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AN HOURLY PRECIPITATION MODEL FOR RALSTON CREEK

by

Robert Nelson Eli II
Thomas E. Croley II

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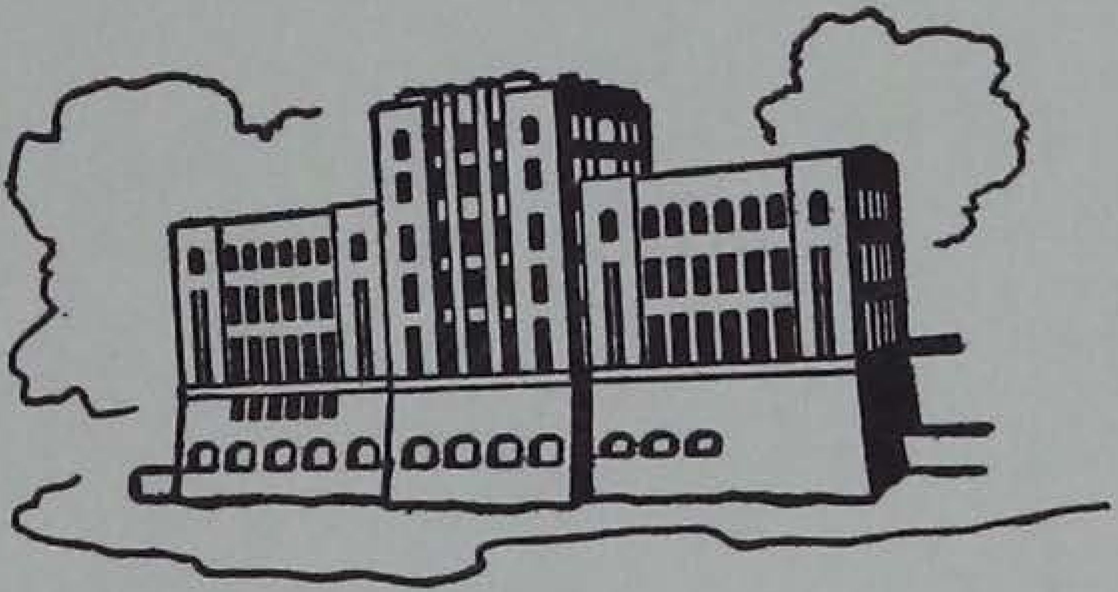

IIHR Report No. 192

Iowa Institute of Hydraulic Research
The University of Iowa
Iowa City, Iowa

August, 1976

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LIST OF SYMBOLS

ACCUM - Storm segment accumulation (inches)

c - Cut-off level corresponding to IATSS maximum (hours)

DURSS - Duration of storm segment (hours)

$f(x)$ - Probability density function of the random variable x

IAT - Interarrival times (hours)

IATSE - Interarrival time of storm event (hours)

IATSS - Interarrival time of storm segment (hours)

LENGTH - Length of storm event (hours)

M - Integer variable denoting period of year

μ - Population mean of the random variable x

$\hat{\mu}$ - Sample mean of the random variable x

NSSSE - Number of storm segments in a storm event

π - Pi, 3.14159

PKHR - Storm segment peak hour (hours)

σ^2 - Variance of the random variable x

TRAIN - Storm event accumulation (inches)

x - A random variable

ABSTRACT

A compilation and analysis of the Iowa City Ralston Creek hourly precipitation record is made prior to the development of a stochastic data generation precipitation model intended for use in urban flooding hazard studies. The model is to be used to estimate the return periods of extreme storm events by means of extensive data generation. An unbroken historical record of 33 years of point hourly precipitation accumulations is constructed from a high density recording gage network within the watershed. A stochastic precipitation model, using statistical values computed from the historical data, is proposed for the time occurrence and intensity of storm events. The model is constructed for each of six divisions of the year to represent the seasonal non-stationarity observed in the historical data.

Related wet time intervals, corresponding to an independent storm event, are scheduled by an interarrival time model using a fitted exponential distribution. Intrastorm structure is described in terms of "storm segments", corresponding to the passage of a storm rainfall cell or group of cells. The location in time and the duration of storm segments can be entirely specified by independent random variables whose distributions are estimated from the data, thus avoiding traditional computation difficulties in modeling the persistence effects encountered in hourly data. The intensity and distribution of precipitation within storm segments are modeled by fitted lognormal intensity probability distributions and by cataloging sample storm segment shapes.

