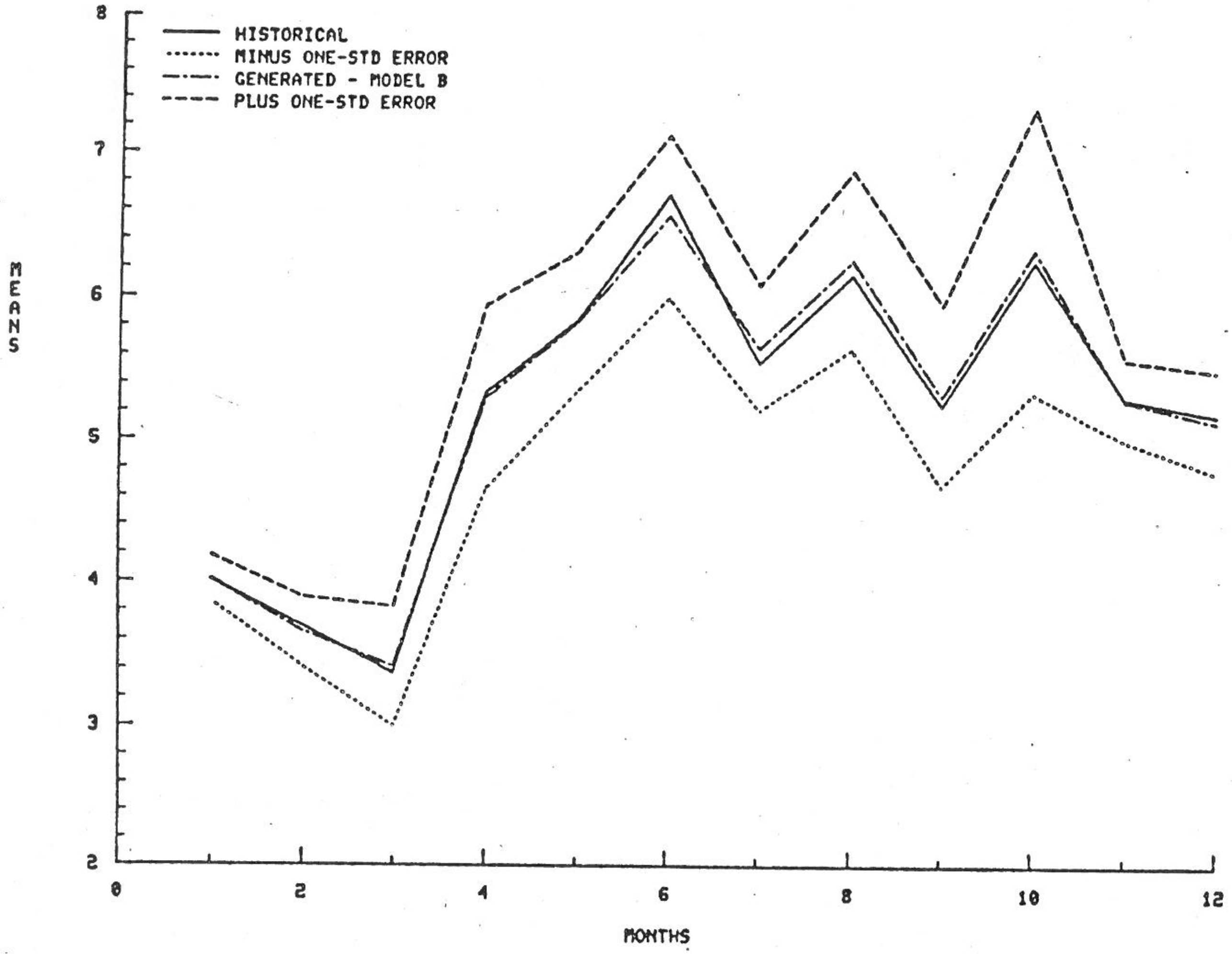

Figure 1.9.E.11. RANCHO - MEANS (ORIGINAL DOMAIN)

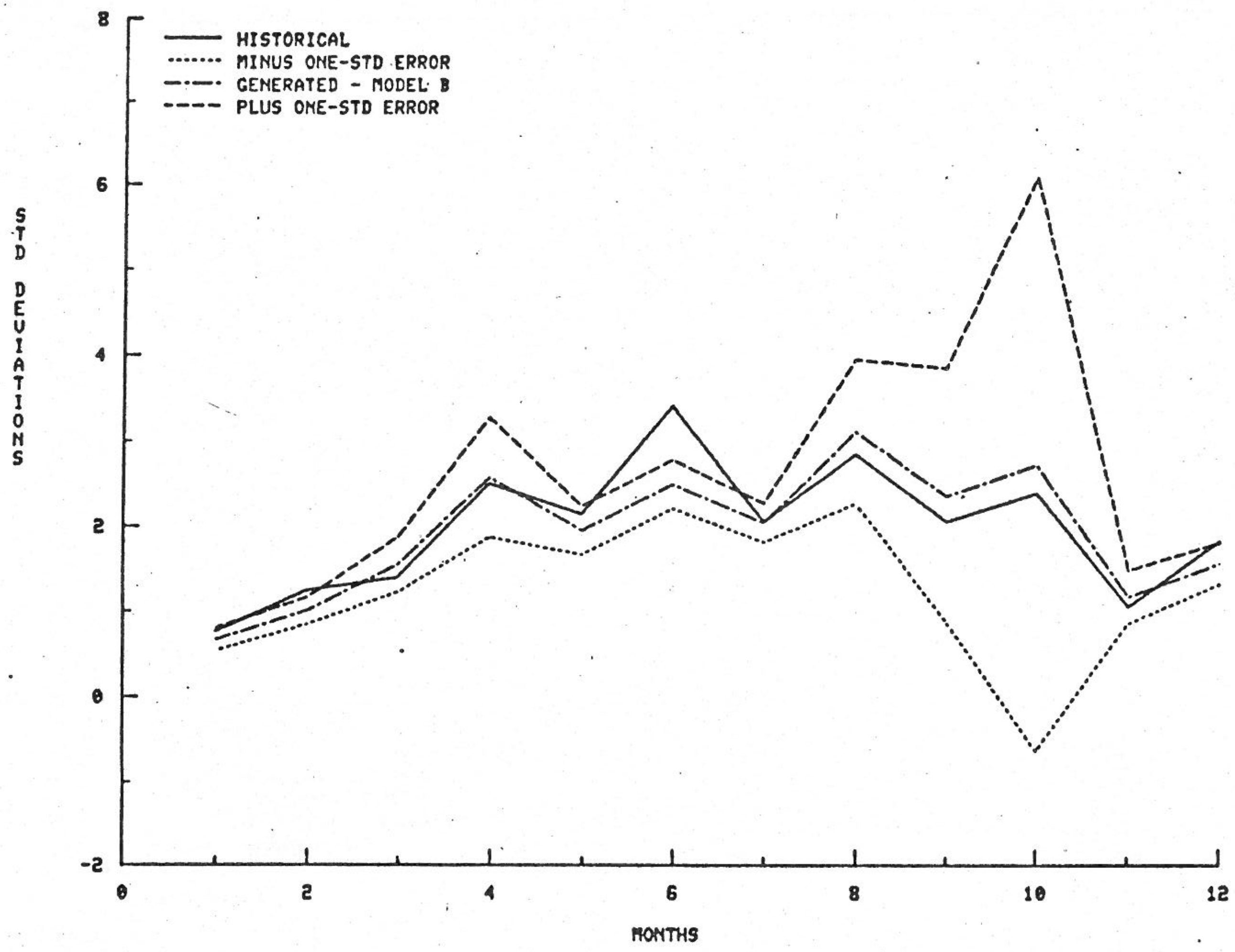

Figure 1.9.E.12. RANCHO - STD DEVIATIONS (ORIGINAL DOMAIN)

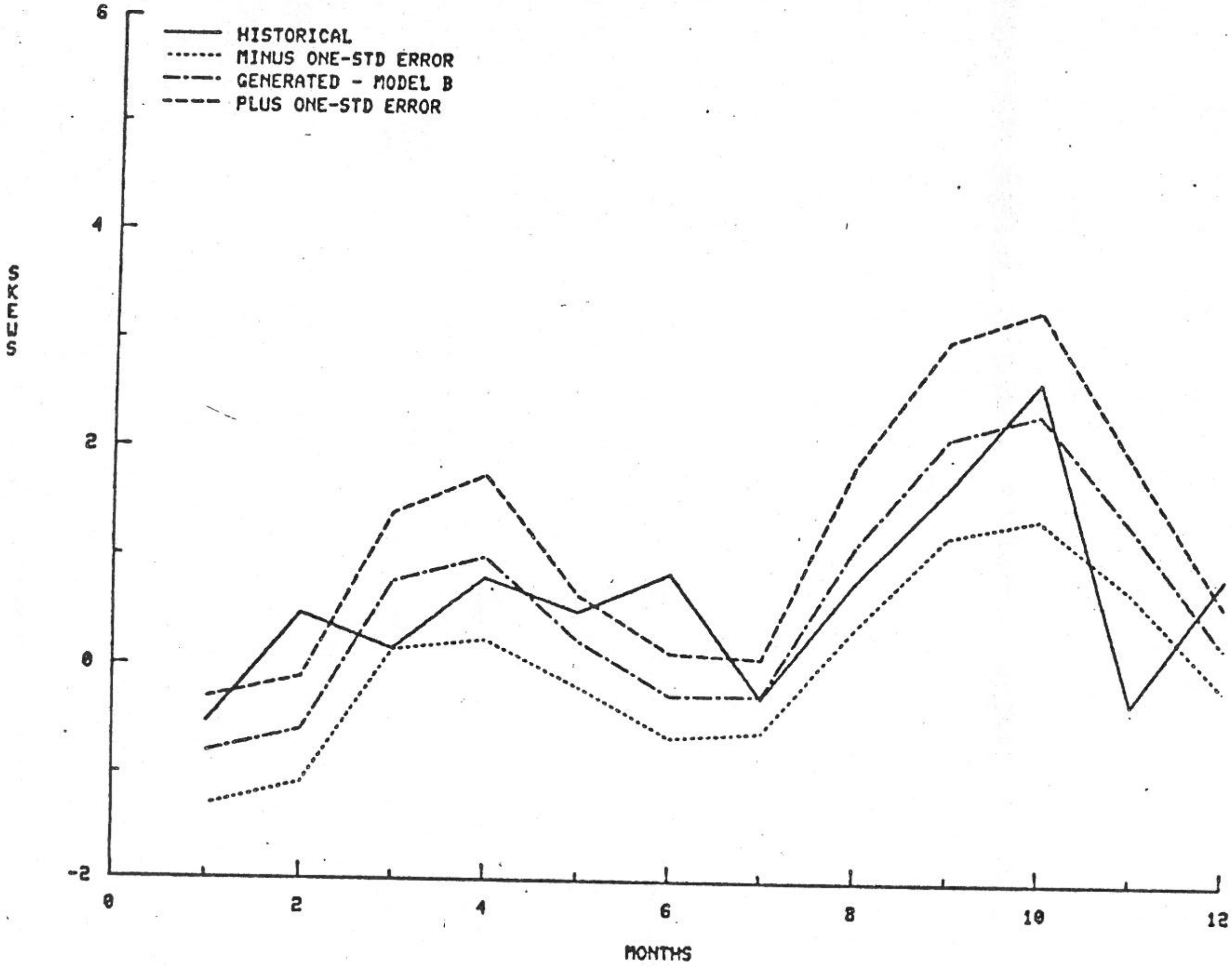

Figure 1.9.E.13. RANCHO - SKEWS (ORIGINAL DOMAIN)

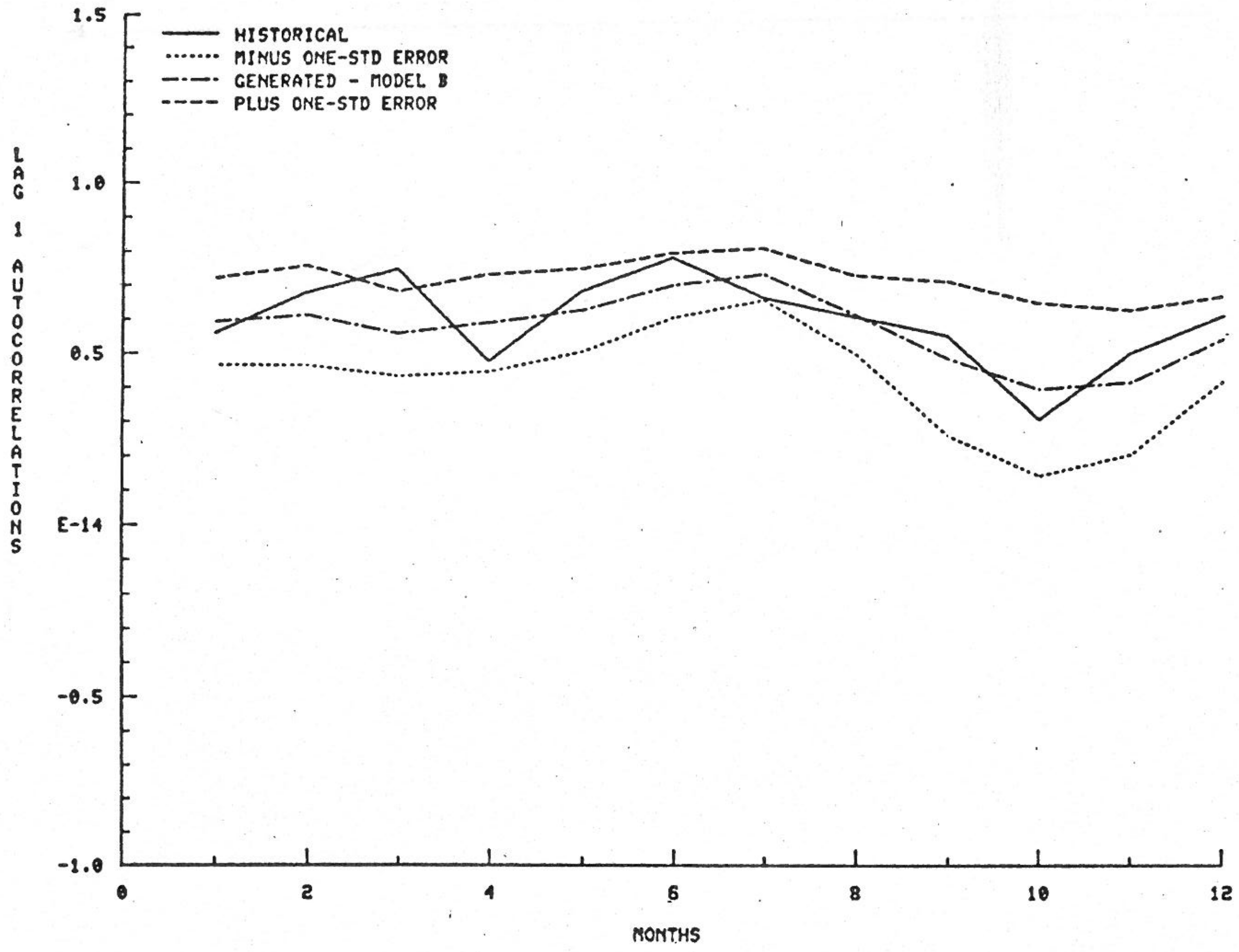

Figure 1.9.E.14. RANCHO - LAG 1 AUTOCORRELATIONS (ORIGINAL DOMAIN)

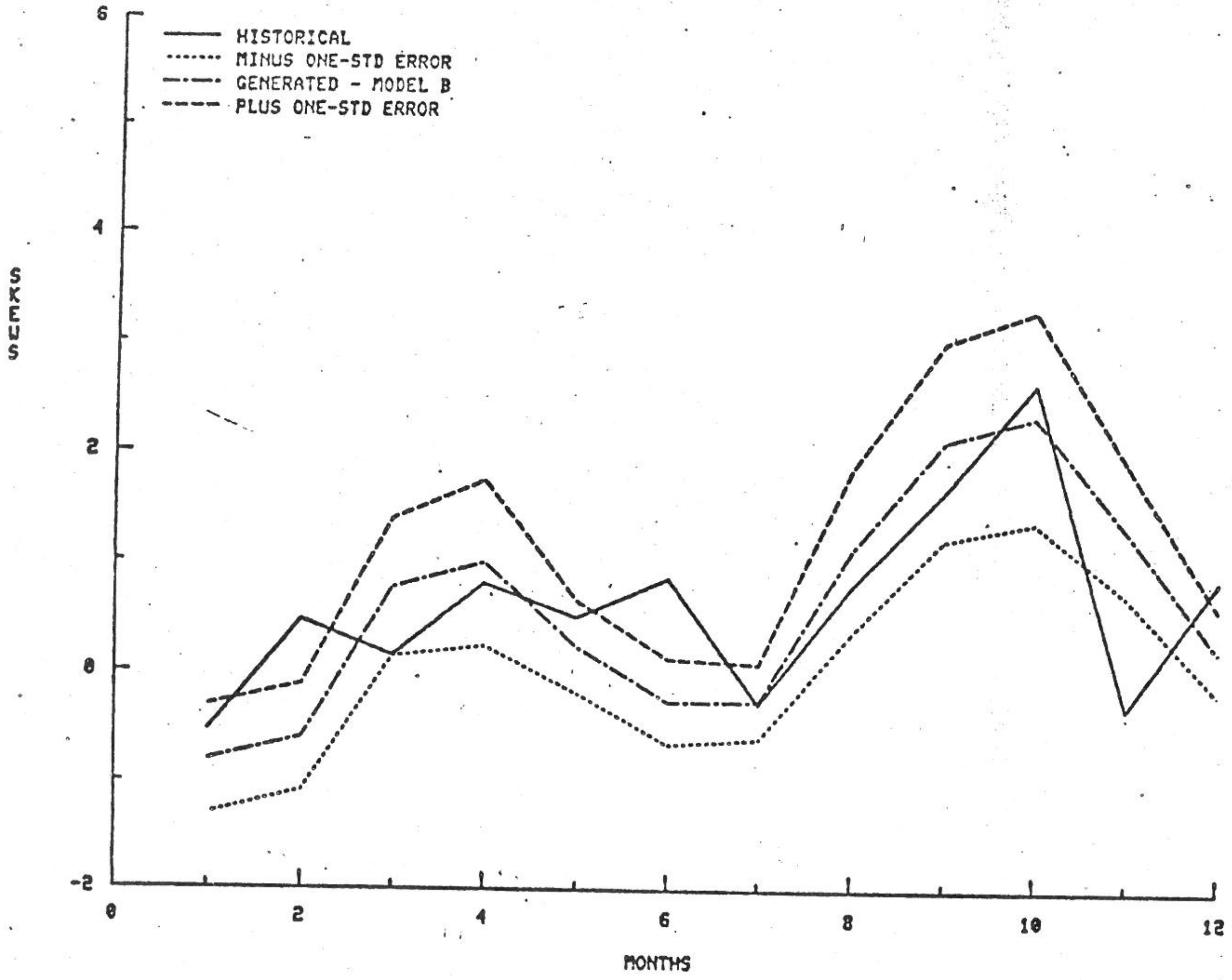

Figure 1.9.E.13. RANCHO - SKEWS (ORIGINAL DOMAIN)

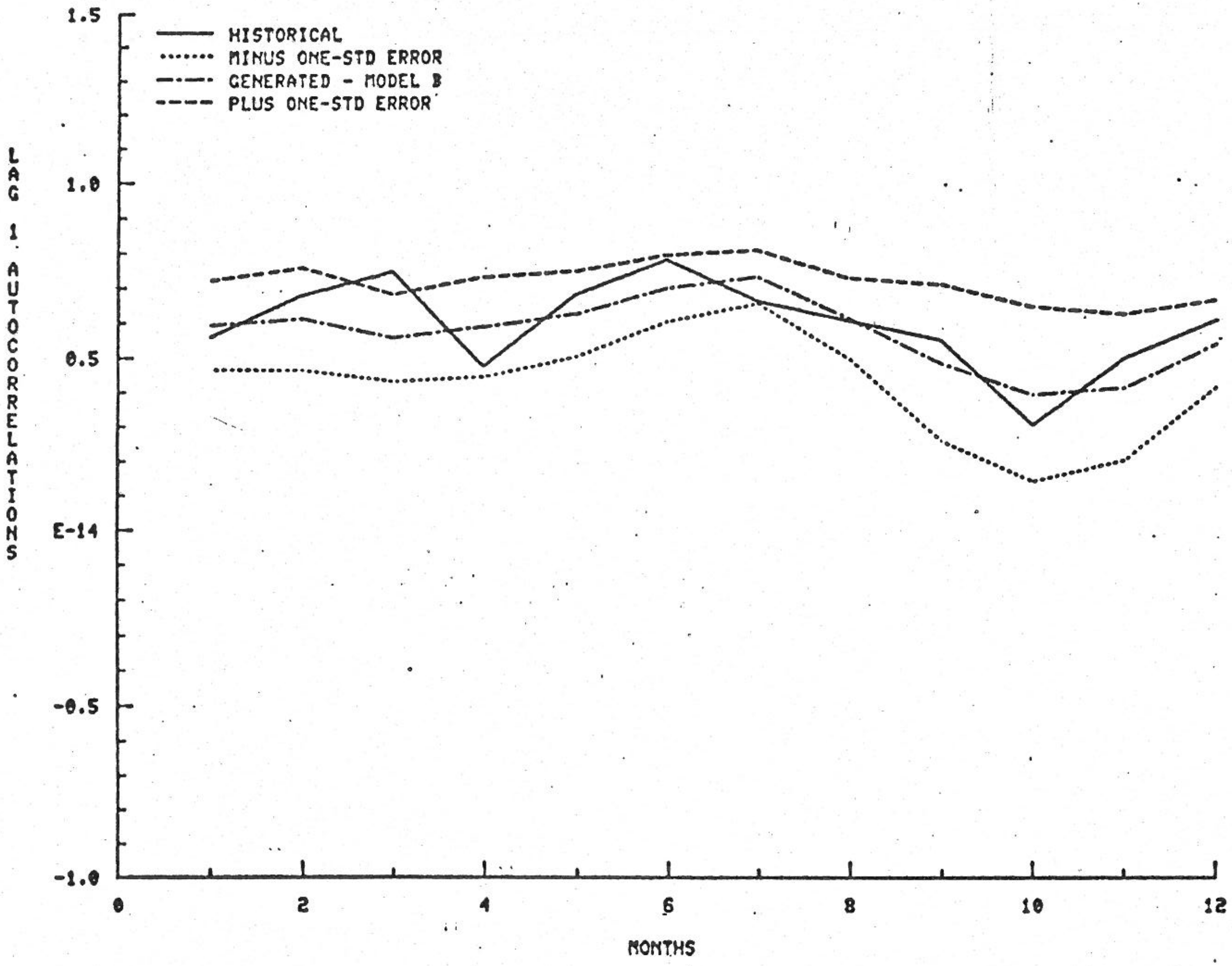

Figure 1.9.E.14. RANCHO - LAG 1 AUTOCORRELATIONS (ORIGINAL DOMAIN)

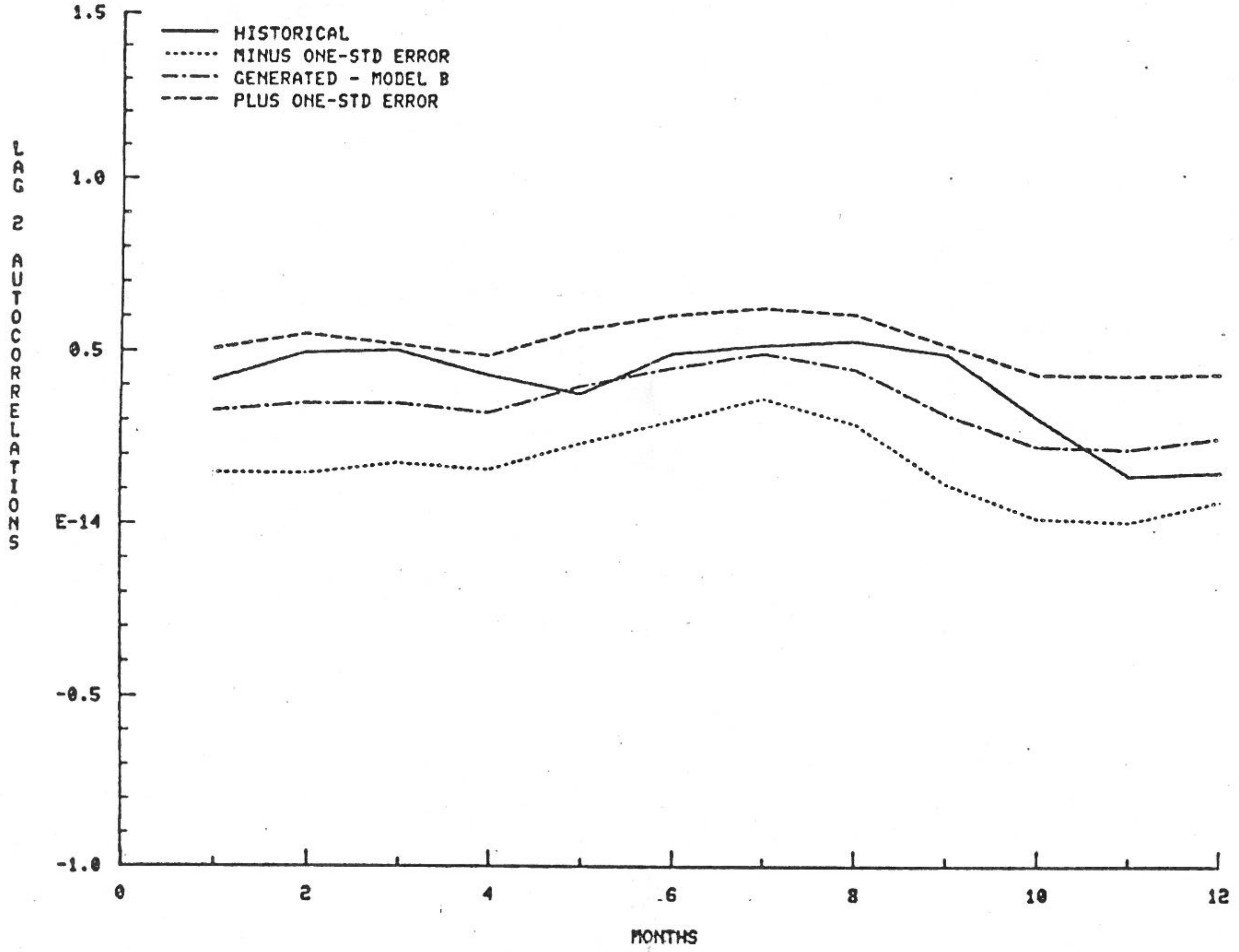

Figure 1.9.E.15. RANCHO - LAG 2 AUTOCORRELATIONS (ORIGINAL DOMAIN)

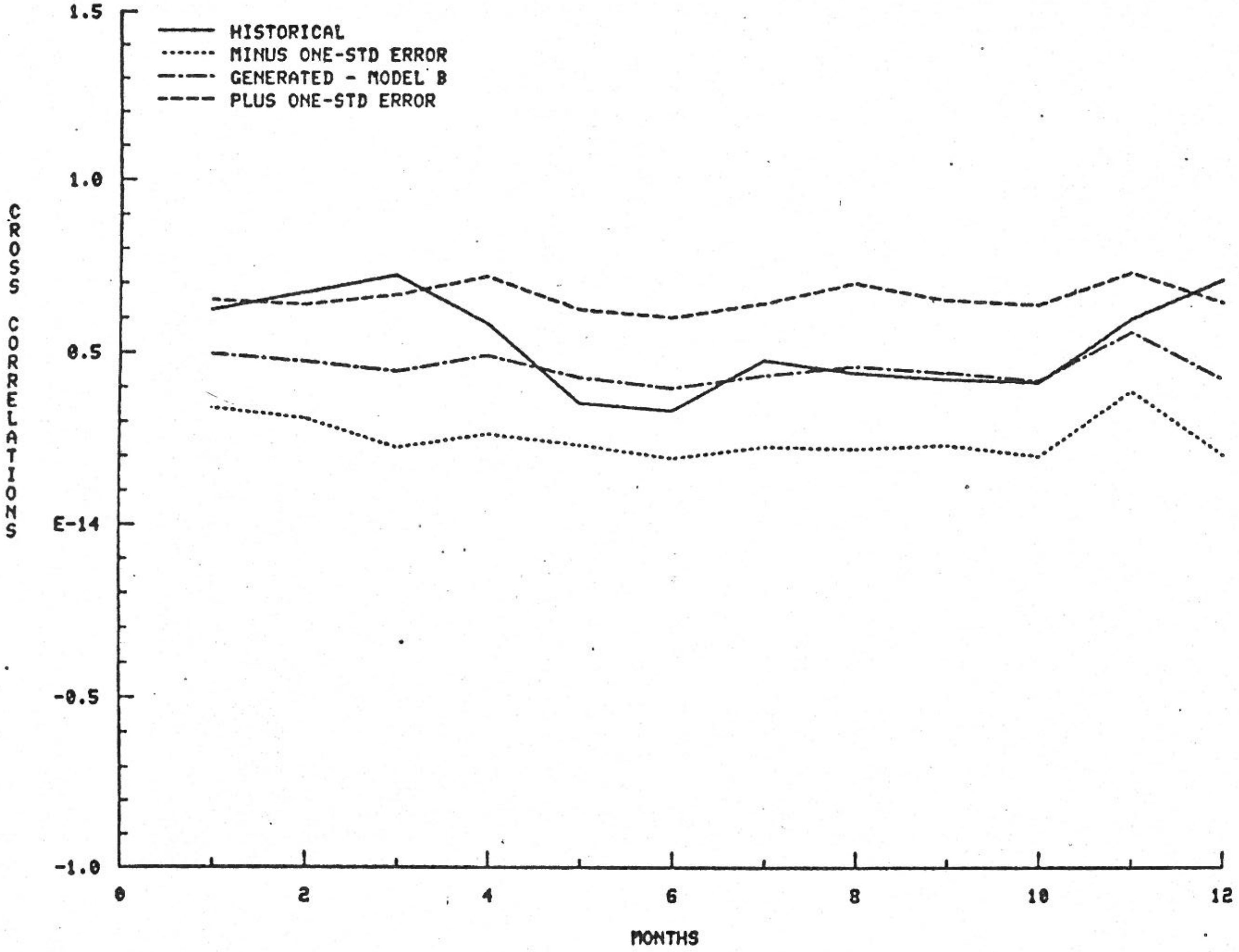

Figure 1.9.E.16. PALODE AND PASODE - CROSS CORRELATIONS (ORIGINAL DOMAIN)

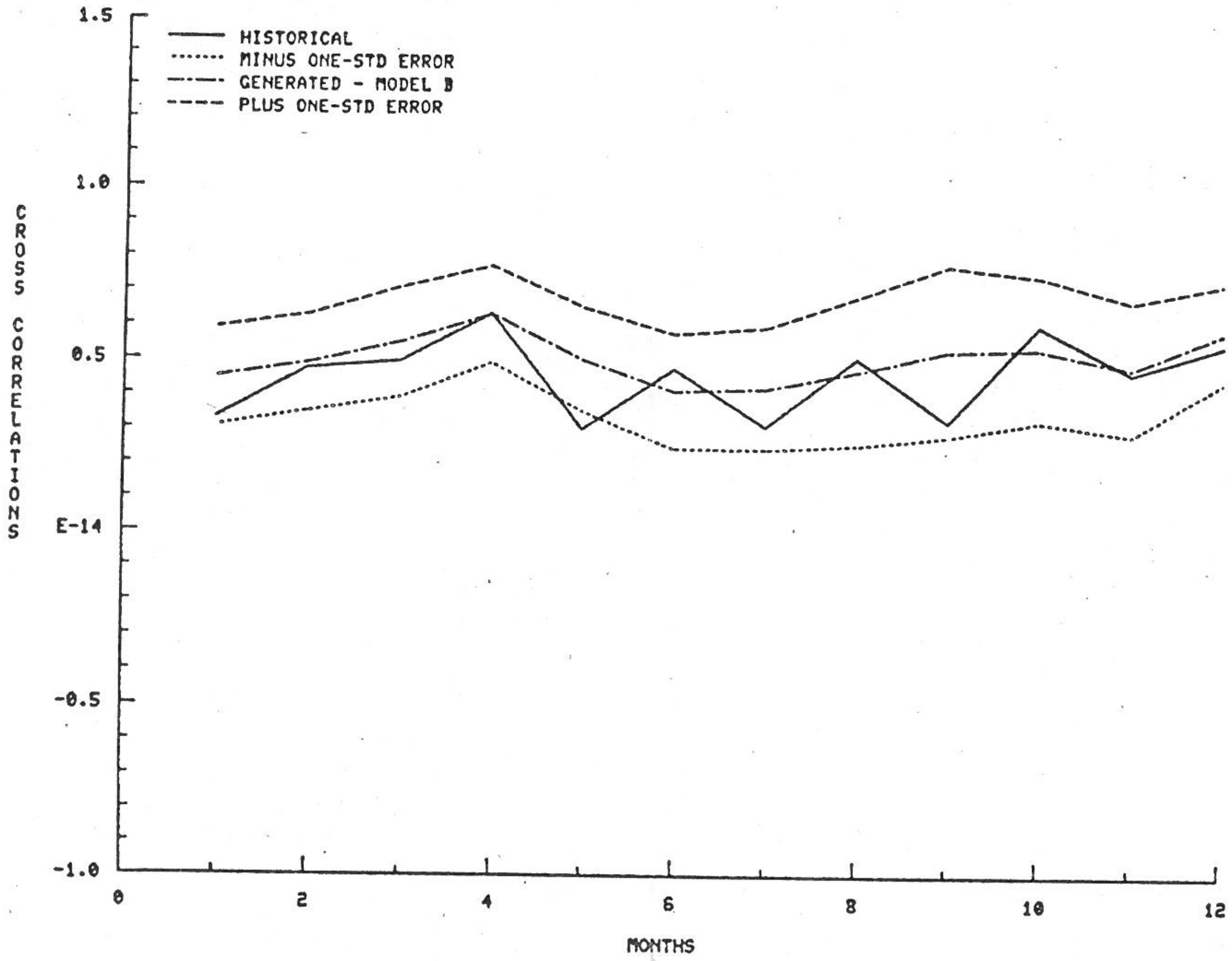

Figure 1.9.E.17. PALODE AND RANCHO - CROSS CORRELATIONS (ORIGINAL DOMAIN)

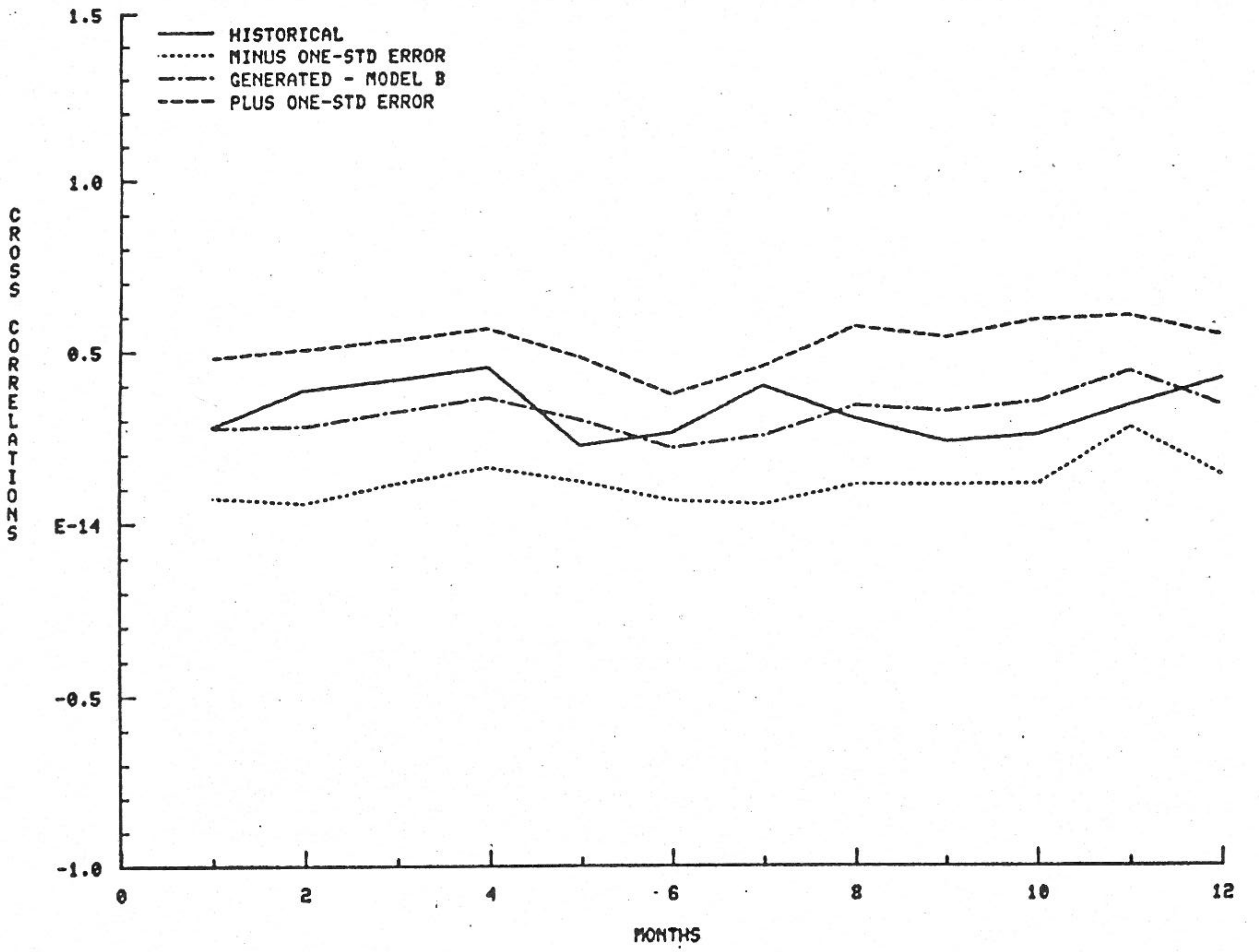

Figure 1.9.E.18. PASODE AND RANCHO - CROSS CORRELATIONS (ORIGINAL DOMAIN)

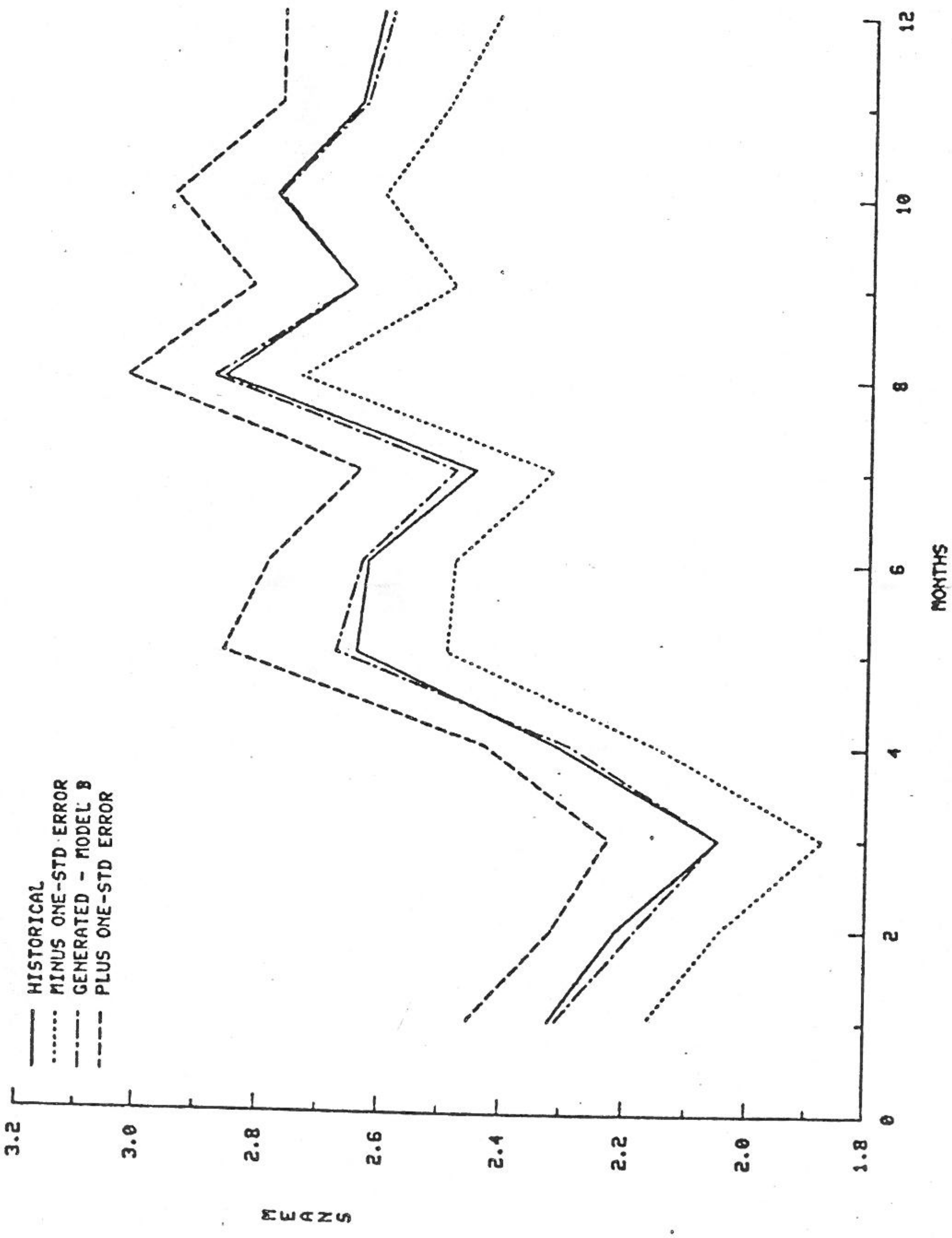

Figure 1.9.E.19. PALODE - MEANS (LOG DOMAIN)

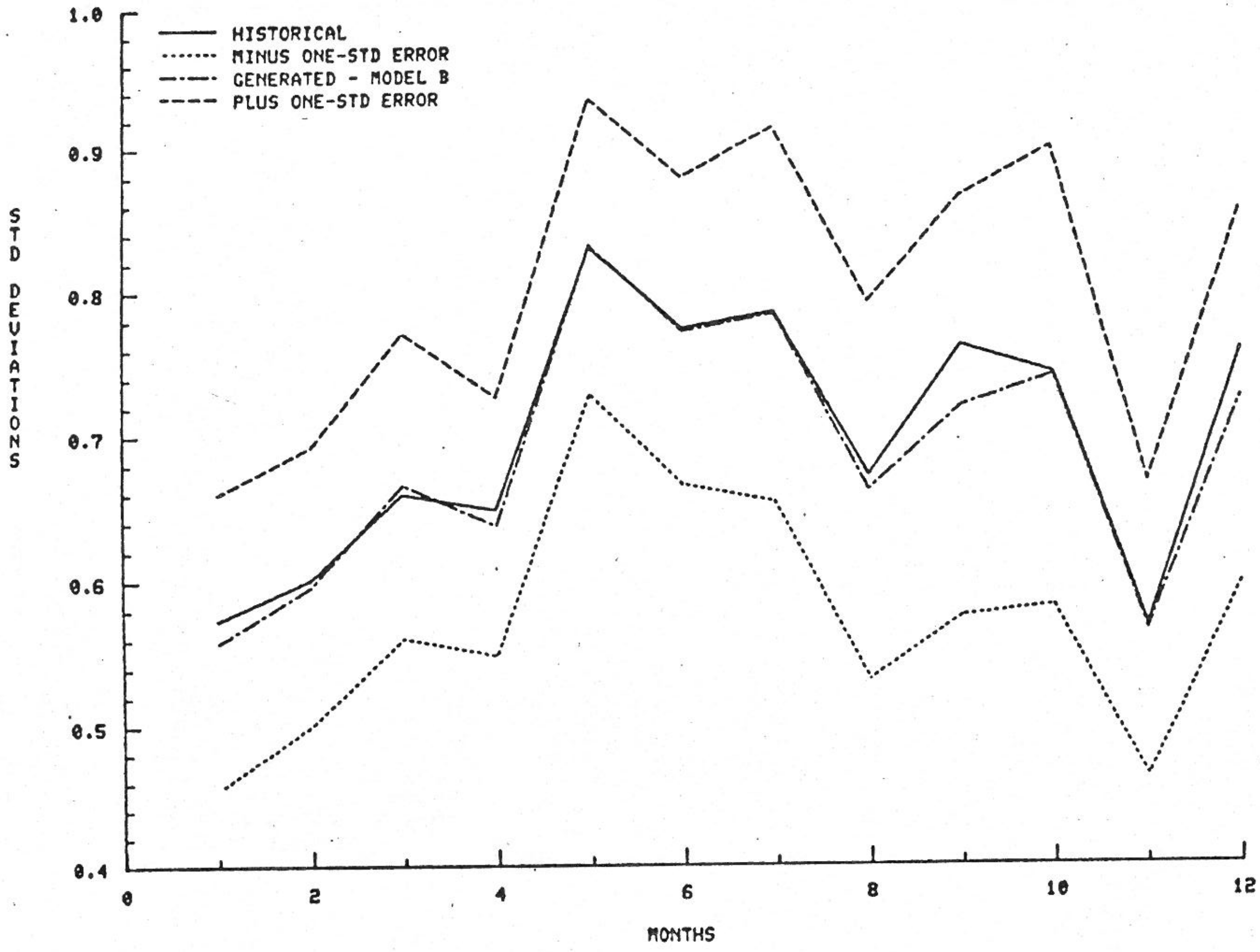

Figure 1.9.E.20. PALODE - STD DEVIATIONS (LOG DOMAIN)

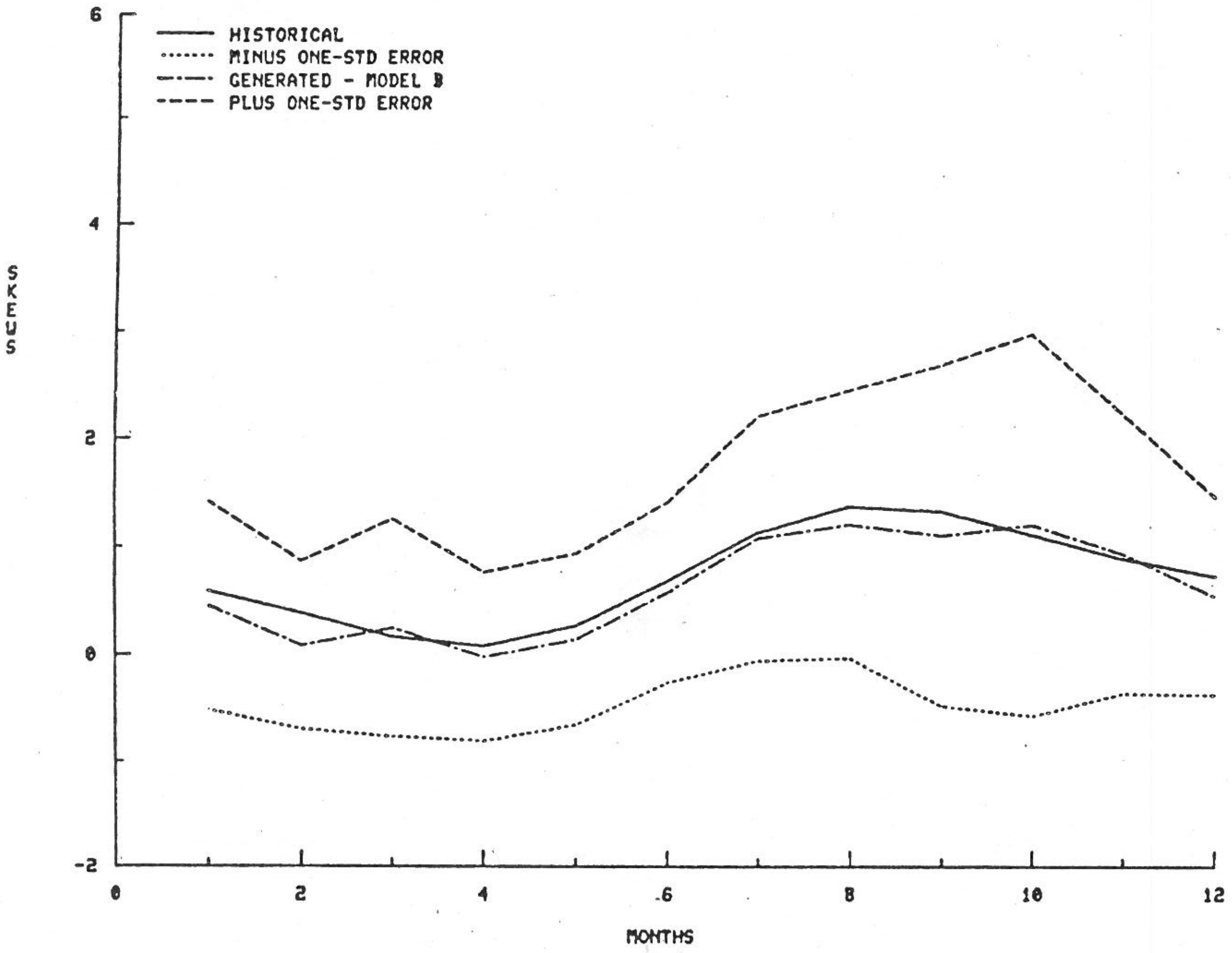

Figure 1.9.E.21. PALODE - SKEWS (LOG DOMAIN)

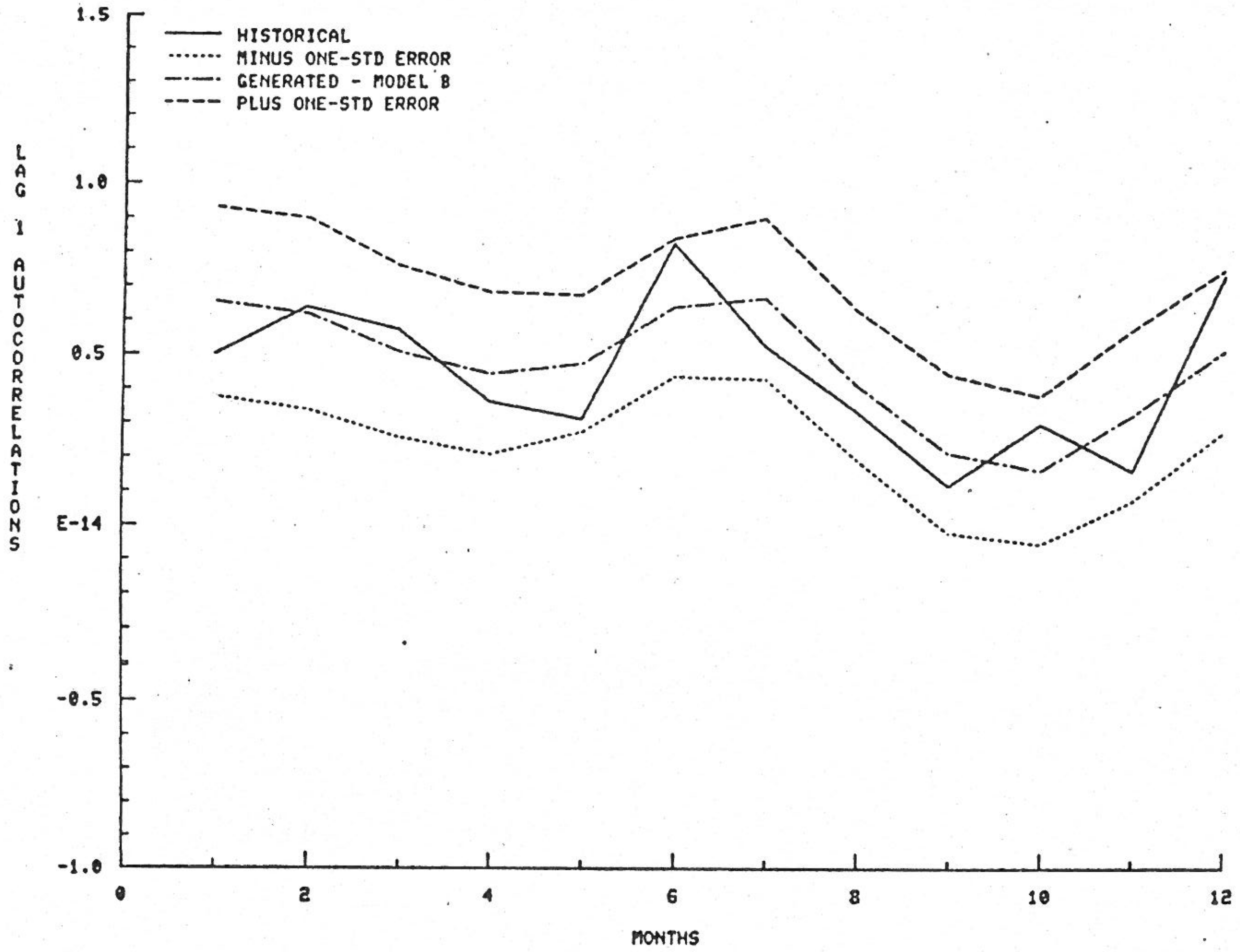

Figure 1.9.E.22. PALODE - LAG 1 AUTOCORRELATIONS (LOG DOMAIN)

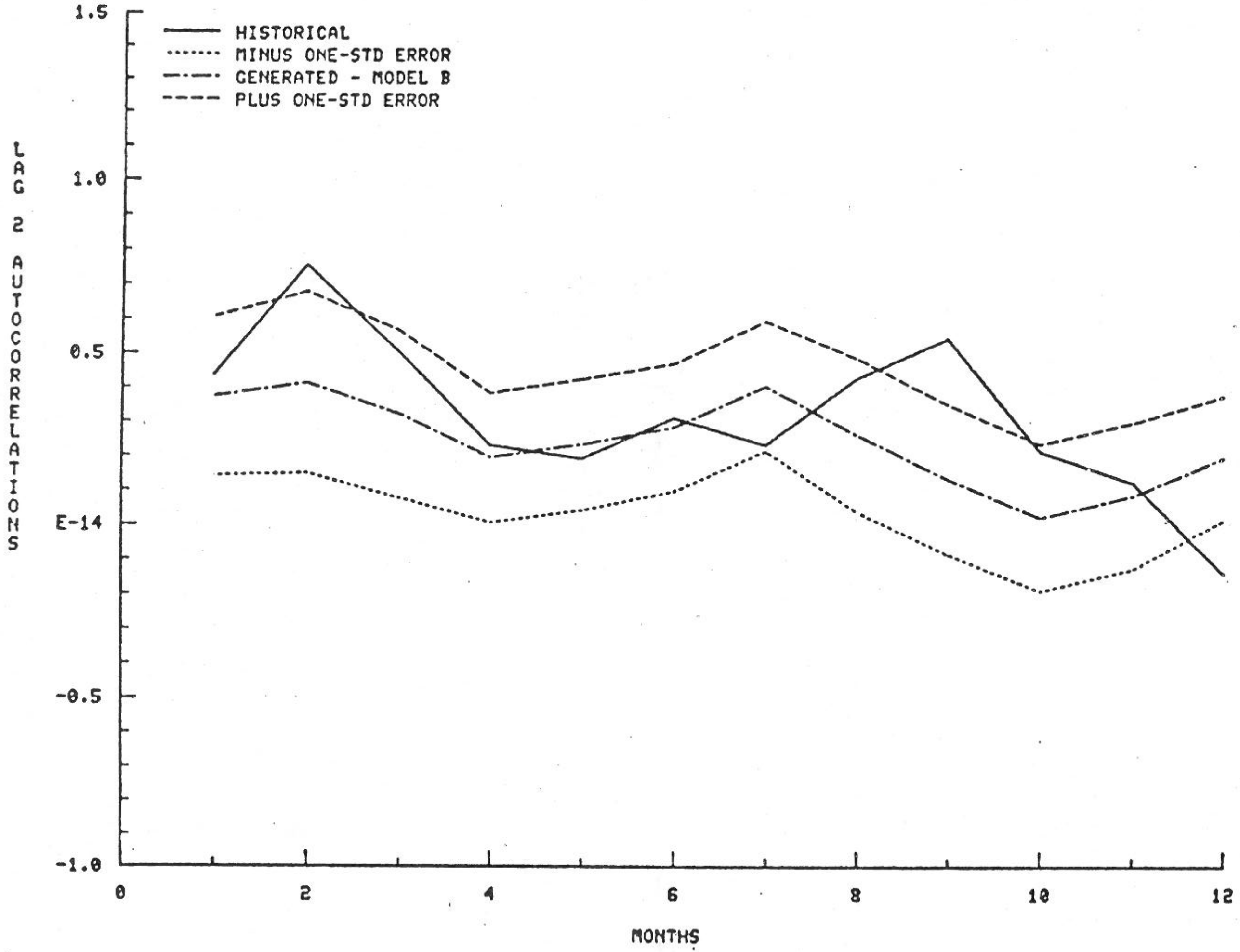

Figure 1.9.E.23. PALODE - LAG 2 AUTOCORRELATIONS (LOG DOMAIN)

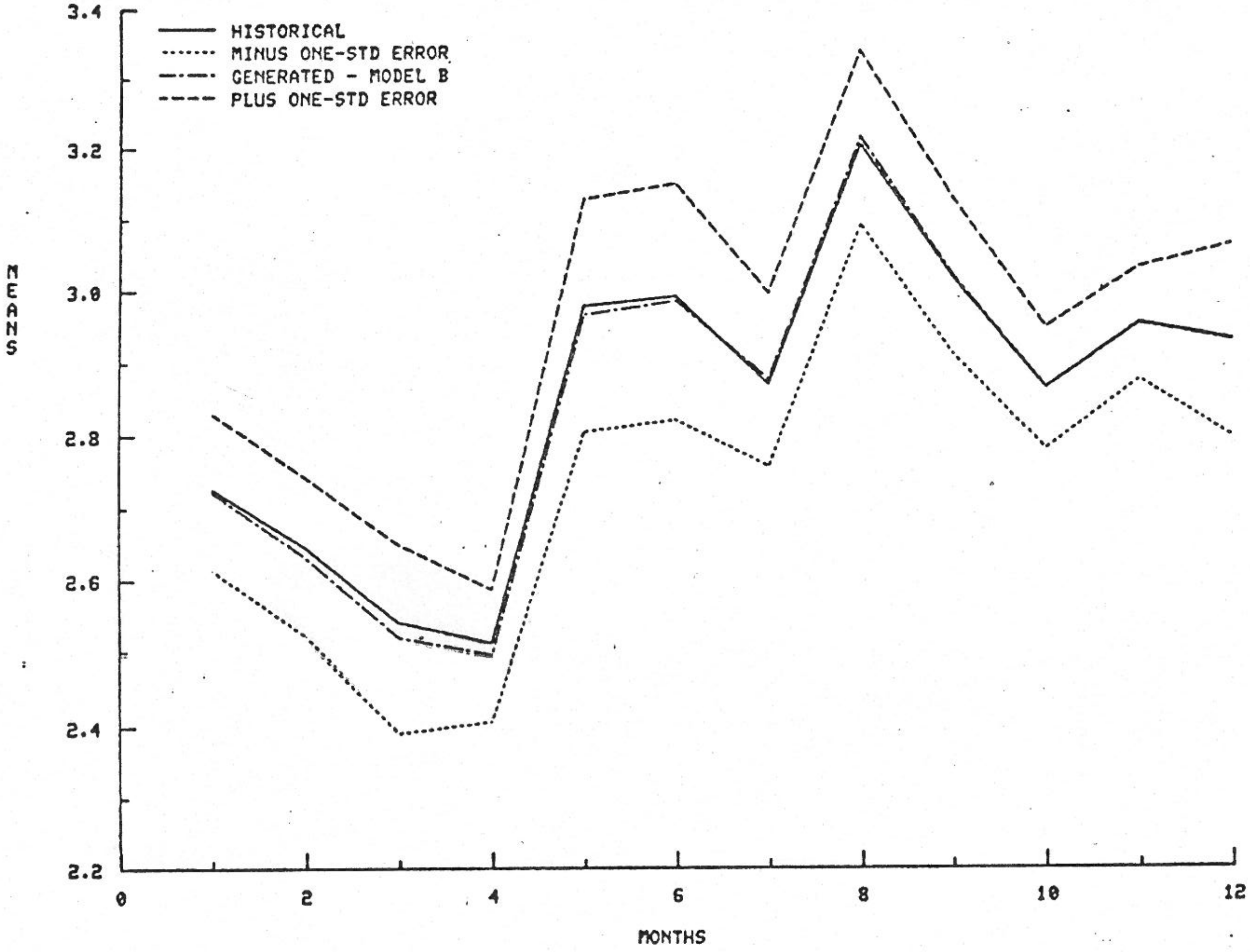

Figure 1.9.E.24. PASODE - MEANS (LOG DOMAIN)

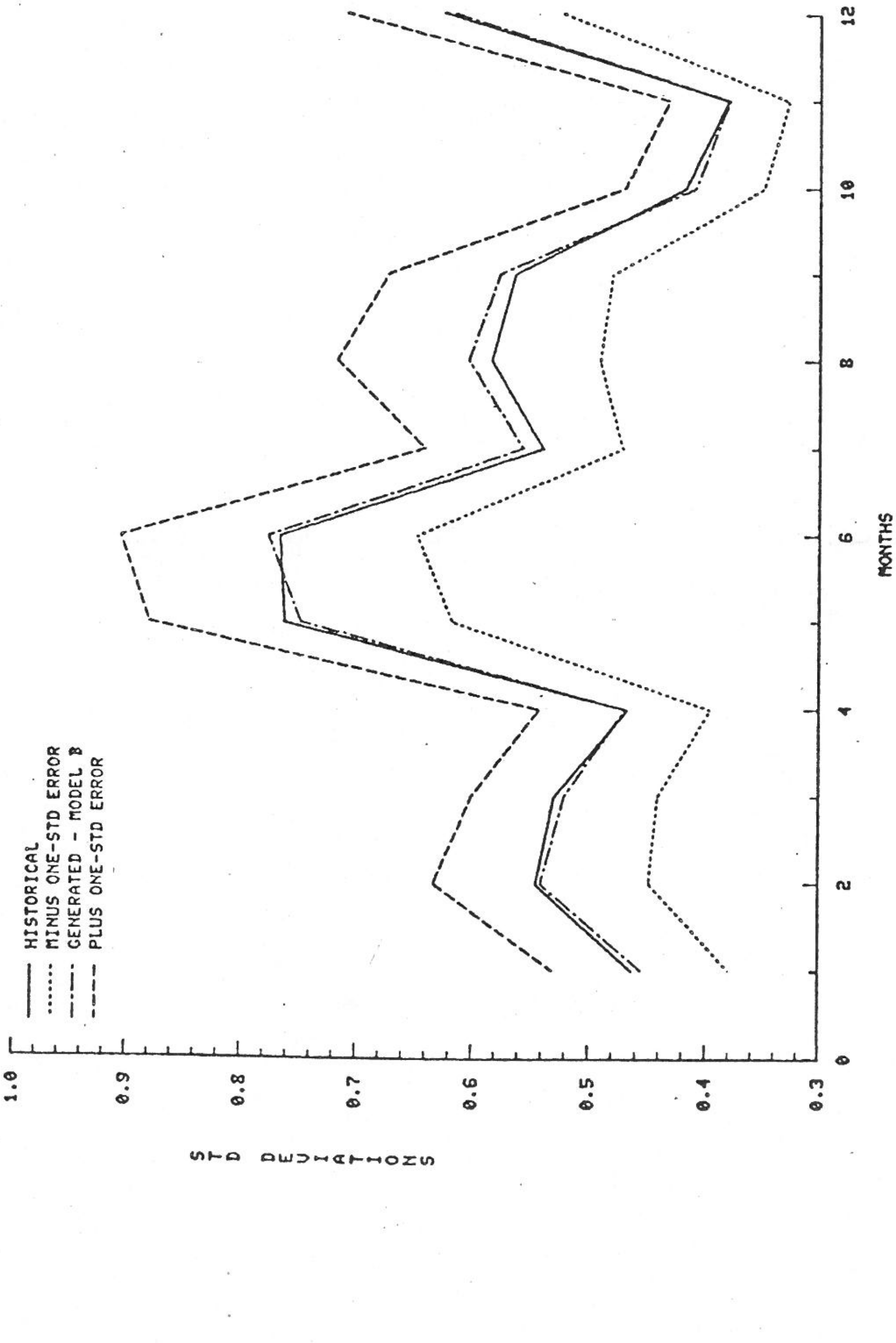

Figure 1.9.E.25. PASODE - STD DEVIATIONS (LOG DOMAIN)

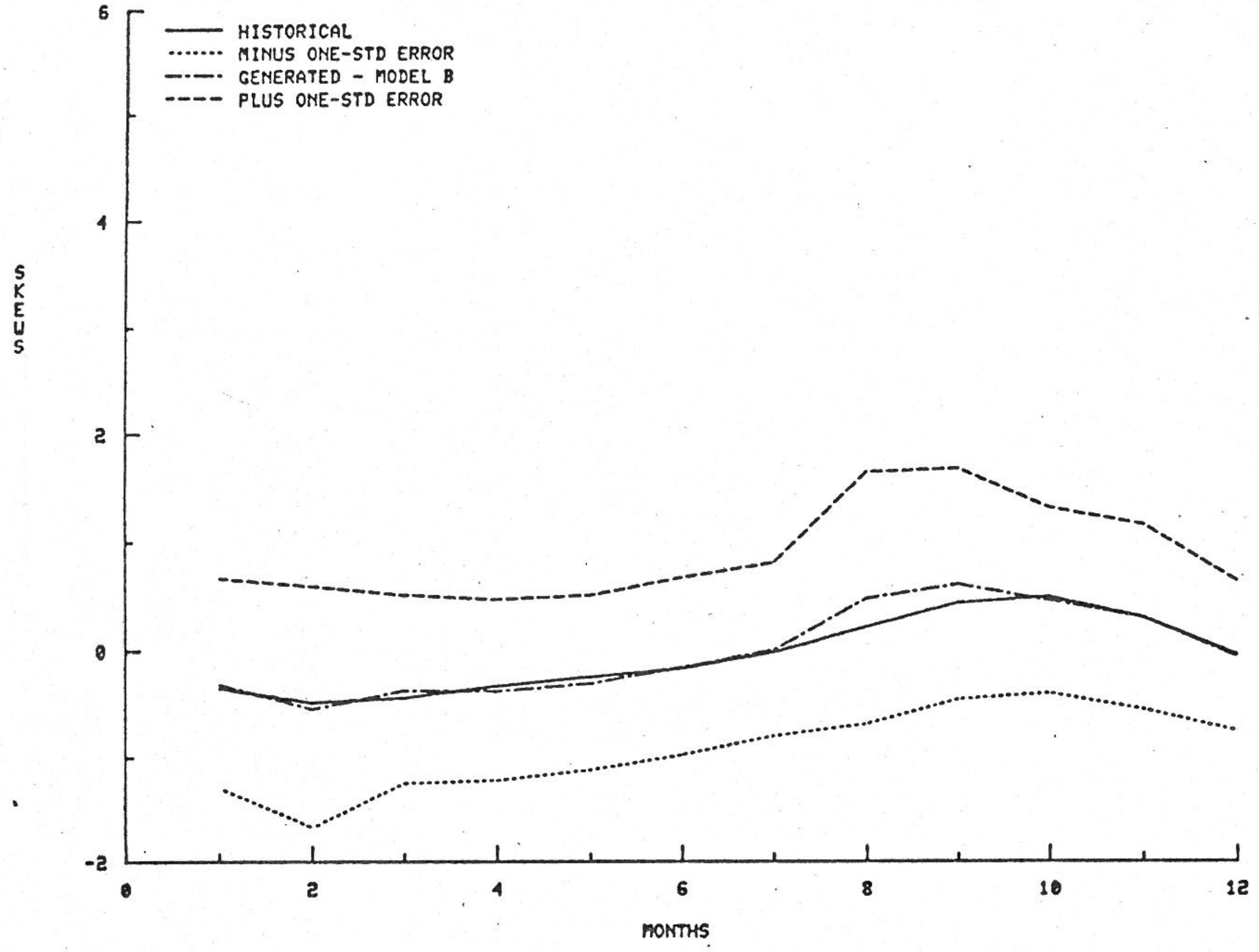

Figure 1.9.E.26. PASODE - SKEWS (LOG DOMAIN)

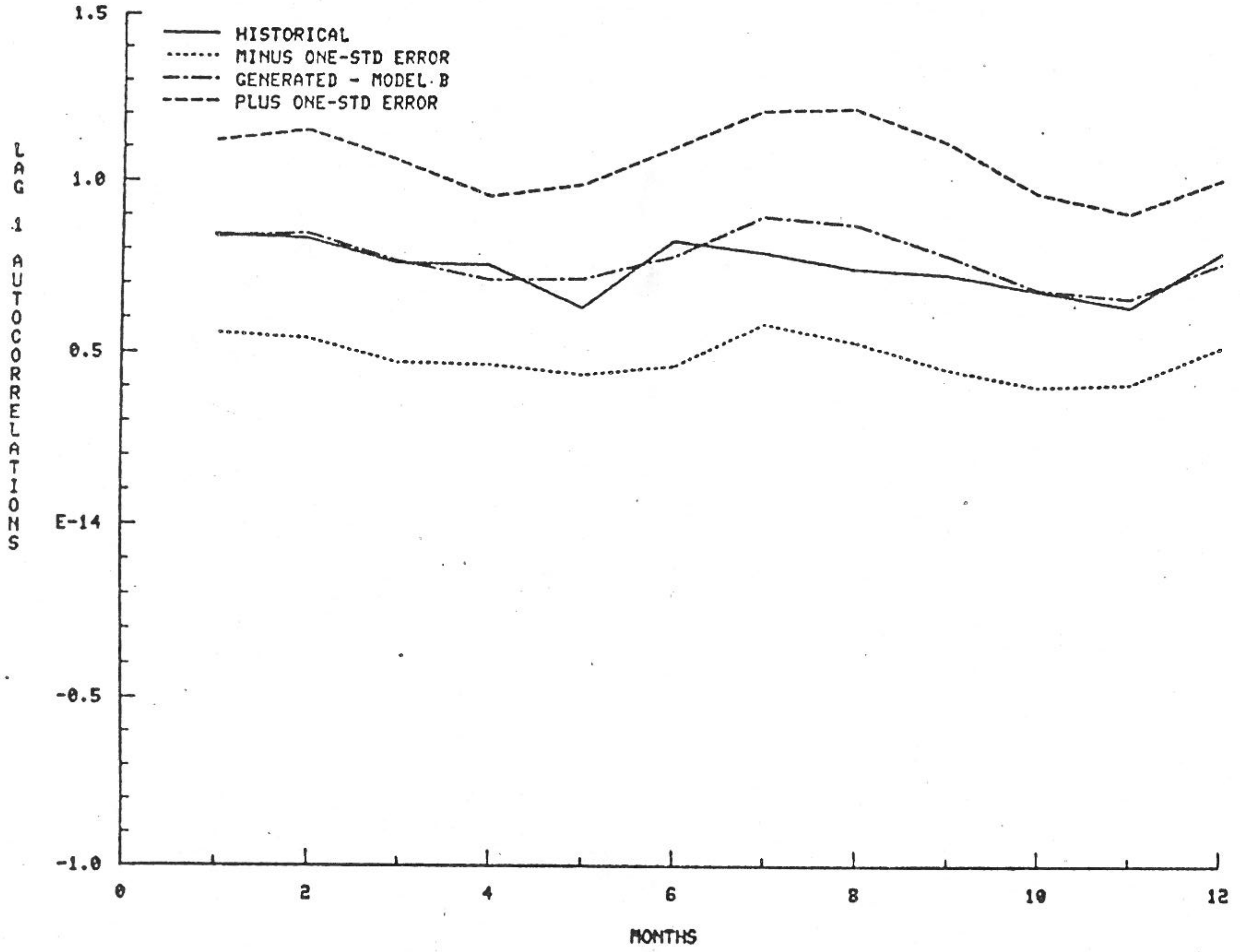

Figure 1.9.E.27. PASODE - LAG 1 AUTOCORRELATIONS (LOG DOMAIN)

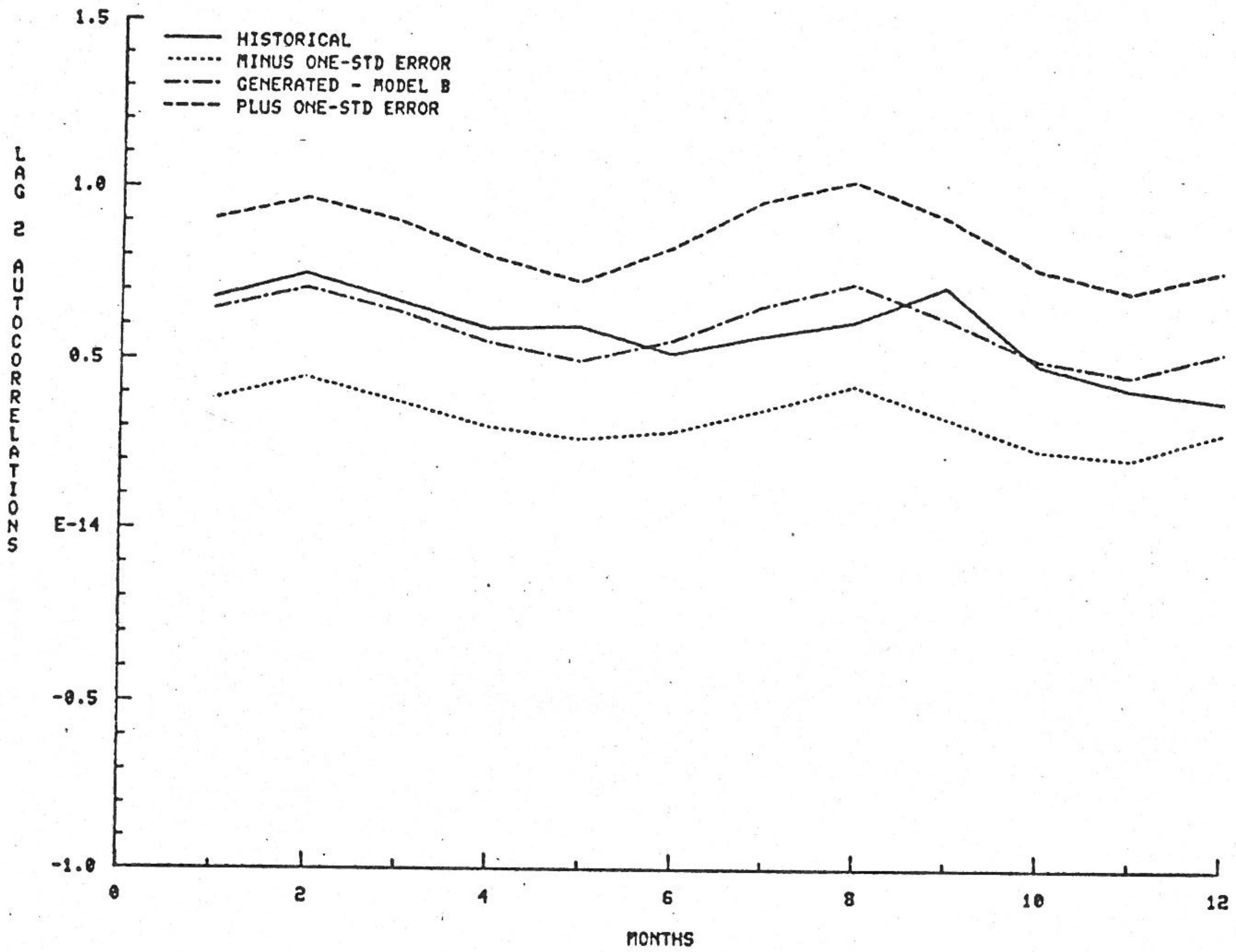

Figure 1.9.E.28. PASODE - LAG 2 AUTOCORRELATIONS (LOG DOMAIN)

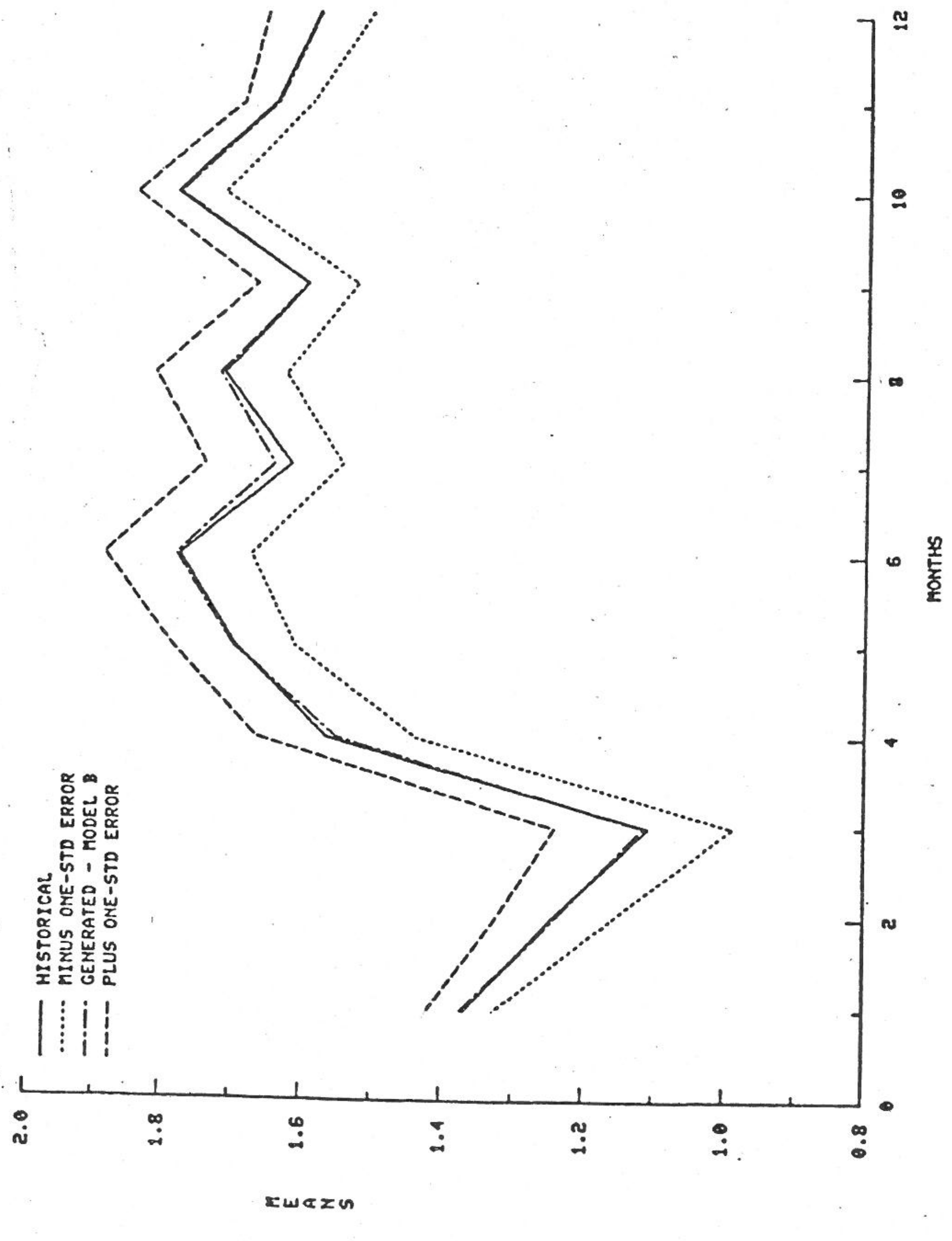

Figure 1.9.E.29. RANCHO - MEANS (LOG DOMAIN)

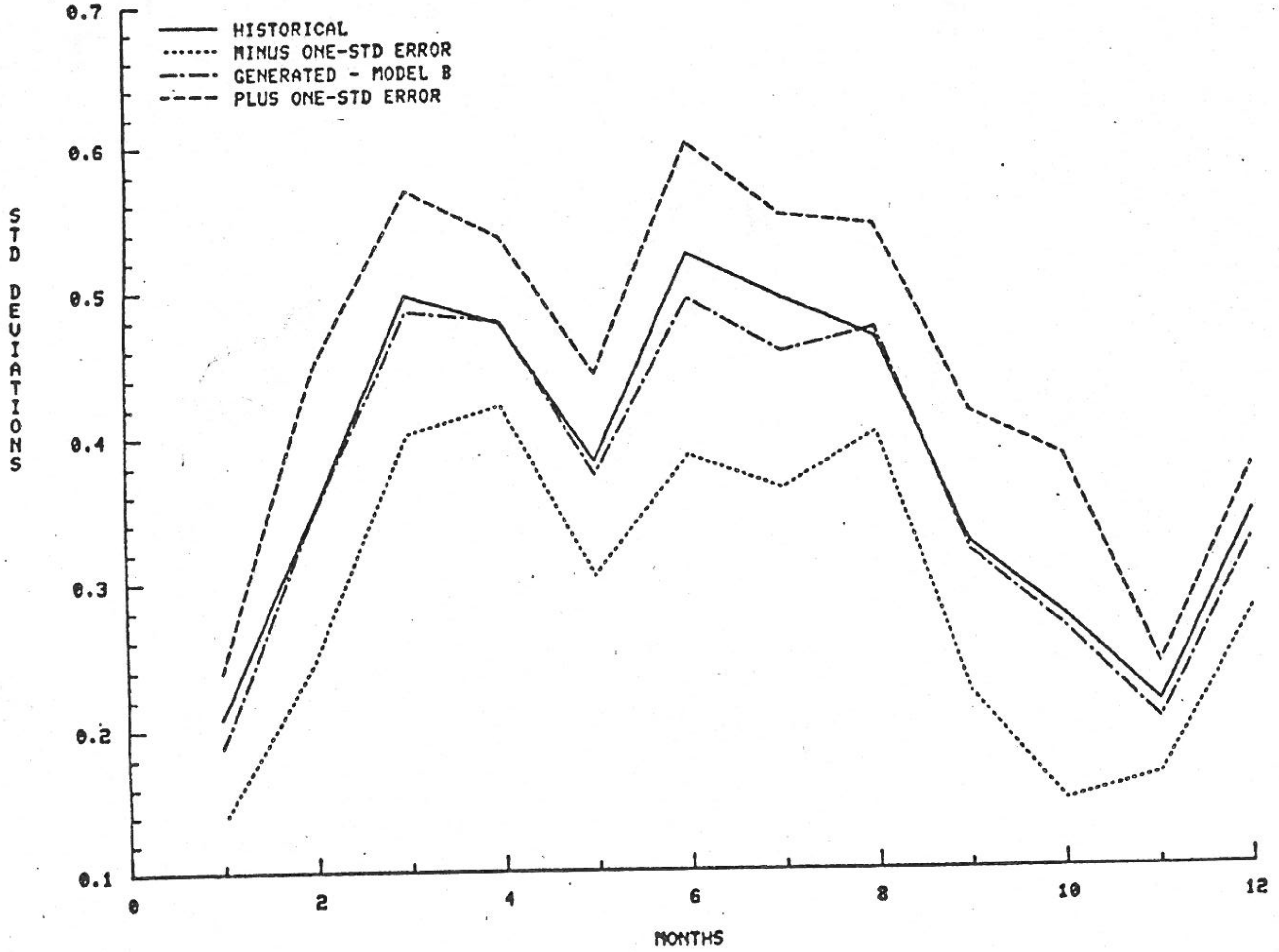

Figure 1.9.E.30. RANCHO - STD DEVIATIONS (LOG DOMAIN)

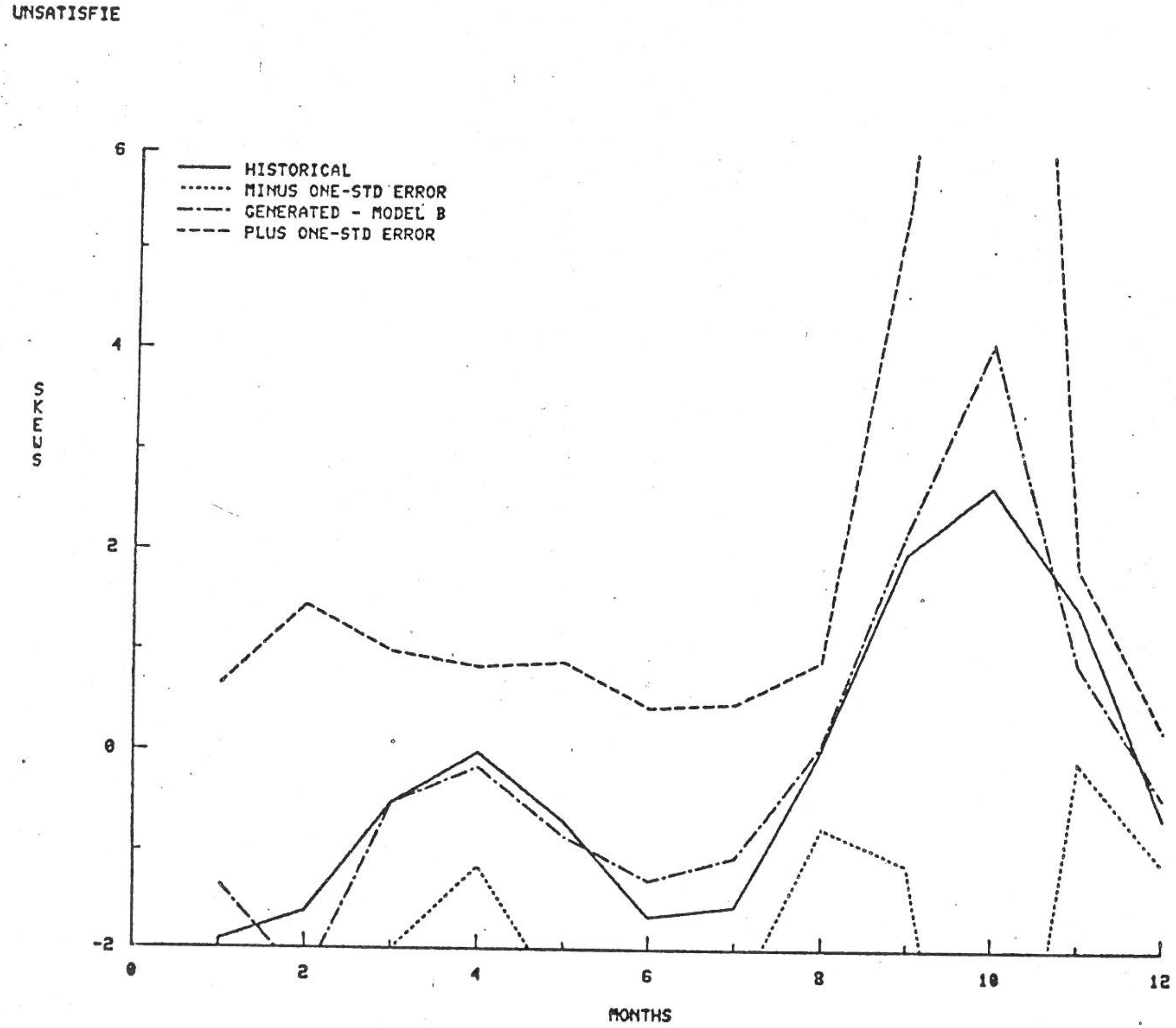

Figure 1.9.E.31. RANCHO - SKEWS (LOG DOMAIN)

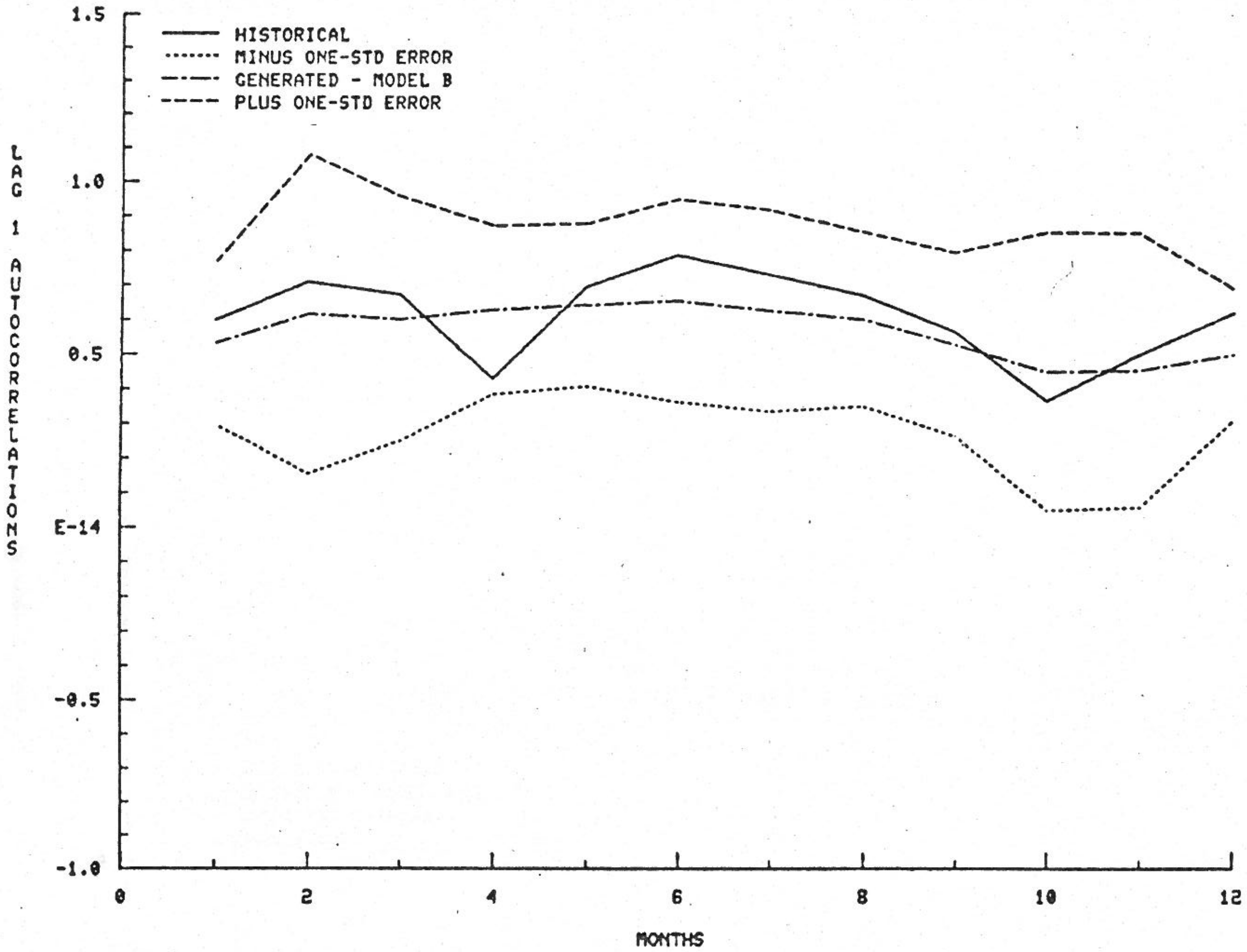

Figure 1.9.E.32. RANCHO - LAG 1 AUTOCORRELATIONS (LOG DOMAIN

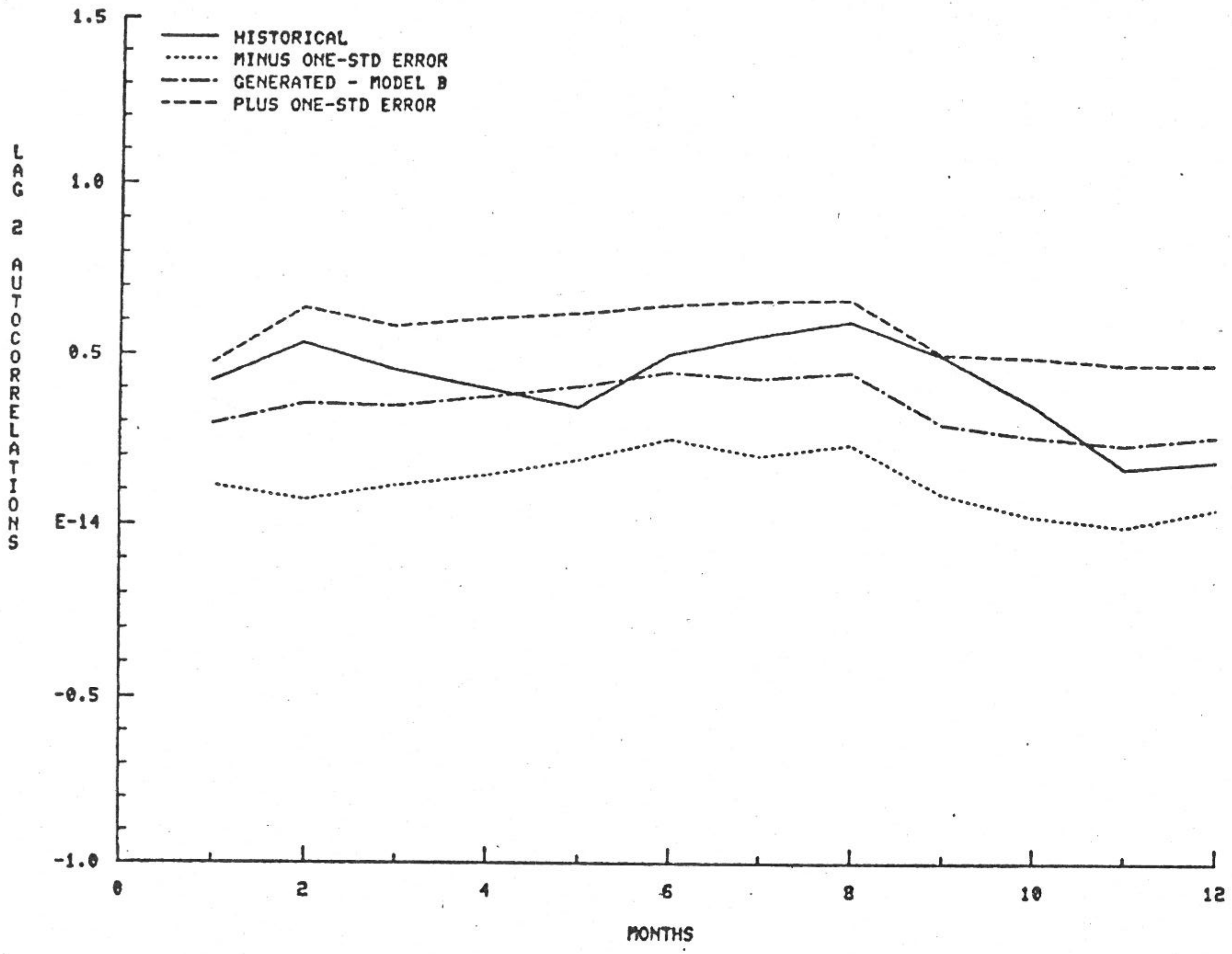

Figure 1.9.E.33. RANCHO - LAG 2 AUTOCORRELATIONS (LOG DOMAIN)

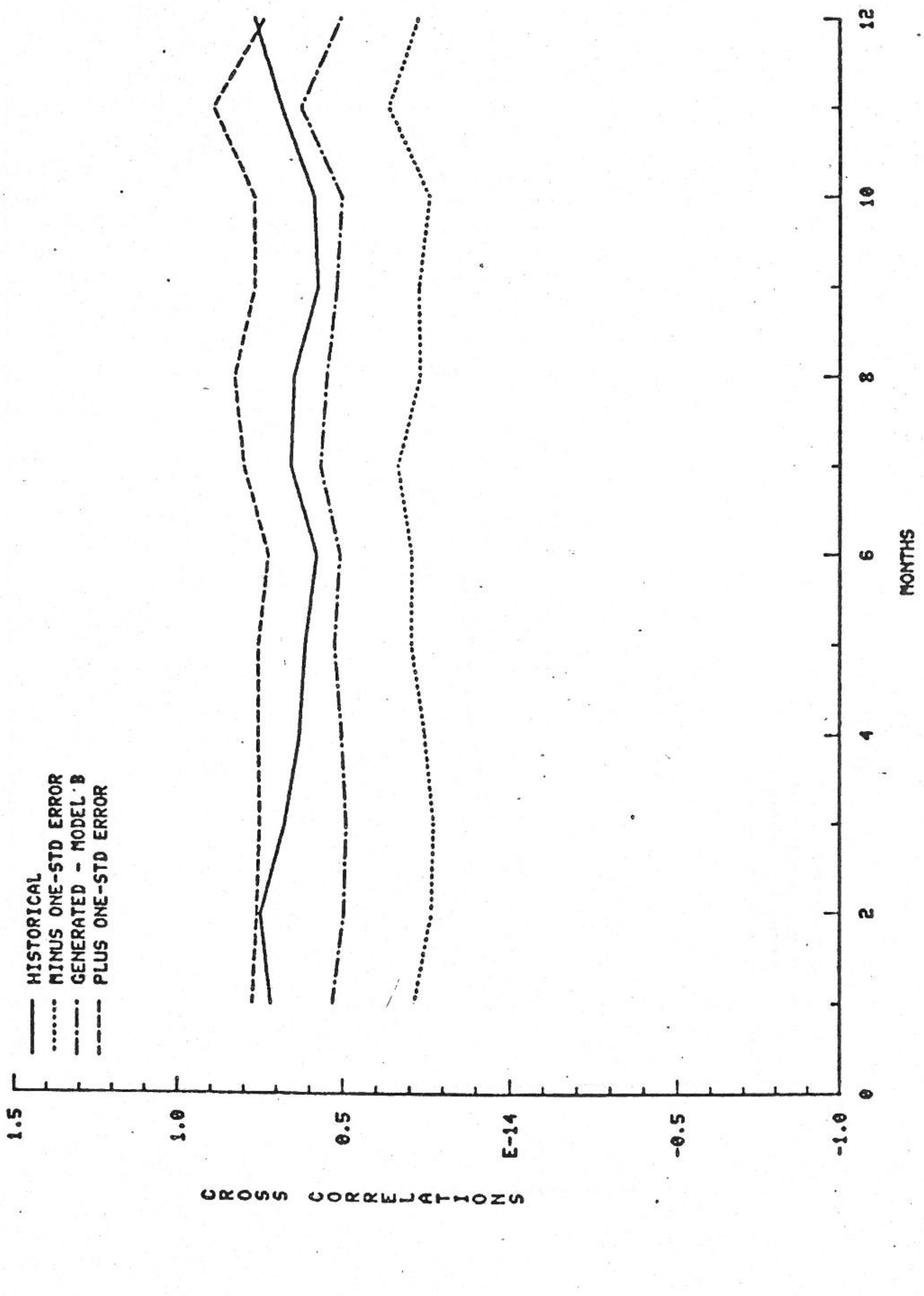

Figure 1.9.E.34. PALODE AND PASODE - CROSS CORRELATIONS (LOG DOMAIN)

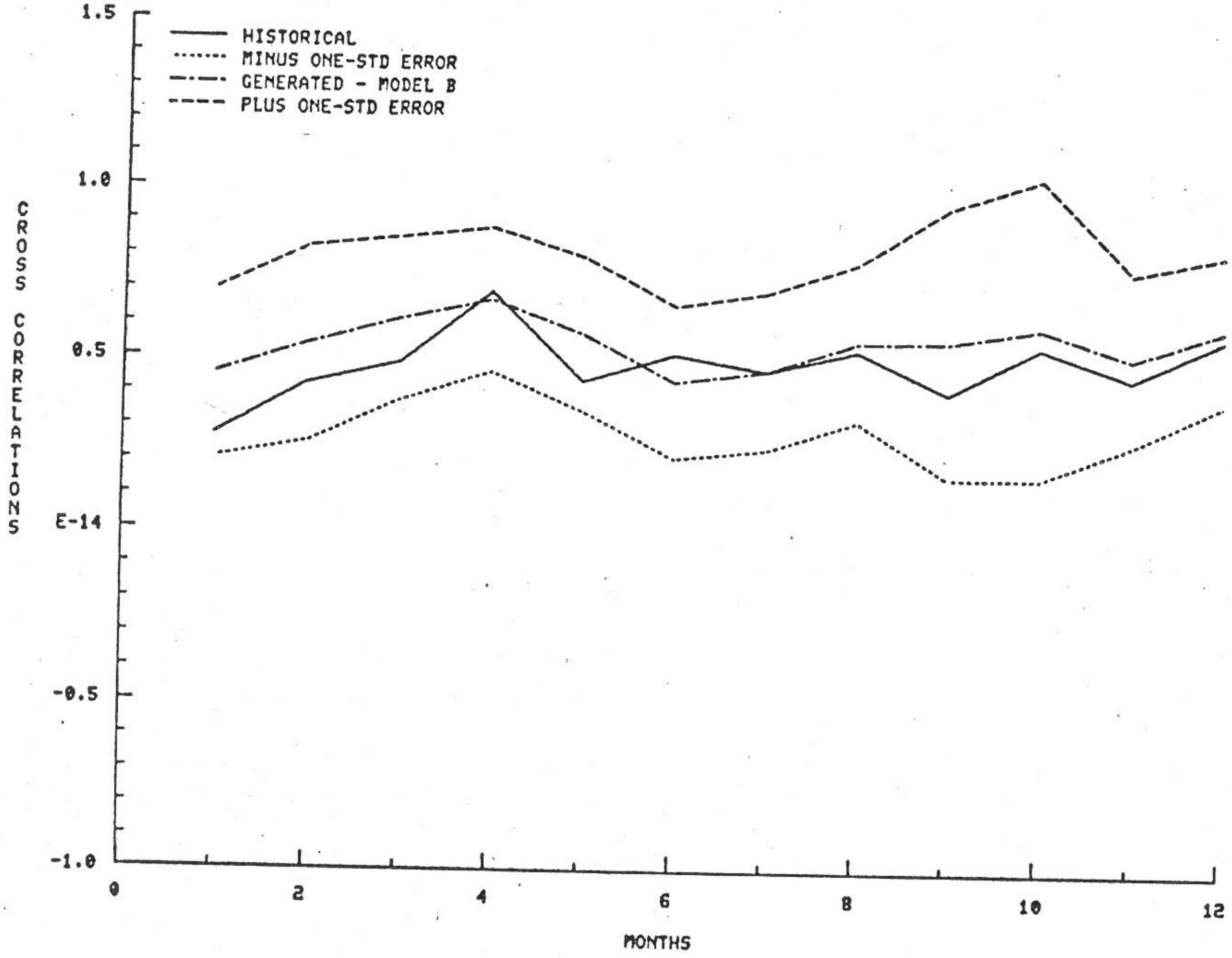

Figure 1.9.E.35. PALODE AND RANCHO - CROSS CORRELATIONS (LOG DOMAIN)