The resulting data generation model is highly efficient, allowing 33 years of hourly data to be generated in less than 30 seconds on the IBM 360 computer at The University of Iowa. Tests of historical versus generated data indicate a very precise modeling of storm events is possible with respect to their rate of occurrence and their duration and intensity. Physical considerations support the possibility of model application to other geographical areas.

AN HOURLY PRECIPITATION MODEL
FOR RALSTON CREEK

I. INTRODUCTION

Objectives

Primary Objective

The primary objective of this study is to develop a suitable point precipitation model for use in a flood hazard study involving the Ralston Creek watershed in and near Iowa City, Iowa. One purpose of the flood hazard study is to determine the average annual flood damages that can be expected in the area. In order to determine these damages, the long-term average return periods of flood events must be estimated as accurately as possible. This is accomplished by modeling both the watershed and the precipitation process. The watershed model is required to convert the precipitation inputs into streamflows. A stochastic precipitation model is required to generate a sufficiently long time series of precipitation values to include those storm events corresponding to the extreme return periods of interest. In order to accomplish this as accurately as possible, a maximum use of the statistical properties of the historical data is required.

The small size of the watershed (only a few square miles) results in the watershed's rapid response to precipitation inputs, thus necessitating the use of hourly time increments in the precipitation model. This relatively small time increment requires that the model be highly efficient in data generation, since hundreds of years may be required to provide good estimates of return periods associated with extreme storm events.

Traditional techniques do not provide the levels of efficiency required, even with the assistance of high speed computers. Therefore, a new highly efficient hourly precipitation modeling technique must be introduced.

Secondary Objective

A secondary objective is to provide some measure of flexibility in the precipitation model to be developed, in order to permit its adaptability to as many other uses as possible. It is expected that the new modeling techniques developed herein will result in several benefits which will be attractive to potential users.

Methodology

A review of the literature reveals that existing precipitation models designed for small time increments are not adaptable to situations requiring lengthy data generation due to problems in efficiency. These inefficiencies are a natural by-product of the modeling techniques. In order to produce practical models, investigators have been forced to compromise the ability of their models to represent the persistent wet intervals corresponding to what is commonly defined as a storm event. The modeling approach proposed herein eliminates these problems, permitting the full use of the statistical properties of the historical data to specify the time occurrence and intensity of wet hours.

A study of the Ralston Creek historical hourly precipitation record and the physical precipitation process in the midwest supports the contention that storm events, as viewed in the hourly data record, can be decomposed into segments of consecutive wet hours that are essentially independent of one another. The location in time and the intensity of these segments can be largely specified by independent random variables. This forms the basis of a new modeling technique from which a data generation model is developed using Monte Carlo methods (i.e., random number generators) to generate values from the distributions of the descriptive random variables. Each random variable is defined and tested for independence before its inclusion in the digital computer data generation model. The computer model is designed to generate values of the random variables in the proper sequence to construct storm events. In order to test the model, a 33-year time series of hourly precipitation values is generated. The generated storm events are tested against storm events from the historical record using depth-duration comparisons. Conclusions are then made with respect to the research objectives.

Plan of Report

The background and definitions section first discusses precipitation models proposed by other investigators, with an emphasis on small-time-increment models. The necessity for using small time increments for studies involving small watersheds is explained and the historical precipitation record for Ralston Creek is introduced. The methods by which the time occurrence of storm events and the internal structure of storm events are modeled are defined and discussed. The relationship of the hourly precipitation data structure to the physical meteorological process is presented in terms of the intensity and motion of storm rainfall cells with respect to a fixed surface viewpoint. Finally, the implications of long term and seasonal non-stationarity are reviewed with respect to the proposed model.

The model development section then introduces the interarrival time variable used to schedule storm events, and continues by defining the "method of storm segments", including the random variables and cataloging procedure required to model the internal structure of storm events. The detailed construction of the model follows and the section is concluded by the adaptation of the model to the digital computer for the purpose of data generation.

The next section presents the analysis of the results of model testing and is followed by the final section which presents the conclusions. The conclusions are presented in terms of the original study objectives and end with an evaluation of the model deficiencies.