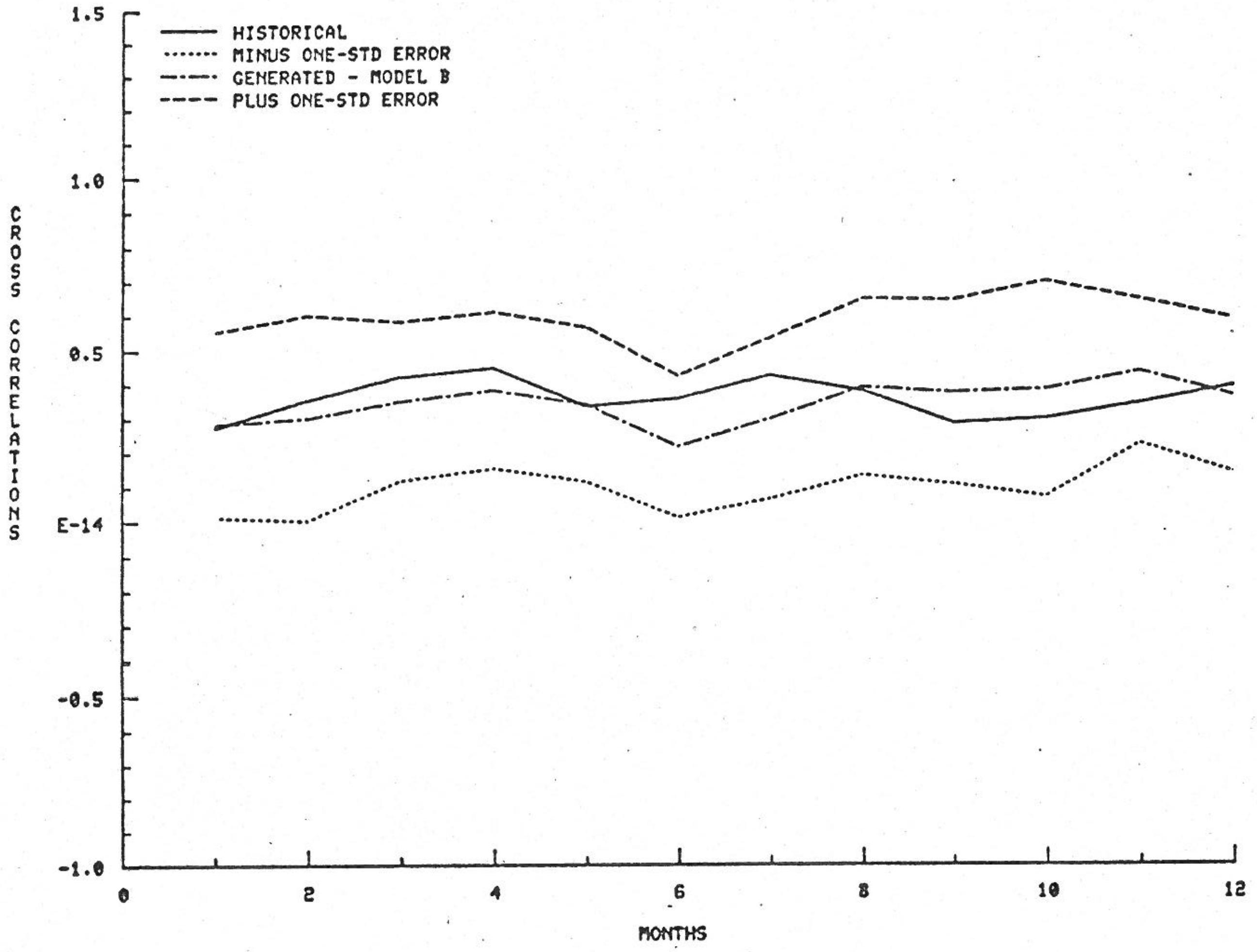

Figure 1.9.E.36. PASODE AND RANCHO - CROSS CORRELATIONS (LOG DOMAIN)

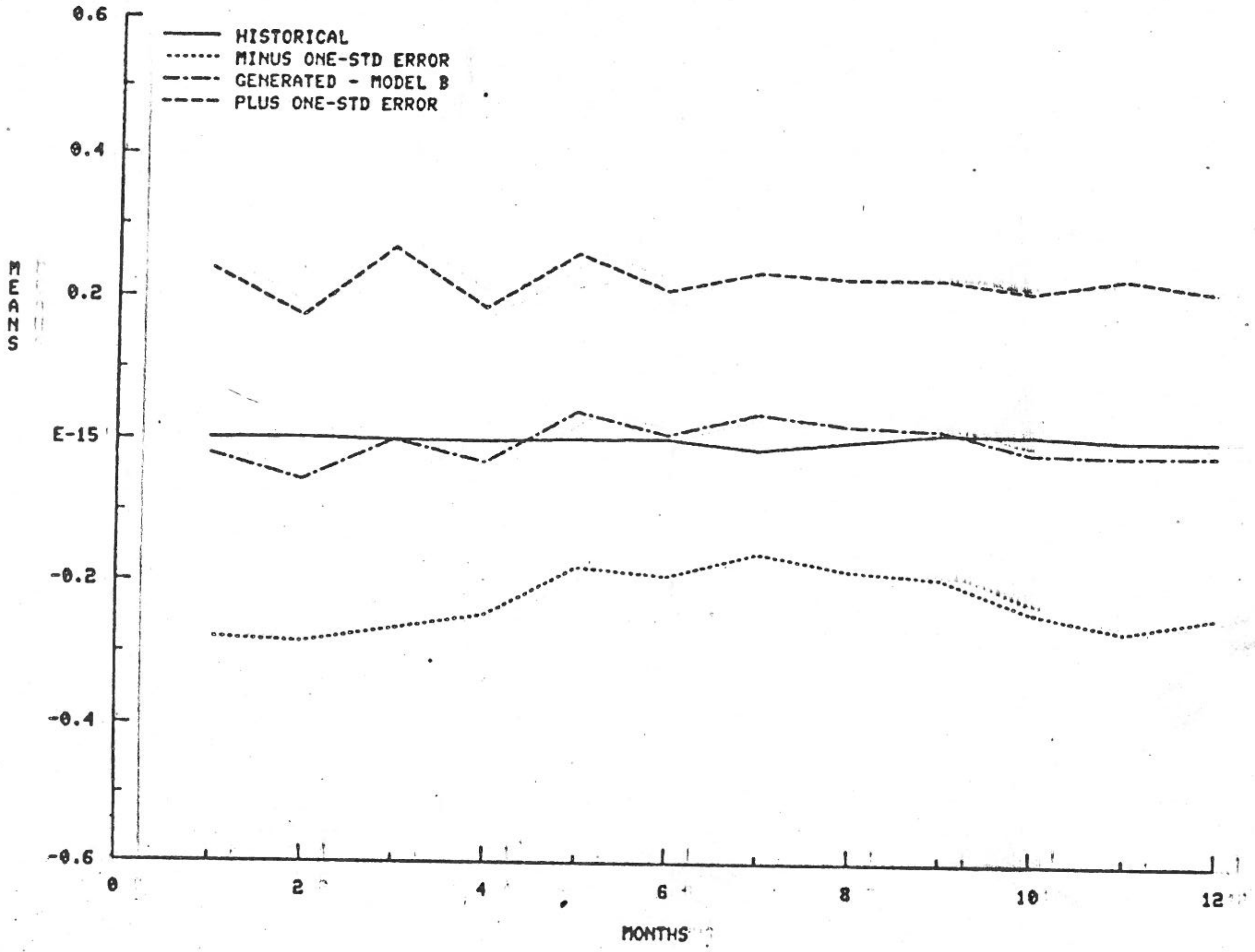

Figure 1.9.E.37. PALODE - MEANS (LWH DOMAIN)

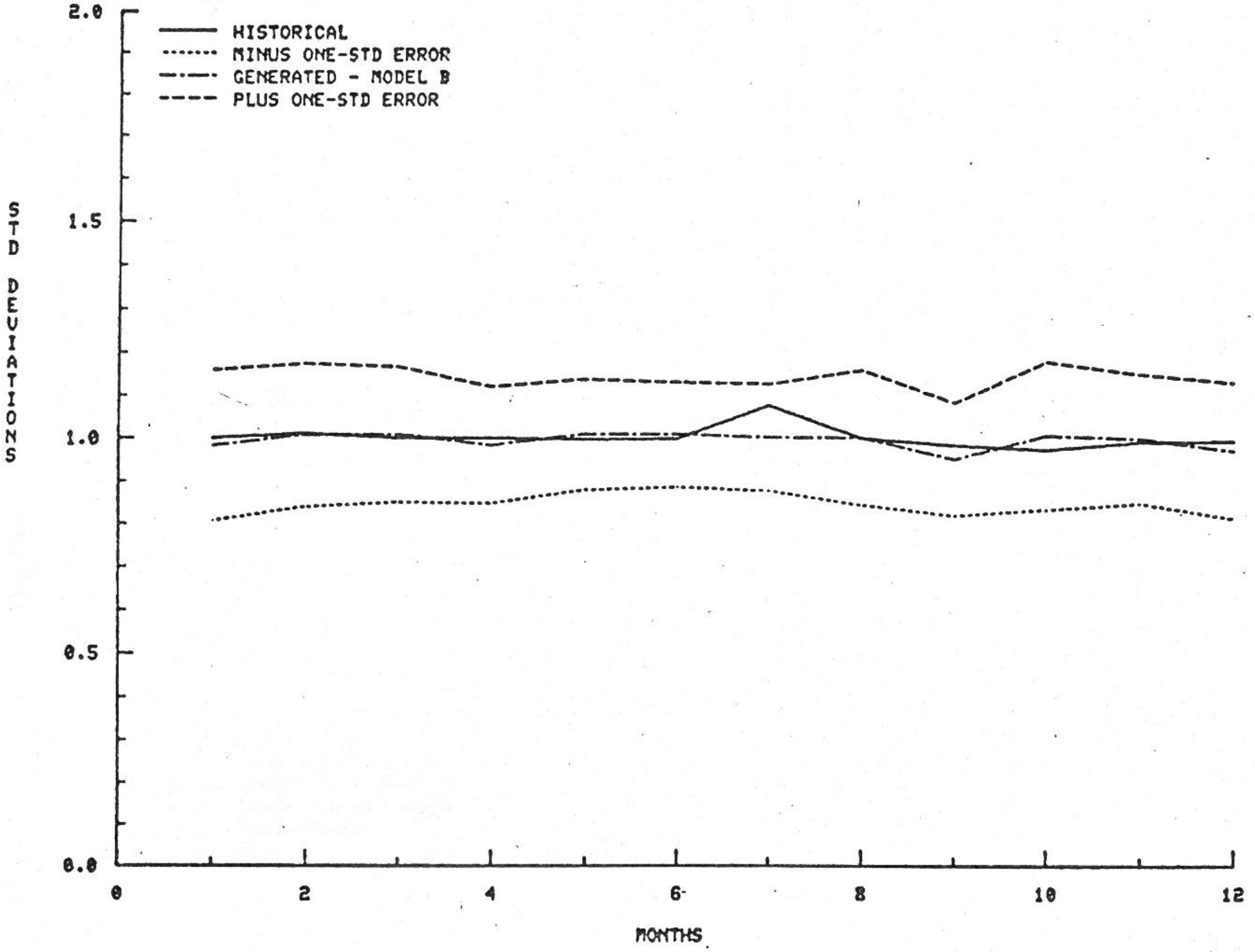

Figure 1.9.E.38. PALODE - STD DEVIATIONS (LWH DOMAIN)

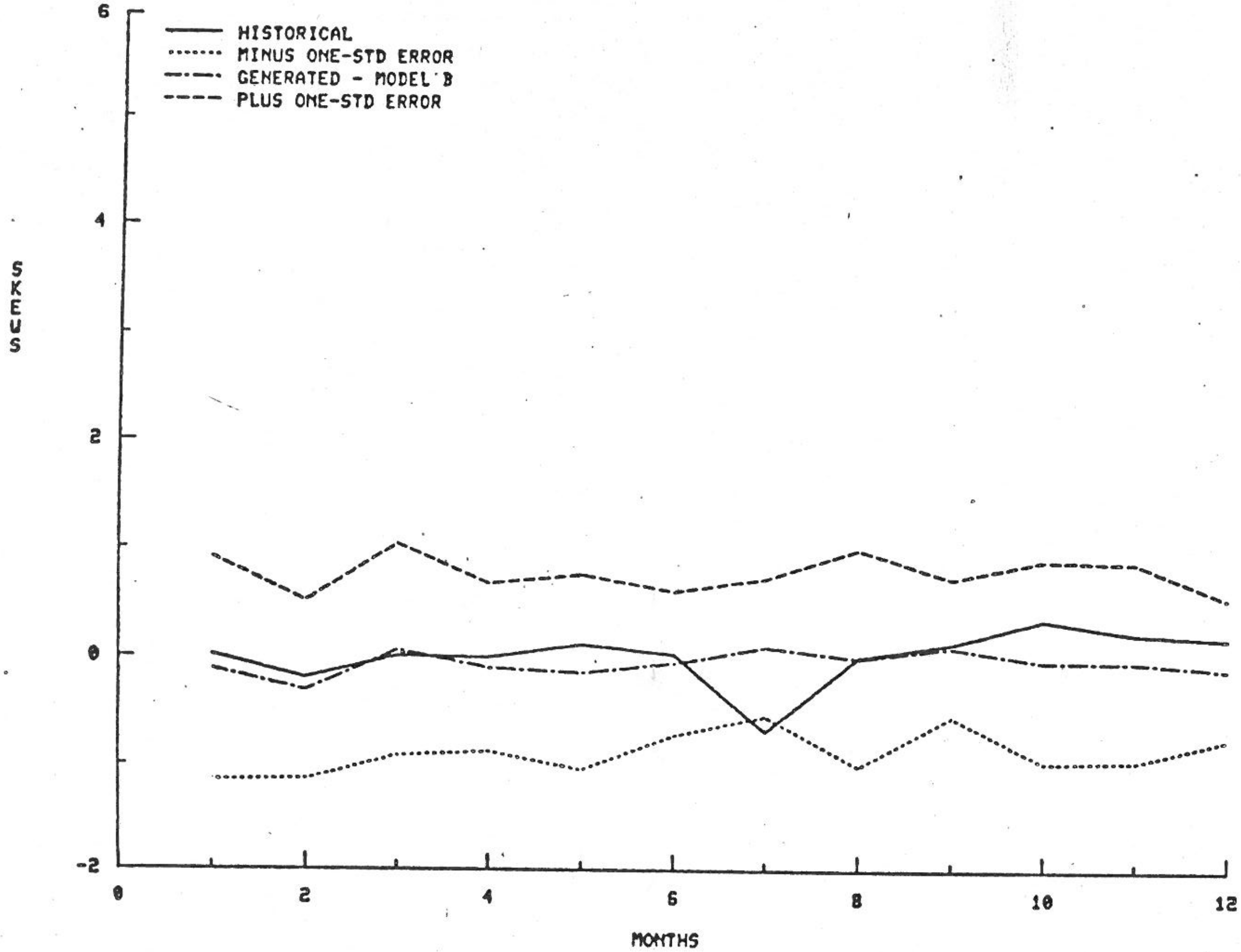

Figure 1.9.E.39. PALODE - SKEWS (LWH DOMAIN)

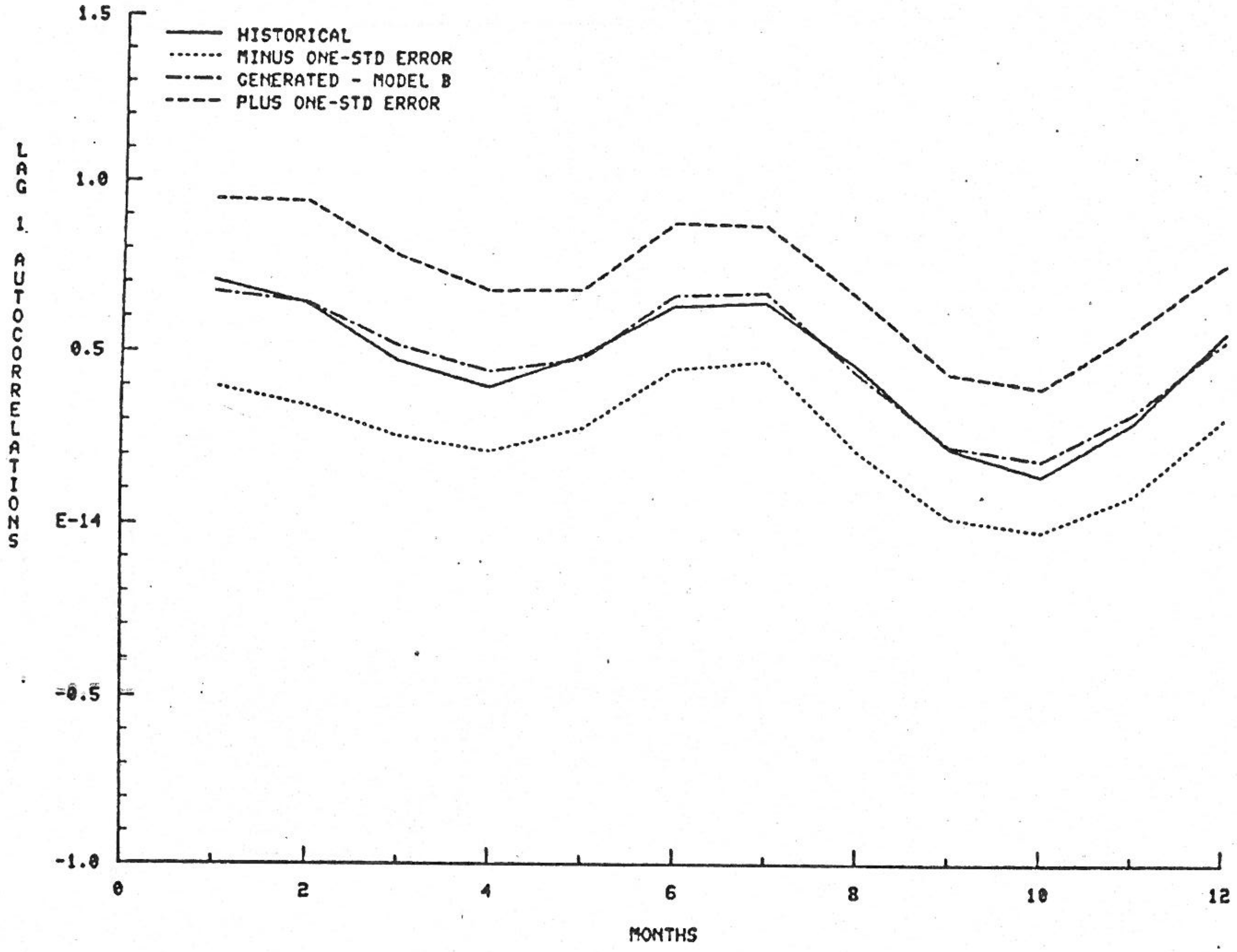

Figure 1.9.E.40. PALODE - LAG 1 AUTOCORRELATIONS (LWH DOMAIN)

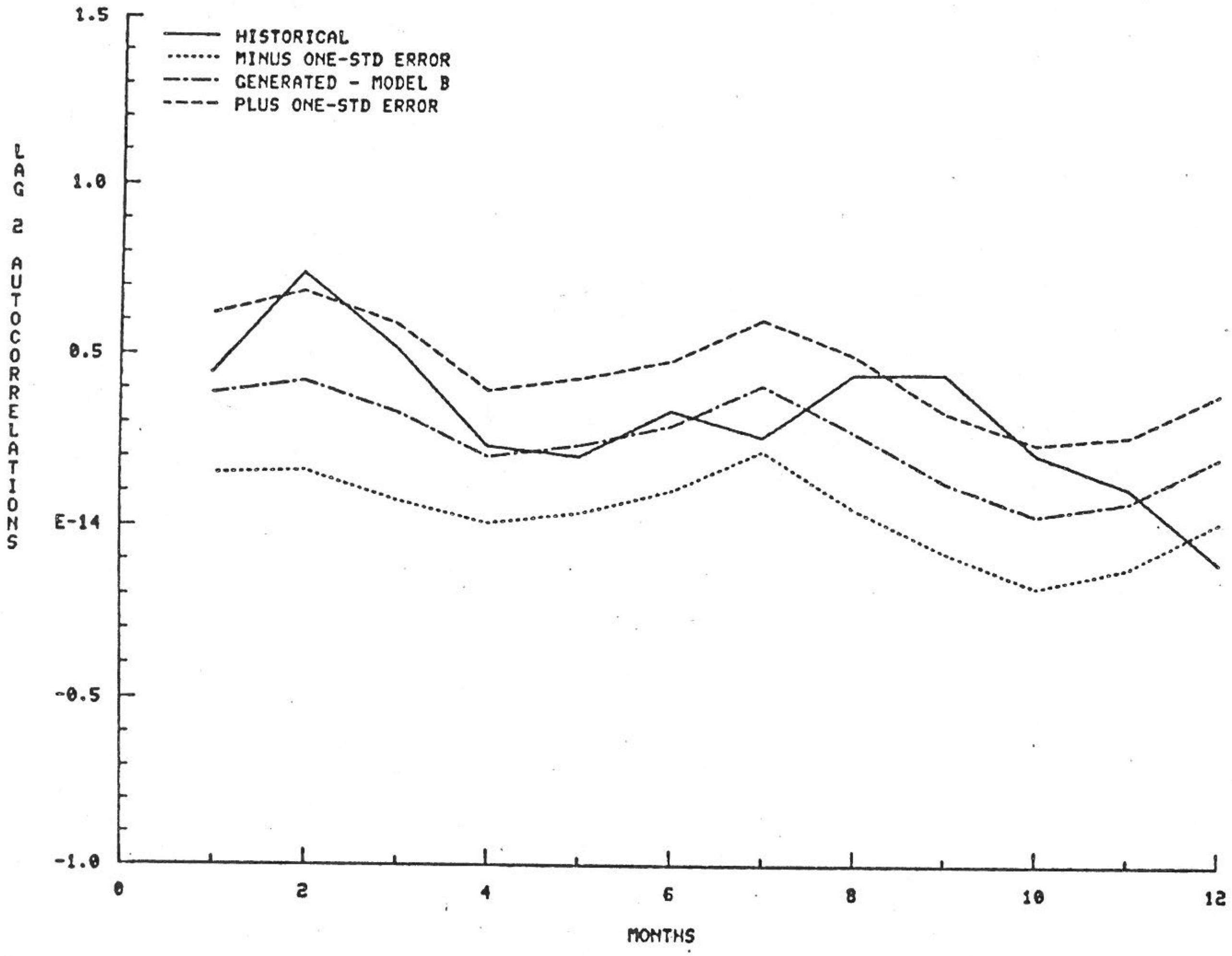

Figure 1:9.E.41. PALODE - LAG 2 AUTOCORRELATIONS (LWH DOMAIN)

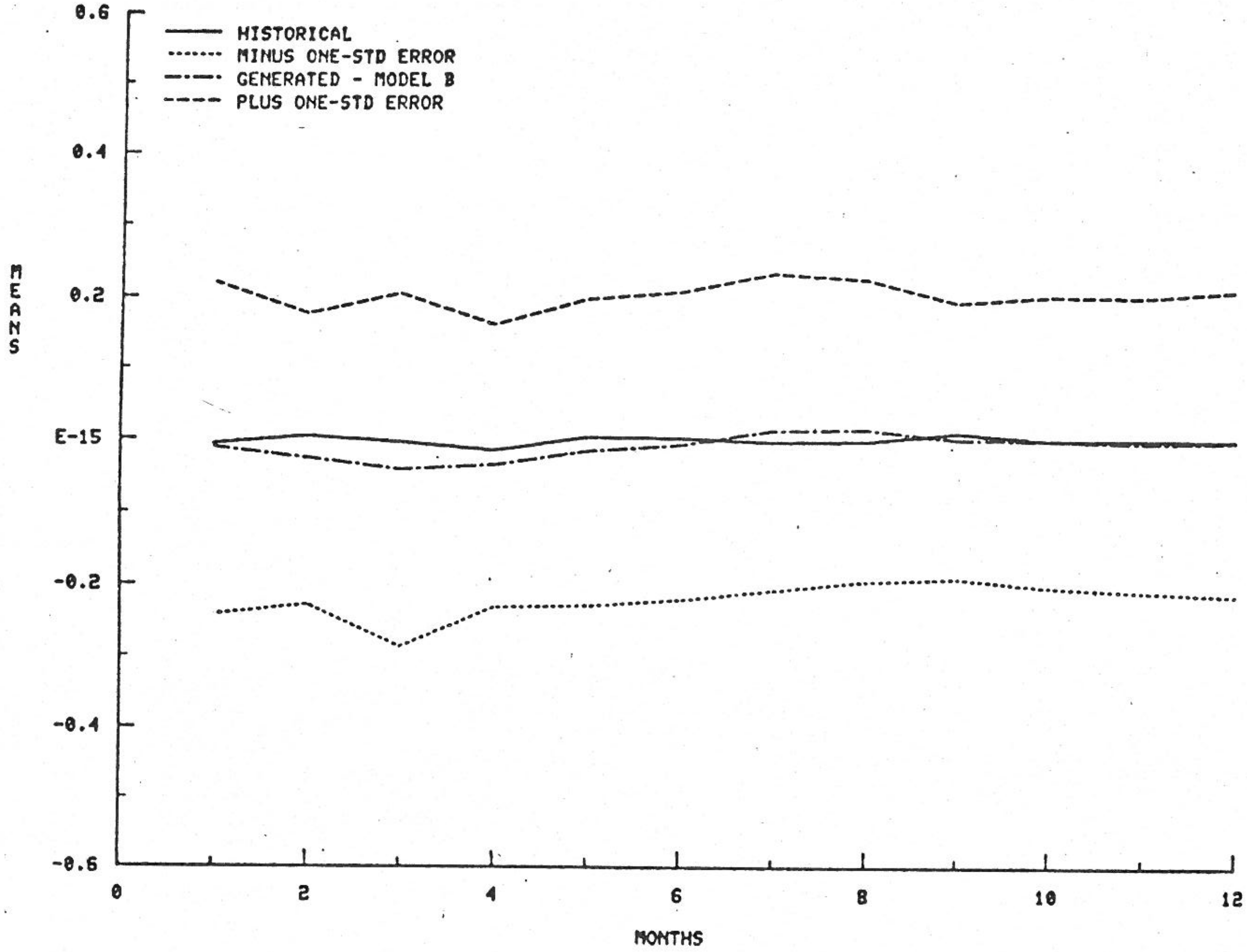

Figure 1.9.E.42. PASODE - MEANS (LWH DOMAIN)

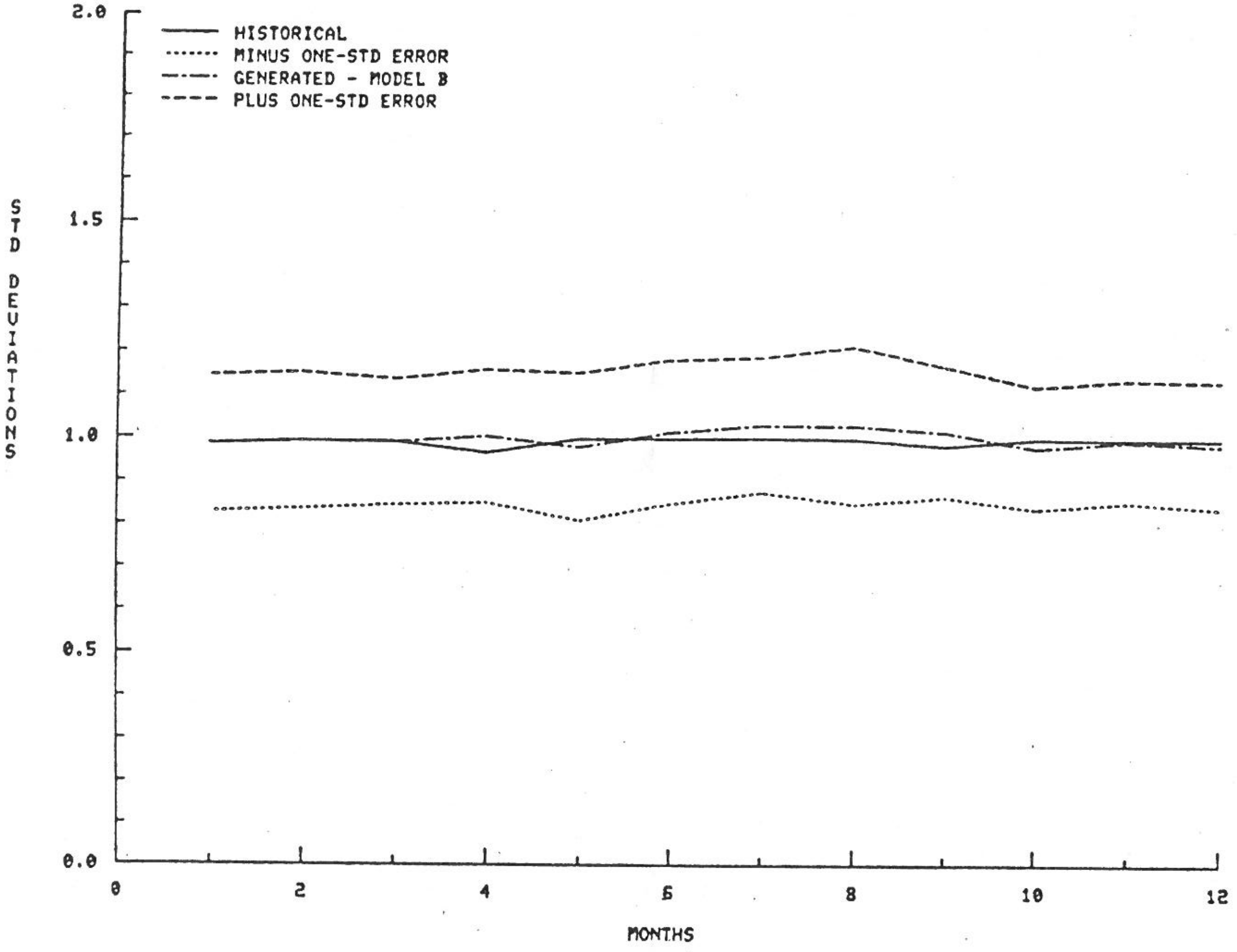

Figure 1.9.E.43. PASODE - STD DEVIATIONS (LWH DOMAIN)

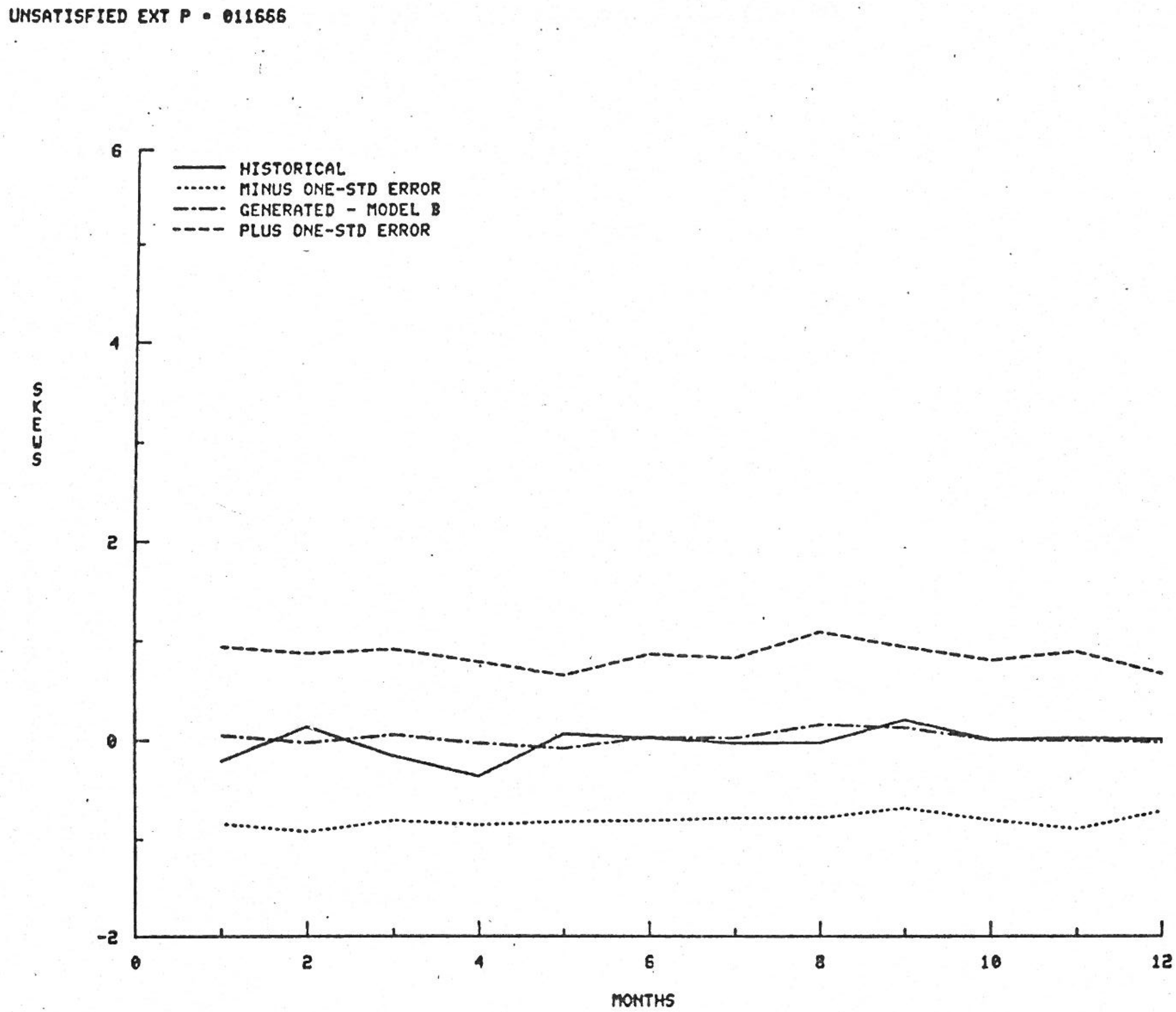

Figure 1.9.E.44. PASODE - SKEWS (LWH DOMAIN)

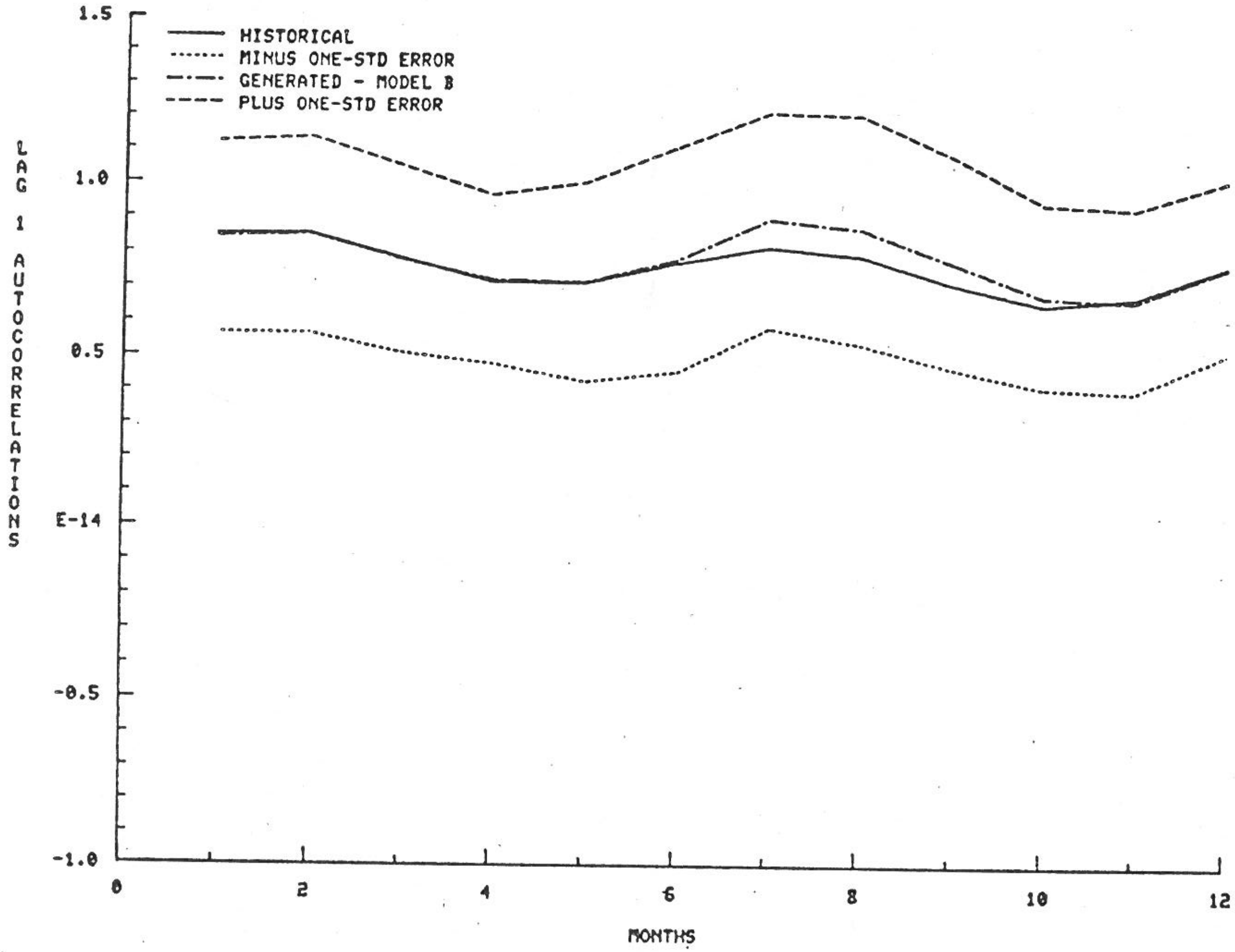

Figure I.9.E.45. PASODE - LAG 1 AUTOCORRELATIONS (LWH DOMAIN)

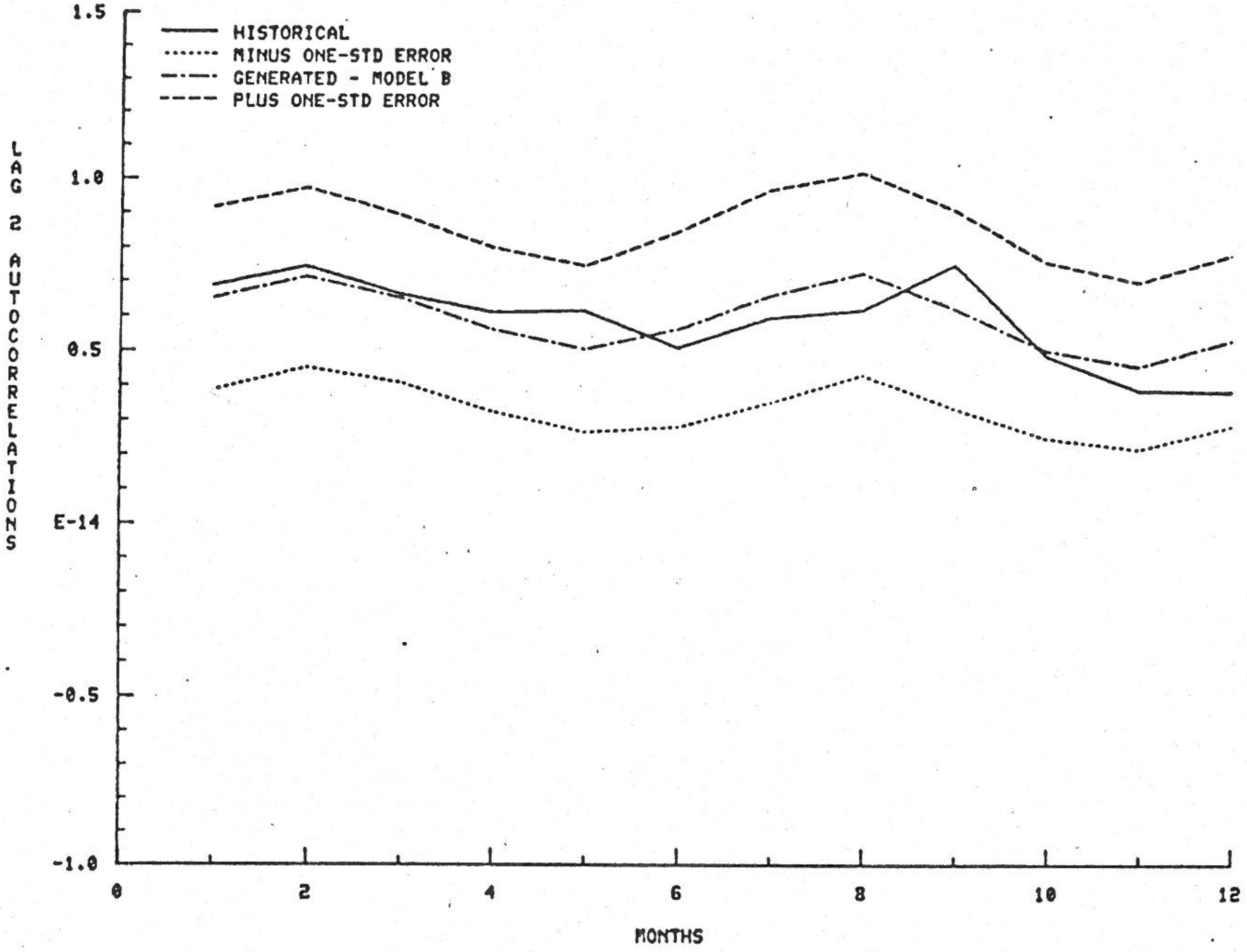

Figure 1.9.E.46. PASODE - LAG 2 AUTOCORRELATIONS (LWH DOMAIN)

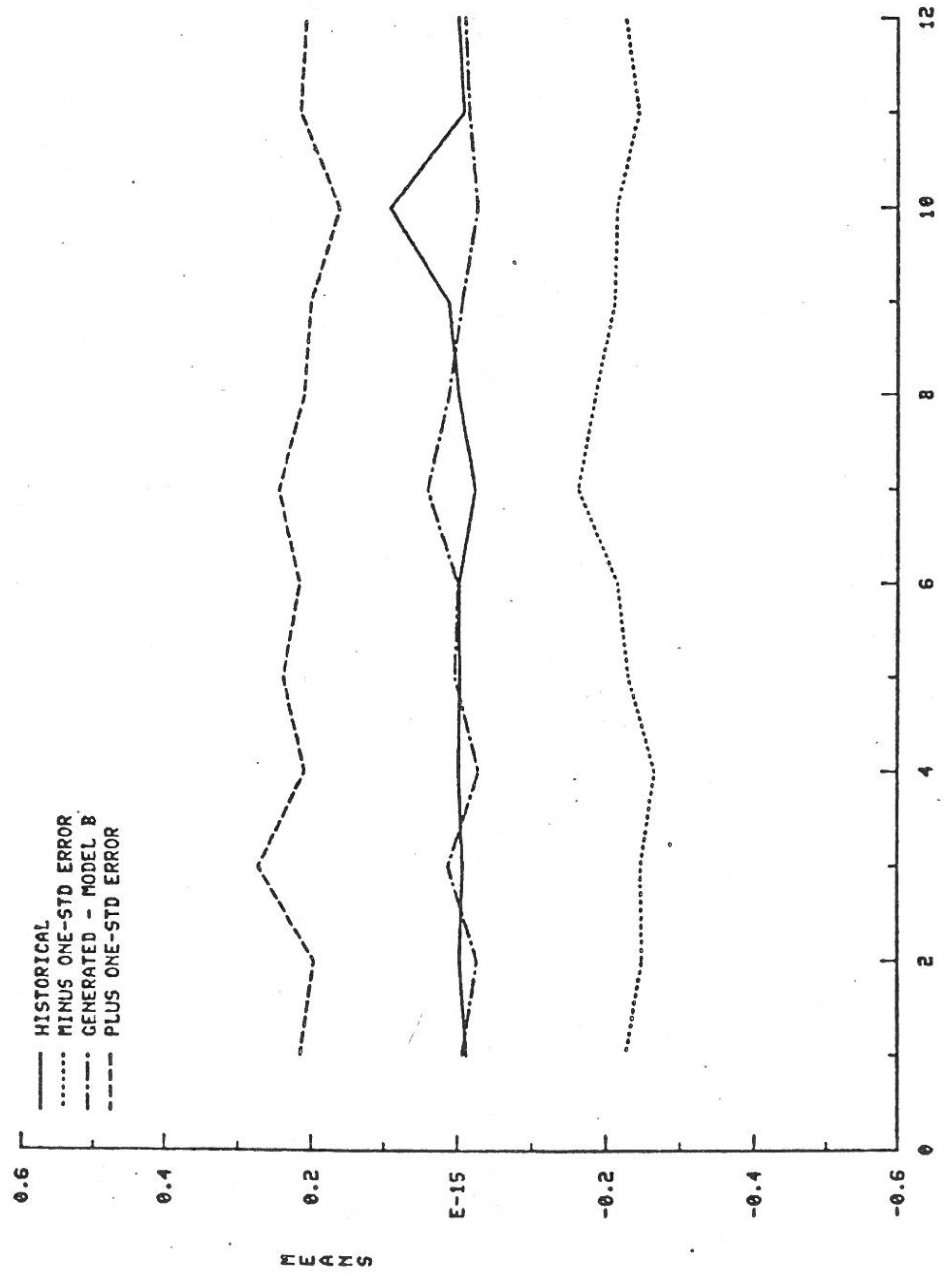

Figure 1.9.E.47. RANCHO - MEANS (LWH DOMAIN)

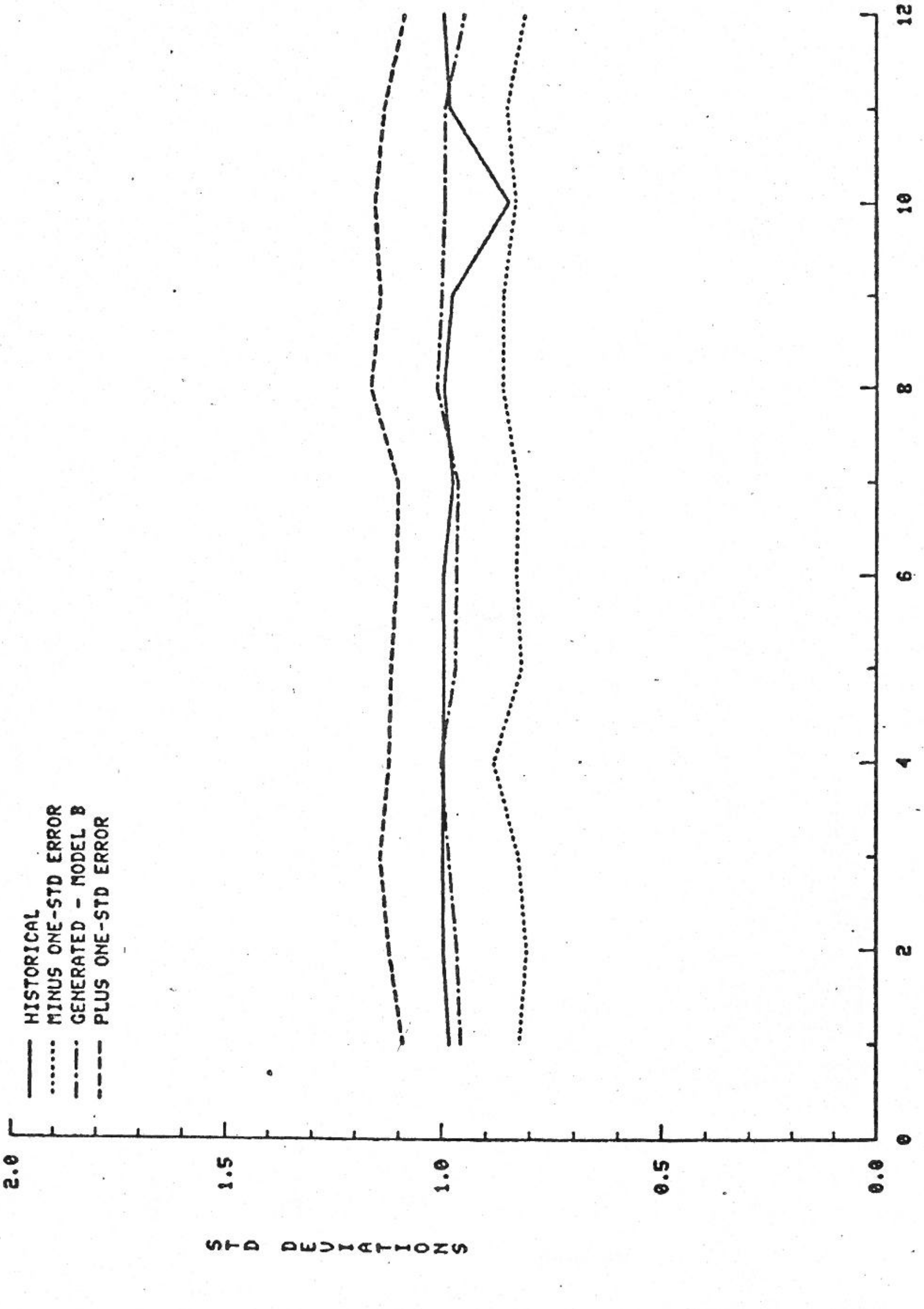

Figure 1.9.E.48. RANCHO - STD DEVIATIONS (LWH DOMAIN)

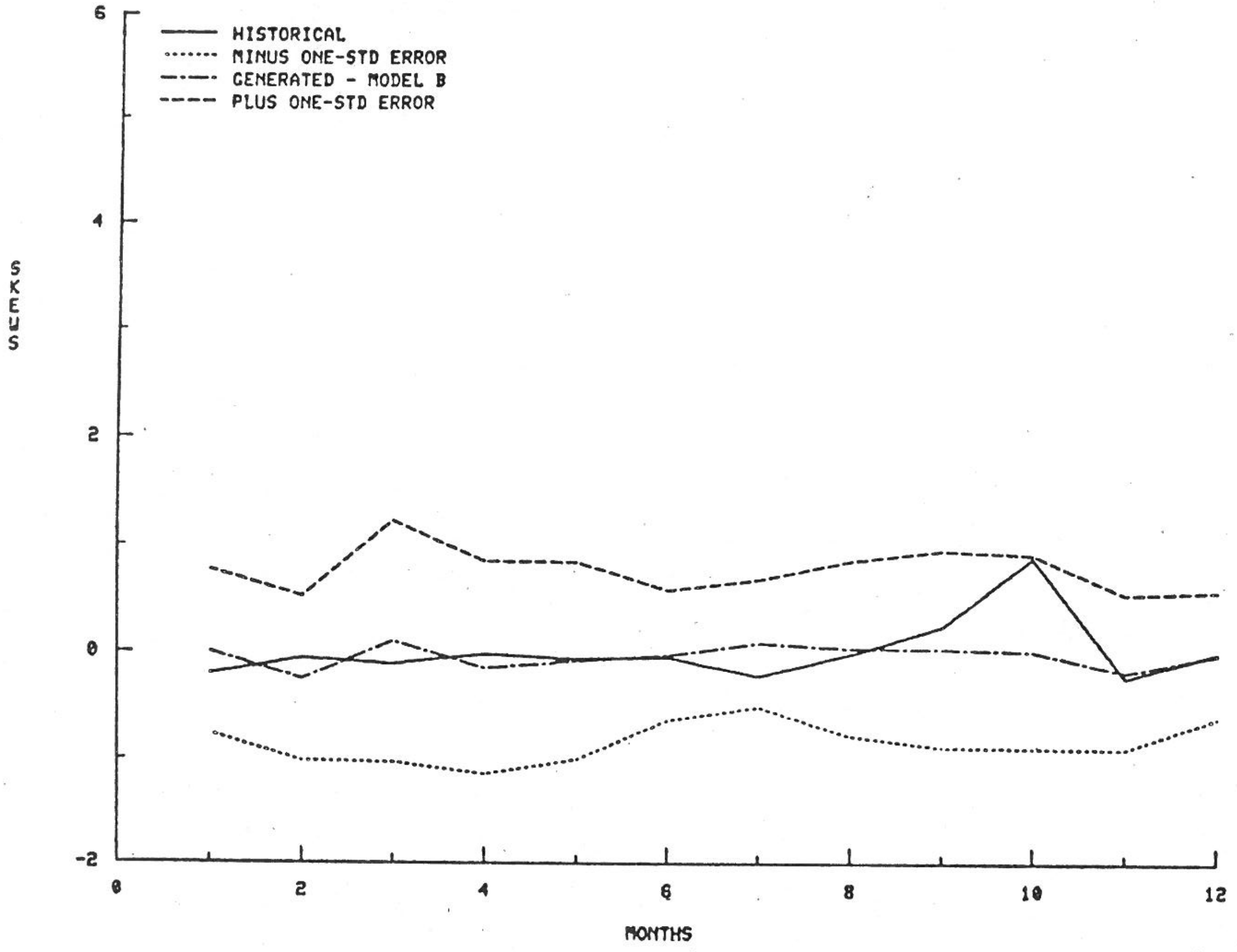

Figure 1.9.E.49. RANCHO - SKEWS (LWH DOMAIN)

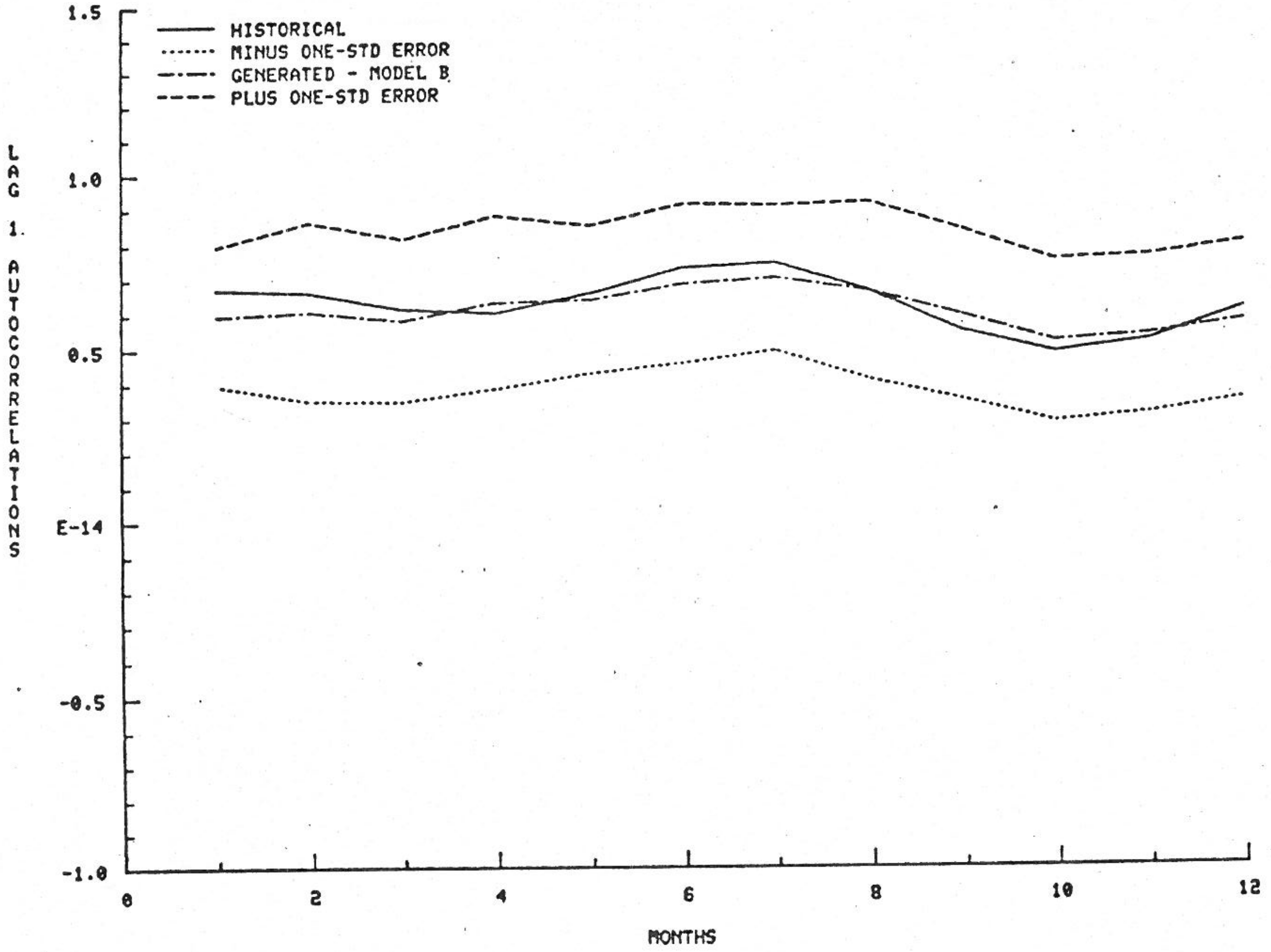

Figure 1.9.E.50. RANCHO - LAG 1 AUTOCORRELATIONS (LWH DOMAIN)

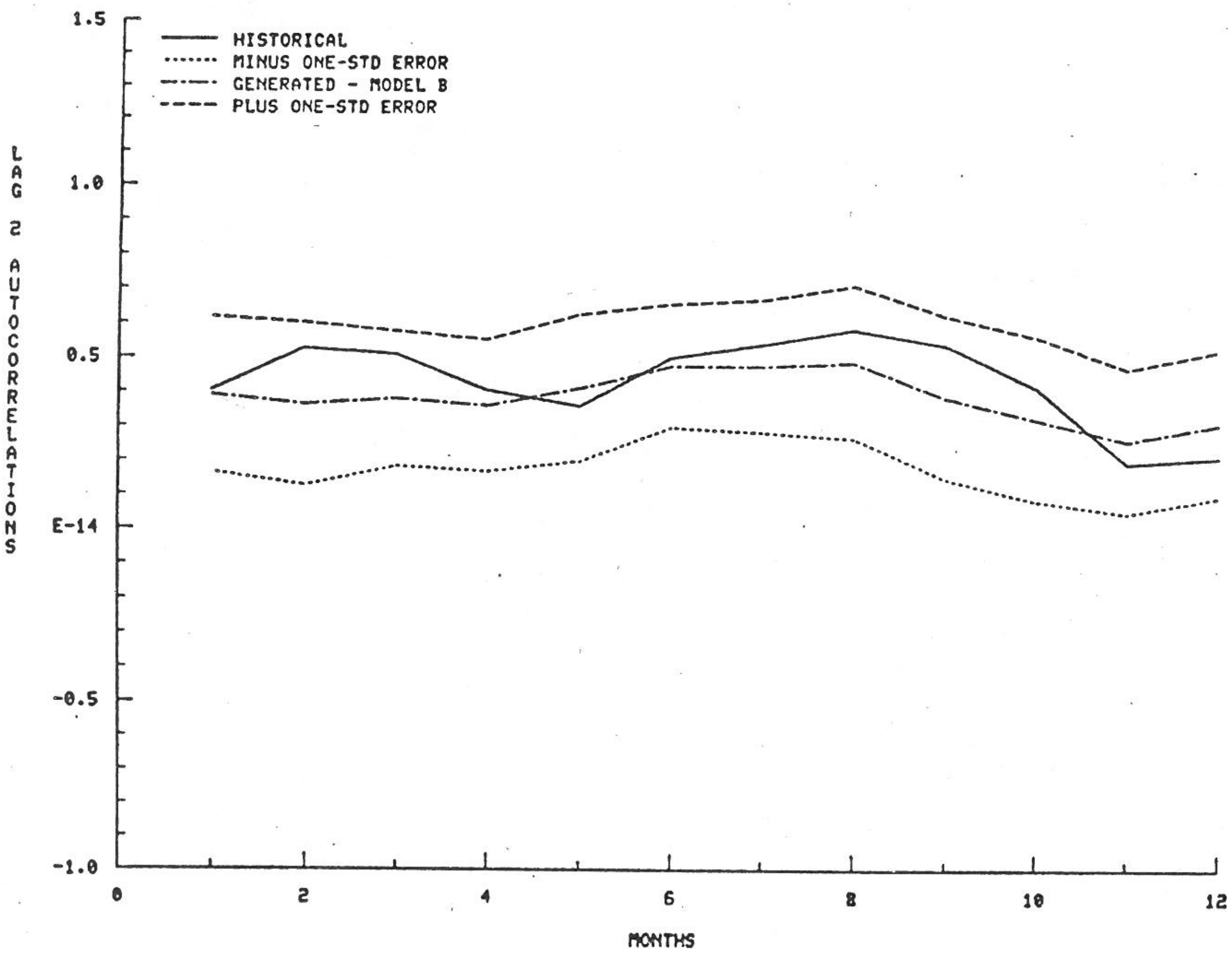

Figure 1.9.E.51. RANCHO - LAG 2 AUTOCORRELATIONS (LWH DOMAIN)

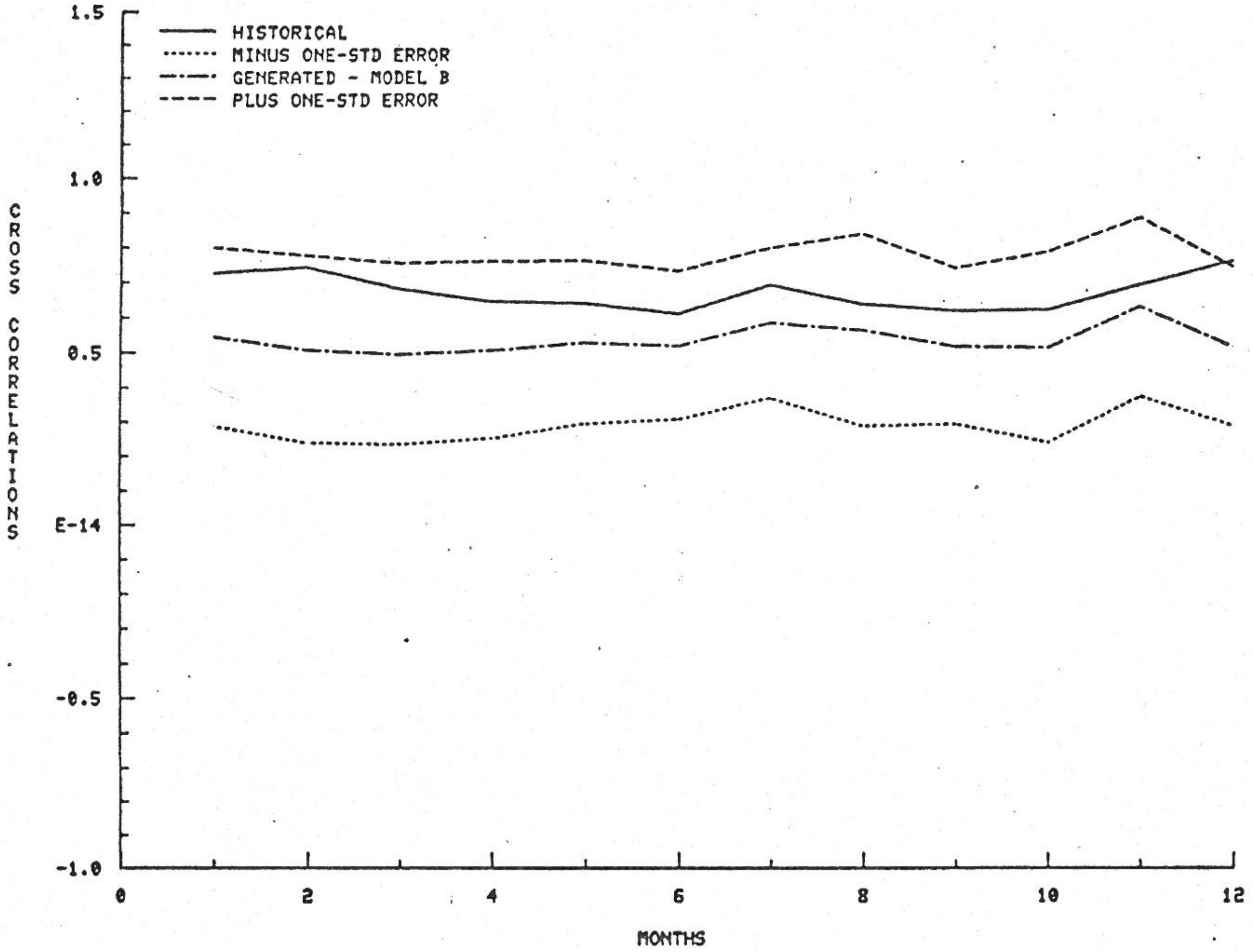

Figure 1.9.E.52. PALODE AND PASODE - CROSS CORRELATIONS (LWH DOMAIN)

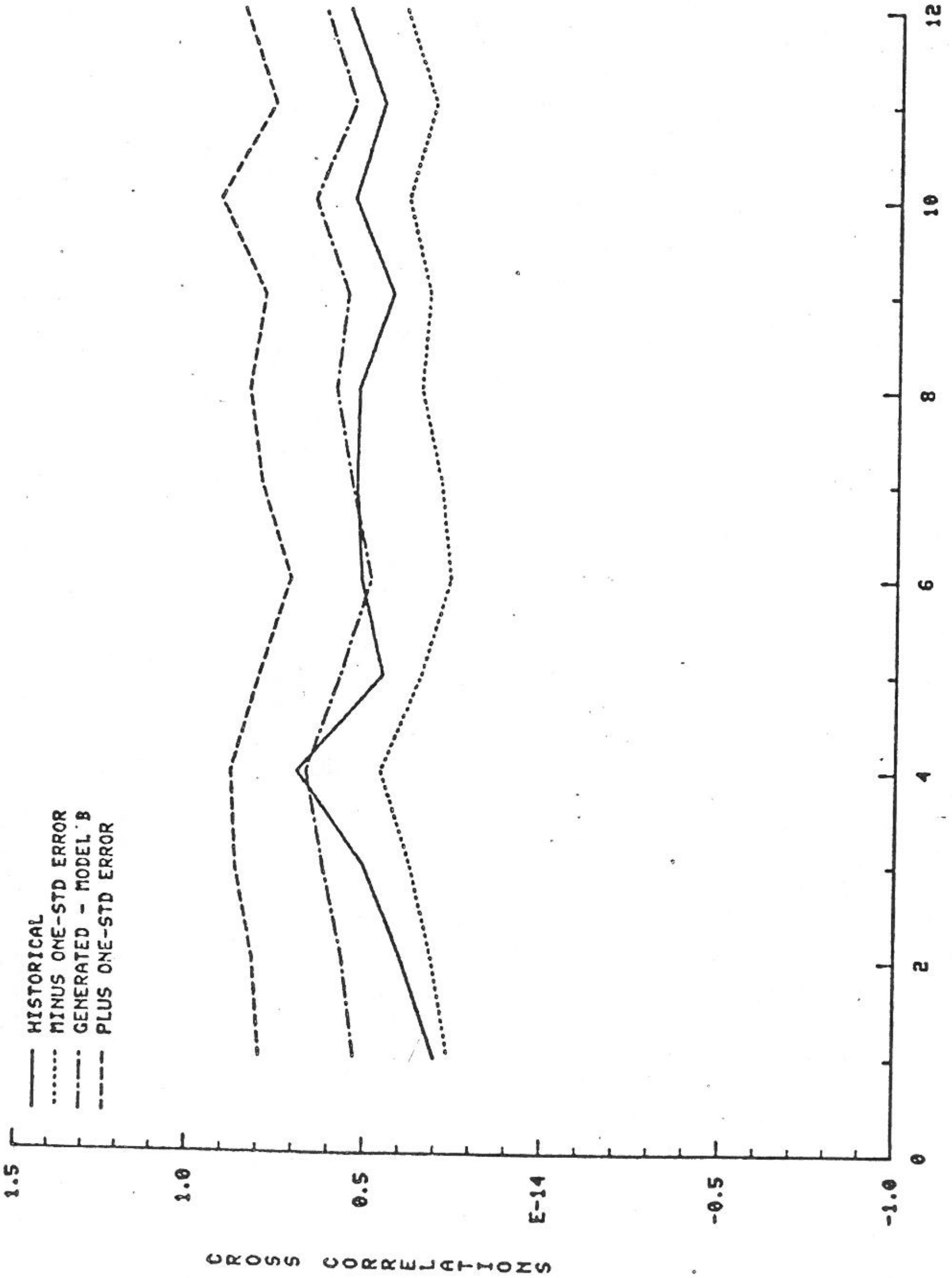

Figure 1.9.E.53. PALODE AND RANCHO - CROSS CORRELATIONS (LWH DOMAIN)

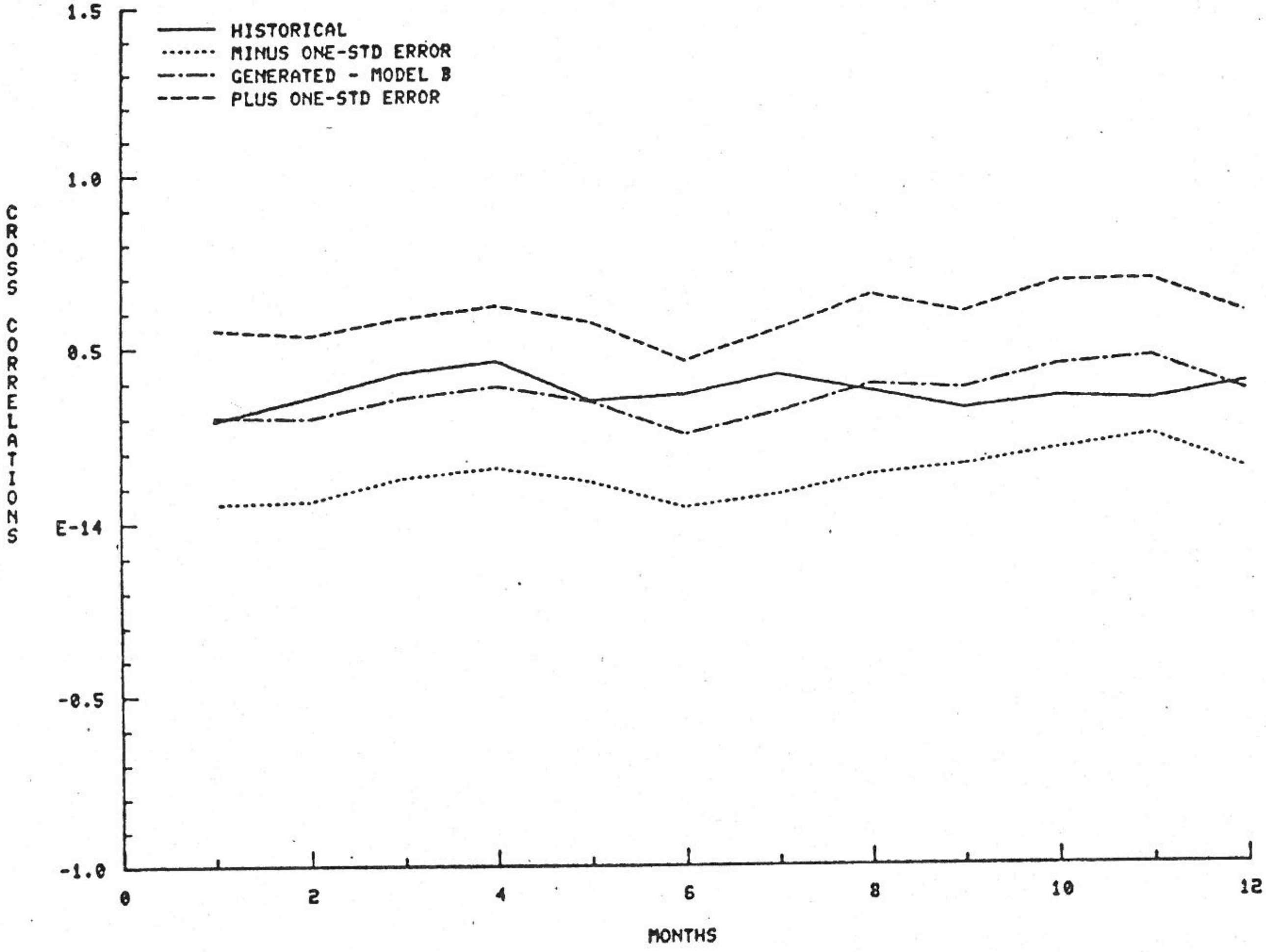

Figure 1.9.E.54. PASODE AND RANCHO - CROSS CORRELATIONS (LWH DOMAIN)

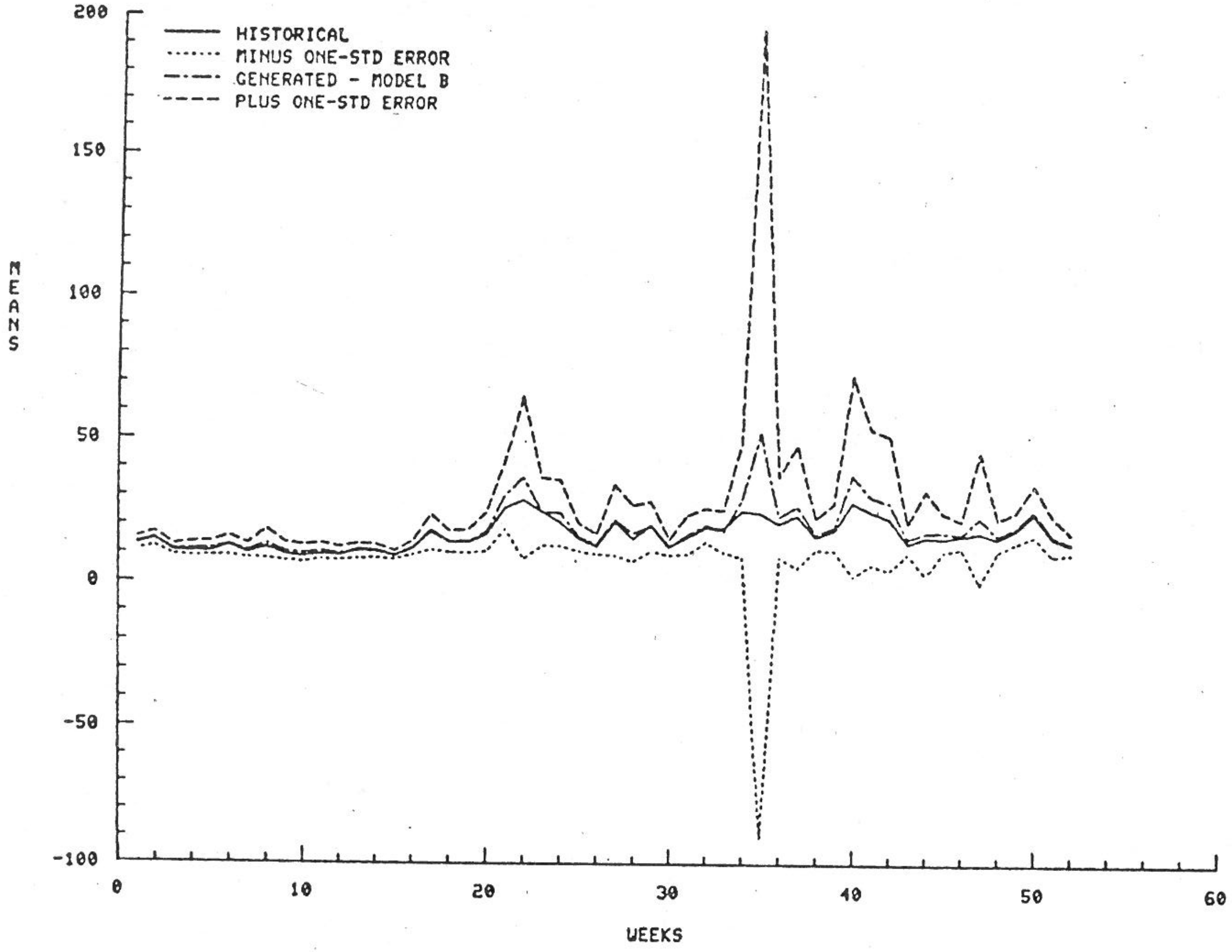

Figure 1.9.E.55. PALODE - MEANS (ORIGINAL DOMAIN)

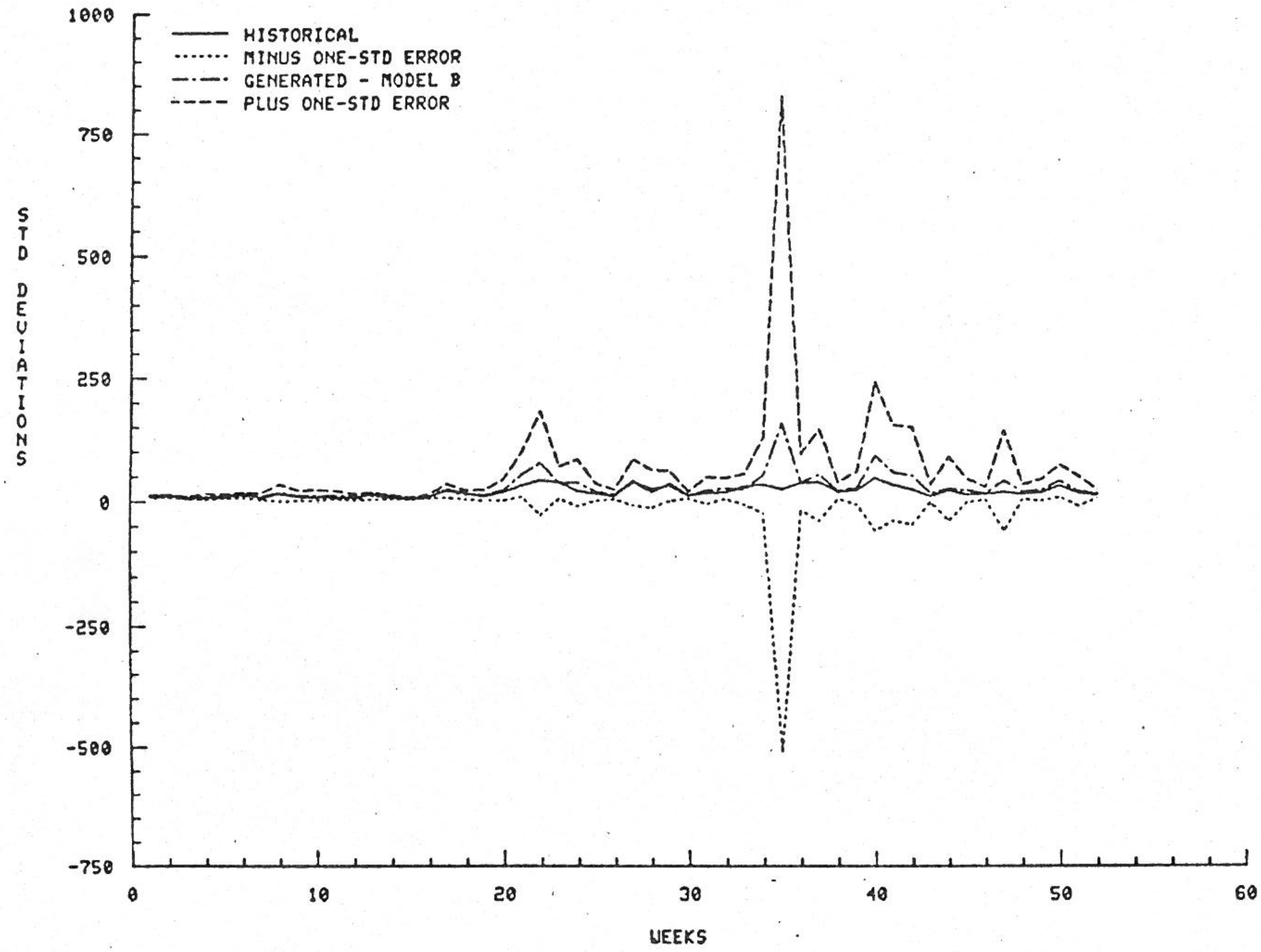

Figure 1.9.E.56. PALODE - STD DEVIATIONS (ORIGINAL DOMAIN)

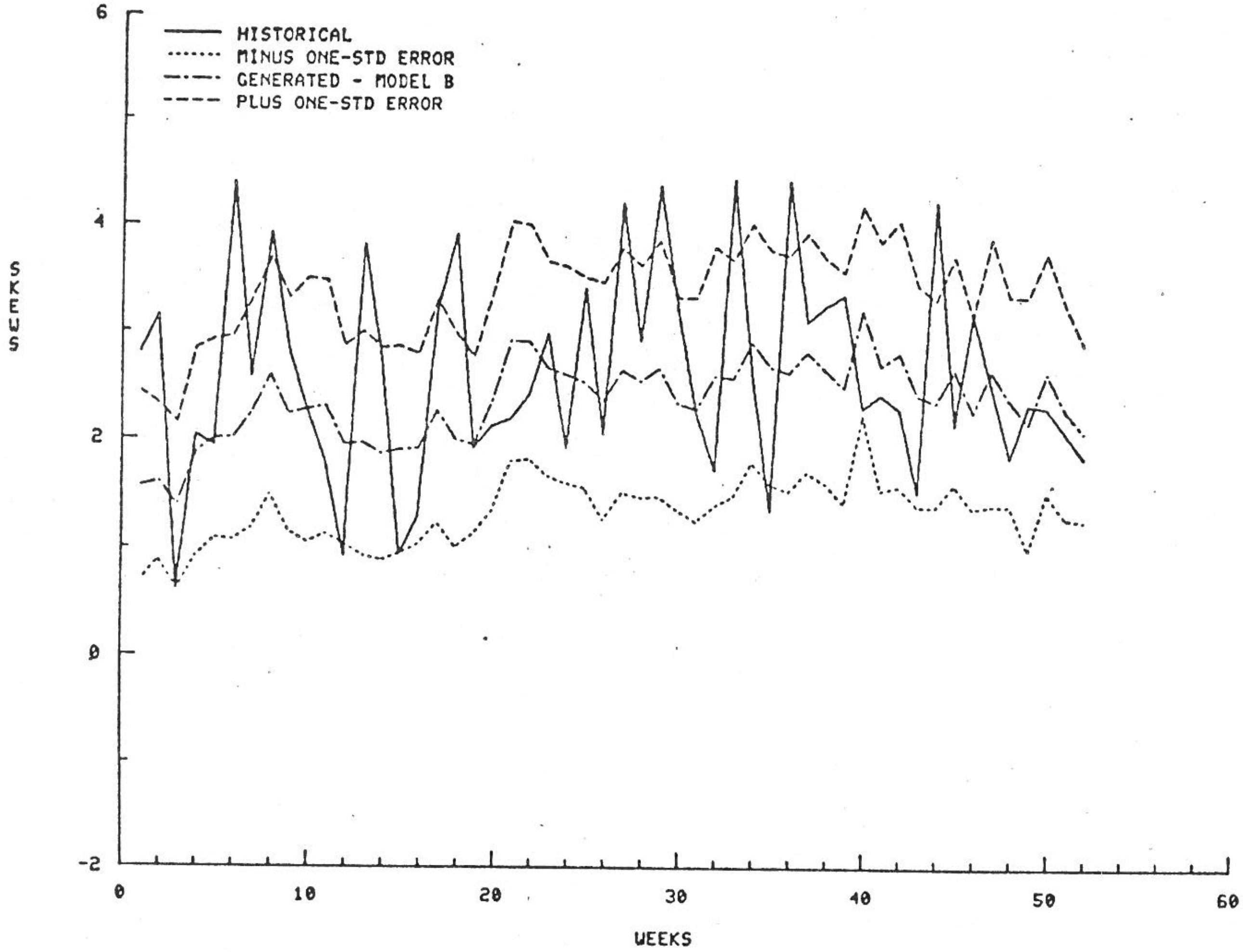

Figure 1.9.E.57. PALODE - SKEWS (ORIGINAL DOMAIN)

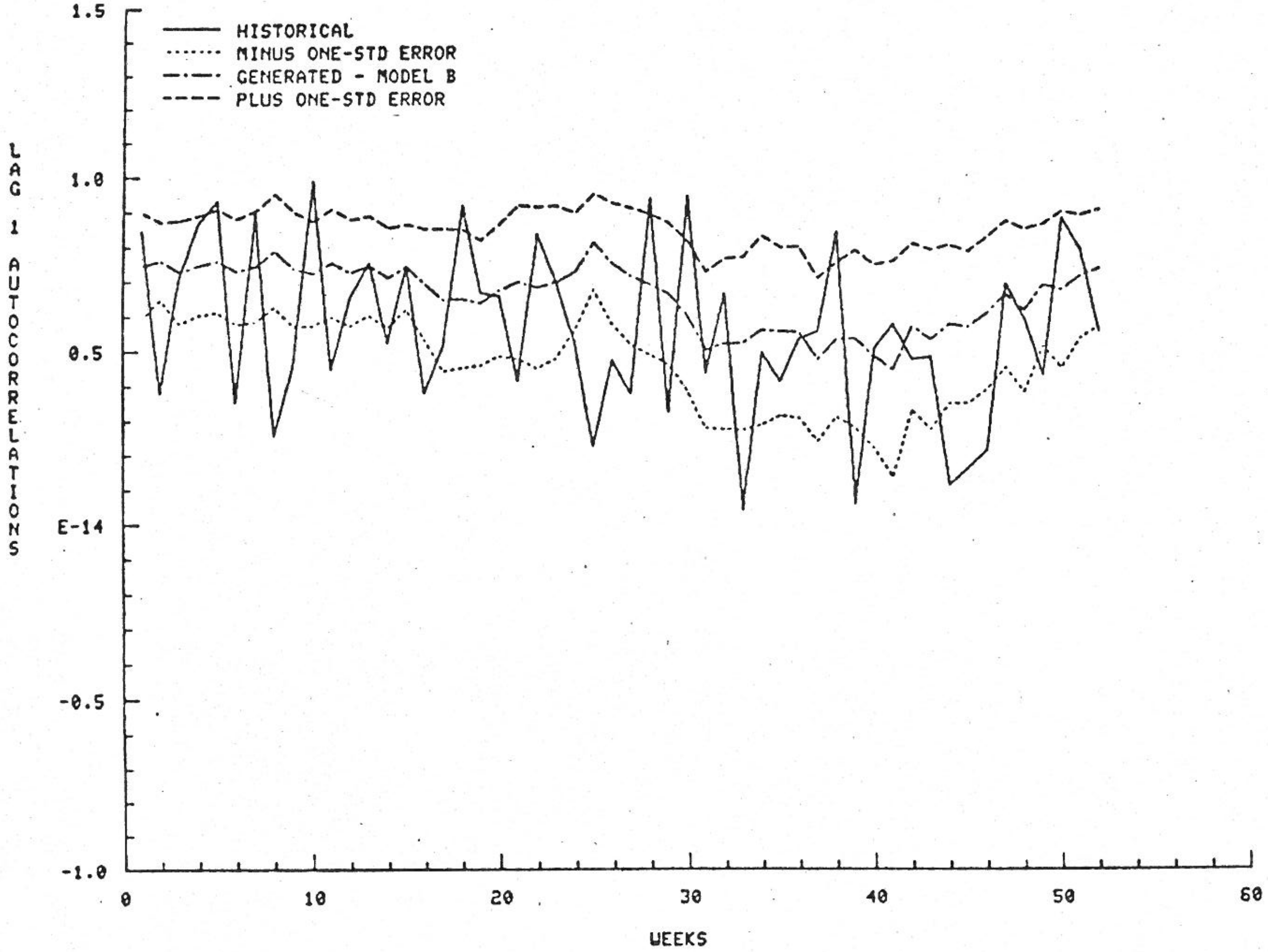

Figure 1.9.E.58. PALODE - LAG 1 AUTOCORRELATIONS (ORIGINAL DOMAIN)

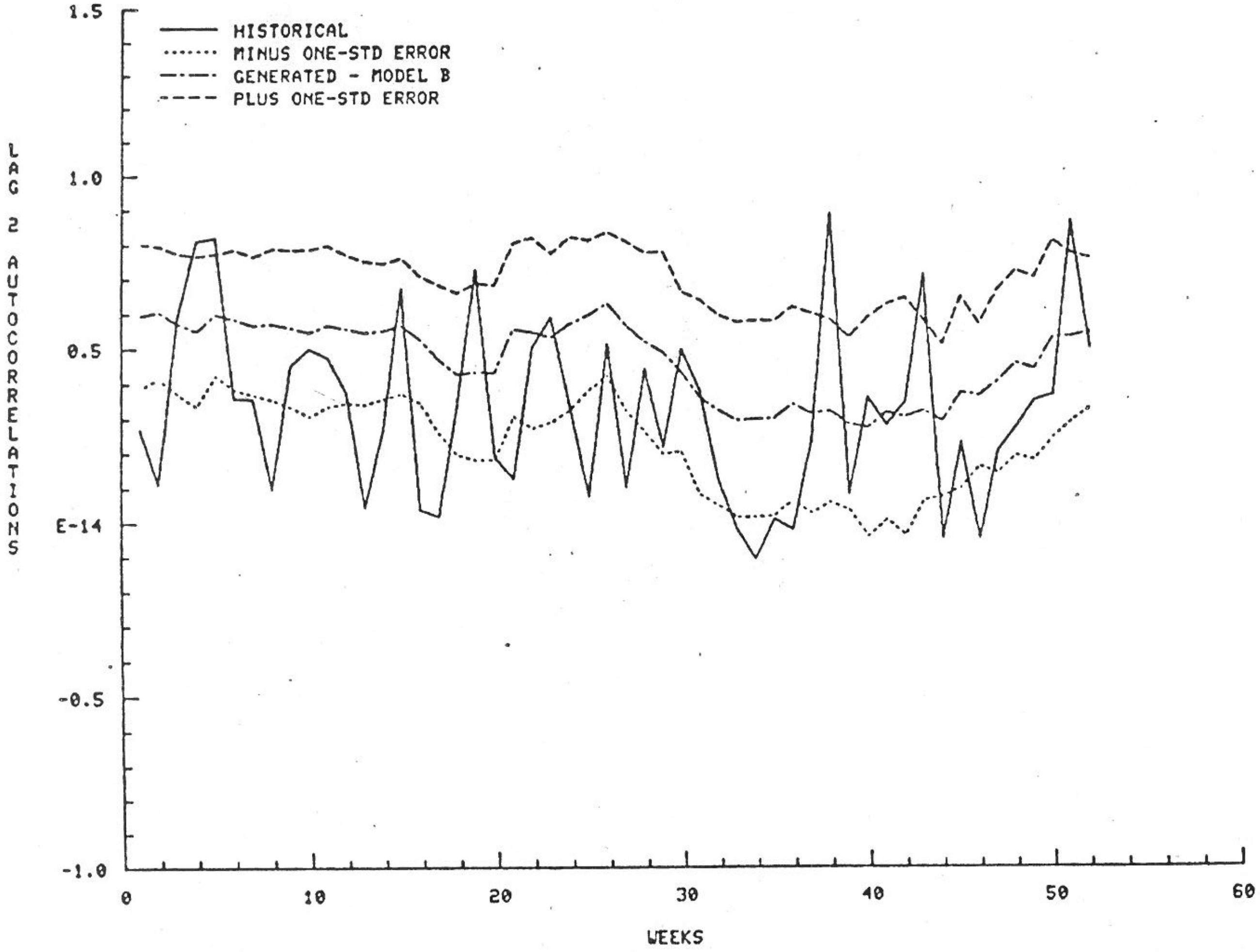

Figure 1.9.E.59. PALODE - LAG 2 AUTOCORRELATIONS (ORIGINAL DOMAIN)

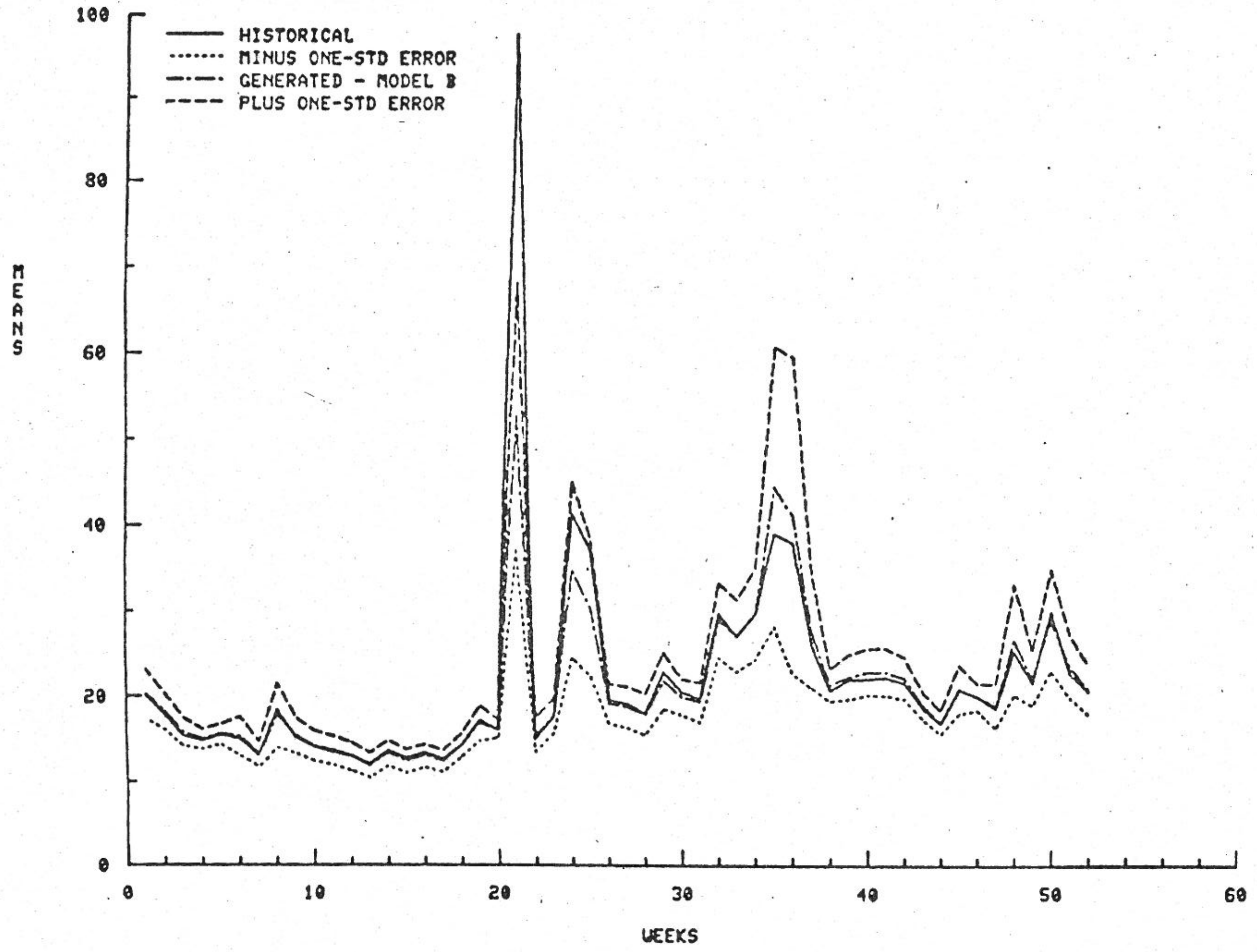

Figure 1.9.E.60. PASODE - MEANS (ORIGINAL DOMAIN)

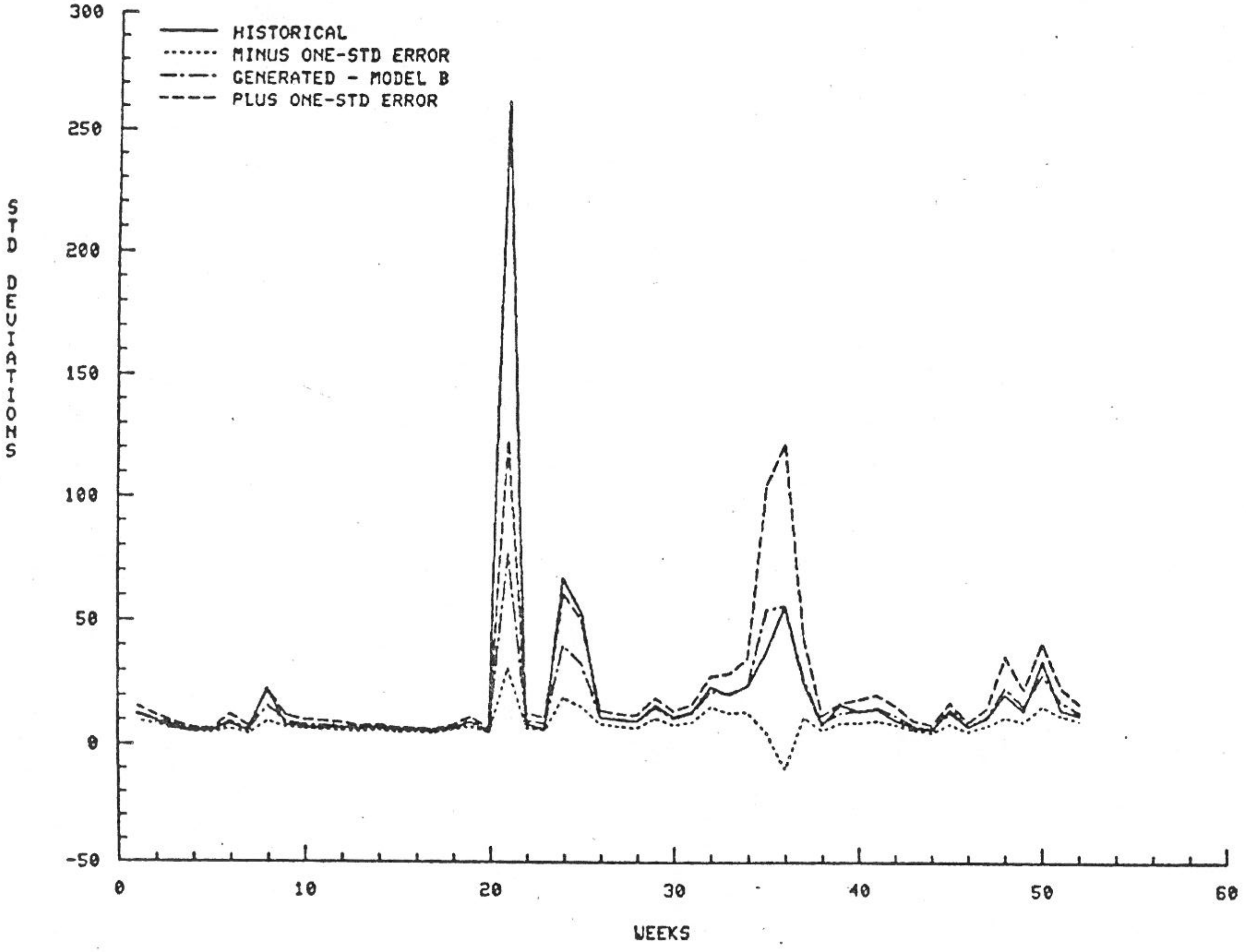

Figure 1.9.E.61. PASODE - STD DEVIATIONS (ORIGINAL DOMAIN)

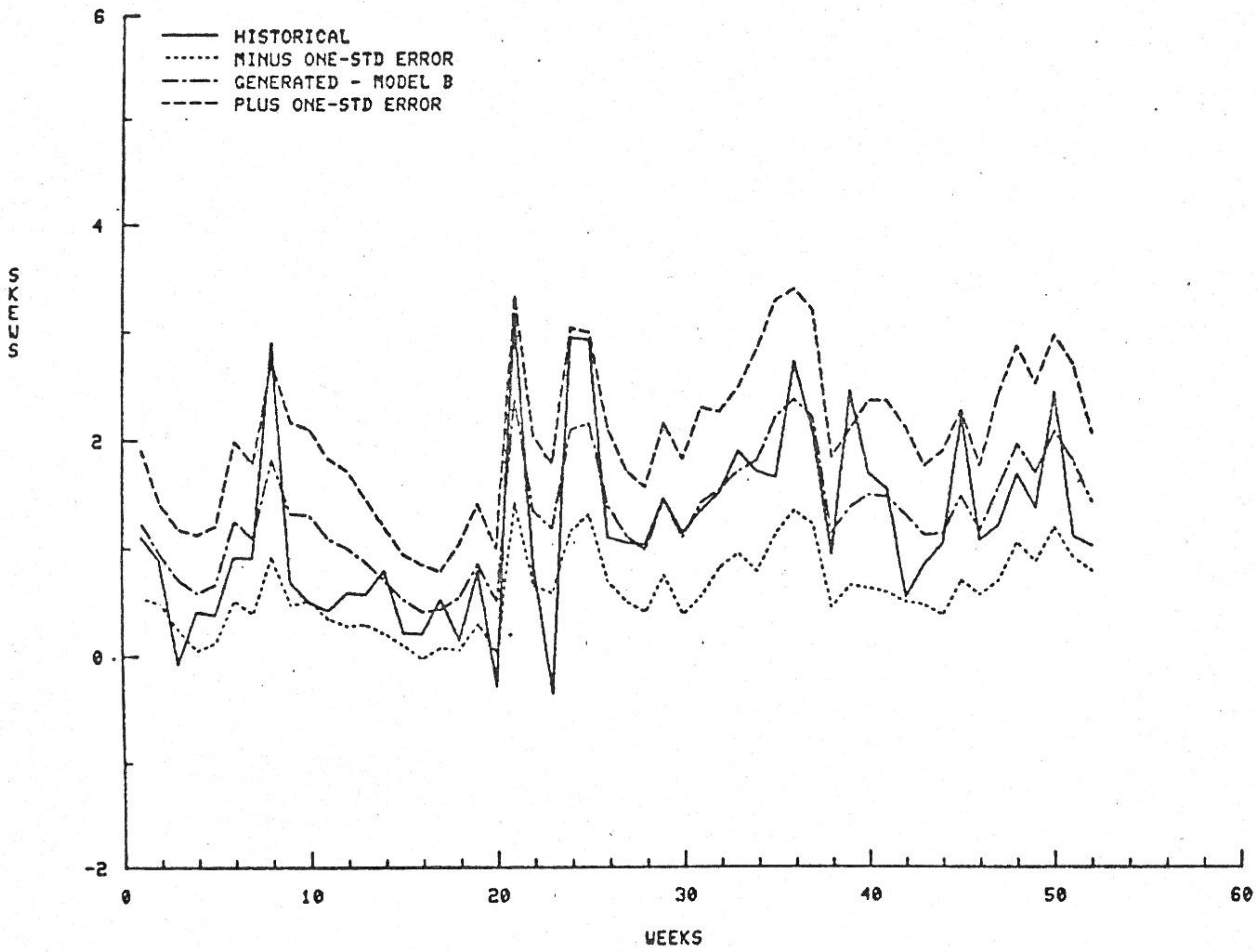

Figure 1.9.E.62. PASODE - SKEWS (ORIGINAL DOMAIN)