II. BACKGROUND AND DEFINITIONS

Recent History in Point Precipitation Modeling

Precipitation modeling has been the subject of a rapid increase in interest in recent years. In the early 1960's a number of investigators proposed models for the simulation of storm precipitation sequences at a single point. These models were based on the assumption that, although the physics of the precipitation process is exceedingly complex, the specific operating laws and governing parameters can be inferred from the statistical properties of a time series of observed precipitation accumulations, using a suitable fixed time increment. Initially, simple urn models (a simple distribution theory approach) and Markov processes were used. Examples of these techniques are presented by Wiser (1965), and are further outlined by Grace and Eagleson (1966).

It was soon evident that simple urn and Markov models were inadequate in modeling the persistence in wet and dry periods observed in most precipitation data. To overcome this deficiency, various Markov Chain or autoregressive schemes were introduced, such as those by Pattison (1965), Wiser (1965), Cole and Sherriff (1972), and Raudkivi and Lawgun (1974). A parallel, and sometimes integral development, has been the use of Monte Carlo methods in the generation of certain random variables describing some aspects of the precipitation process. As an example, particular success has been achieved in fitting the Weibull distribution to the historical distribution of the times between storm events and using it to generate interarrival times. Investigators reporting success in the application of this technique include Grace and Eagleson (1966), Rao and Chenchayya (1974), and Amorocho and Wu (1975).

Choice of Time Increment Size

Historically, the first precipitation modeling efforts were based upon relatively large time increments such as daily increments. Recently, there has been great interest in the response of small watersheds, particularly the flooding response of urban watersheds. The small size of the watersheds, often no more than a few square miles, precludes the use of precipitation models based on daily time increments and mandates the use of hourly or smaller time increments. Examples of hourly increment models are presented by Wiser (1965), Pattison (1965), Todorovic (1969), and Rao and Chenchayya (1975). Examples of smaller increments (10 or 15 minute intervals in particular) are presented by Grace and Eagleson (1966), Sorman and Wallace (1972), Raudkivi and Lawgun (1974), and Rao and Chenchayya (1975).

Due to the small size of the Ralston Creek watershed (and availability of historical data), hourly time increments were chosen for use in the subsequent model development.

The Historical Data Set

In general, a stochastic precipitation model is based upon the statistical properties of the historical data. Therefore, the quality and size of the historical data set becomes extremely important in developing a useful model. The Ralston Creek North Branch watershed has been well instrumented since 1924. The resulting hydrologic record is extensive, and has been summarized by Mavis and Soucek (1936) and Howe and Warnock (1960).

Using data from recording precipitation gages, a 33 year record of unbroken hourly accumulations was constructed by combining five incomplete gage records from 1941 to 1973 inclusive. As far as can be determined, this unbroken hourly time series is, by an order of magnitude, the longest of its type ever assembled. The quality of the data is also believed to be exceptional. The acquisition and processing of this data is detailed in Appendix A. Due to the high density of the gaging network and the small watershed size, the combination of five gage records into one final record did not result in significant smoothing of the data.

Scheduling the Time Occurrence of "Storm Events"

Consideration of the meteorological conditions commonly found in the midwest indicates that the time occurrence of one entire collection of related wet hour and dry hour sequences (defined herein as a single "storm event") is expected to be independent of other such events at any time during the year. Inspection of the Ralston Creek historical record indicates that these storm events are separated from each other by long dry periods such that the events can be considered independent. Furthermore, the probability of another storm event occurring within a few hours of a preceeding event (representing the arrival of a second front or local storm) is expected to be small. Thus, the possibility of two simultaneous storm events can be ignored. Also, the probability of a storm event occurrence in a given time interval can be expected to be proportional to the length of the time interval, for time intervals of the order of a few days. A study of the Ralston Creek historical record seems to validate these observations. Therefore, storm event occurrences can be described as a Poisson process [Hogg and Craig (1970)], although the mean Poisson occurrence rate may well be a function of the time of year. Similar analyses are available in the literature [Todorovic and Yevjevich (1971), Todorovic and Zelenhasic (1970), and Todorovic and Rousselle (1971)]. Although not used directly herein, the concept of a Poisson process provides the key to a computationally efficient method of modeling the time occurrence of storm events, since the interarrival times of storm events are exponentially distributed.