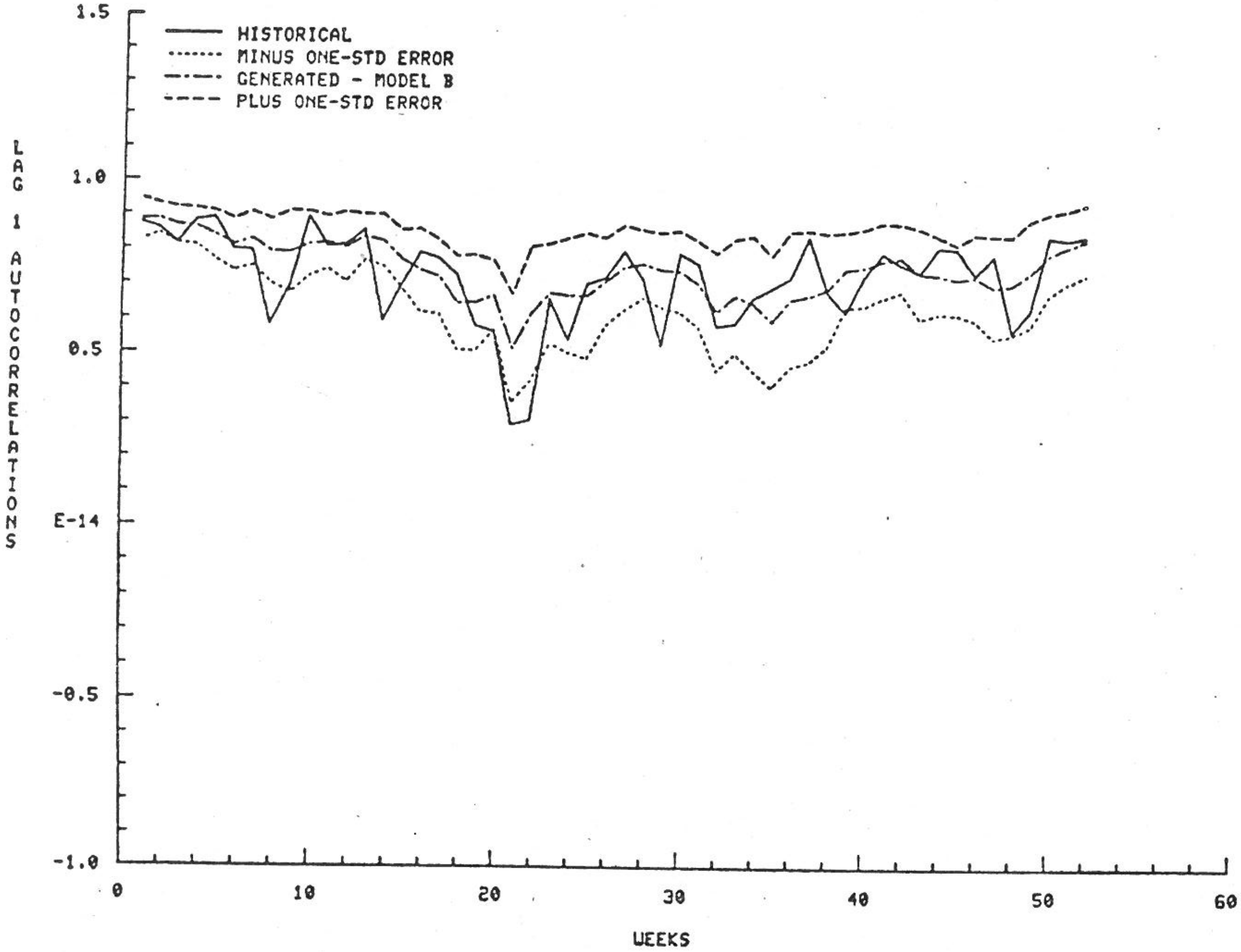

Figure 1.9.E.63. PASODE - LAG 1 AUTOCORRELATIONS (OR

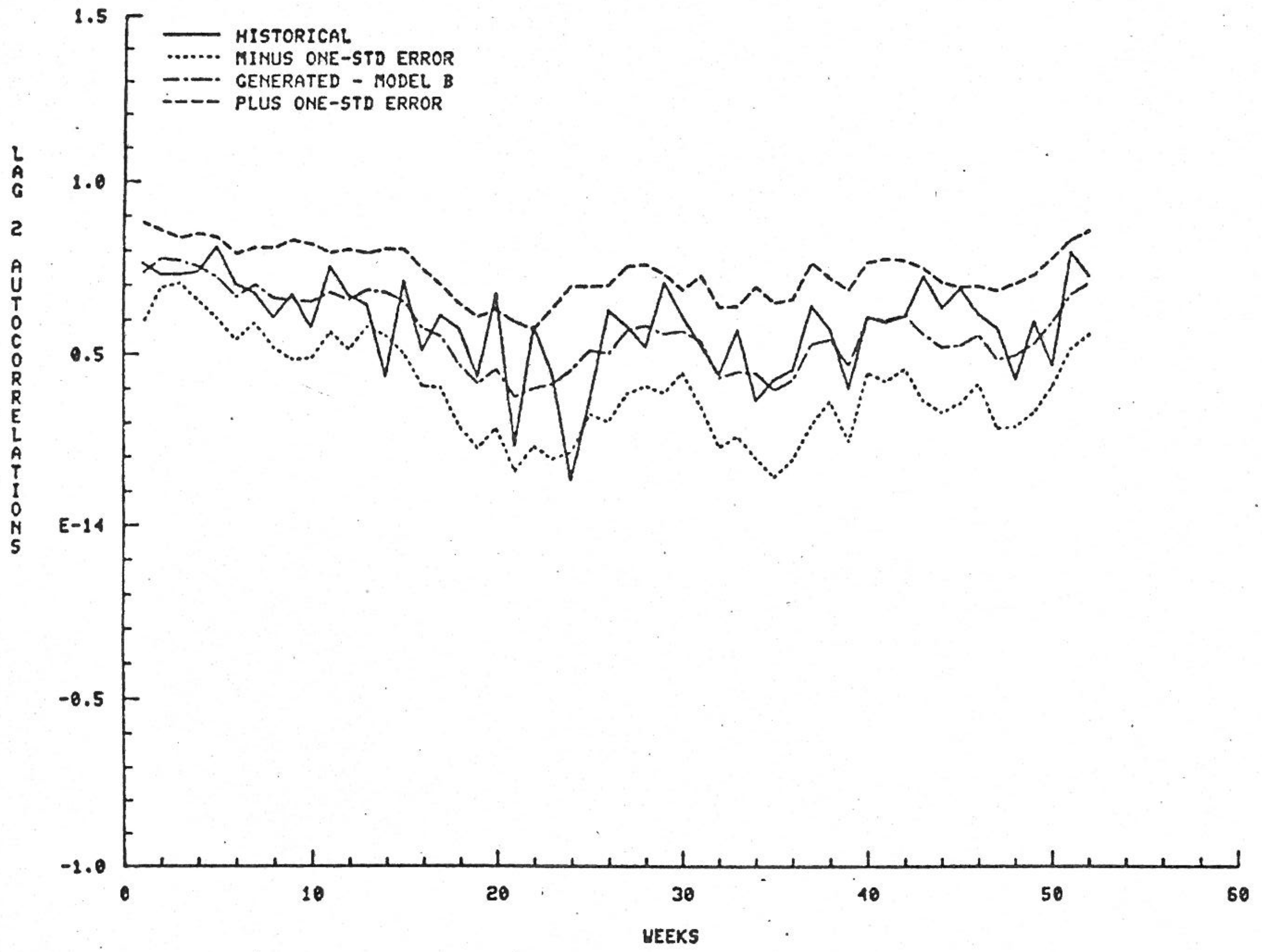

Figure 1.9.E.64. PASODE - LAG 2 AUTOCORRELATIONS (ORIGINAL DOMAIN)

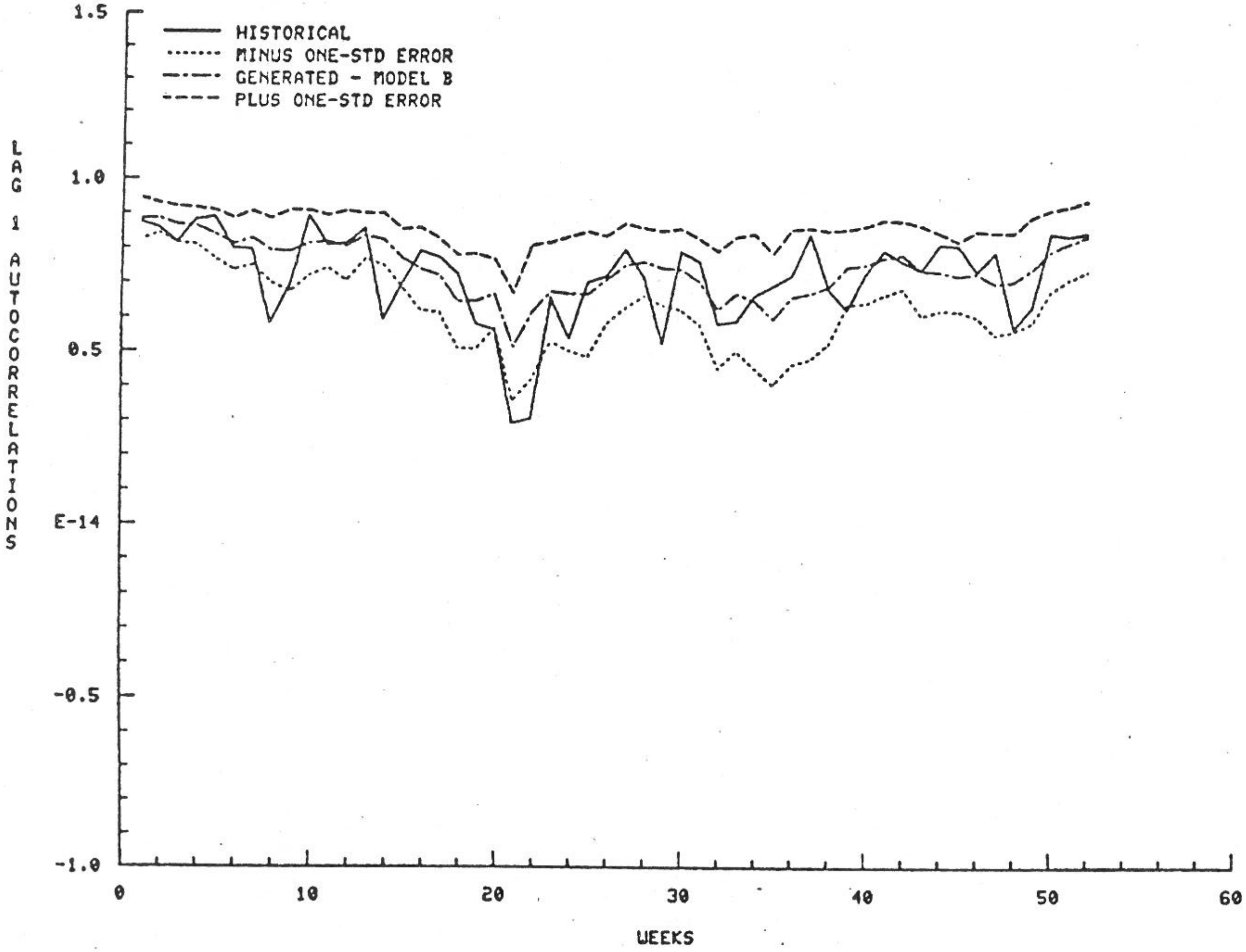

Figure 1.9.E.63. PASODE - LAG 1 AUTOCORRELATIONS (OR

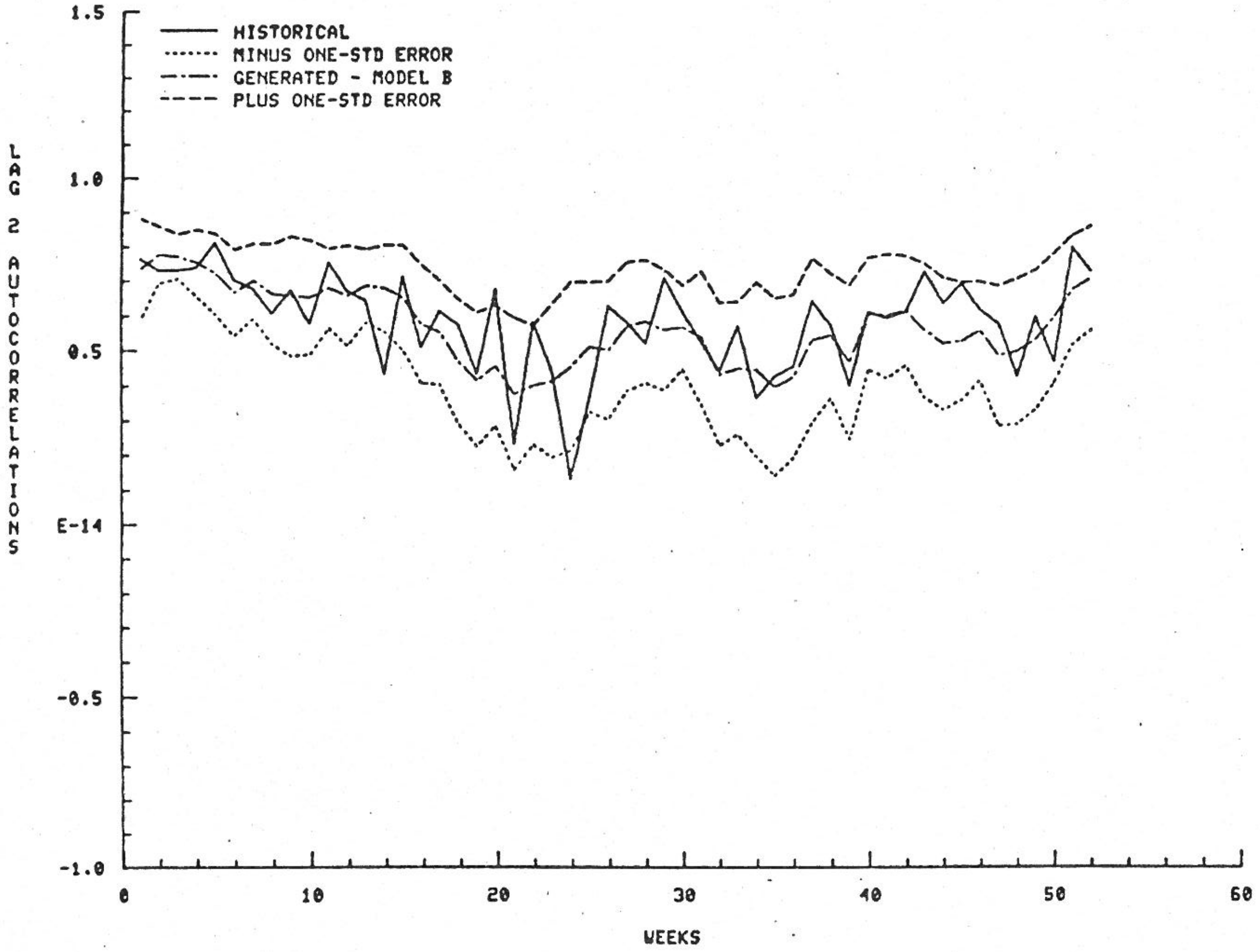

Figure 1.9.E.64. PASODE - LAG 2 AUTOCORRELATIONS (ORIGINAL DOMAIN)

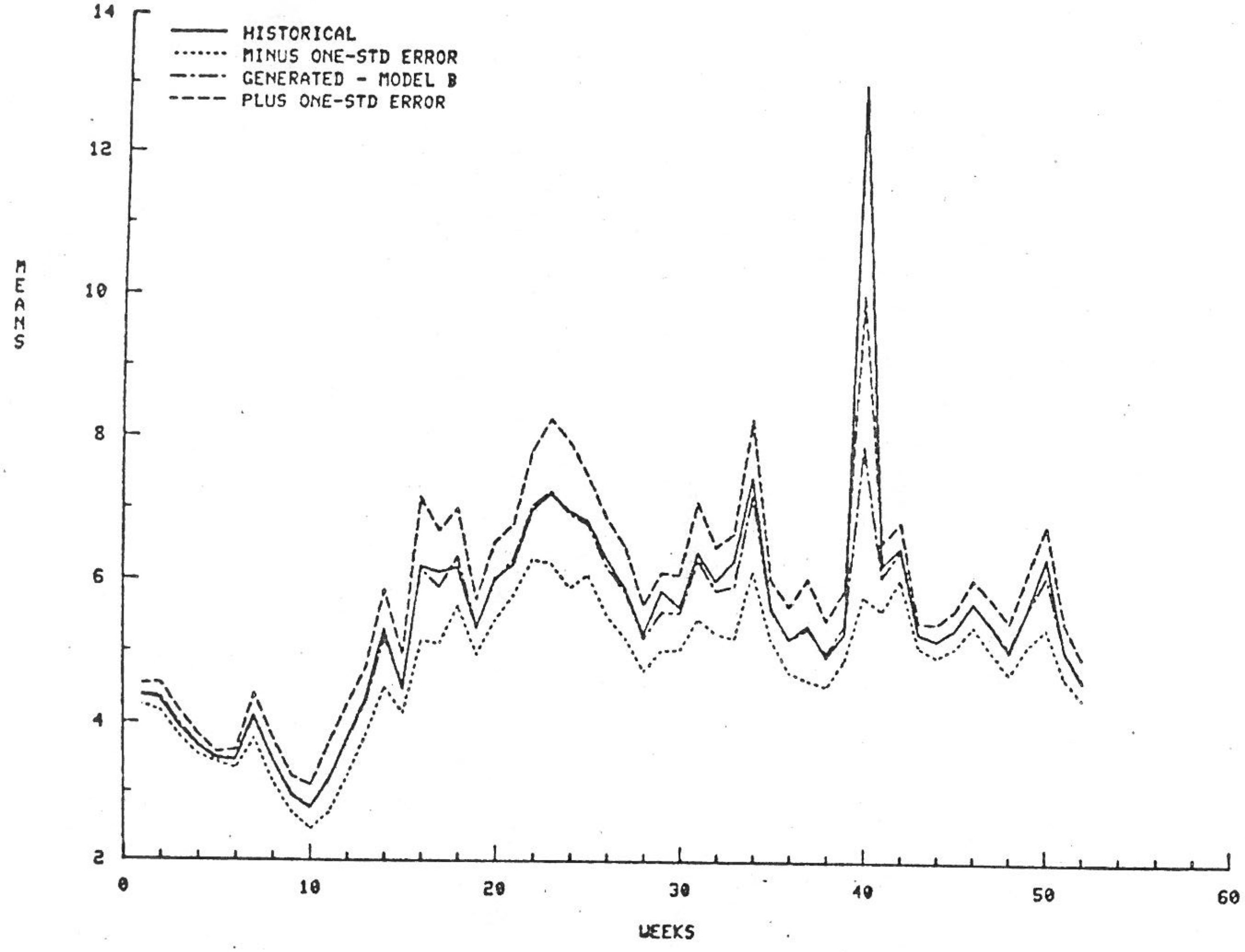

Figure 1.9.E.65. RANCHO - MEANS (ORIGINAL DOMAIN)

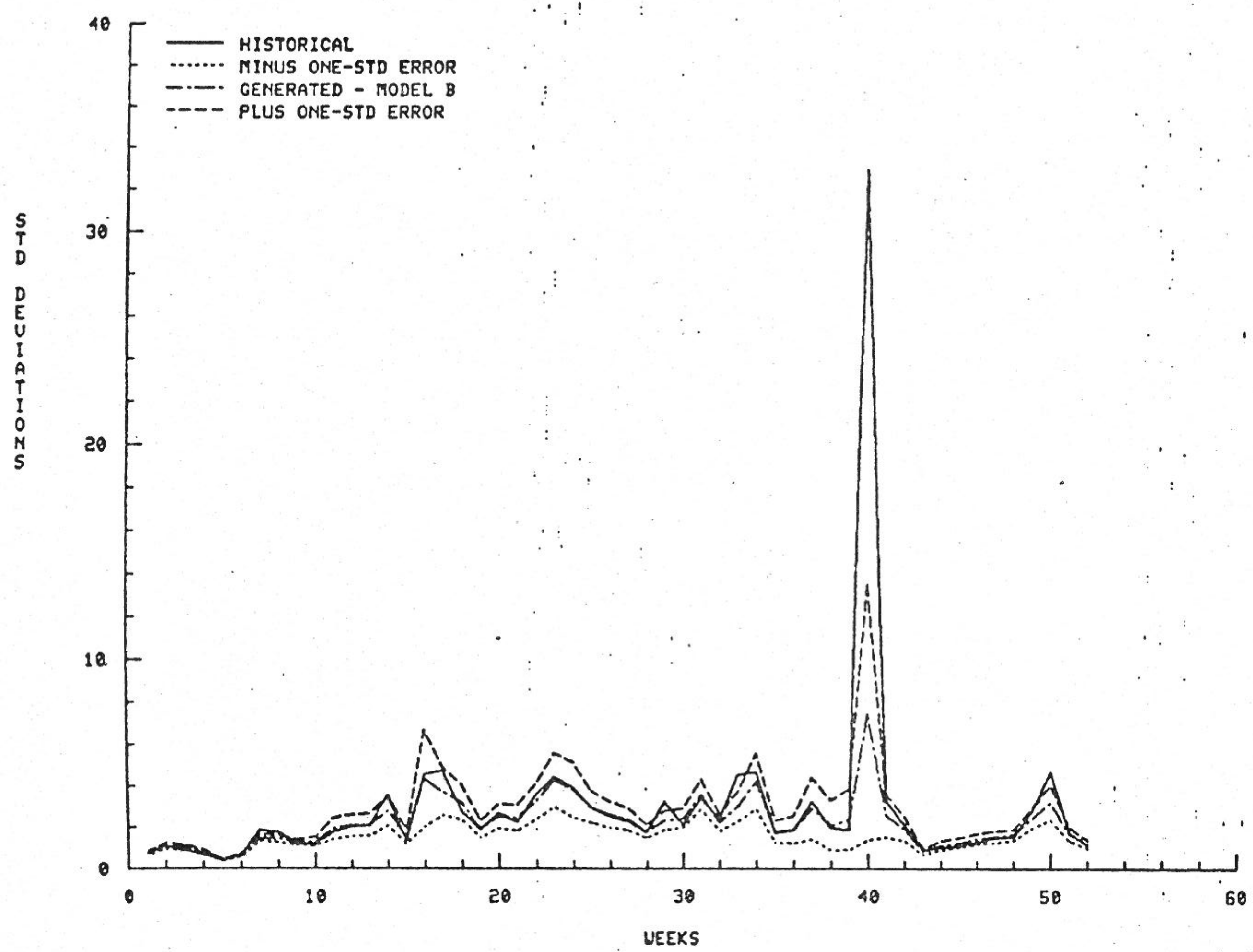

Figure 1.9.E.66. RANCHO - STD DEVIATIONS (ORIGINAL DOMAIN)

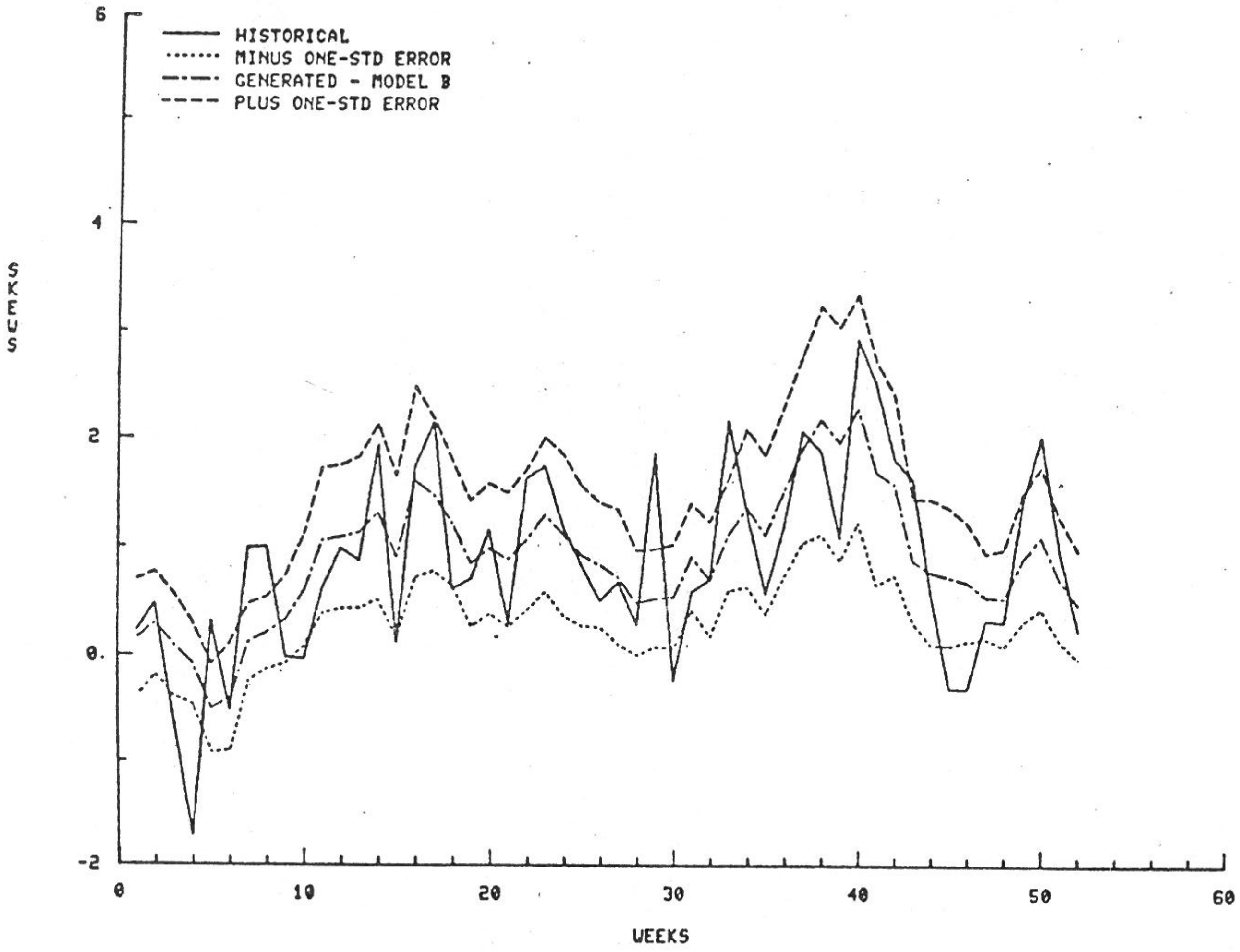

Figure 1.9.E.67. RANCHO - SKEWS (ORIGINAL DOMAIN)

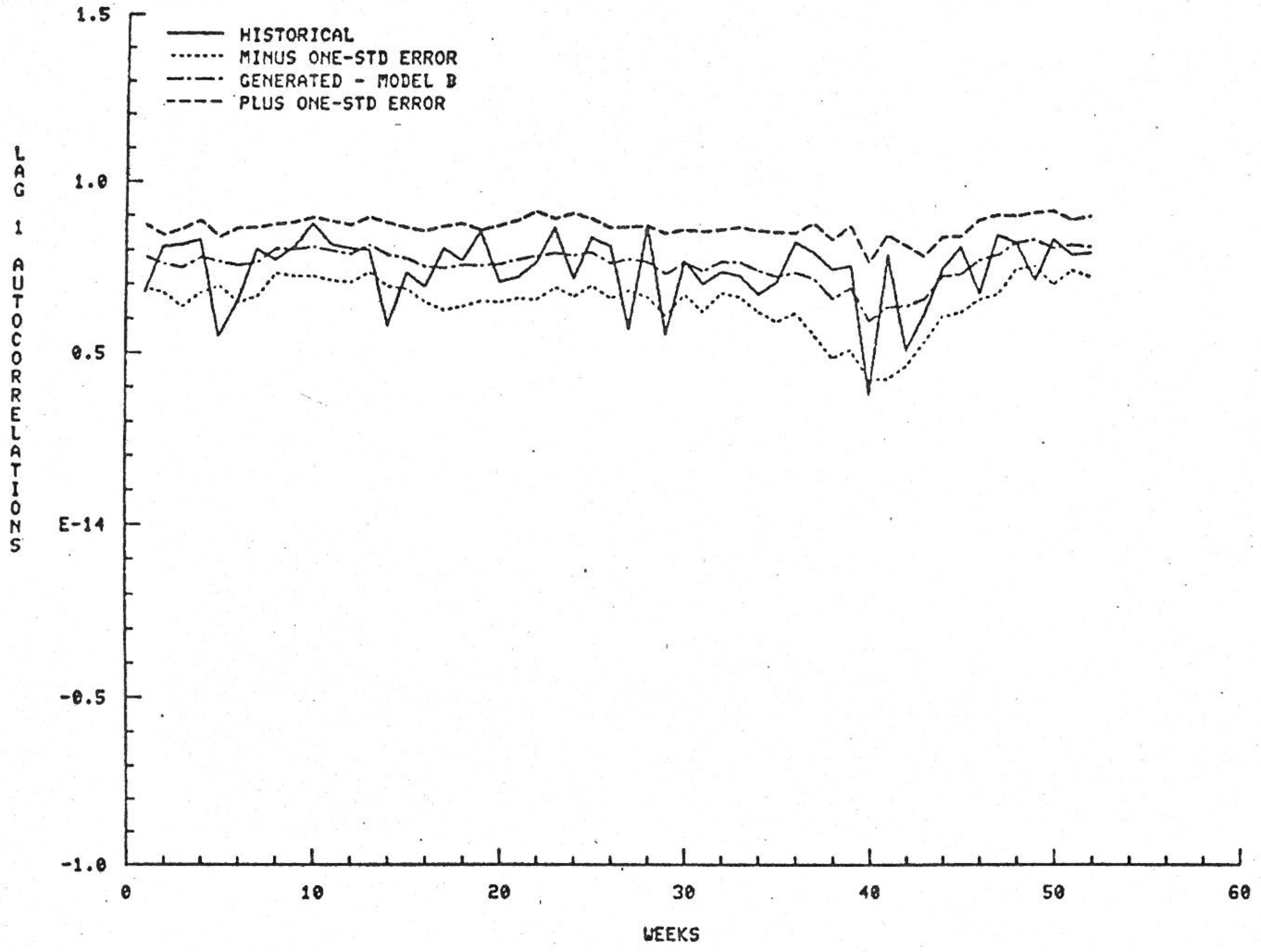

Figure 1.9.E.68. RANCHO - LAG 1 AUTOCORRELATIONS (ORIGINAL DOMAIN)

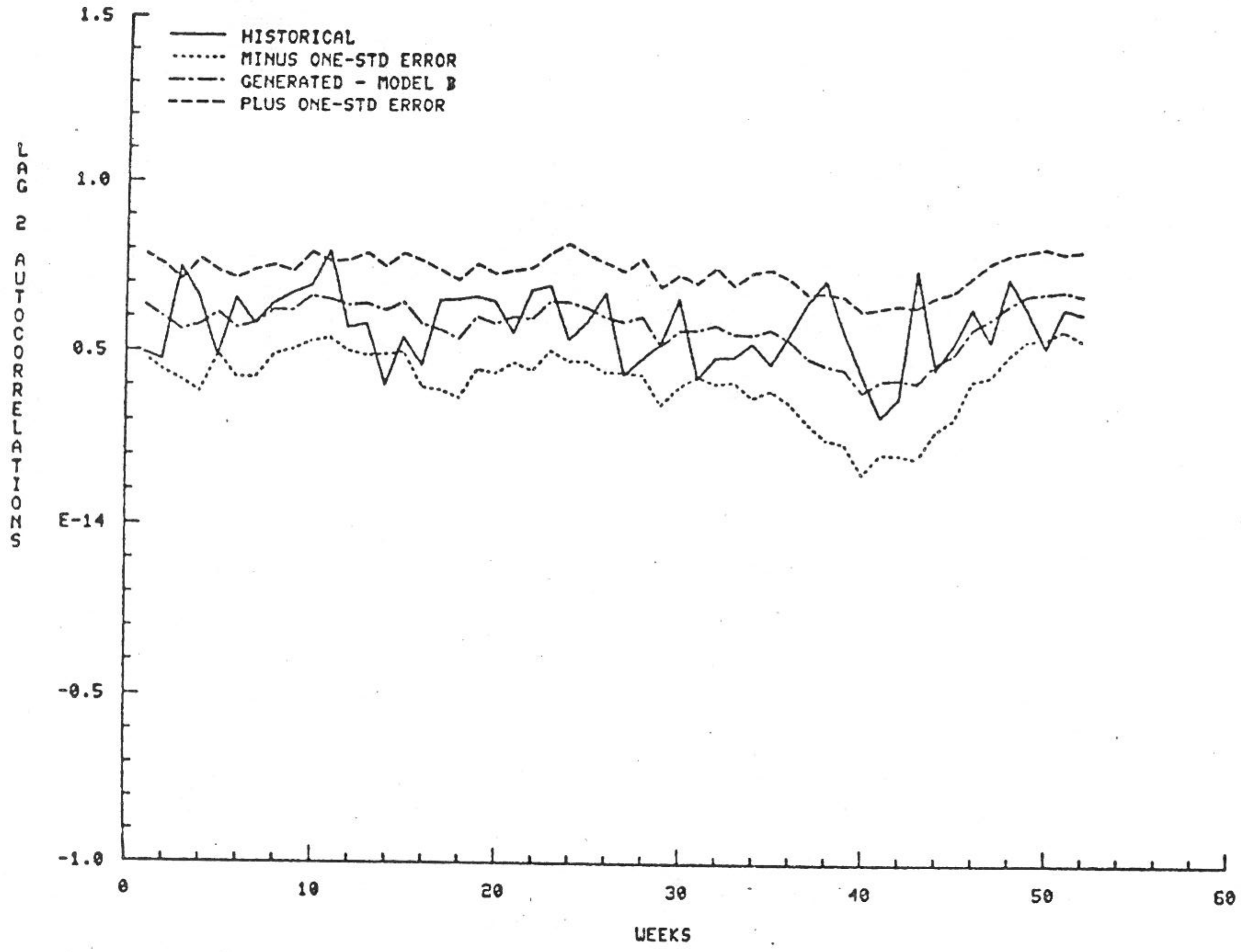

Figure 1.9.E.69. RANCHO - LAG 2 AUTOCORRELATIONS (ORIGINAL DOMAIN)

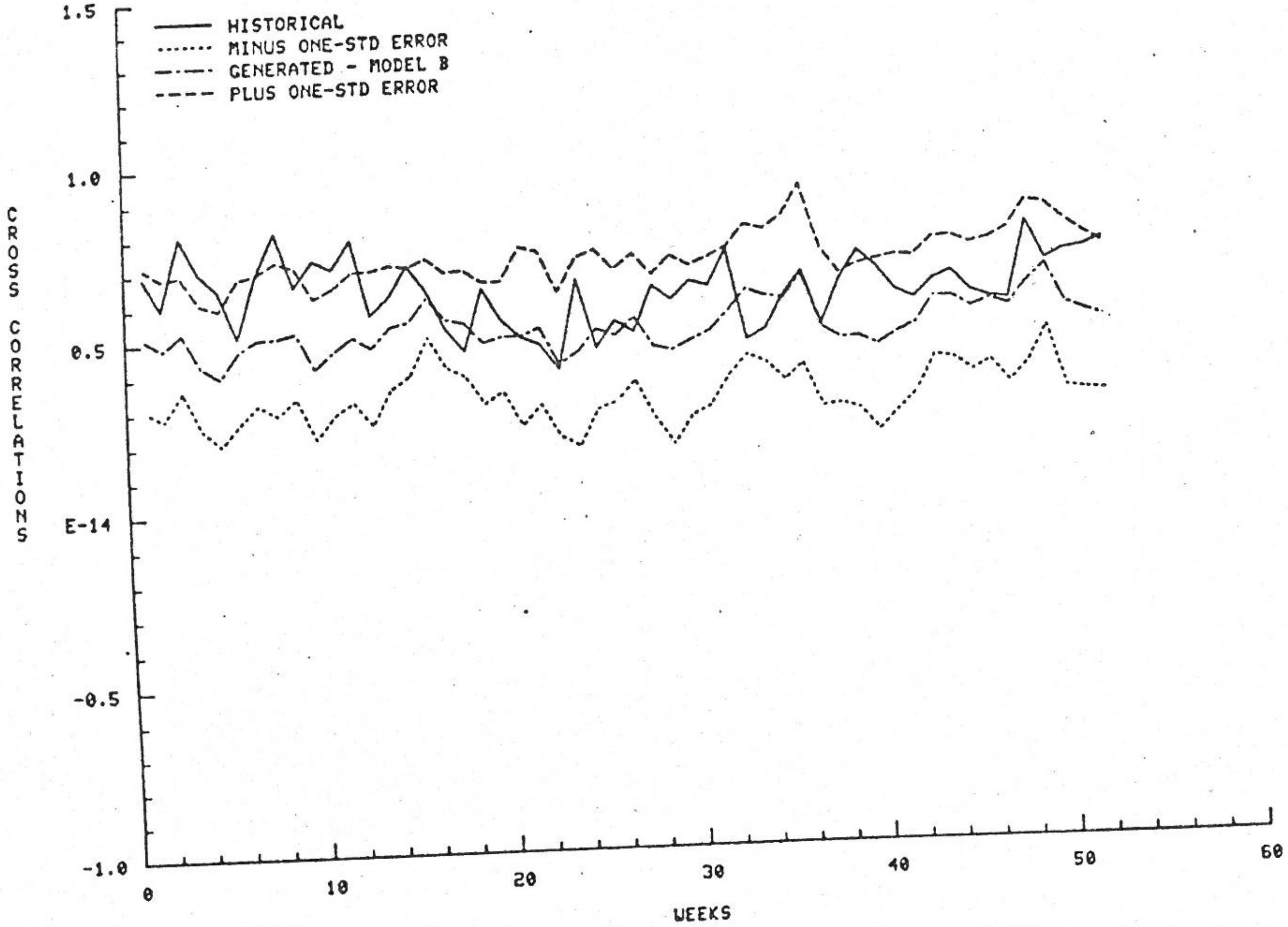

Figure 1.9.E.70. PALODE AND PASODE - CROSS CORRELATIONS (ORIGINAL DOMAIN)

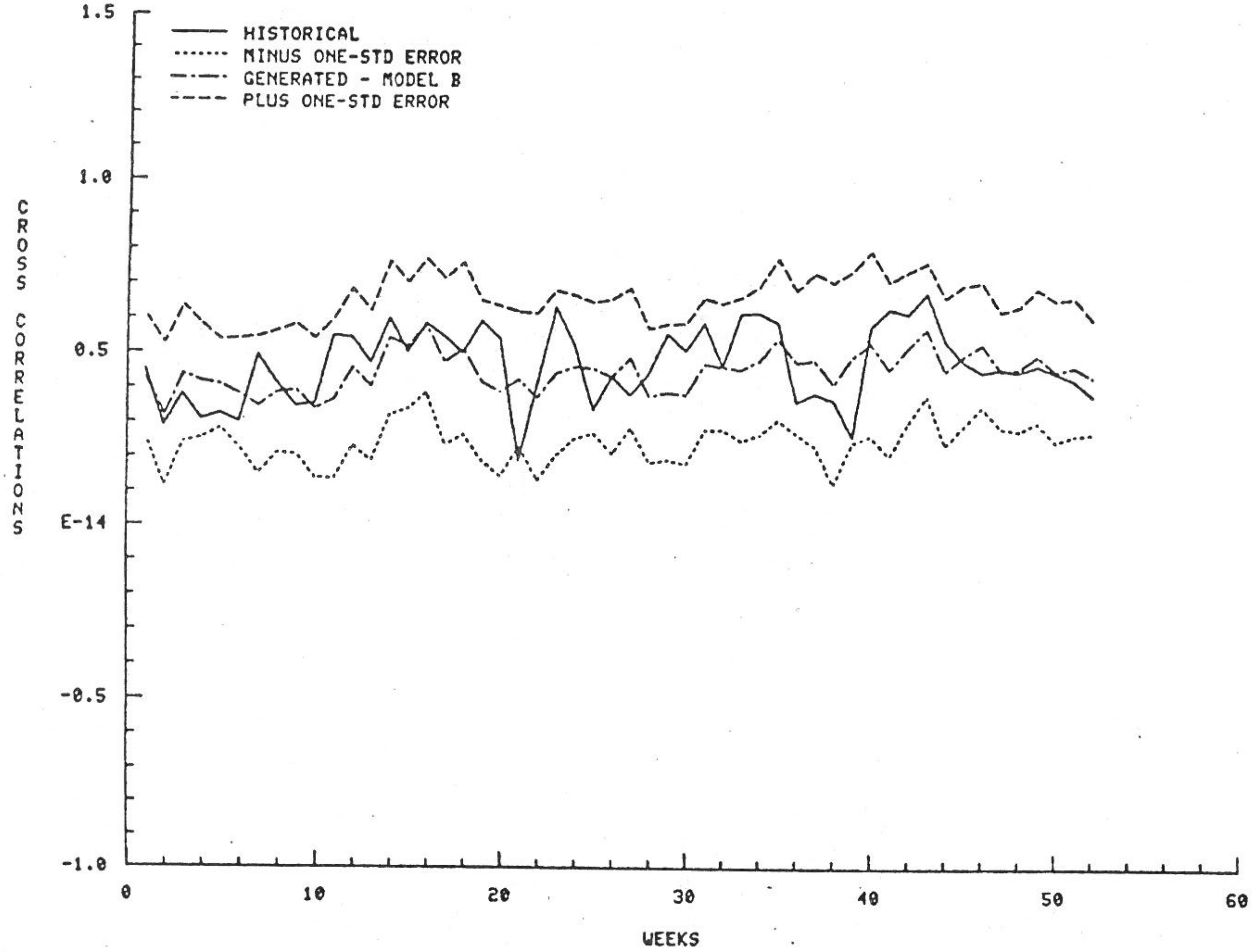

Figure 1.9.E.71. PALODE AND RANCHO - CROSS CORRELATIONS (ORIGINAL DOMAIN)

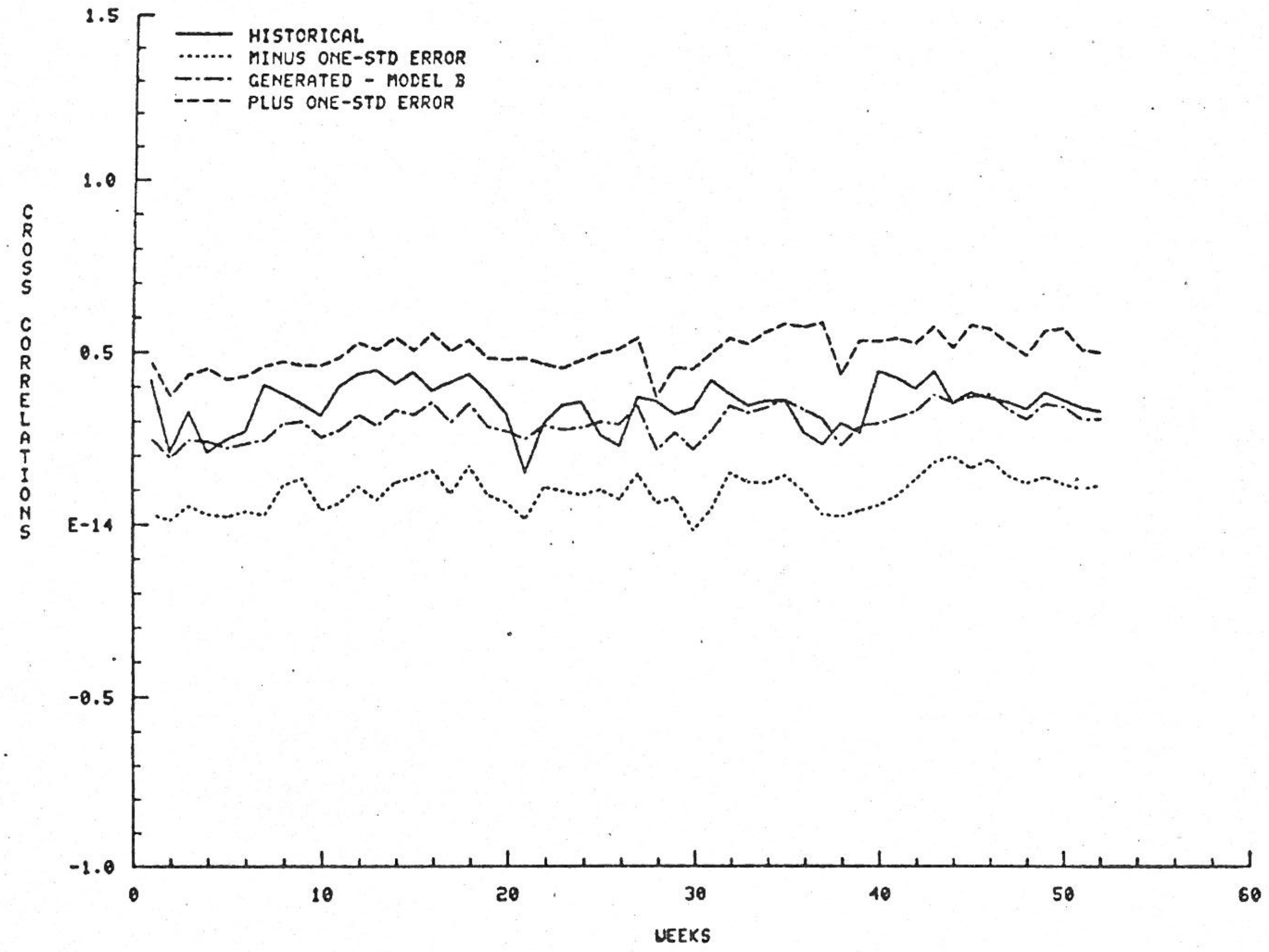

Figure 1.9.E.72. PASODE AND RANCHO - CROSS CORRELATIONS (ORIGINAL DOMAIN)

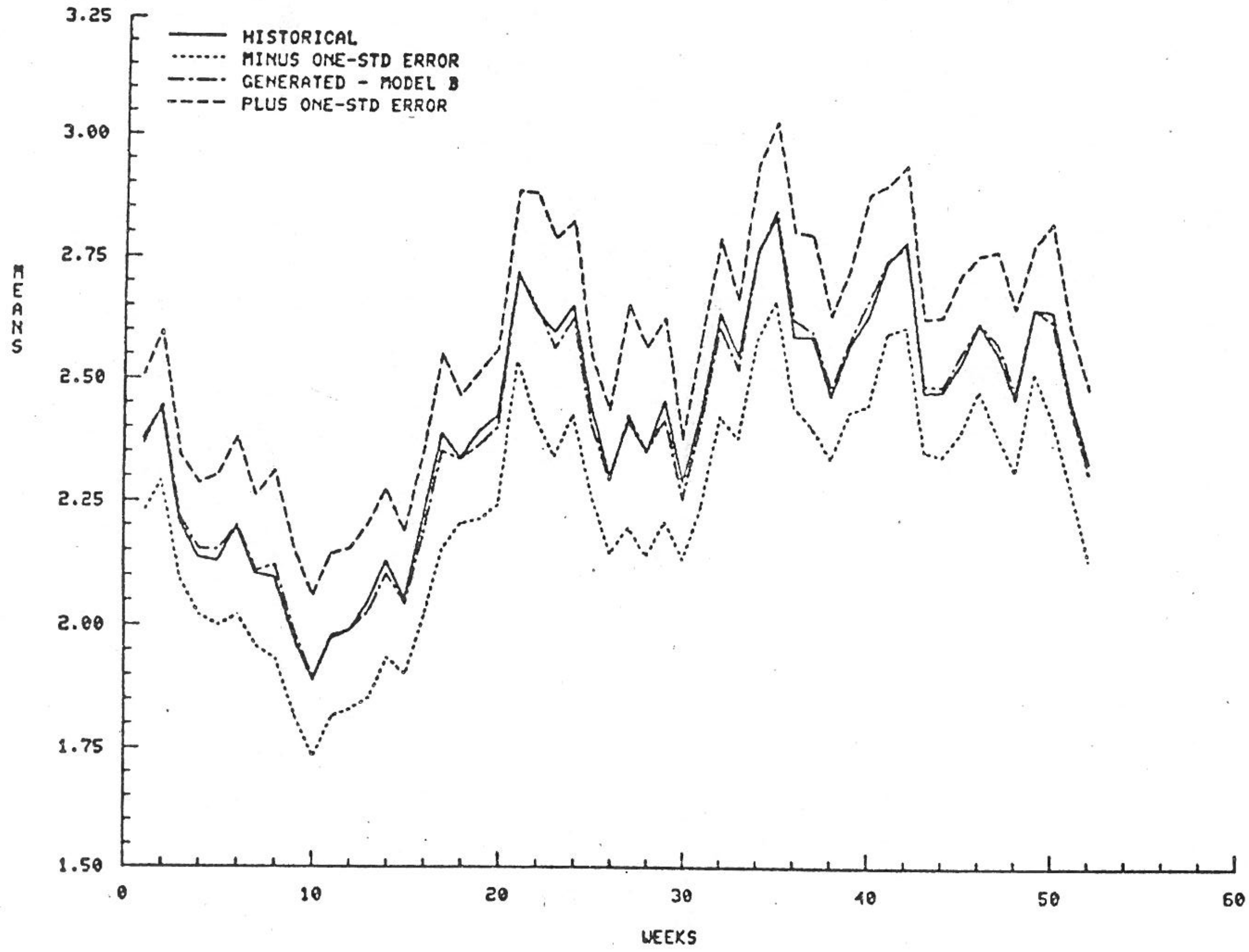

Figure 1.9.E.73. PALODE - MEANS (LOG DOMAIN)

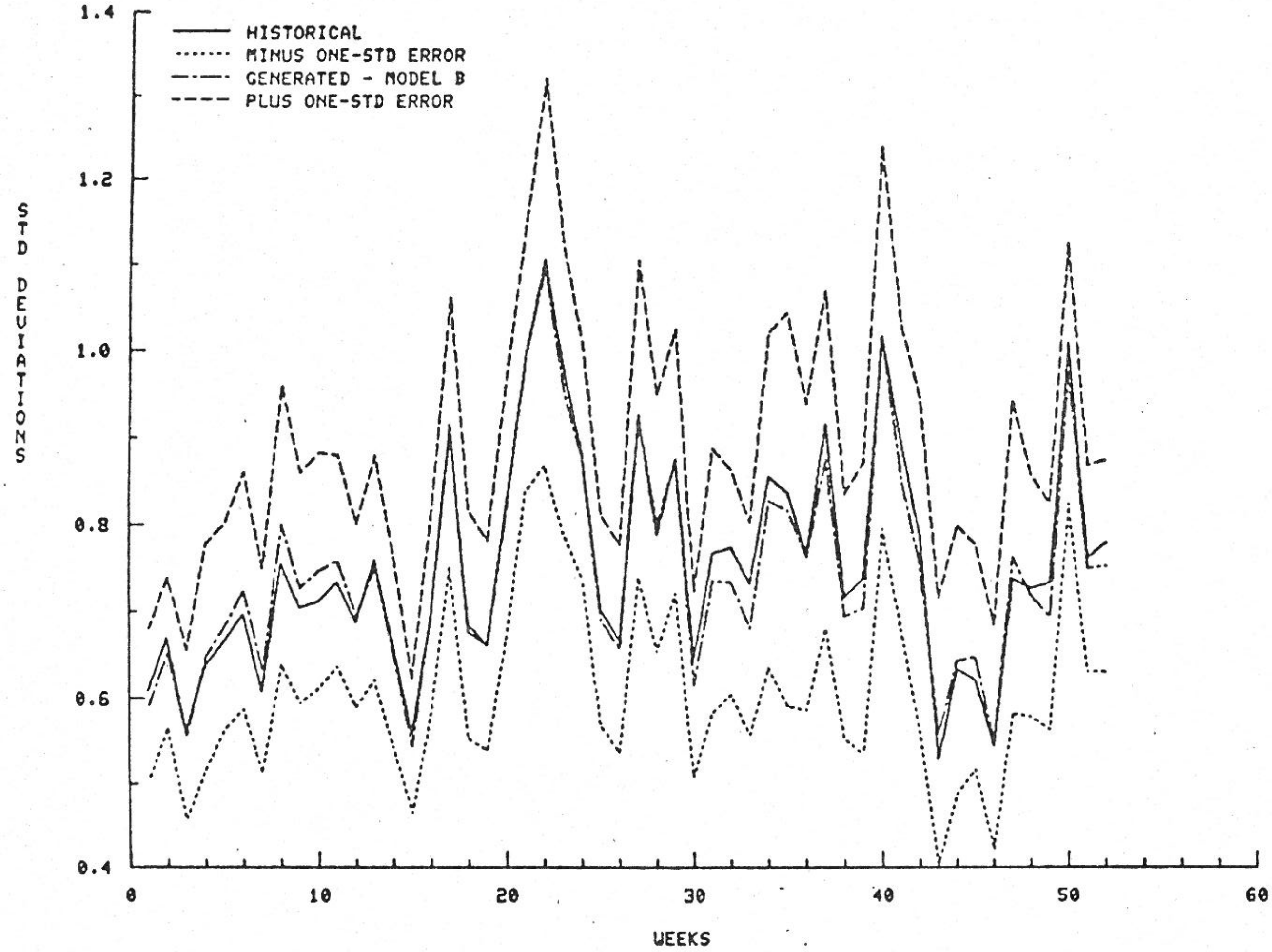

Figure 1.9.E.74. PALODE - STD DEVIATIONS (LOG DOMAIN)

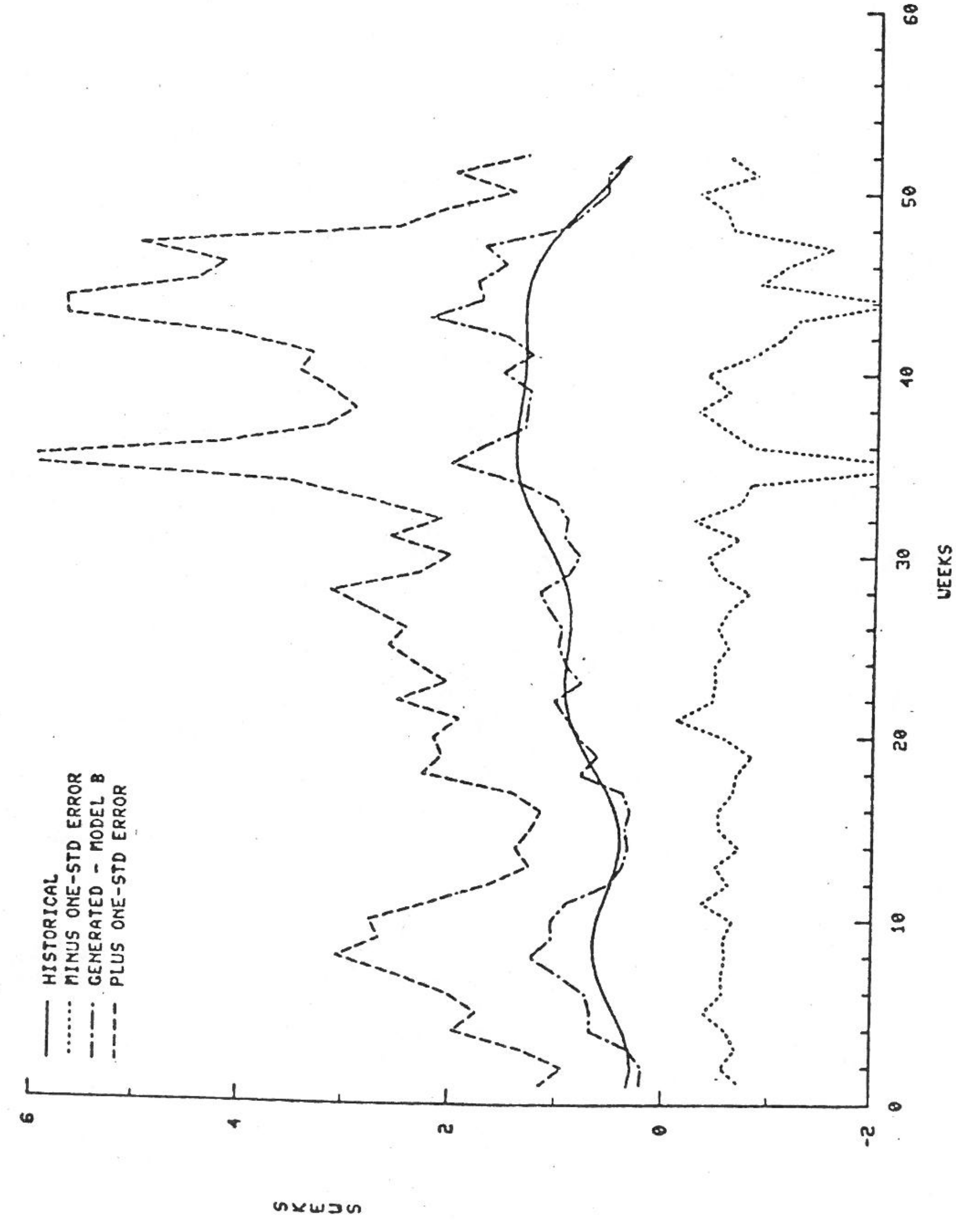

Figure 1.9.E.75. PALODE - SKEWS (LOG DOMAIN)

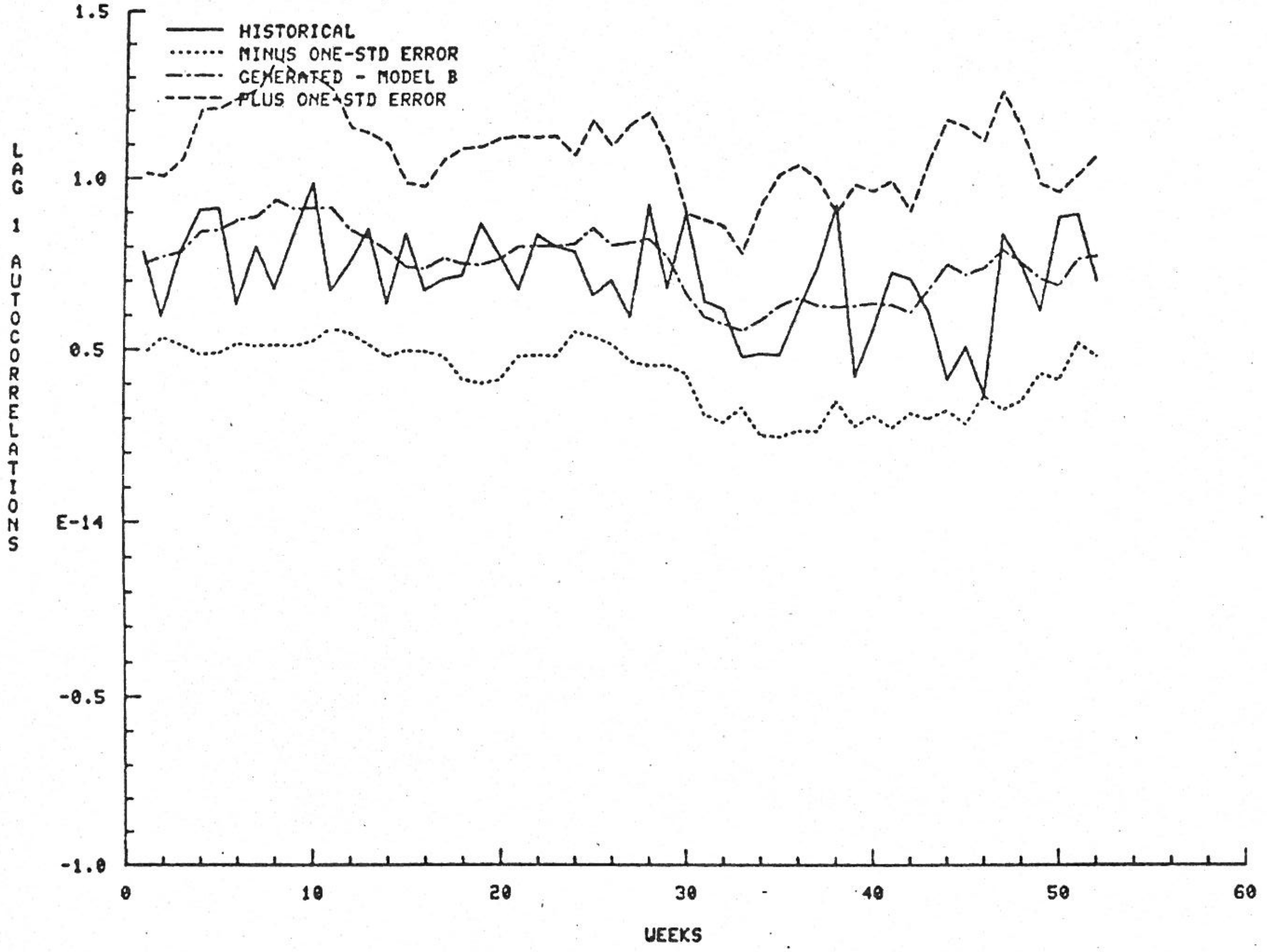

Figure 1.9.E.76. PALODE - LAG 1 AUTOCORRELATIONS (LOG DOMAIN)

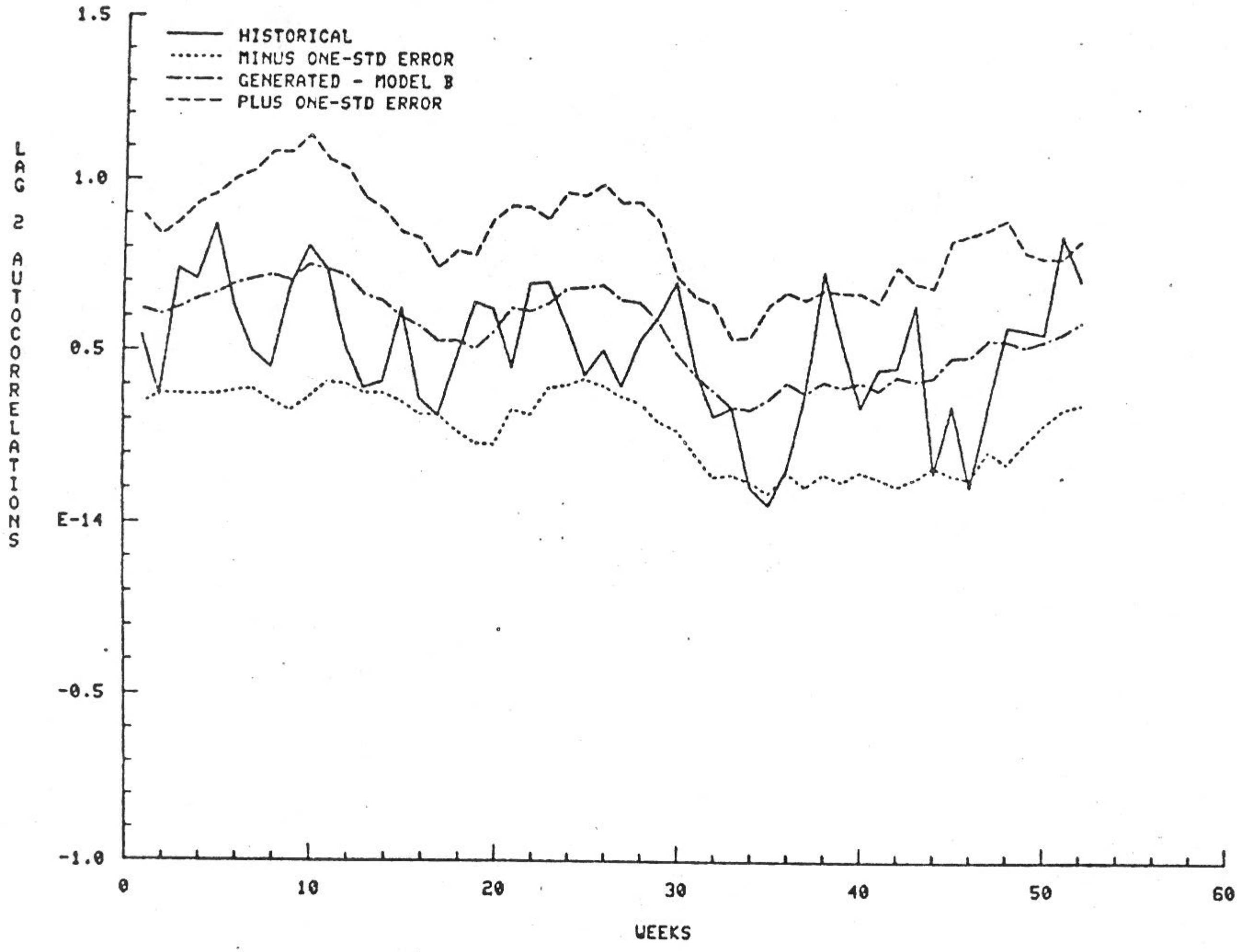

Figure 1.9.E.77. PALODE - LAG 2 AUTOCORRELATIONS (LOG DOMAIN)

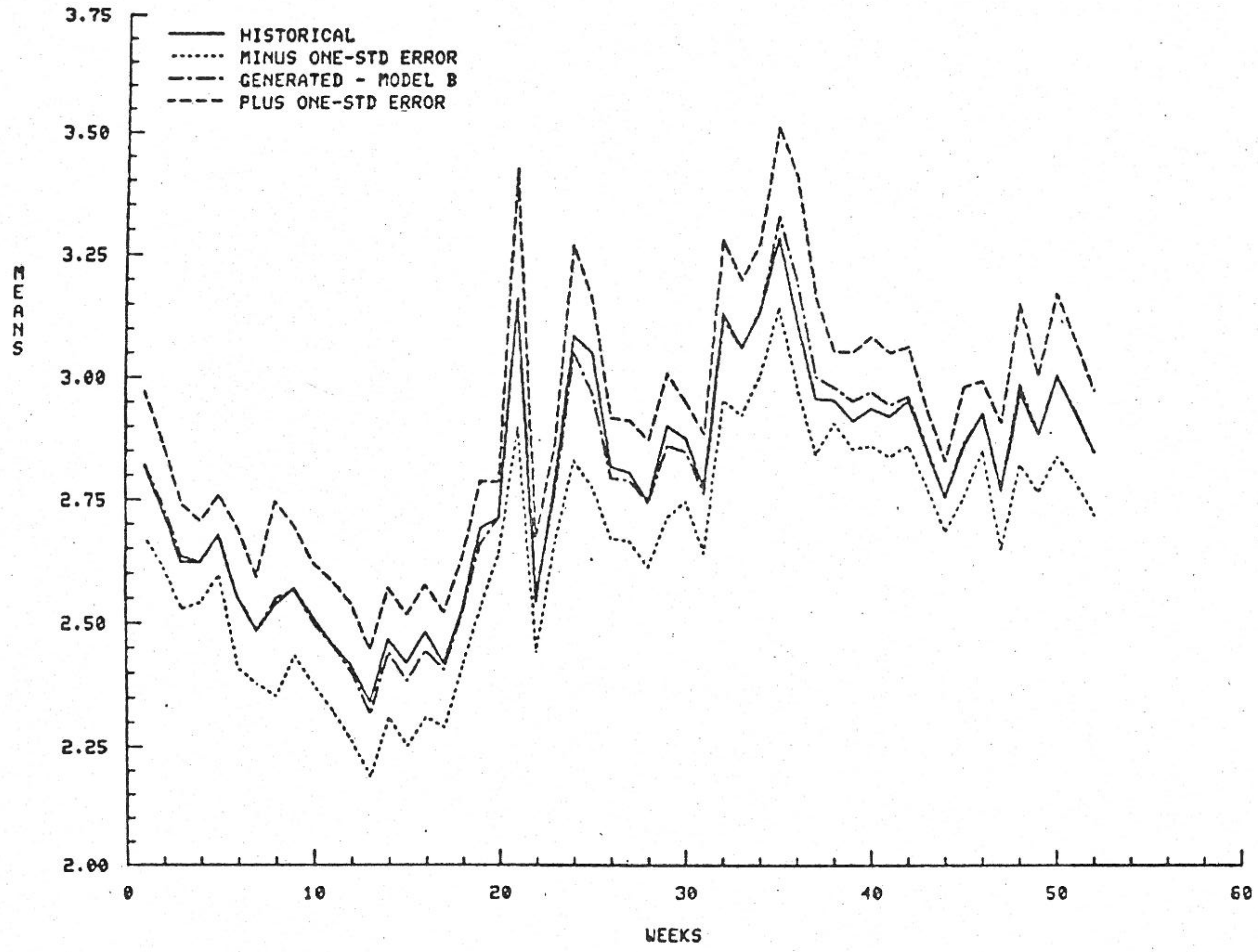

Figure 1.9.E.78. PASODE - MEANS (LOG DOMAIN)

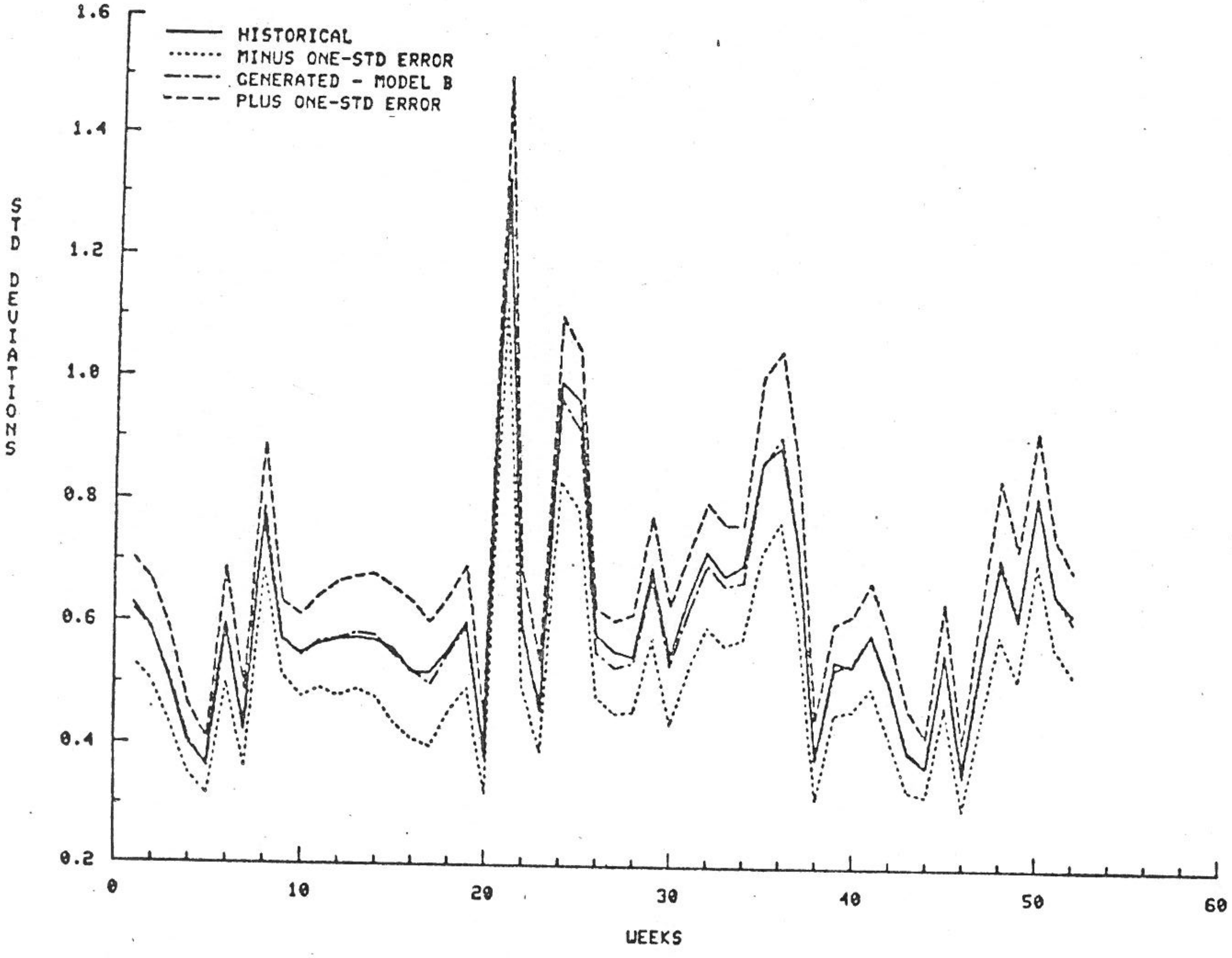

Figure 1.9.E.79. PASODE - STD DEVIATIONS (LOG DOMAIN)

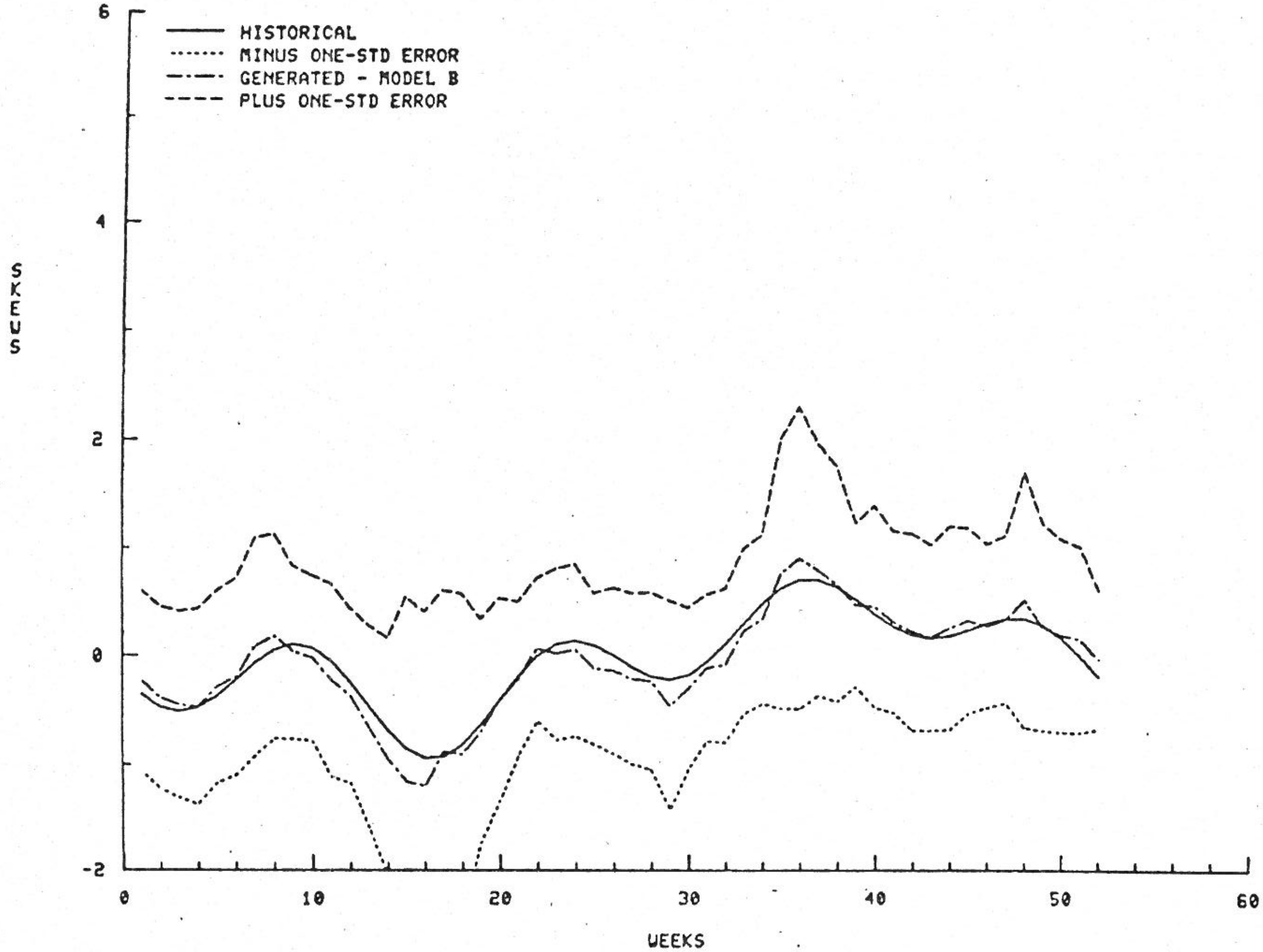

Figure 1.9.E.80. PASODE - SKEWS (LOG DOMAIN)

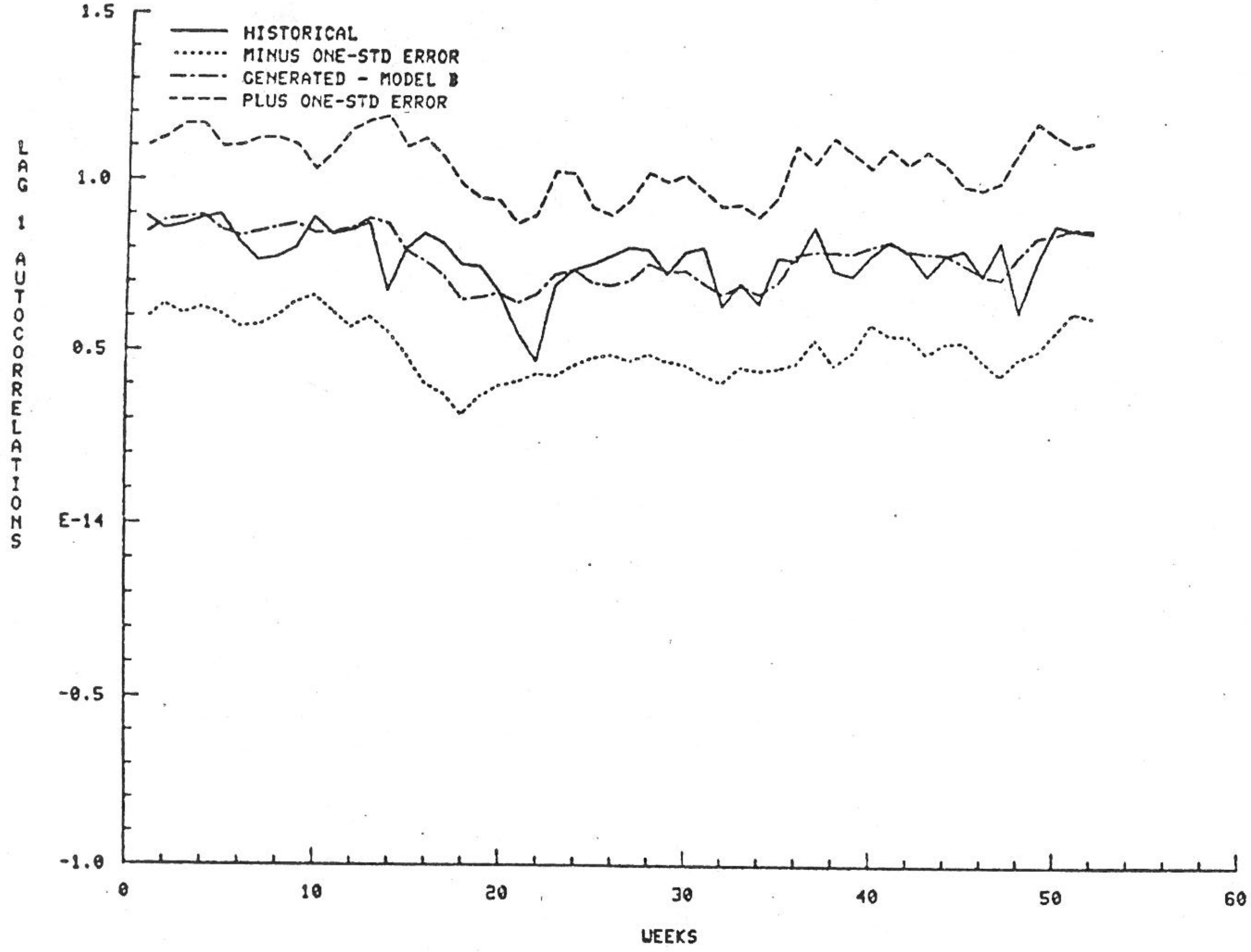

Figure 1.9.E.81. PASODE - LAG 1 AUTOCORRELATIONS (LOG DOMAIN)

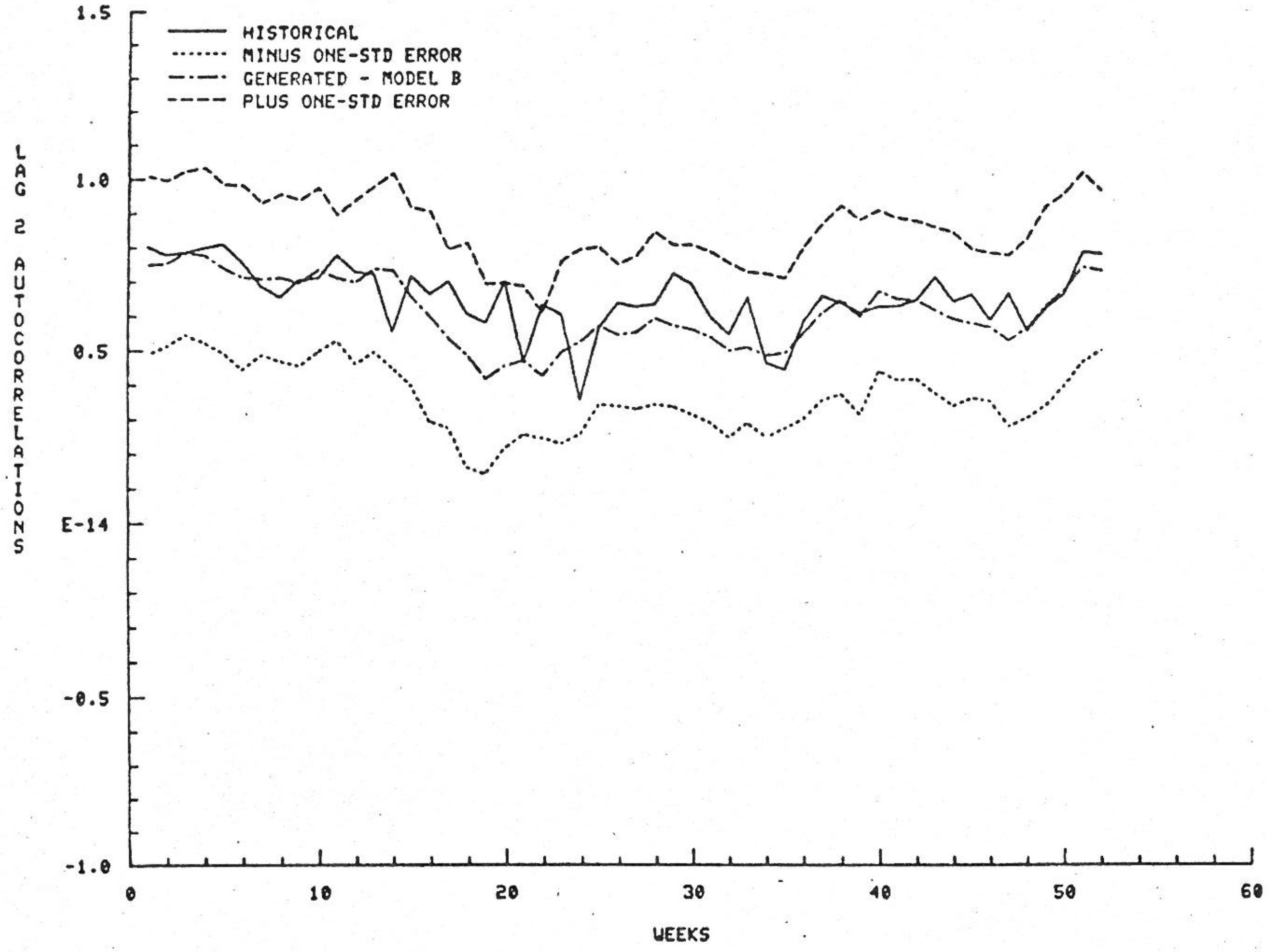

Figure 1.9.E.82. PASODE - LAG 2 AUTOCORRELATIONS (LOG DOMAIN)

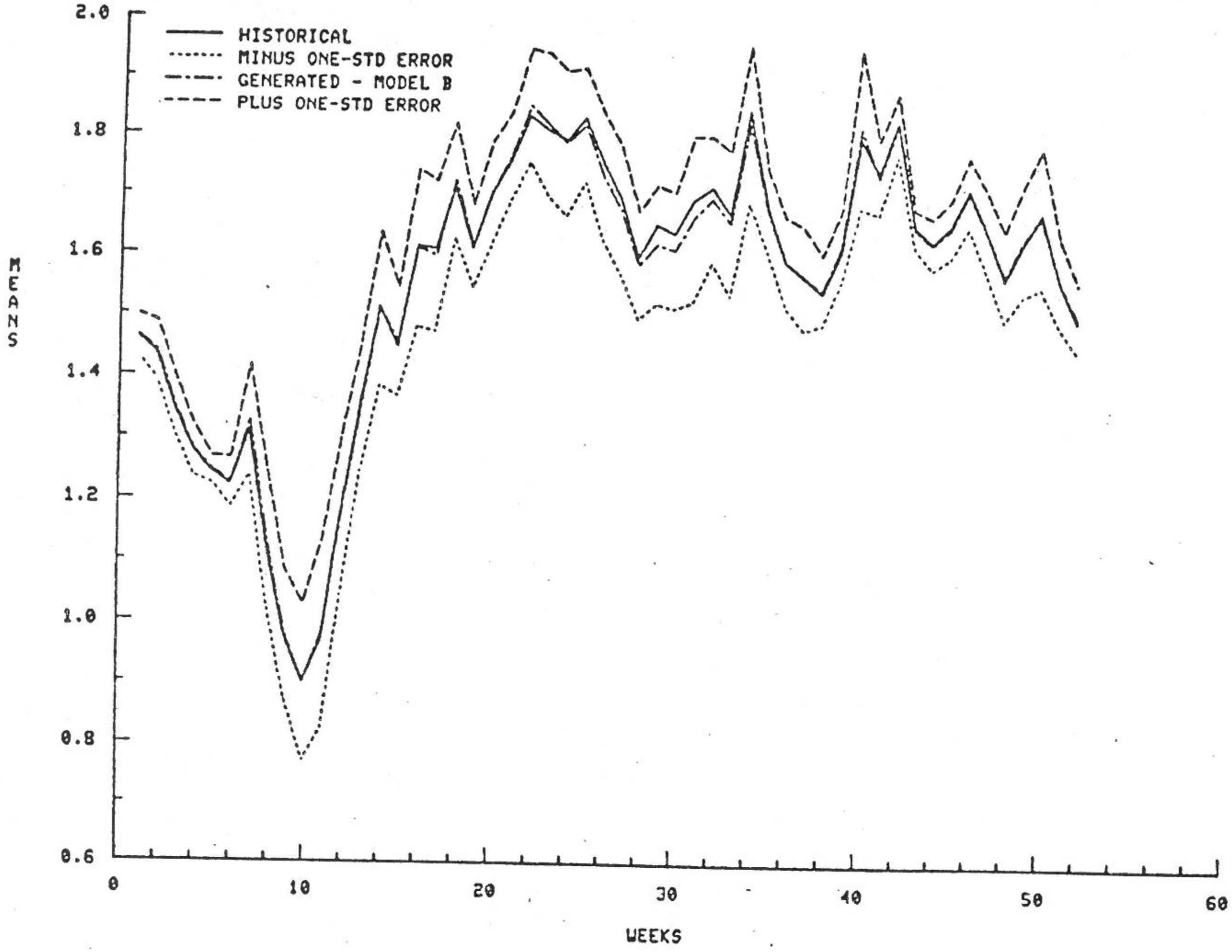

Figure 1.9.E.83. RANCHO - MEANS (LOG DOMAIN)

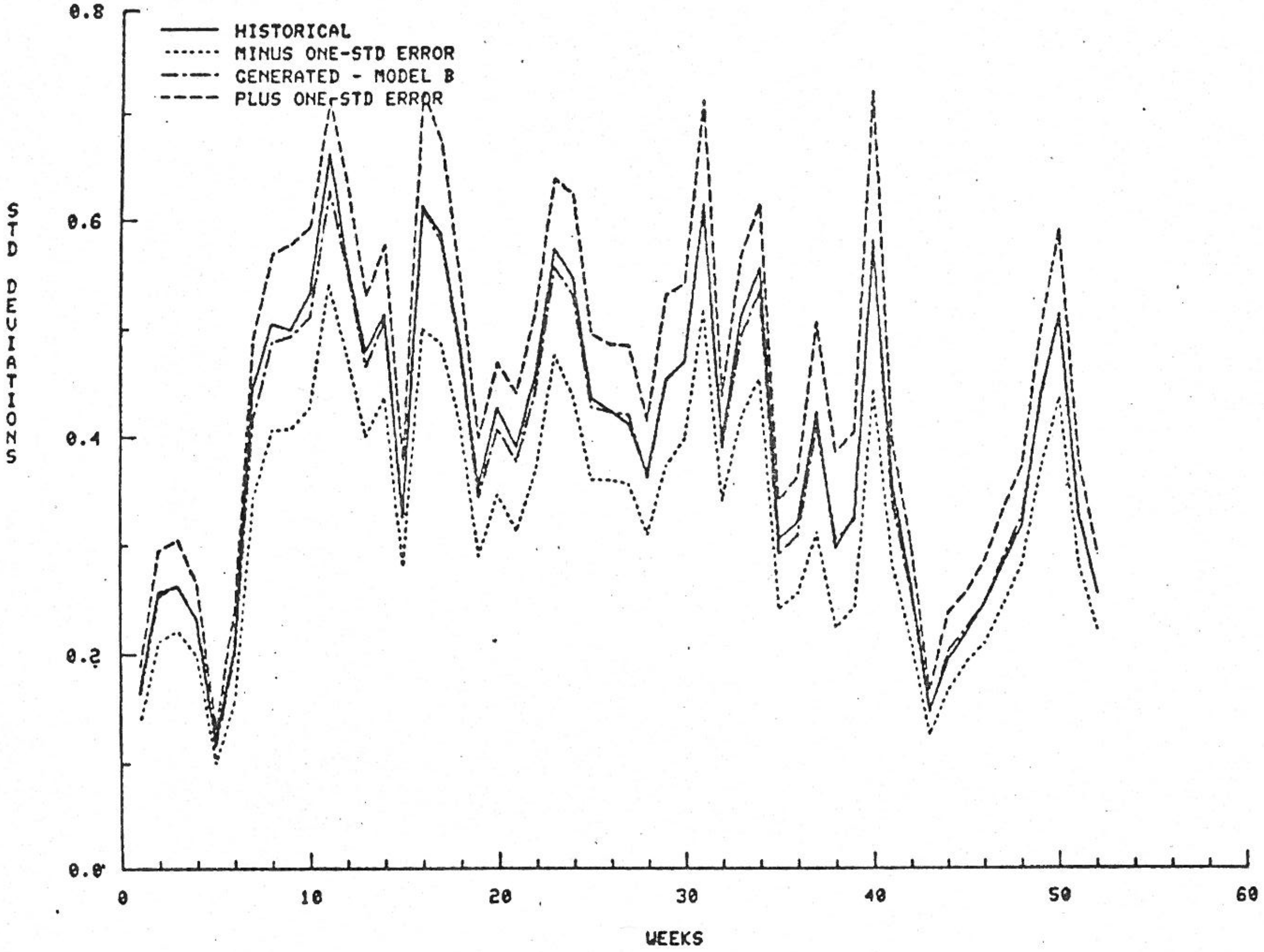

Figure 1.9.E.84. RANCHO - STD DEVIATIONS (LOG DOMAIN)

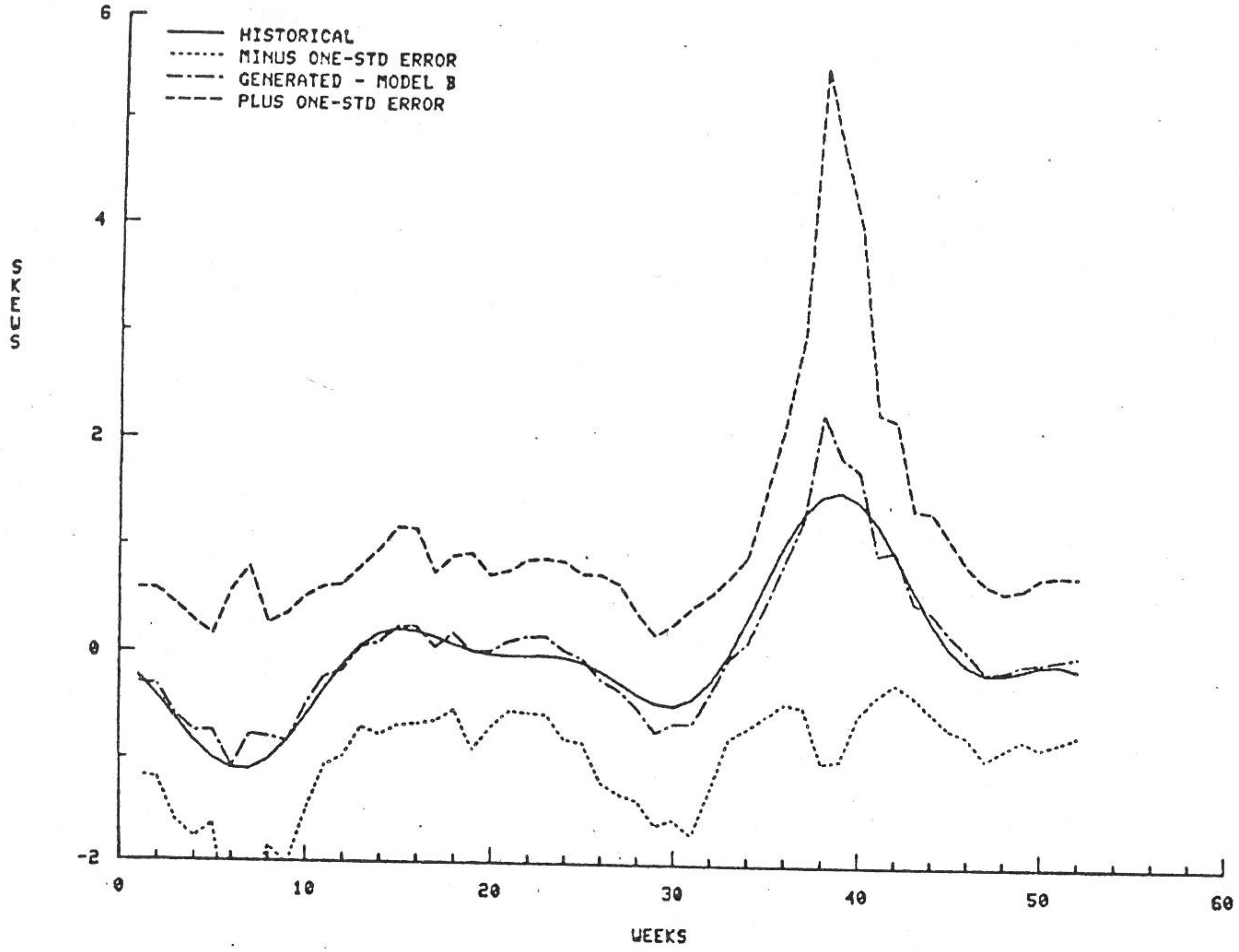

Figure 1.9.E.85. RANCHO - SKEWS (LOG DOMAIN)

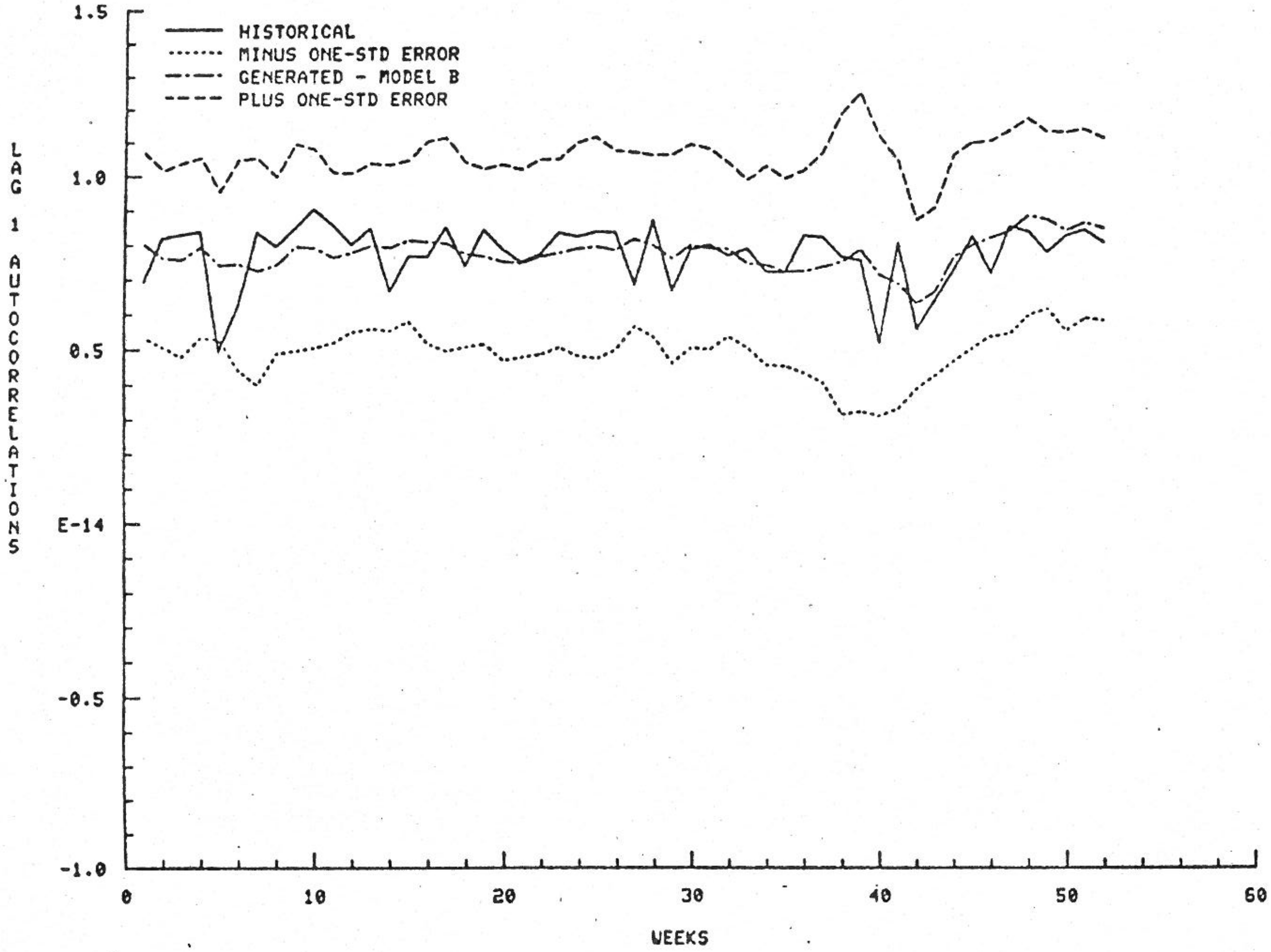

Figure 1.9.E.86. RANCHO - LAG 1 AUTOCORRELATIONS (LOG DOMAIN)