Modeling Persistence Effects by Method of "Storm Segments"

Two modeling problems, which are usually encountered, become even more pronounced with small time increments. The first is procurement of sufficient historical data for the time increment size desired. The second is the modeling of the persistence effects of wet and dry periods. Fortunately, an adequate historical record of hourly precipitation accumulations is available for this analysis. Most often, the persistence effects are modeled by Markov chains or autoregressive schemes, as in some of the above references. Except in those few cases that are modeled adequately by first-order schemes, the computation associated with parameter estimation or transitional probabilities can rapidly approach unwieldly proportions. This is a handicap from a data generation viewpoint. This problem is avoided herein through the use of an alternate modeling procedure involving the division of the precipitation record into independent storm events, which are in turn subdivided into "storm segments". The position in time and the intensity of these storm segments can, in large part, be modeled through use of independent random variables. This approach facilitates the construction of a highly efficient data generation model to be described herein.

Relationship of Hourly Data Structure to the Physical Process

It has been long recognized that significant precipitation events consist of one or more convective cells [Eagleson (1970), Stall and Huff (1971), Sorman and Wallace (1972), and Amorocho and Wu (1975)]. Of particular interest is the thunderstorm cell. These cells range from 3 to 6 miles across and characteristically have lifetimes of 30 to 60 minutes, moving at speeds of 20 to 30 mph. Critical design rainfalls in the midwest occur most frequently in conjunction with lines or groups of thunderstorms. Studies in neighboring Illinois by Stall and Huff (1971), using radar and dense networks of precipitation gages, have shown that these thunderstorms are usually multicellular. The propagation of the larger, more violent cells seem to occur in conjunction with strong winds aloft. These winds change direction with increasing altitude such that the cells move at an angle to the mean wind. Each cell goes through a short life cycle of growth and decay while translating at a characteristic angle to the mean wind, as represented schematically in Figure 1.

Large groups of these cells sometimes form a line of thunderstorms, called a "squall line", with the growth and decay of cells occurring continously within the storm structure. Squall lines are often associated with fronts and/or intense low-pressure centers. Less intense rainfall

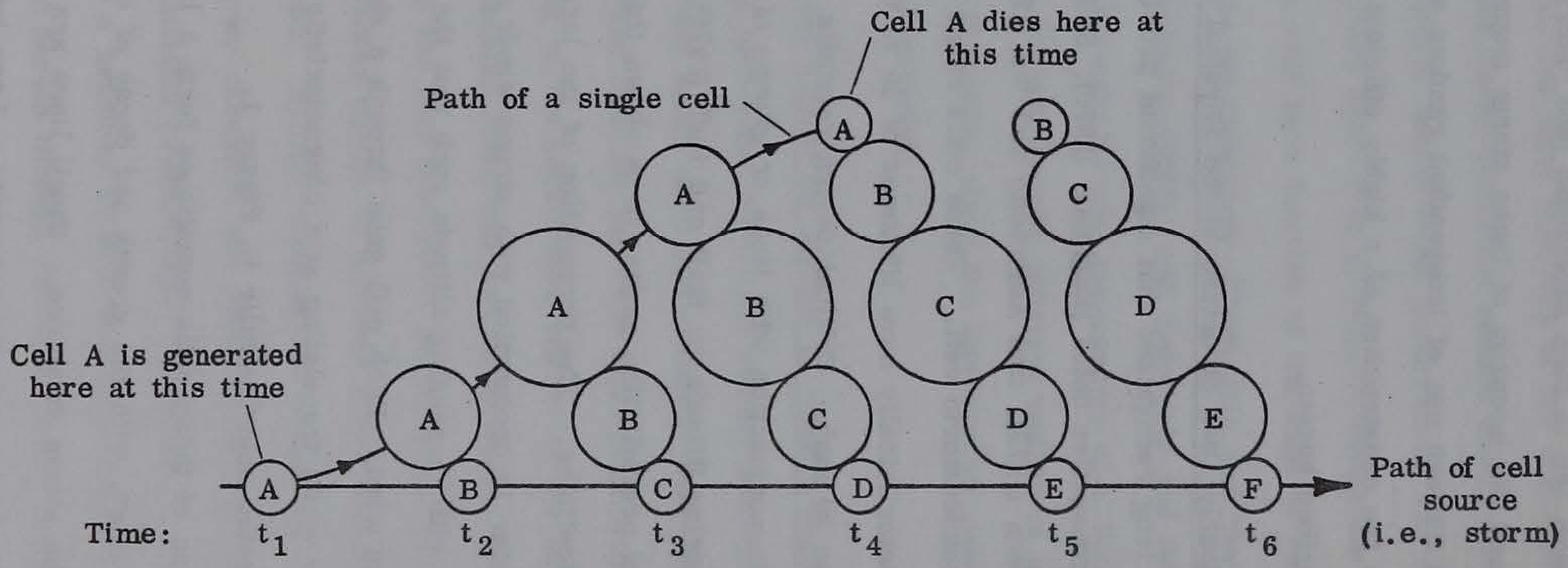

Figure 1. Idealized Cell Growth and Propagation Within a Strong Storm, After Eagleson (1970)

associated with passing fronts or weak thunderstorms also exhibits a cellular structure, but with a tendency toward a random motion of cells superimposed on the overall air mass movement.