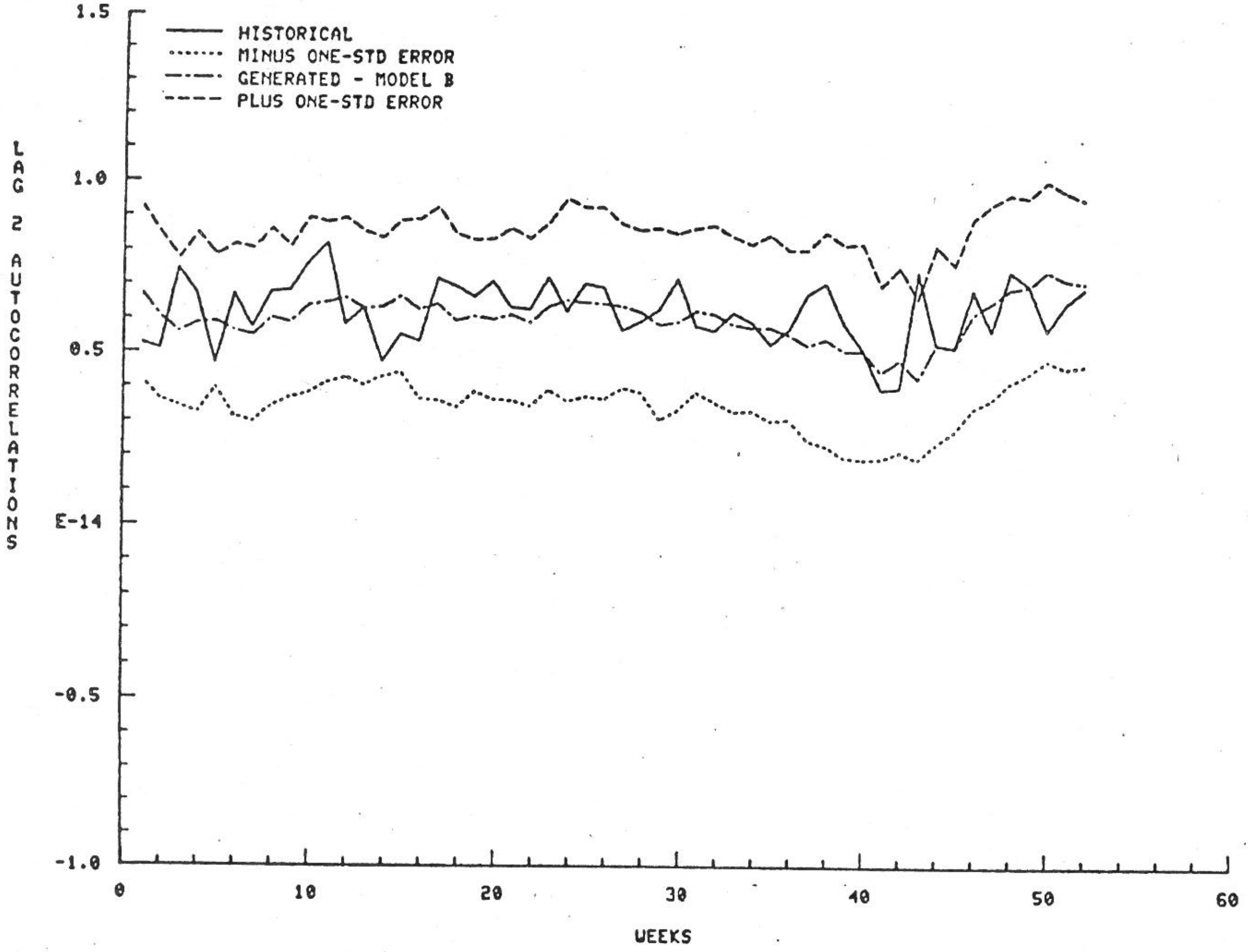

Figure 1.9.E.87. RANCHO - LAG 2 AUTOCORRELATIONS (LOG DOMAIN)

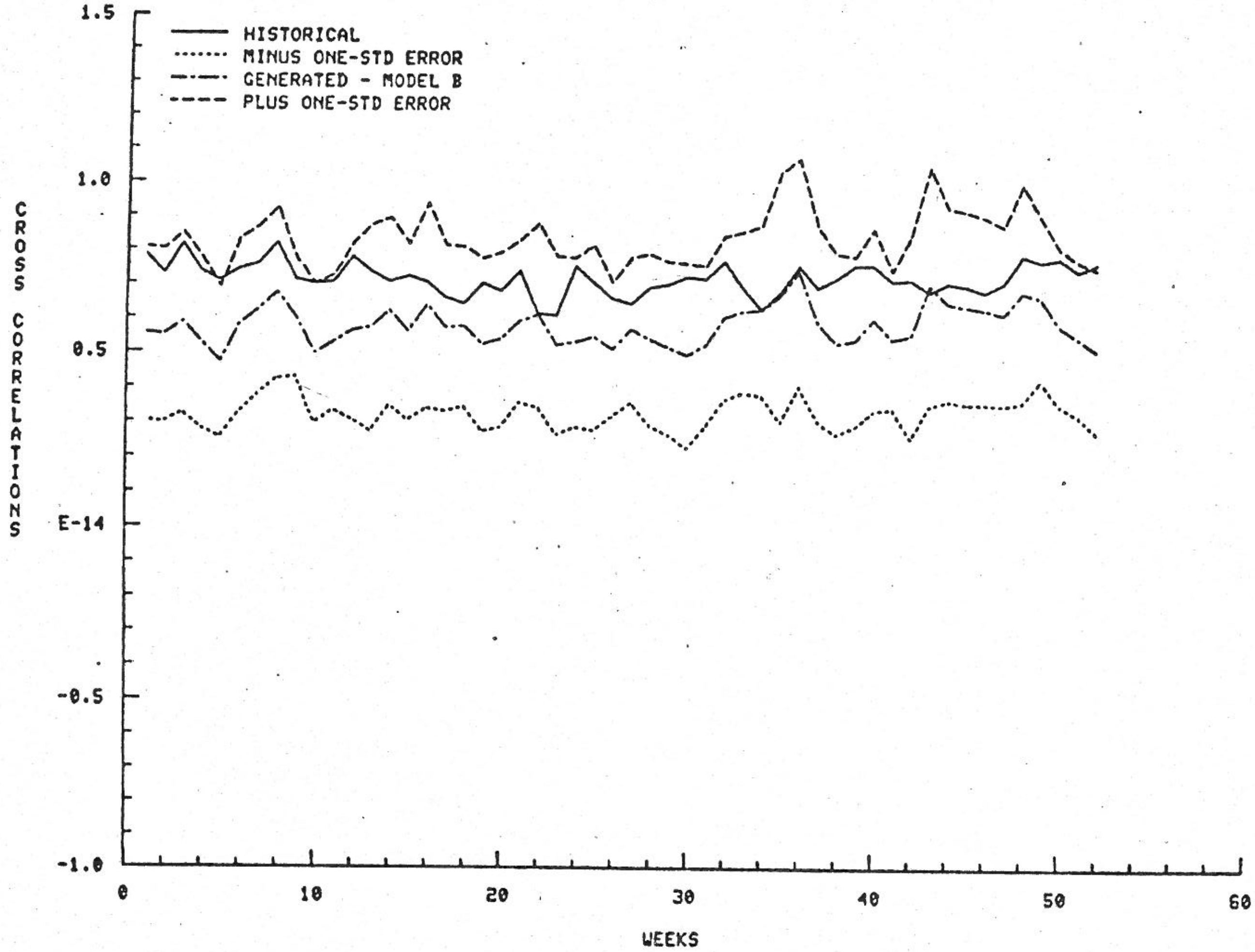

Figure 1.9.E.88. PALODE AND PASODE - CROSS CORRELATIONS (LOG DOMAIN)

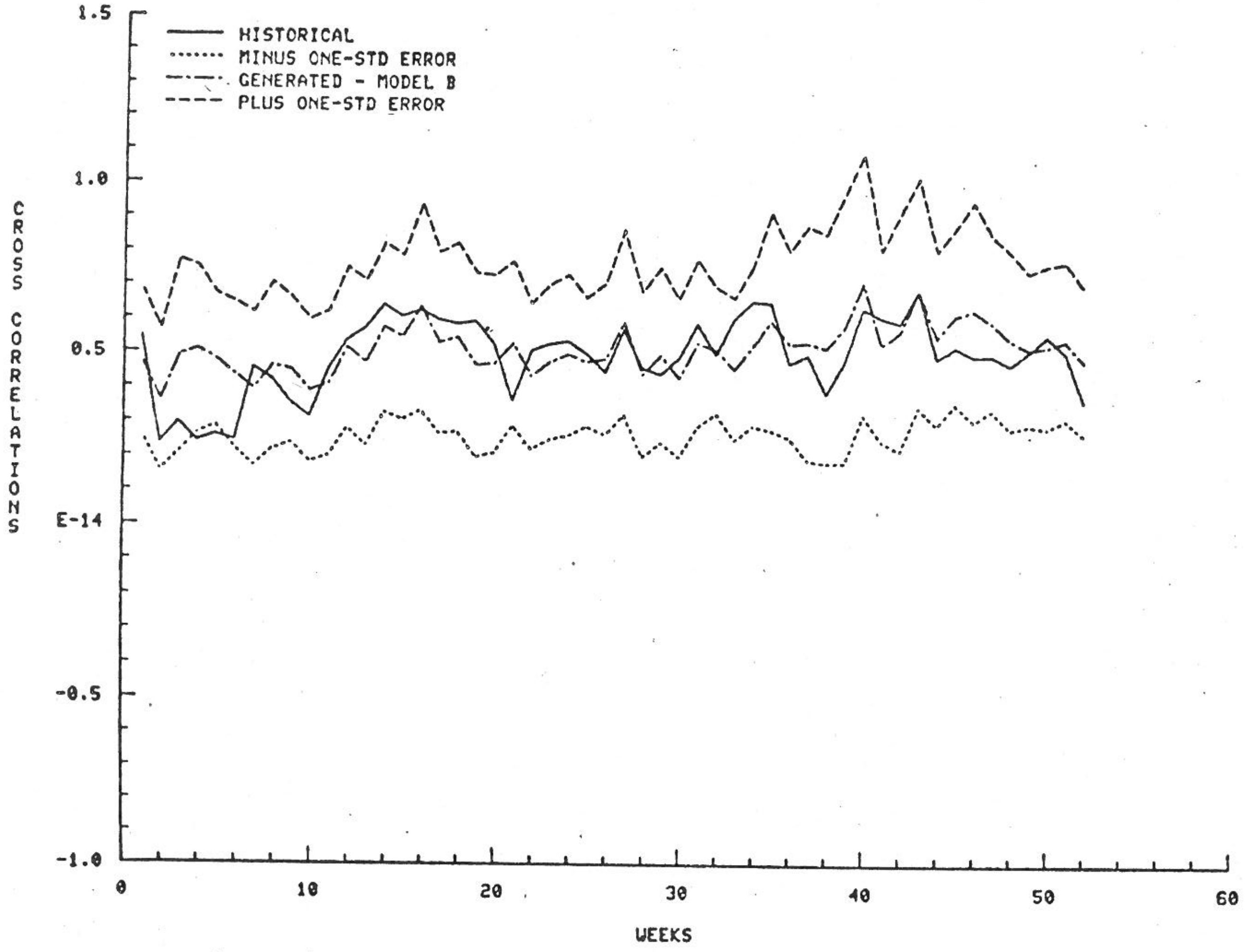

Figure 1.9.E.89. PASODE AND PASODE - CROSS CORRELATIONS (LOG DOMAIN)

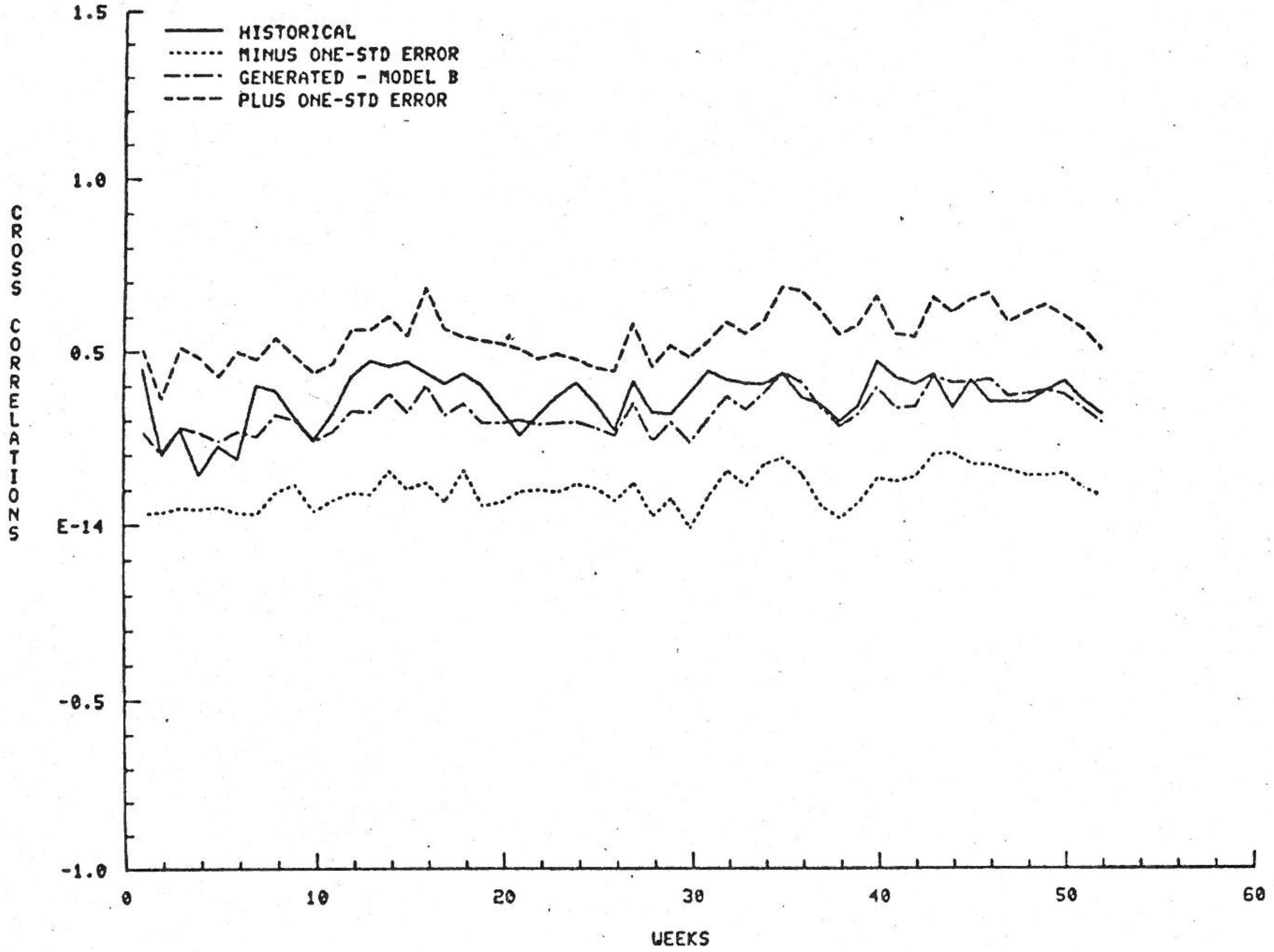

Figure 1.9.E.90. PASODE AND RANCHO - CROSS CORRELATIONS (LOG DOMAIN)

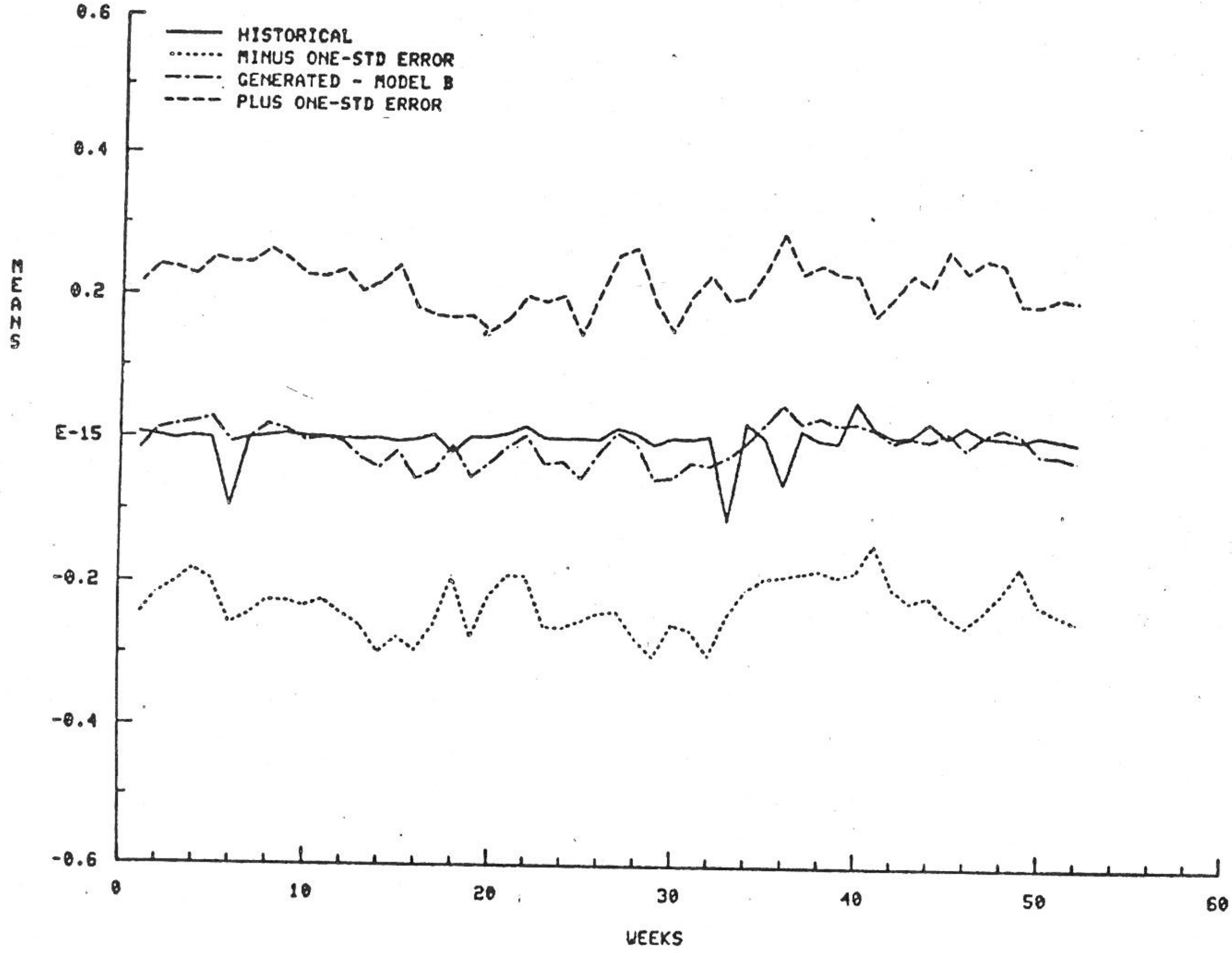

Figure 1.9.E.91. PALODE - MEANS (LWH DOMAIN)

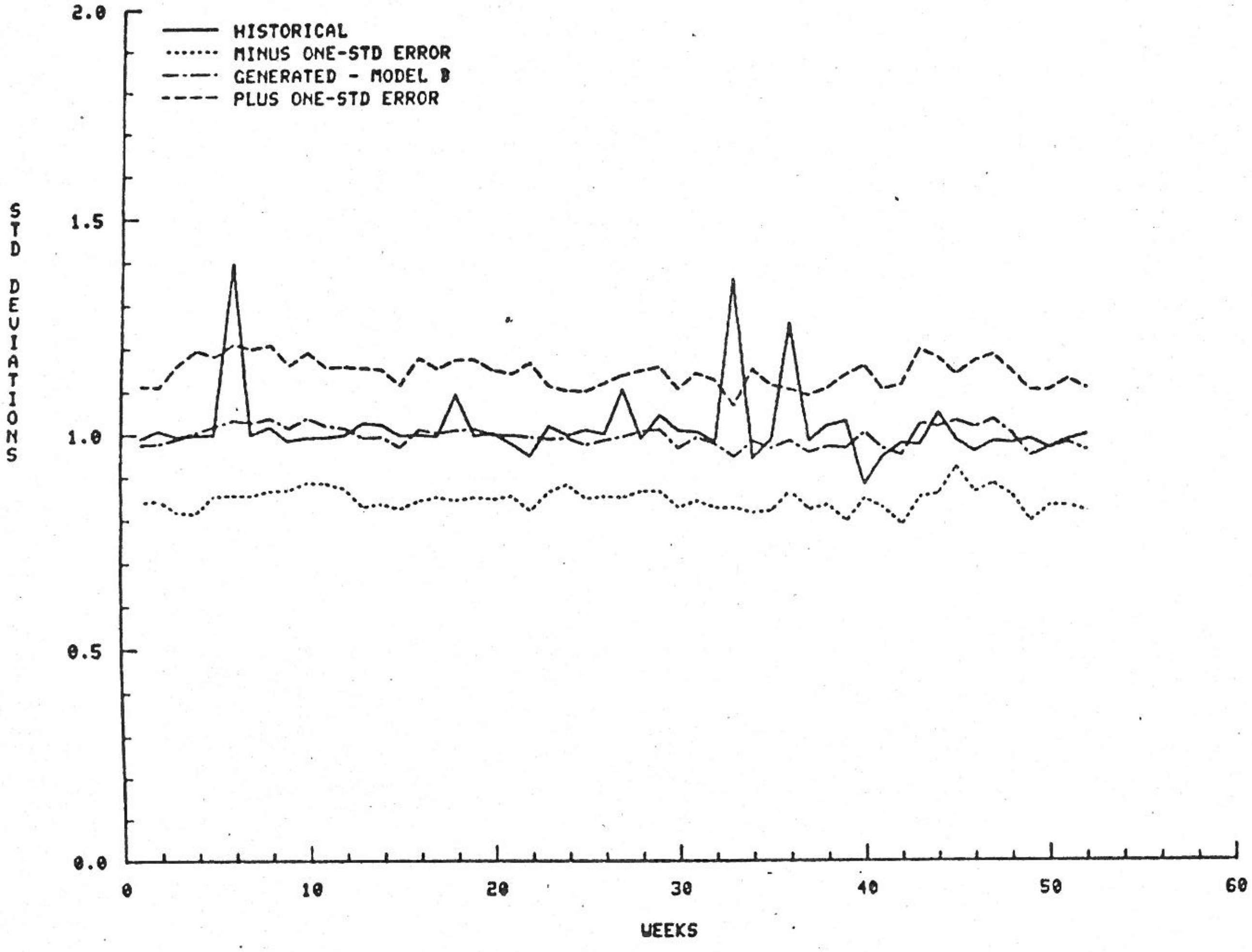

Figure 1.9.E.92. PALODE - STD DEVIATIONS (LWH DOMAIN)

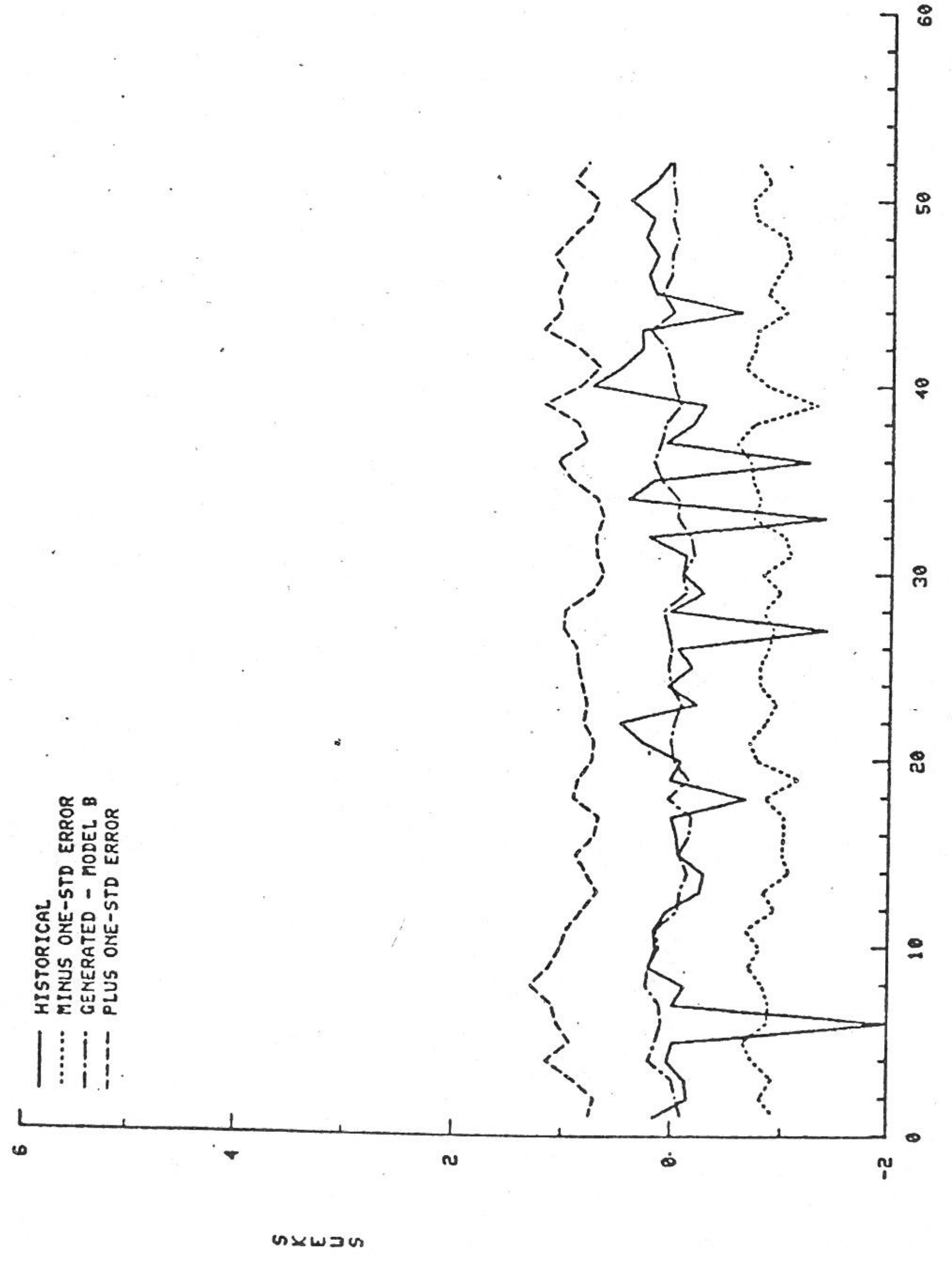

Figure 1.9.E.93. PALODE - SKEWS (LWH DOMAIN)

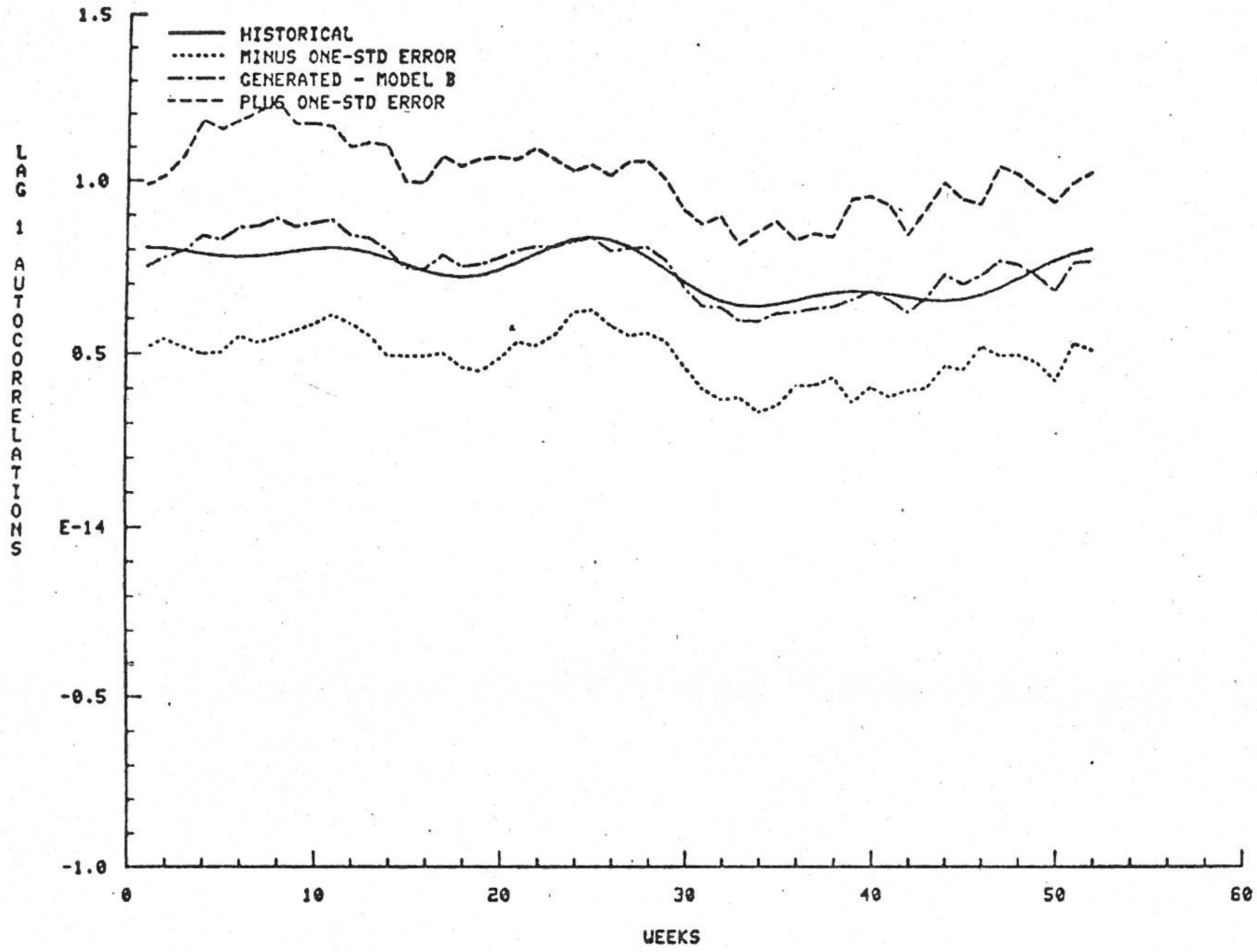

Figure 1.9.E.94. PALODE - LAG 1 AUTOCORRELATIONS (LWH DOMAIN)

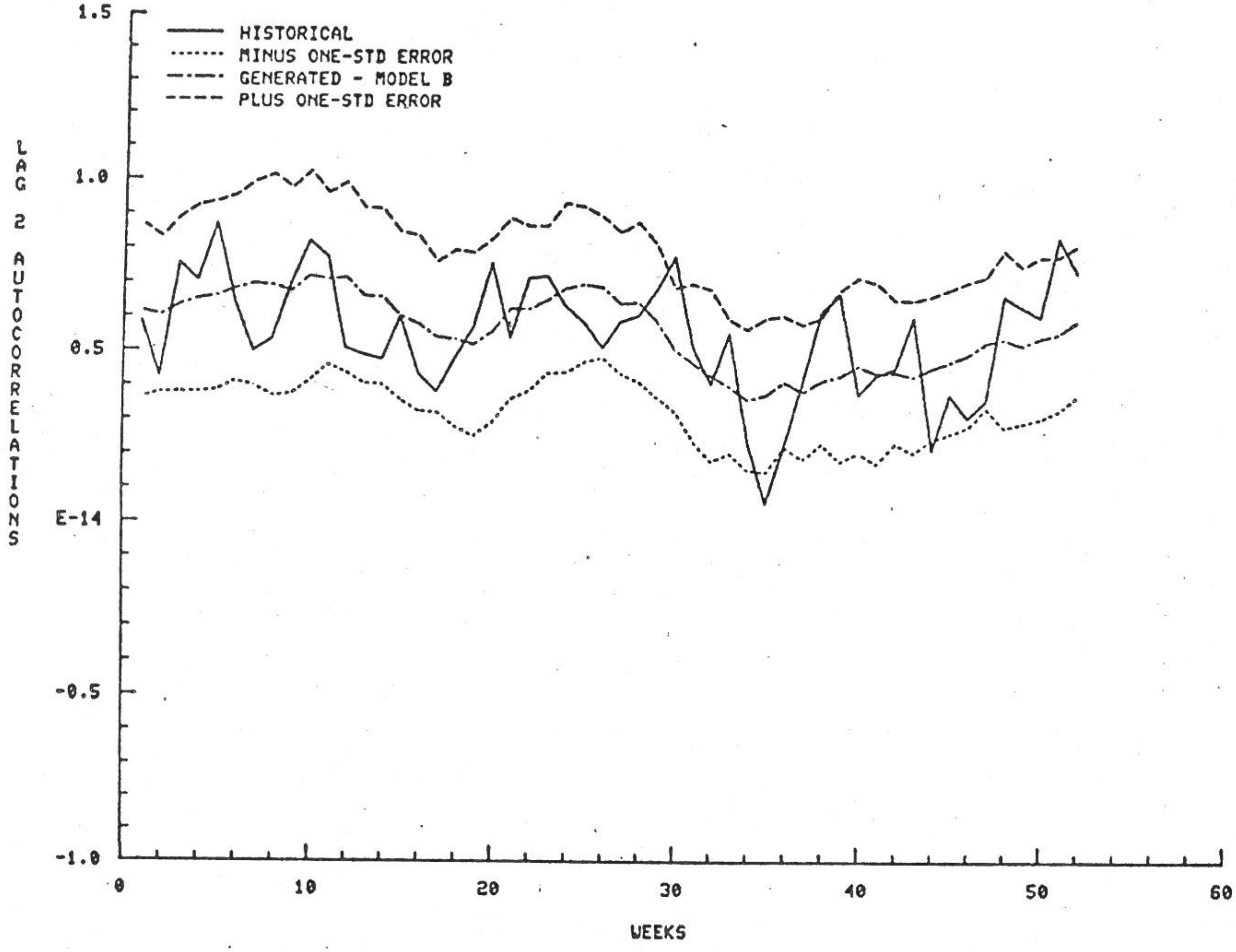

Figure 1.9.E.95. PALODE - LAG 2 AUTOCORRELATIONS (LWH DOMAIN)

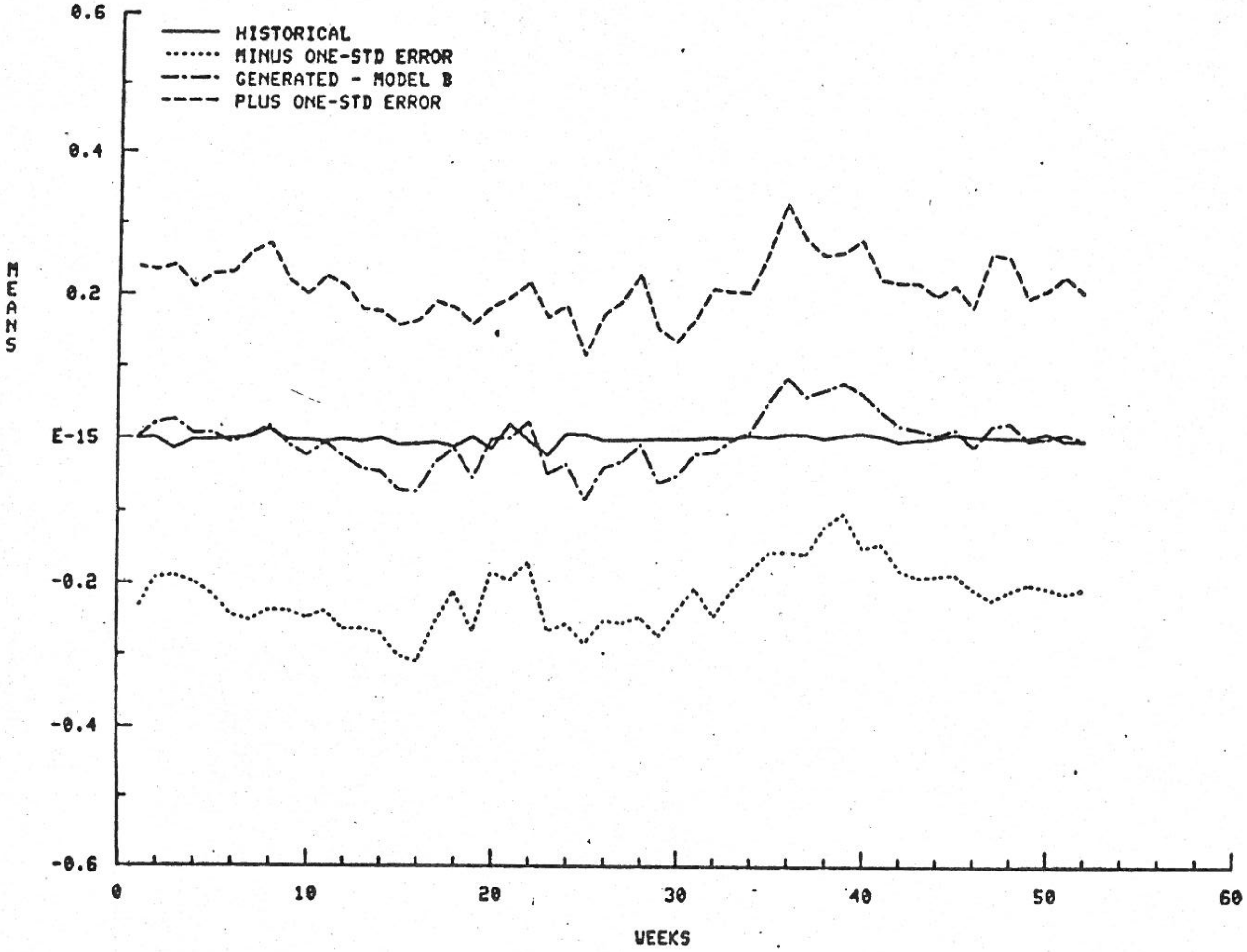

Figure 1.9.E.96. PASODE - MEANS (LWH DOMAIN)

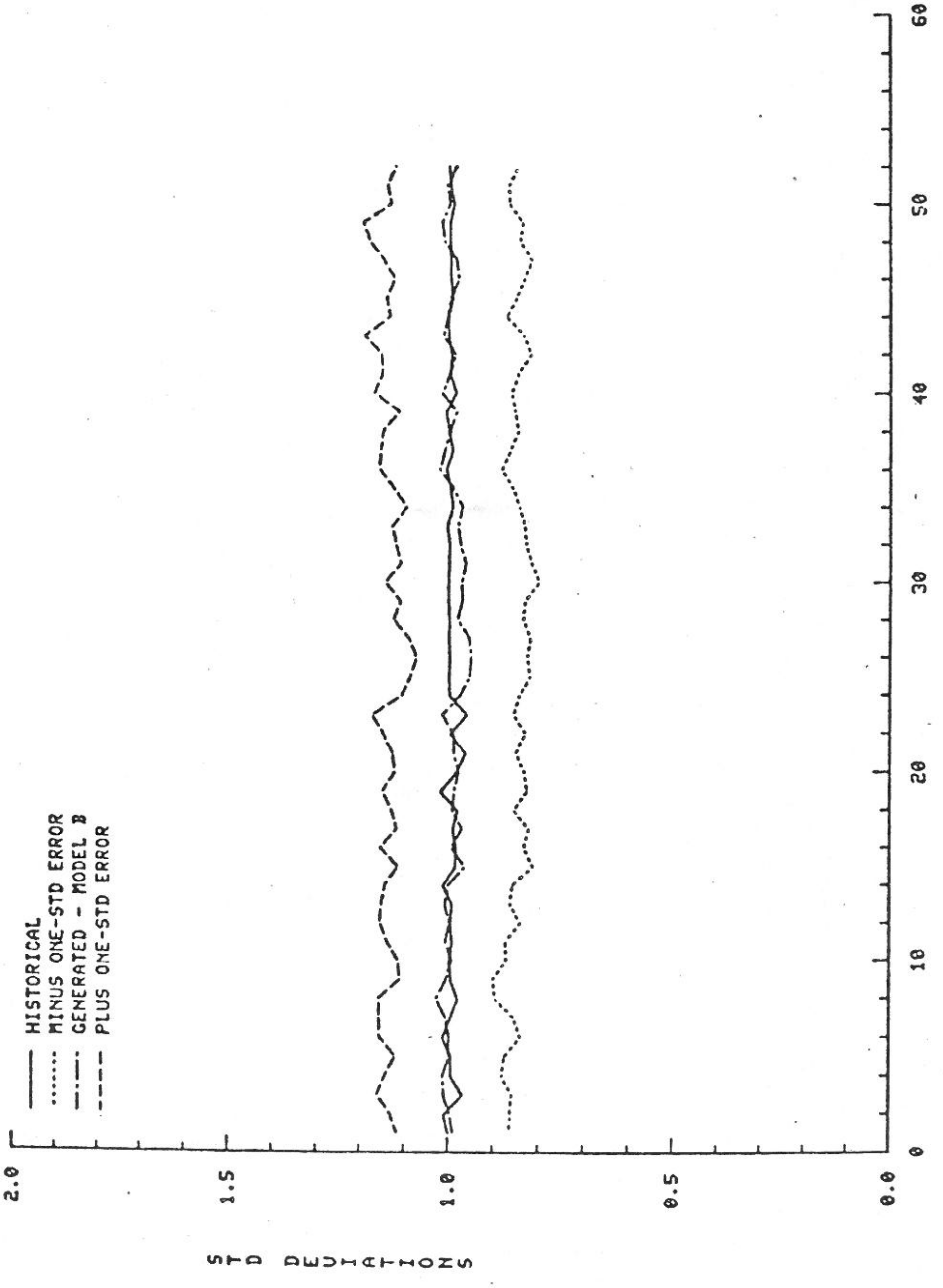

Figure 1.9.E.97. PASODE - STD DEVIATIONS (LWH DOMAIN)

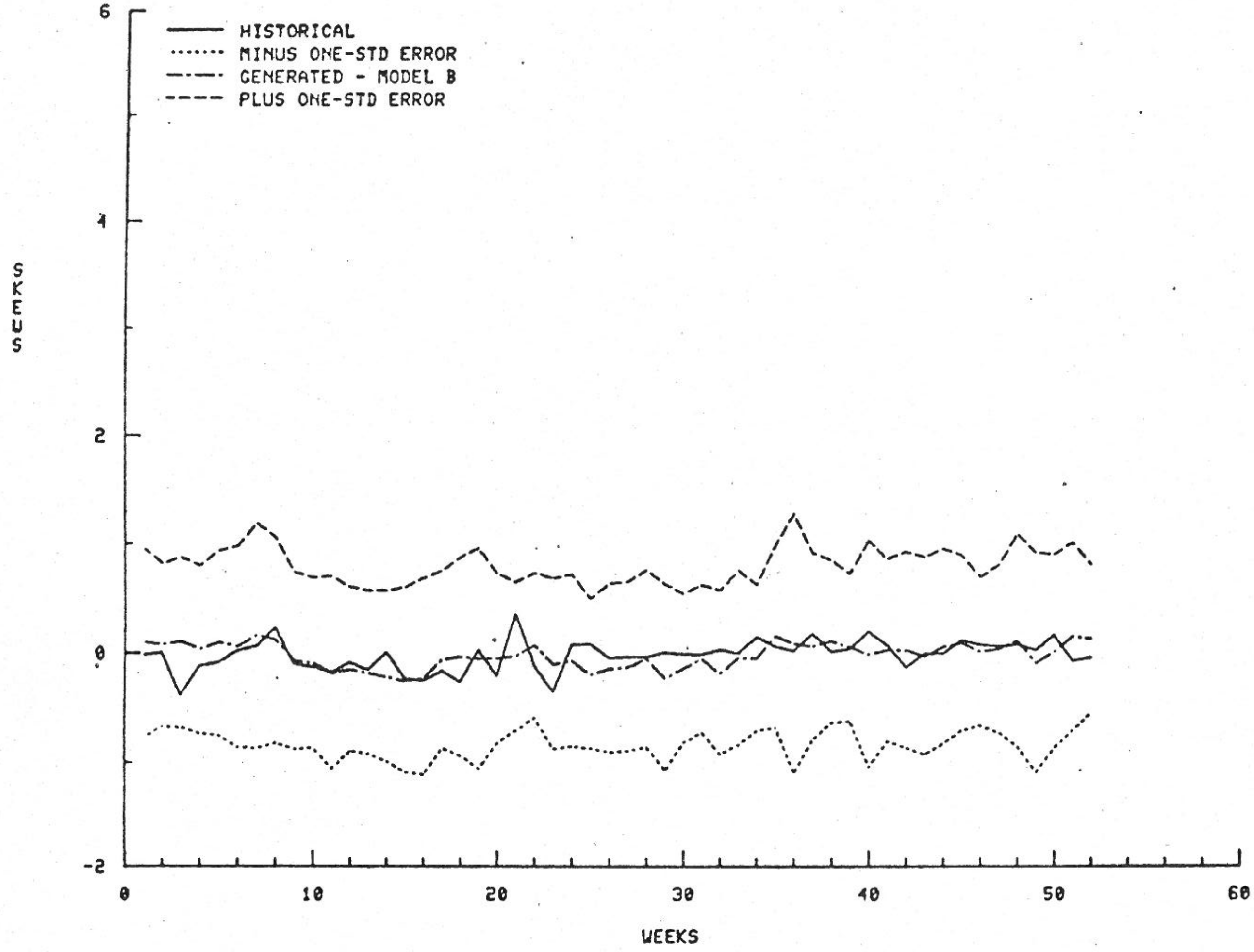

Figure 1.9.E.98. PASODE - SKEWS (LWH DOMAIN)

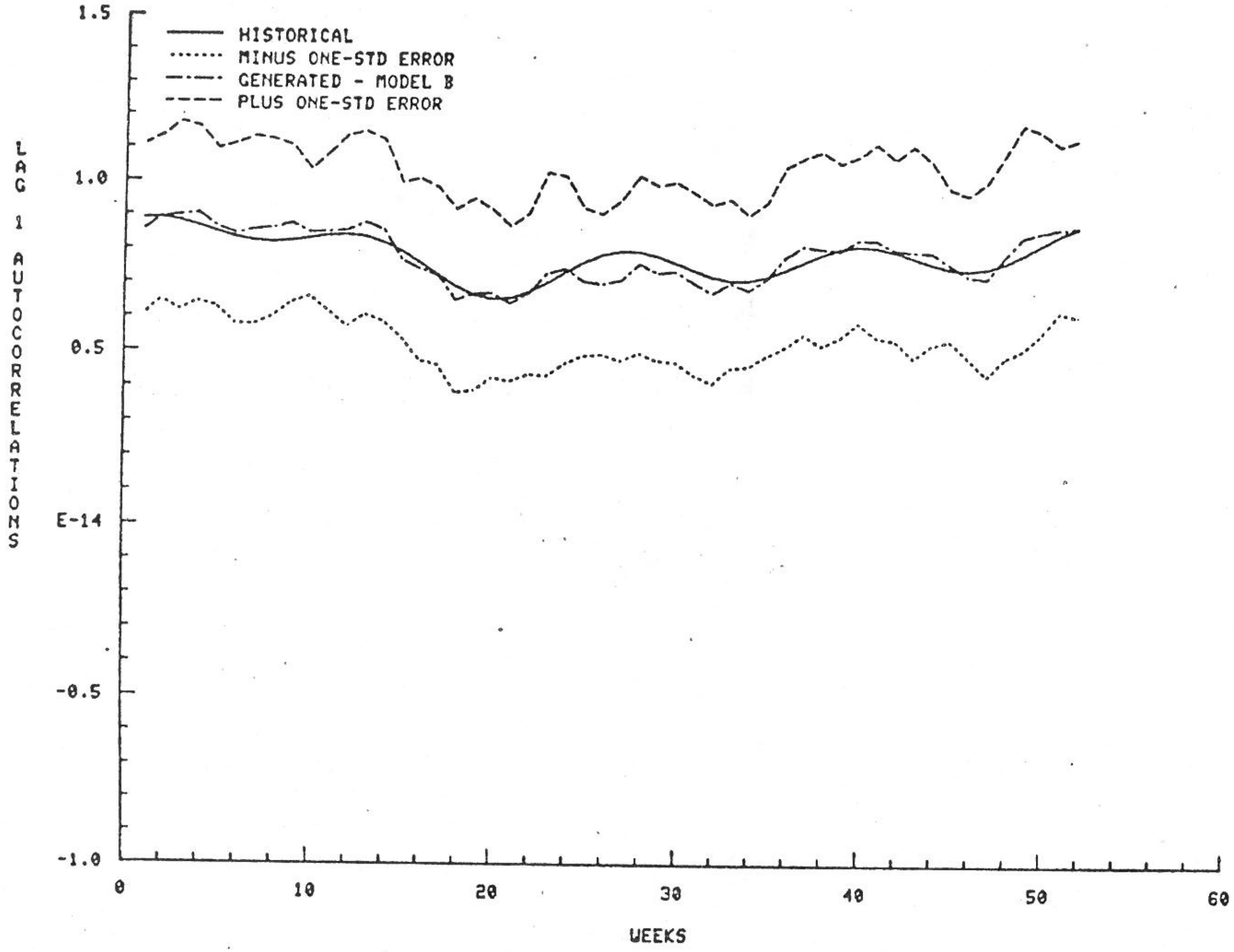

Figure 1.9.E.99. PASODE - LAG 1 AUTOCORRELATIONS (LWH DOMAIN)

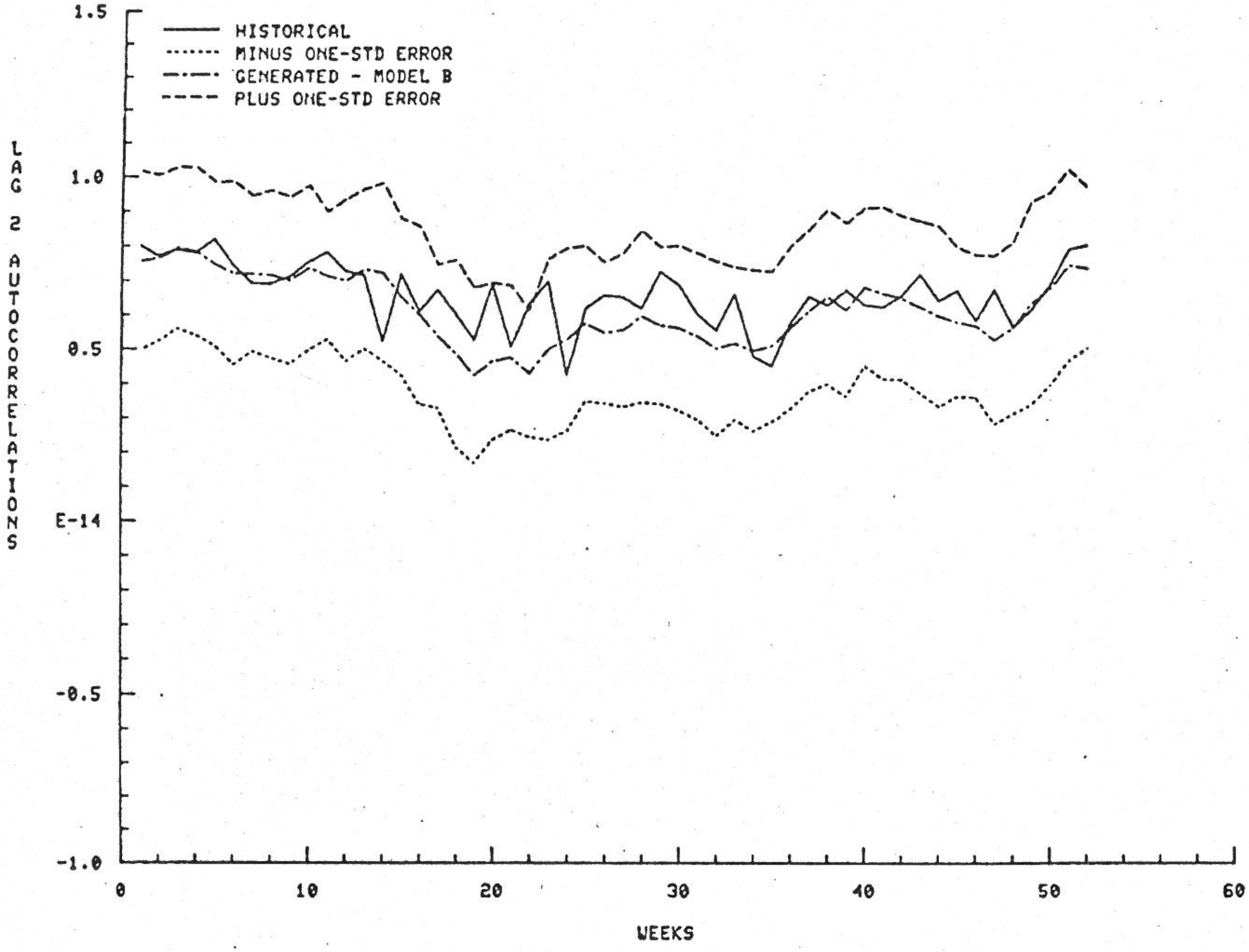

Figure 1.9.E.100. PASODE - LAG 2 AUTOCORRELATIONS (LWH DOMAIN)

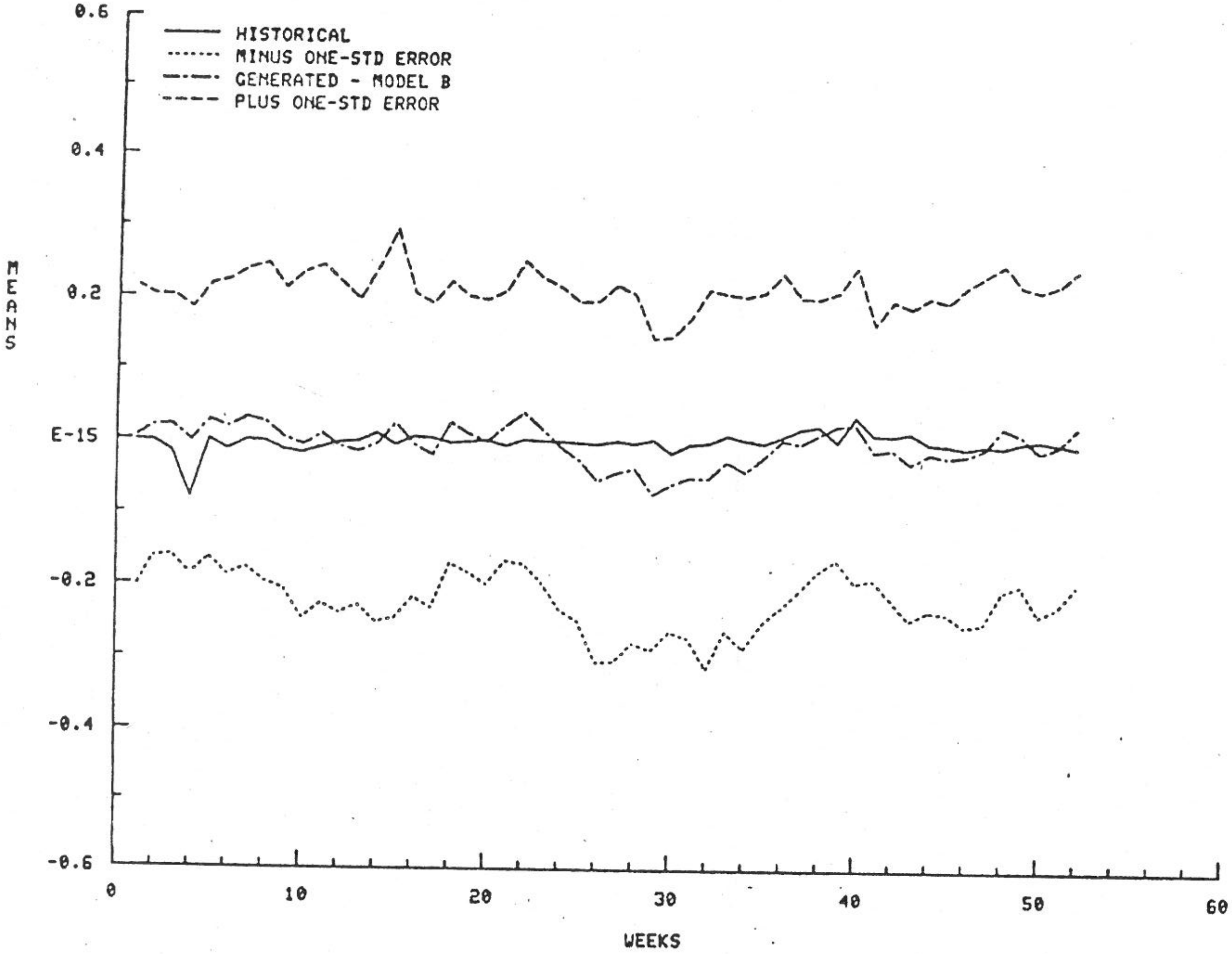

Figure 1.9.E.101. RANCHO - MEANS (LWH DOMAIN)

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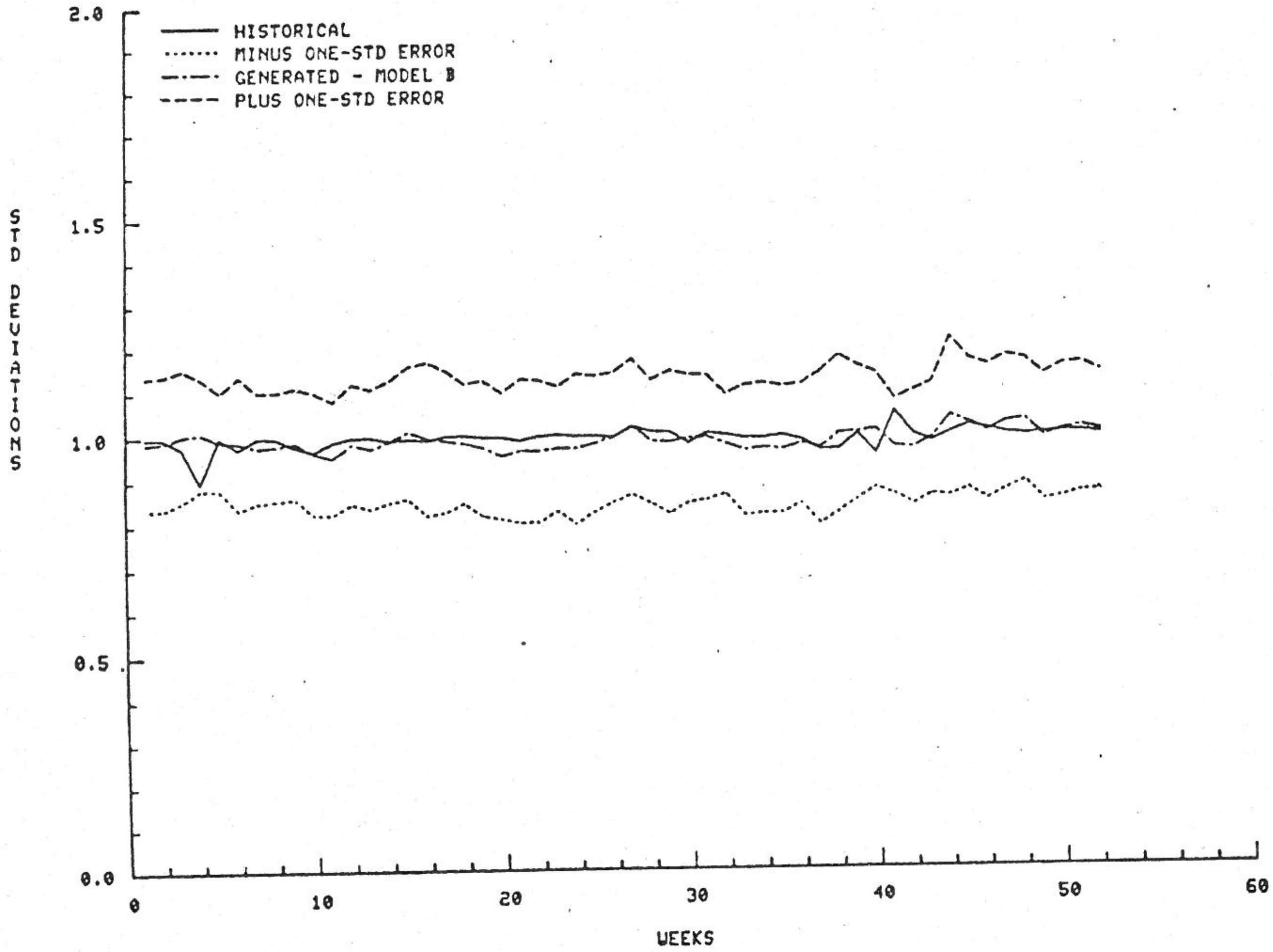

Figure 1.9.E.102. RANCHO - STD DEVIATIONS (LWH DOMAIN)

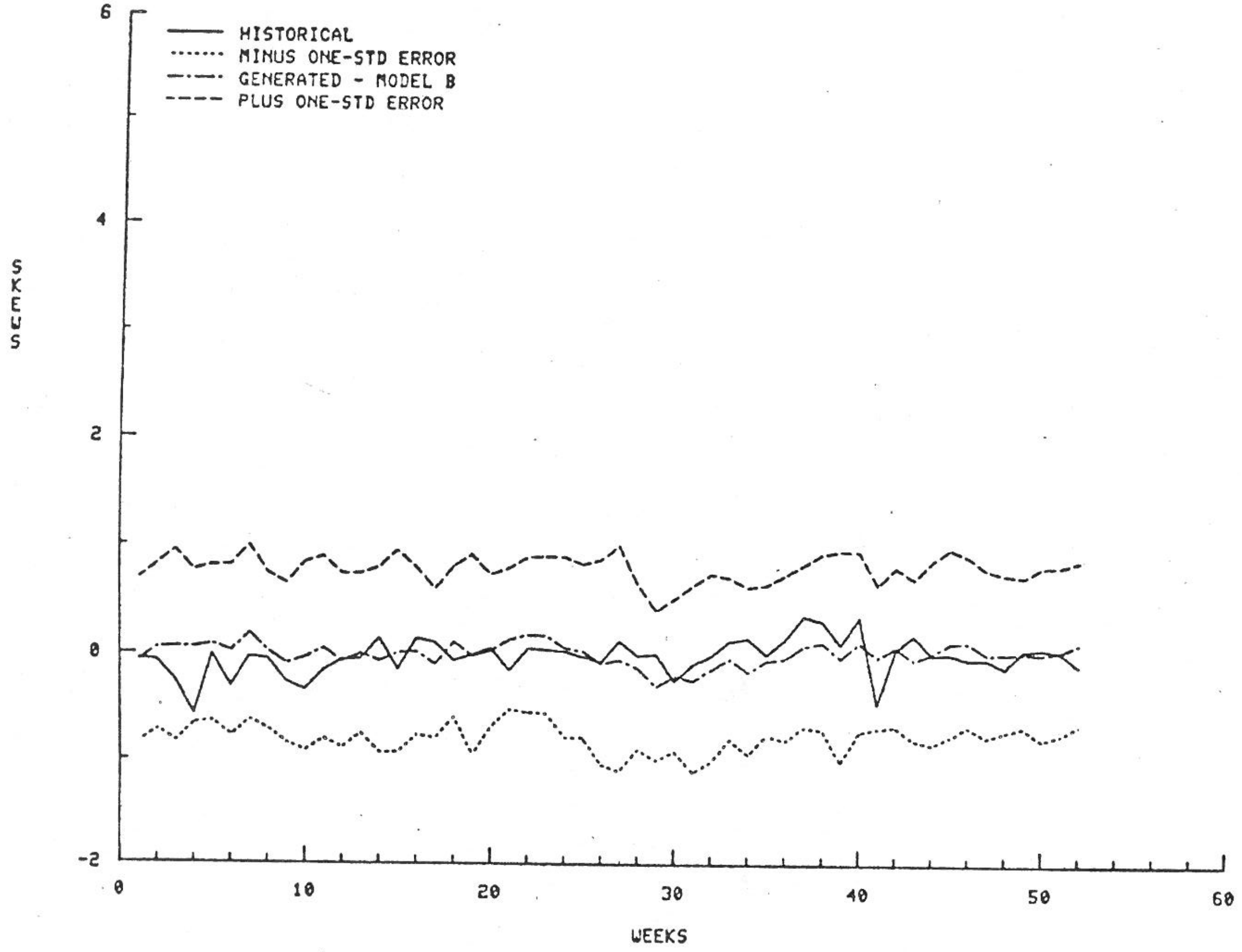

Figure 1.9.E.103. RANCHO - SKEWS (LWH DOMAIN)

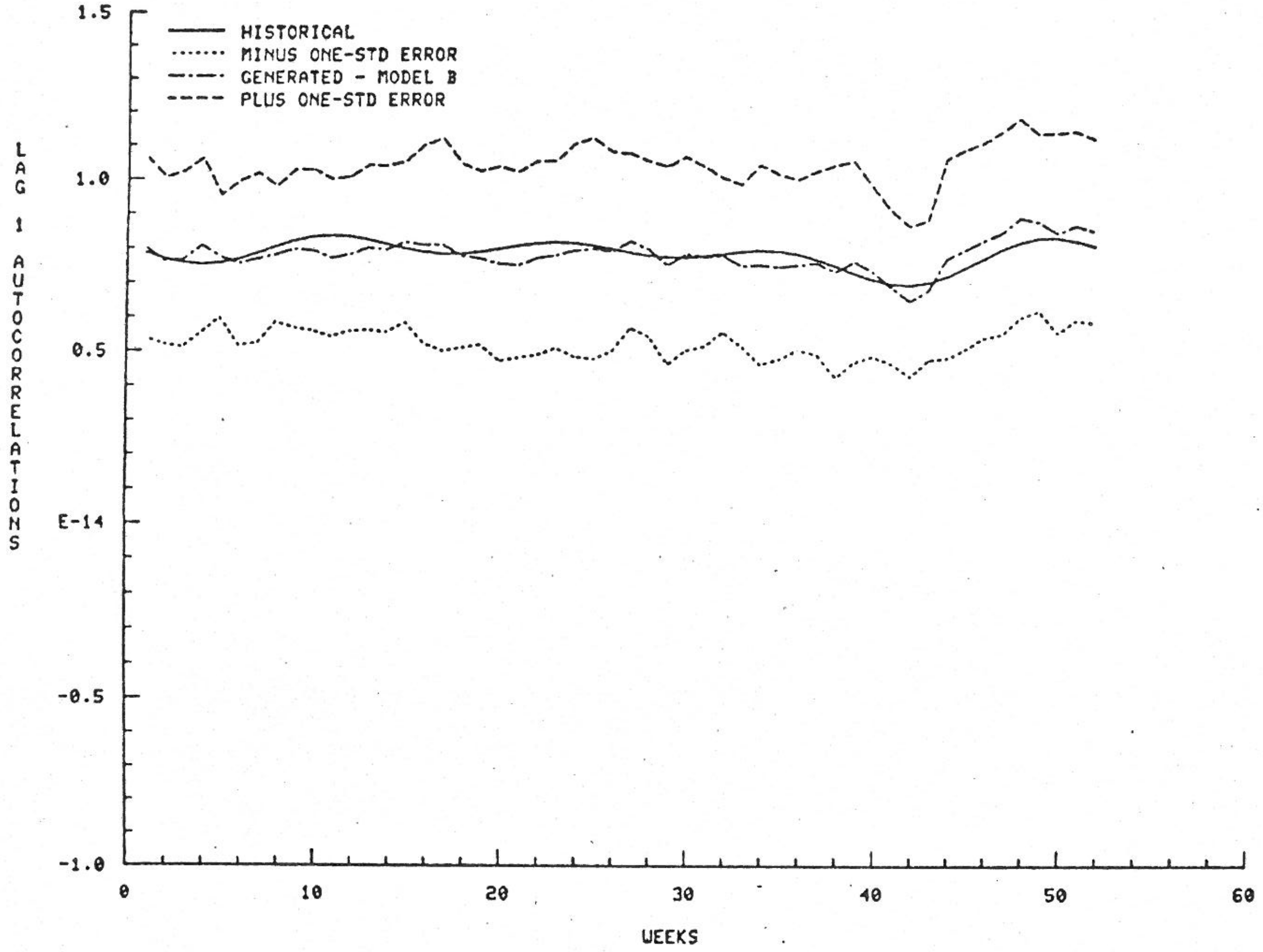

Figure 1.9.E.104. RANCHO - LAG 1 AUTOCORRELATIONS (LWH DOMAIN)

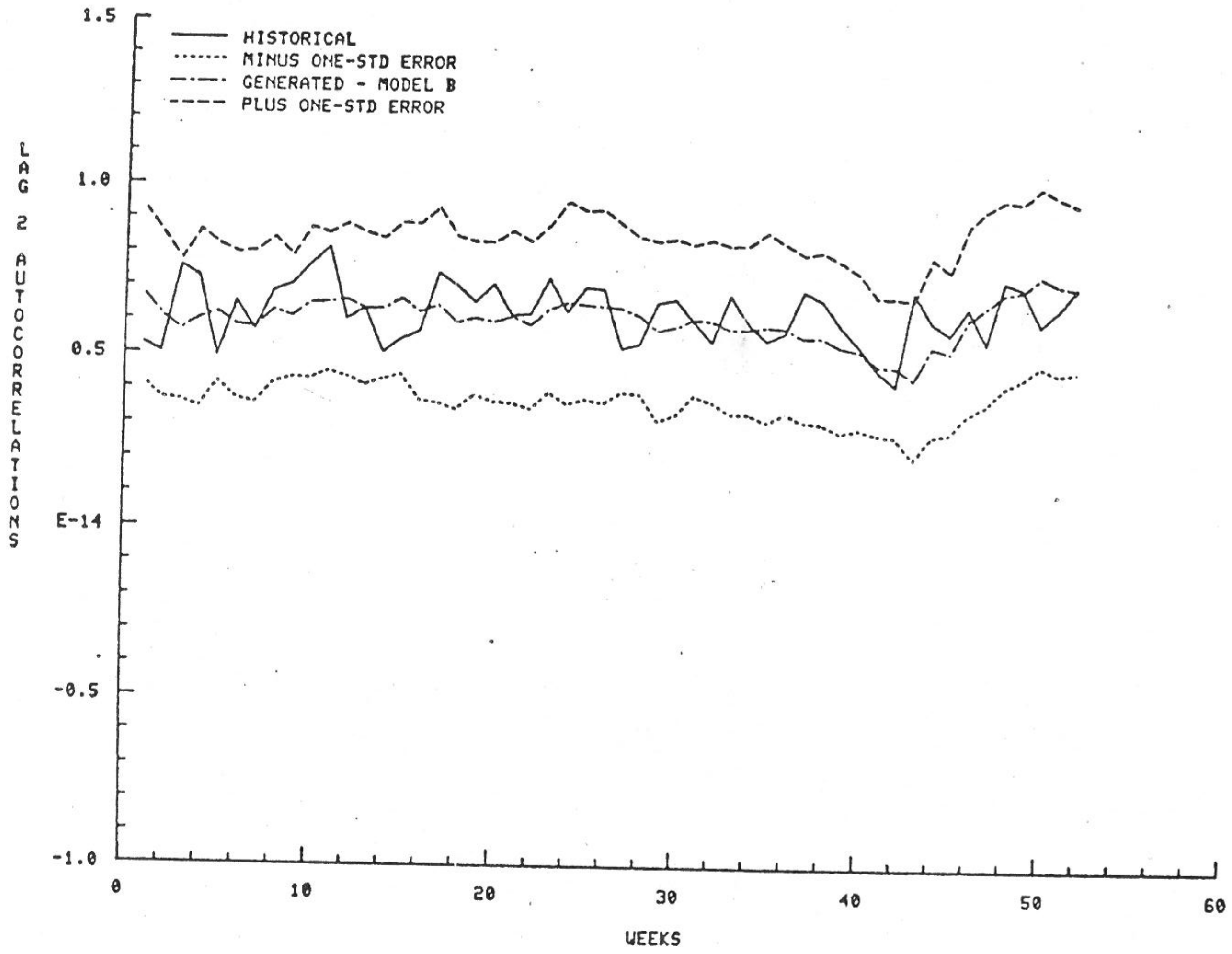

Figure 1.9.E.105. RANCHO - LAG 2 AUTOCORRELATIONS (LWH DOMAIN)

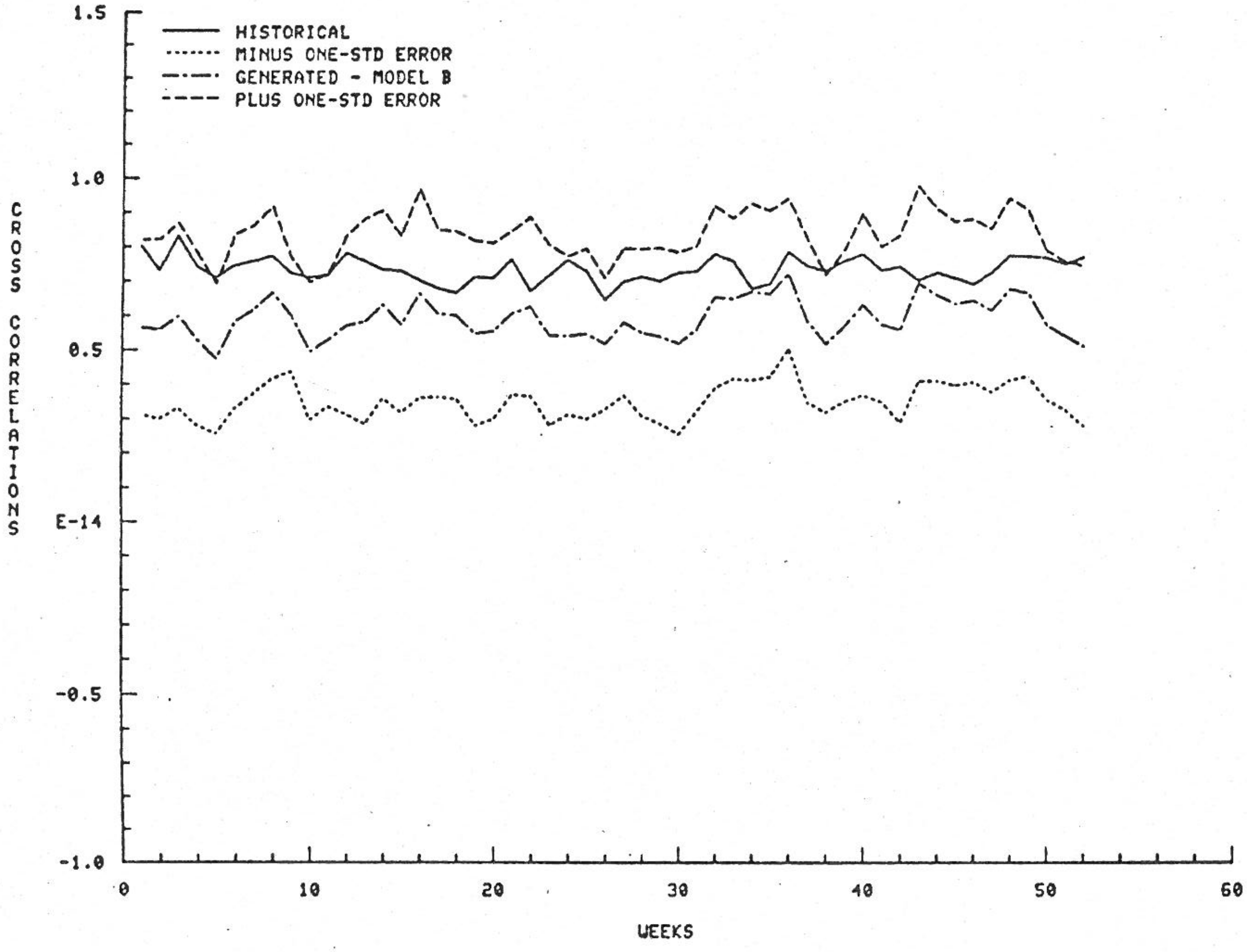

Figure 1.9.E.106. PALODE AND PASODE - CROSS CORRELATIONS (LWH DOMAIN)

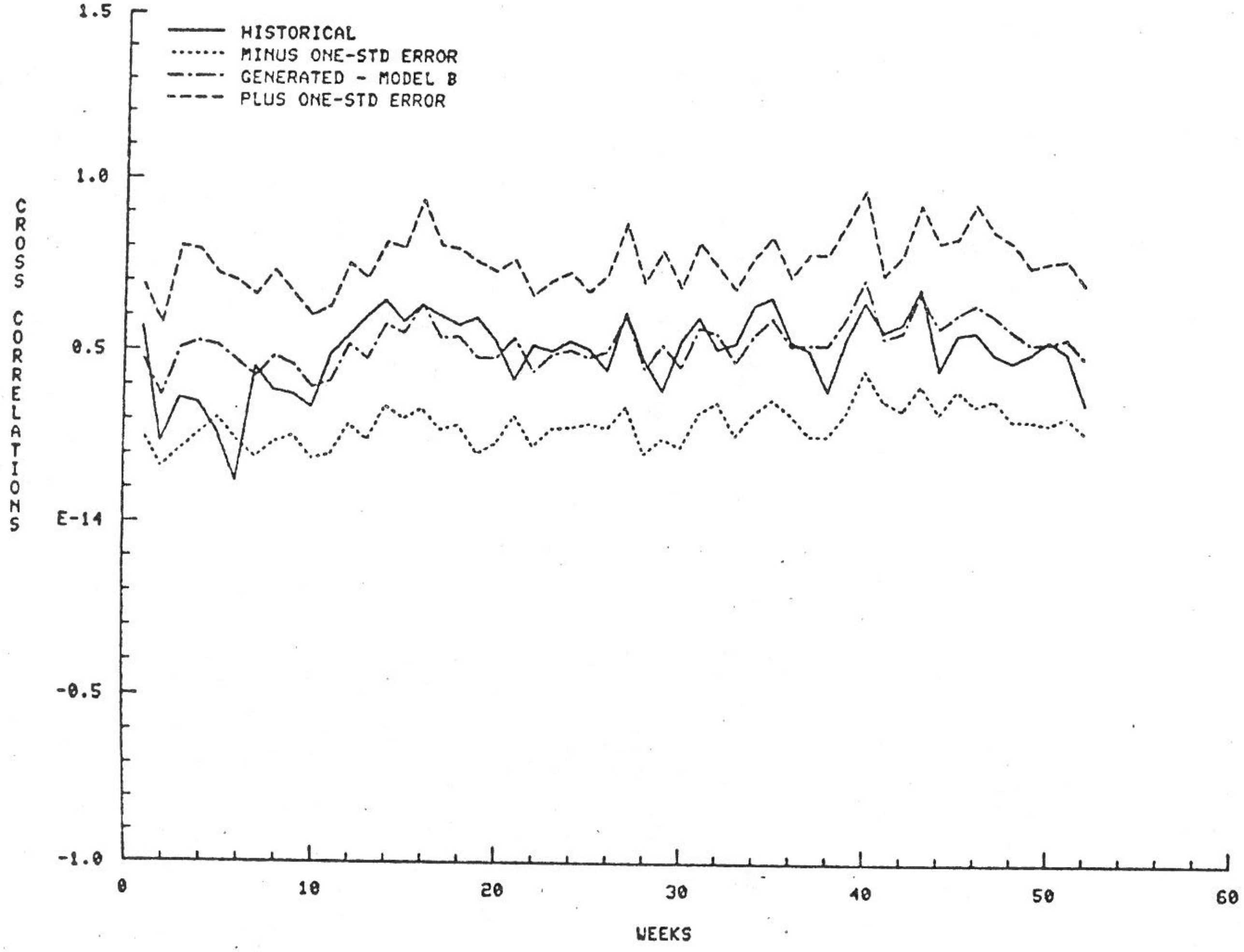

Figure 1.9.E.107. PALODE AND RANCHO - CROSS CORRELATIONS (LWH DOMAIN)

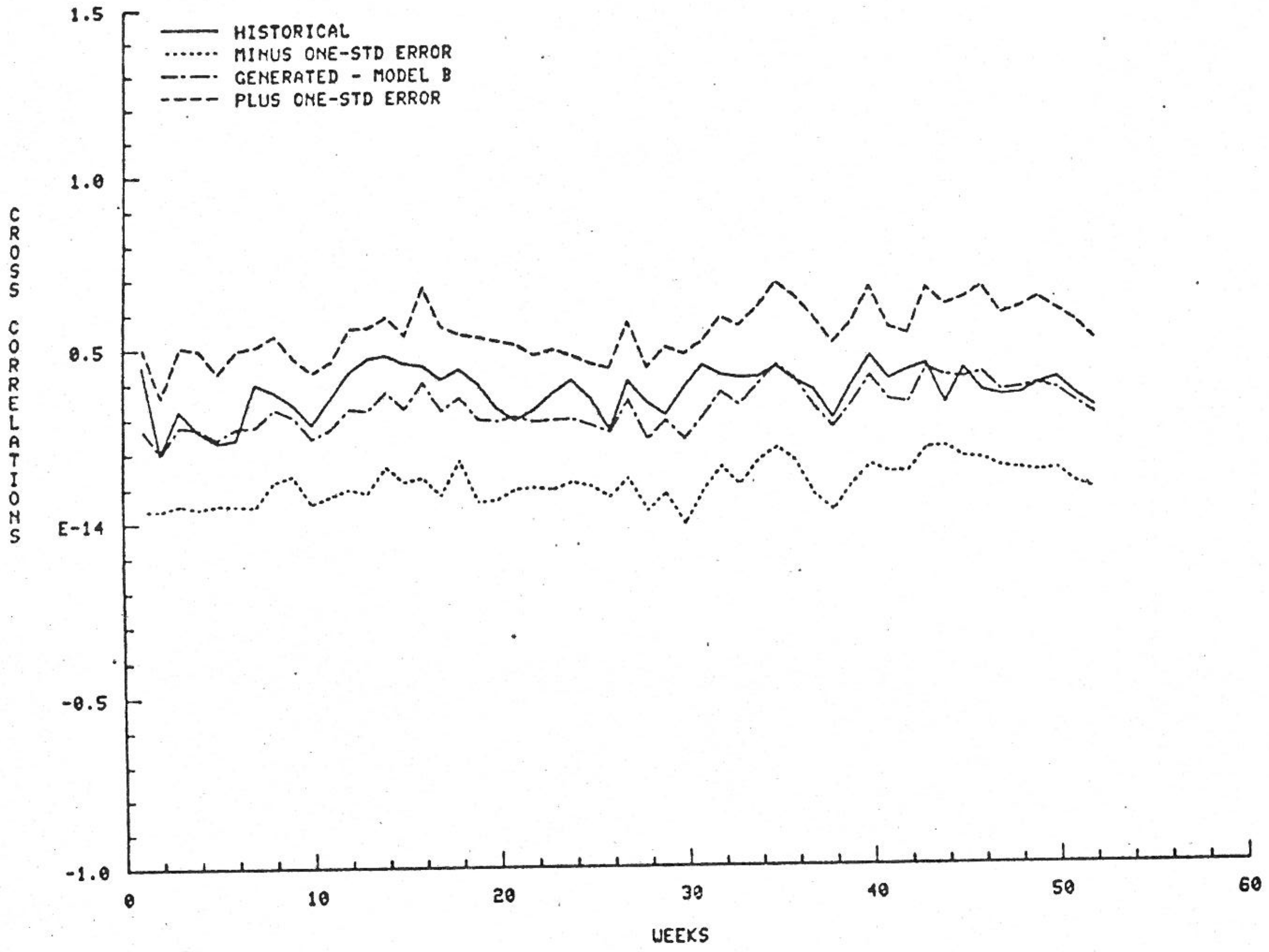

Figure 1.9.E.108. PASODE AND RANCHO - CROSS CORRELATIONS (LWH DOMAIN)

APPENDIX 1.9.F

HISTORICAL AND GENERATED STATISTICS OF MONTHLY TURBINE OPERATING HOURS TIME SERIES OF VALDESIA RESERVOIR

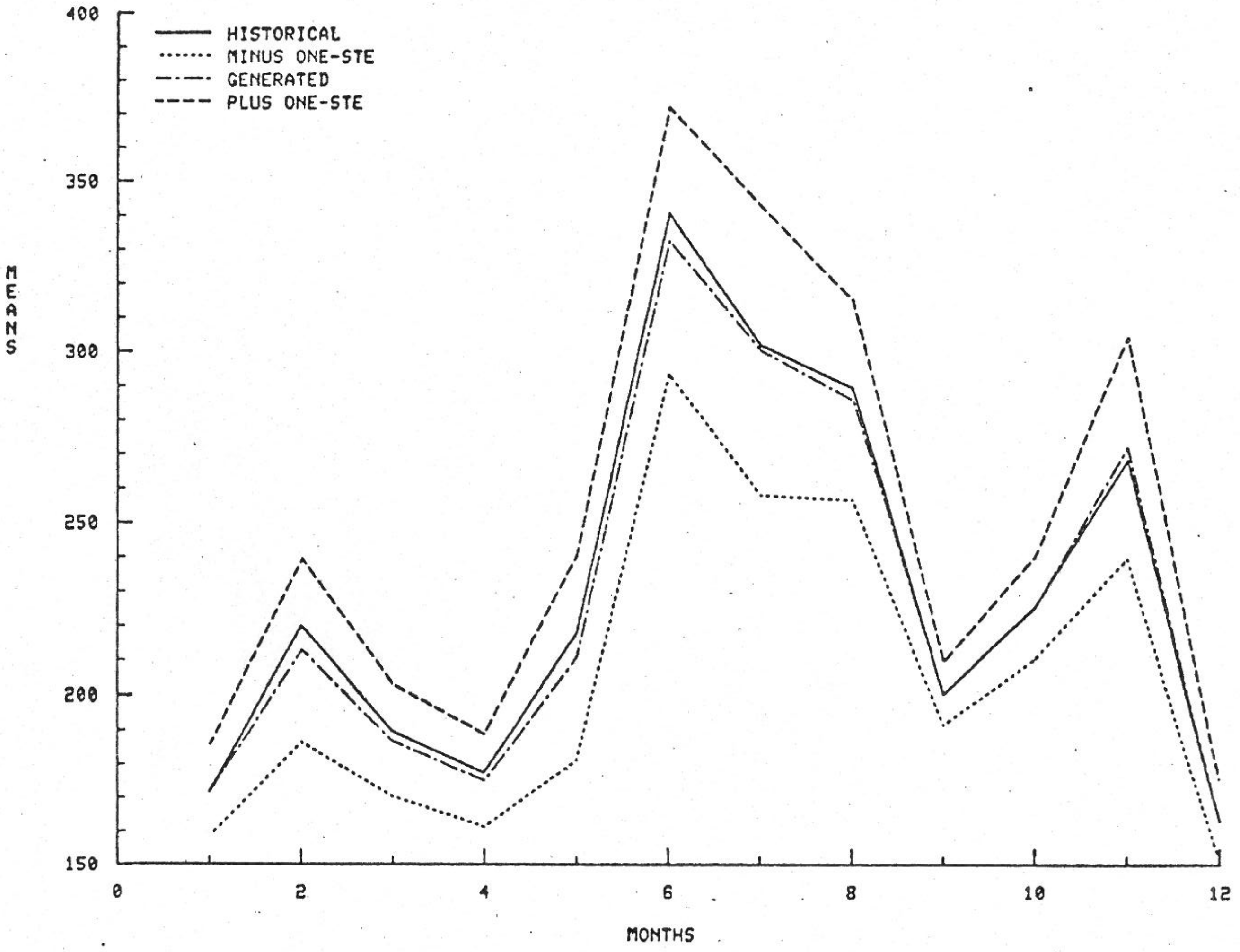

Figure 1.9.F.1. Historical and generated monthly means of turbine operating hours at Valdesia reservoir.

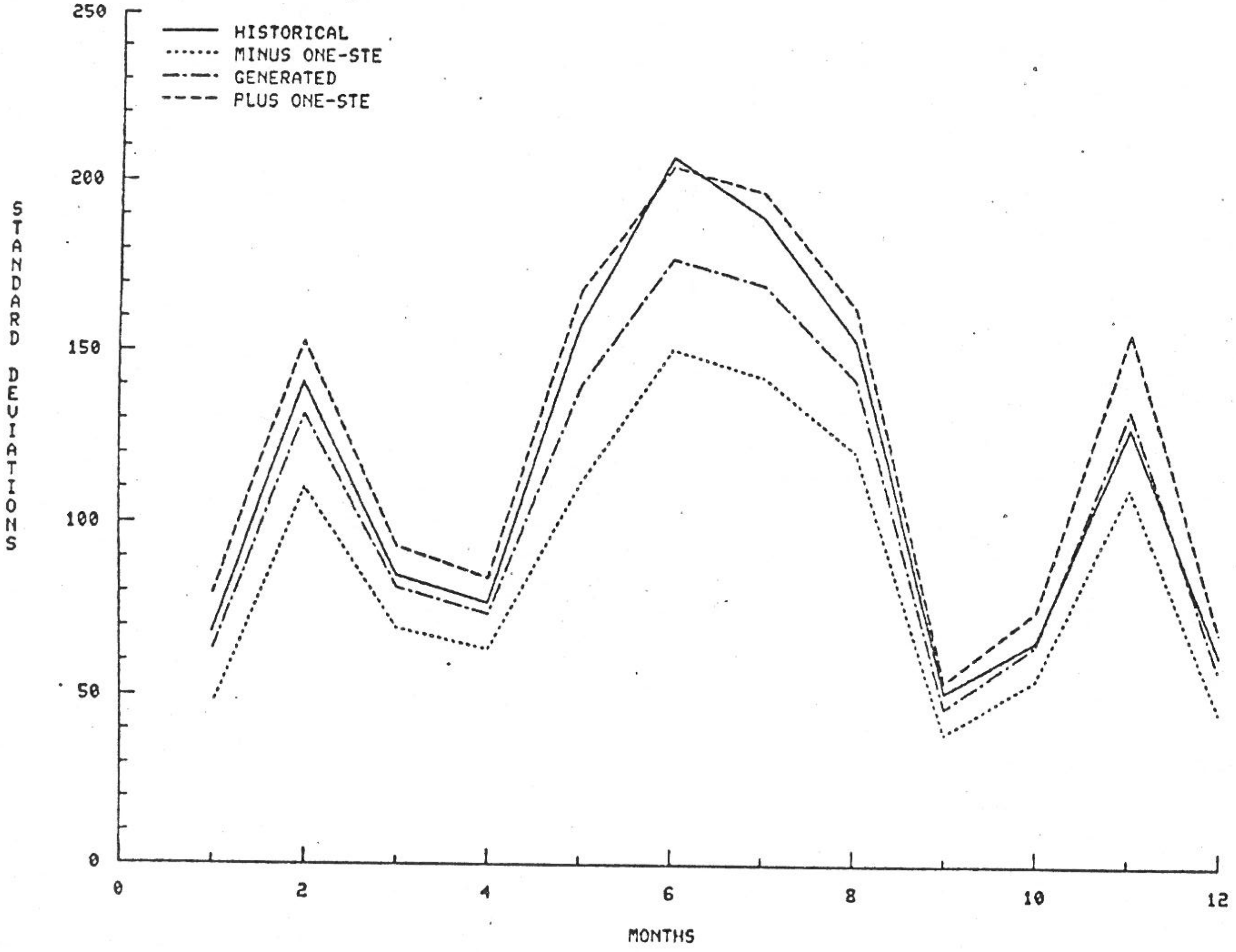

Figure 1.9.F.2. Historical and generated monthly standard deviations of turbine operating hours at Valdesia reservoir.

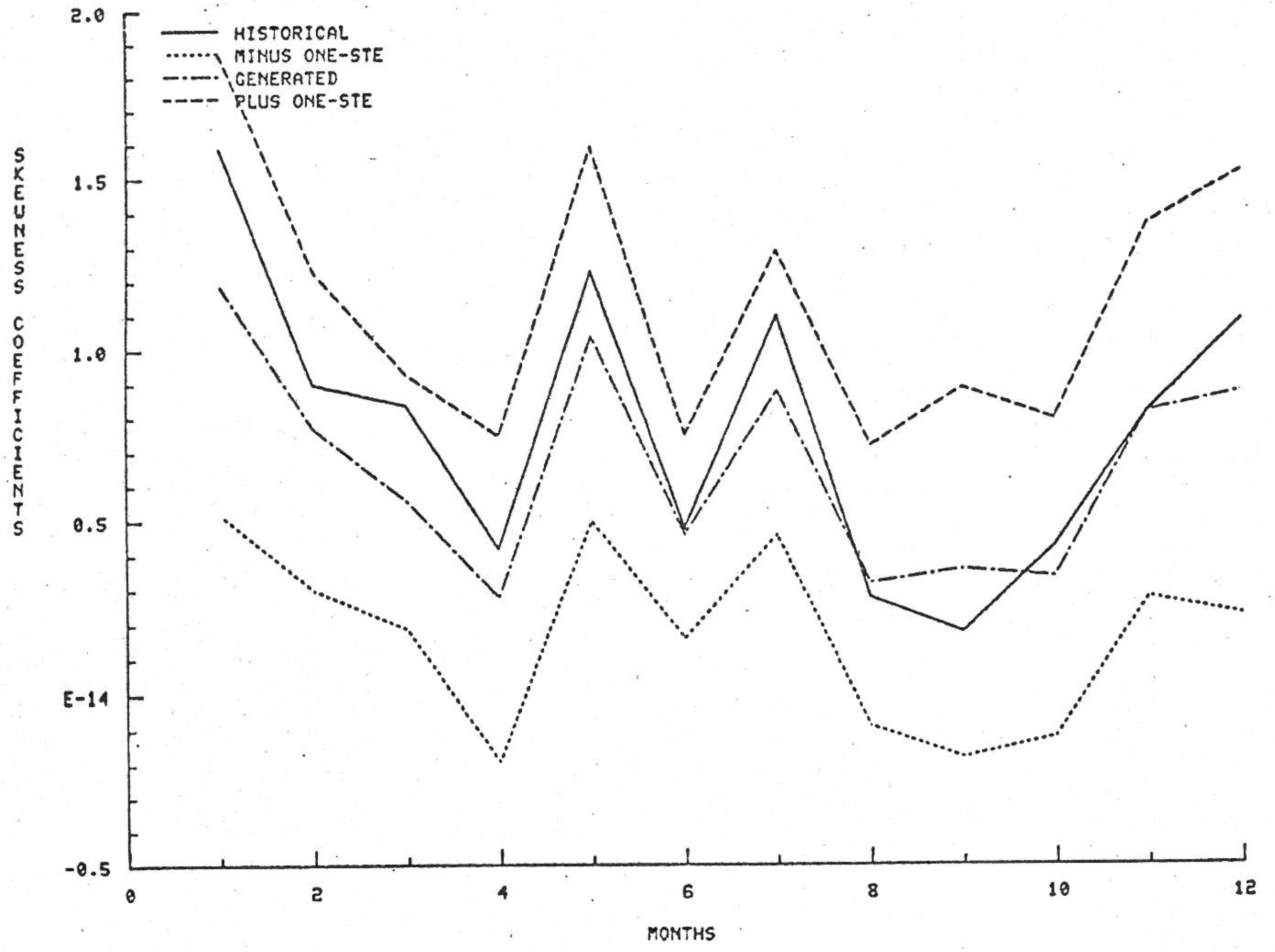

Figure 1.9.F.3. Historical and generated monthly skewness coefficients of turbine operating hours at Valdesia reservoir.

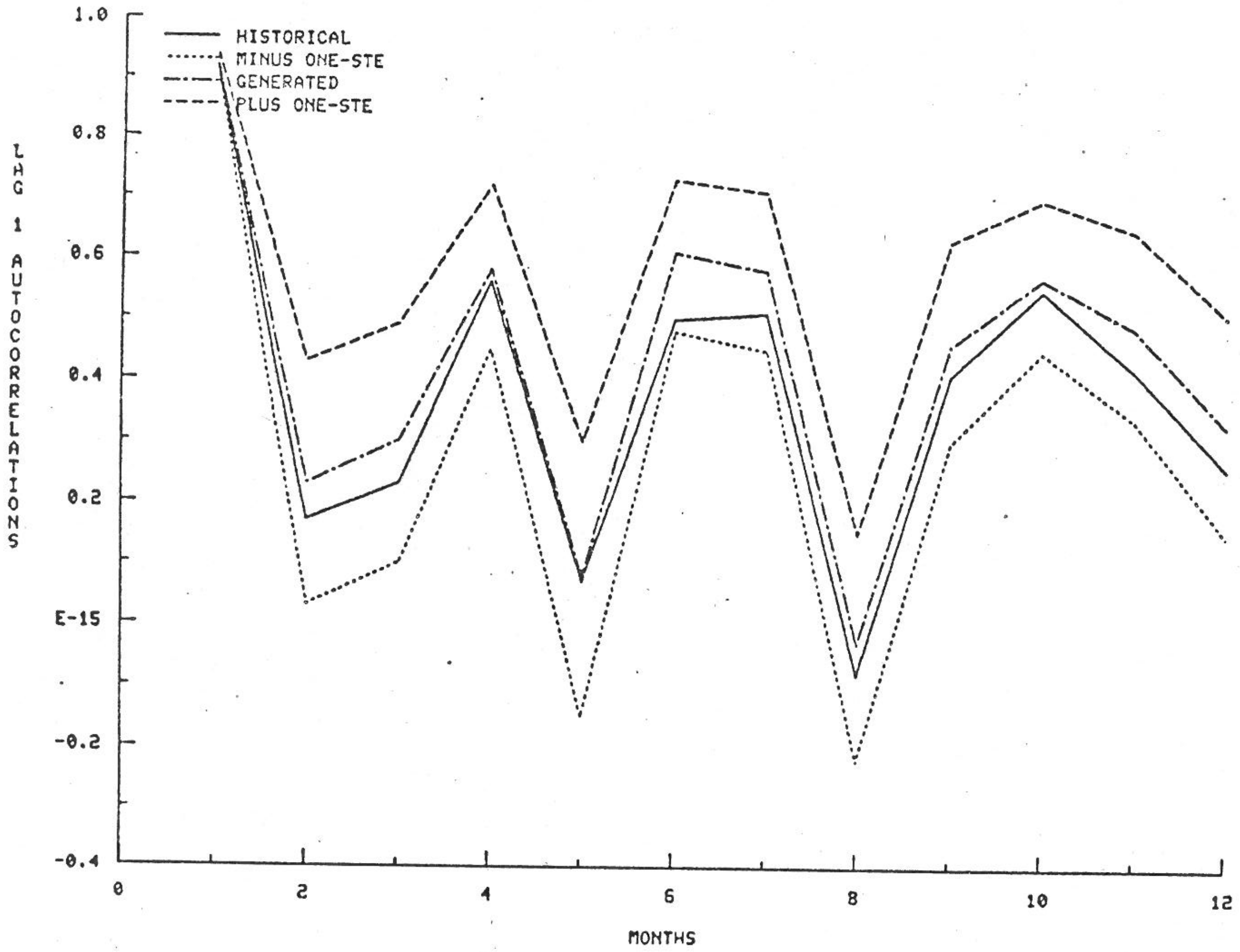

Figure 1.9.F.4. Historical and generated monthly lag-1 autocorrelation coefficients of turbine operating hours at Valdesia reservoir.

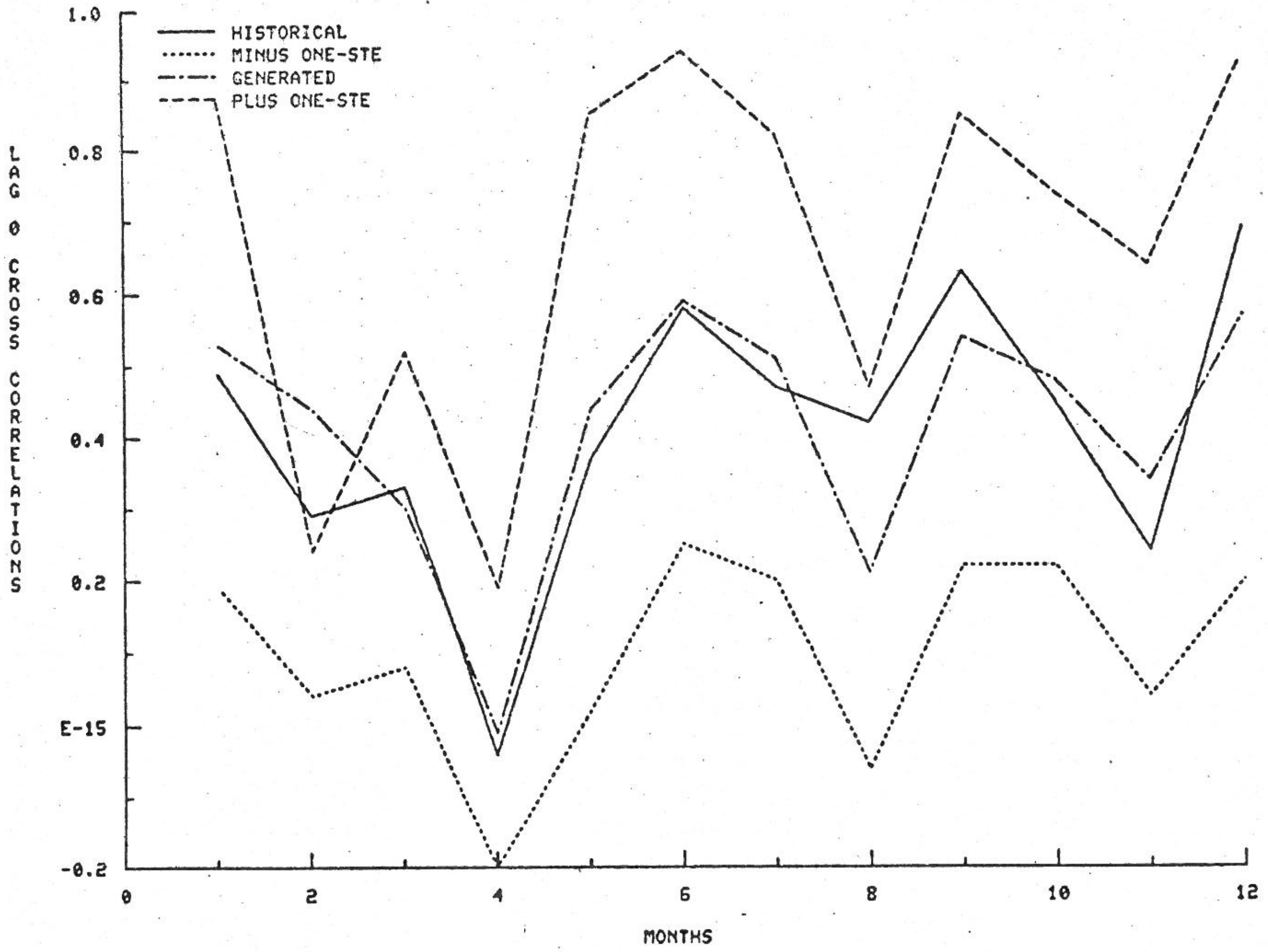

Figure 1.9.F.5. Historical and generated monthly lag-0 cross-correlation coefficients between turbine operating hours and streamflows.