A single precipitation gage records a seemingly random rainfall trace due to the unpredictable nature of the growth, decay, and position of individual cells. Even in the apparently ordered structure of a squall line, the growth and decay of cells is not related to any single point on the surface but is a function of a large number of variables, primarily related to the given meteorological conditions. Since the typical storm cell will pass a given point in a fraction of an hour, an hourly precipitation record will contain only a gross reproduction of the actual precipitation distribution. It is quite possible that several cells will pass a given point, each in a different phase of the growth-decay cycle, in a period totaling less than an hour. Therefore, an hourly precipitation model can only hope to reproduce the gross characteristics of the precipitation process. The peaks or surges of rainfall in an hourly precipitation record, such as graphically presented in Figure 2, may be related to the passage of one or more rainfall cells.

Using the above meteorological considerations, one can logically expect to find little or no evidence of dependence between the peaks or surges of rainfall in a point hourly accumulation record of a typical independent storm event. This lack of dependence in the detailed structure of the hourly record is used in the model development.

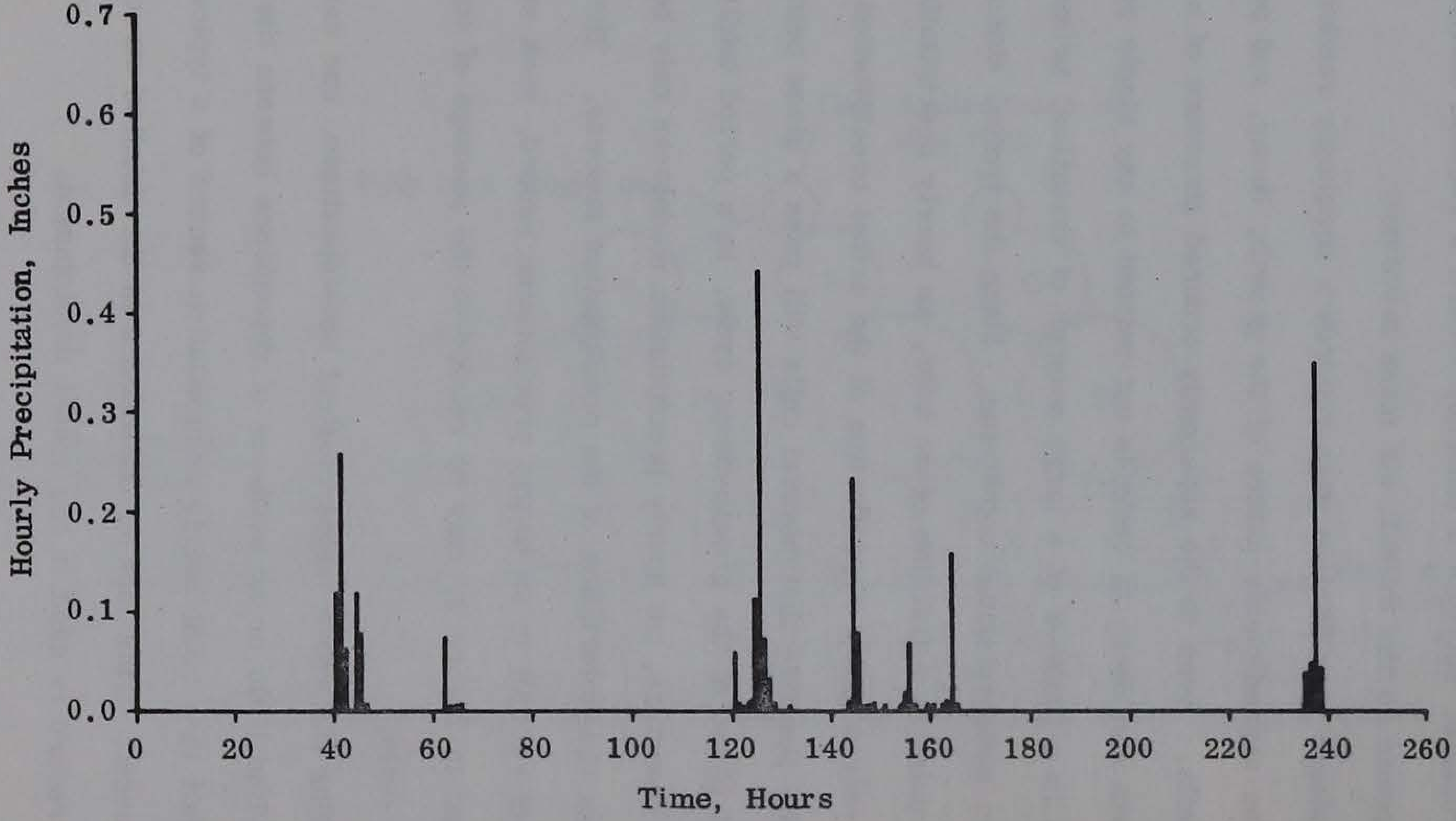

Figure 2. Sample Historical Hourly Precipitation Record

Long Term and Seasonal Non-Stationarity of Data Parameters

The long term historical data record for Ralston Creek and the adjacent Iowa City area indicates a pronounced lack of stationarity in the annual precipitation accumulations. The results of one study by Howe and Warnock (1960), using 101 years (1857-1957) of annual precipitation values, are illustrated in Figure 3. Another study of the midwest area by Klugman (1976) indicates several drought cycles during the period 1931-1969. The historical record (1941-1973) used in the model development, therefore, cannot be considered to represent a segment of record taken from a stationary historical time series of annual values since it appears to contain several complete "cycles" of droughts and wet seasons. However, long term stationarity must be assumed in building a data generation model due to insufficient historical data to establish trends, and a lack of understanding of long term climatic trends. Since the non-stationarity is cyclical and no continually increasing or decreasing trends are present, then it is expected that the assumption of stationarity will result in suitable long-term estimates of precipitation related phenomenon.

Within-the-year, or seasonal non-stationarity, is of prime importance since individual storm events can be a strong function of the seasons. The Ralston Creek 33 year hourly precipitation record appears to be more than adequate for building the seasonal models by a simple division of the record into seasonal components, such that the record within each division is approximately stationary.

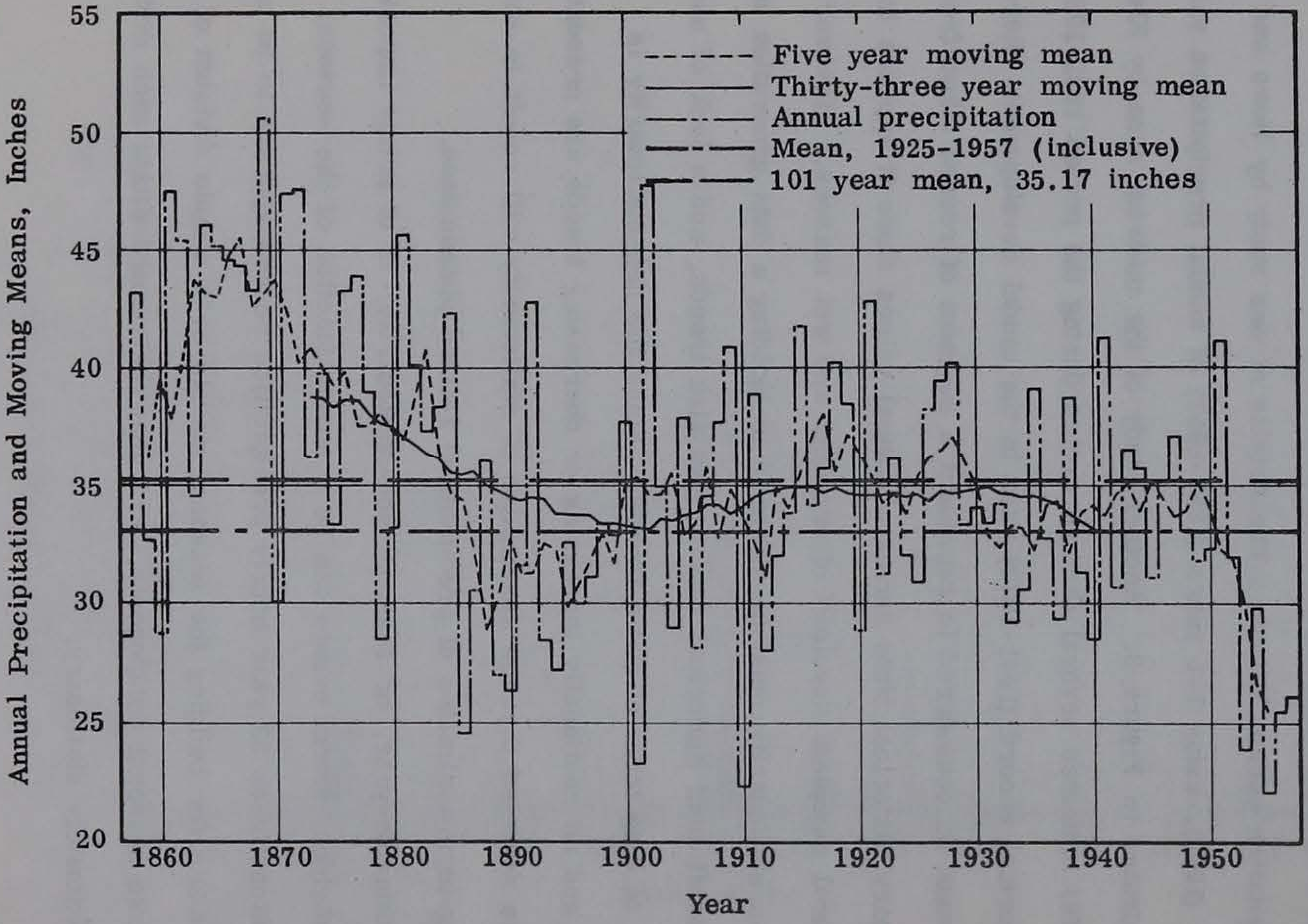

Figure 3. Variation in Annual Precipitation at Iowa City, Iowa, From Howe and Warnock (1960)

III. MODEL DEVELOPMENT

Modeling "Storm Events"

Time Occurrence of "Storm Events"

A storm event normally consists of a collection of wet hour sequences of varying lengths, interspersed with short sequences of dry hours. Obviously, these short sequences are only segments of the storm event. Therefore, the Poisson process of storm events cannot be used to schedule all "storm segments" that make up a storm event. However, the Poisson process can be utilized indirectly to schedule the first storm segment, corresponding to the beginning of a storm event. The interarrival time between events in a Poisson process is a continuous random variable, while only integer values (in hours) can be computed from the historical data. Also, events in a Poisson process have zero length, while real storm events are greater than zero length. These differences are considered negligible since the interarrival time between storm events averages approximately 10 times the length of storm events, and 100 times the time increment used (one hour). In hourly precipitation data, the interarrival time is measured (in hours) from the end of one storm event to the beginning of the next. This interarrival time is defined herein as "interarrival time of storm events" (IATSE). By the Poisson postulates, they are independent random variables.

Modeling Storm Events by Method of "Storm Segments"

The "storm segment" is defined as any consecutive series of wet hours containing a single peak value. Division of a consecutive series of non-zero wet hours into storm segments is made so as to place the minimum wet hour, between two peaks, at the end of the storm segment. Figure 4 illustrates a typical decomposition of a storm event of the precipitation record.

Independent storm events are scheduled by means of the IATSE random variable already defined. With the introduction of the storm segment, additional random variables and a cataloging procedure can be defined to fully specify the time occurrence and intensity of wet hours within storm events. These are briefly introduced and defined below. The detailed modeling presentation follows in the next section.

IATSS.-- The interarrival time (dry hours) between two storm segments within a storm event will be referred to herein as "interarrival time of storm segment" (IATSS). IATSS is an integer valued random variable, approximating the continuous interarrival times of the physical process. The IATSS random variables appear to be independent, both serially and with regard to other random variables.

NSSSE.-- The "number of storm segments in a storm event" (NSSSE) can be counted for each storm event in the historical record. Physically, NSSSE is a discrete random variable whose values are positive integers. Since the independence of storm events is confidently assumed, it is logically consistent to expect that the internal characteristics of a given storm event will be independent of like characteristics in previous storm

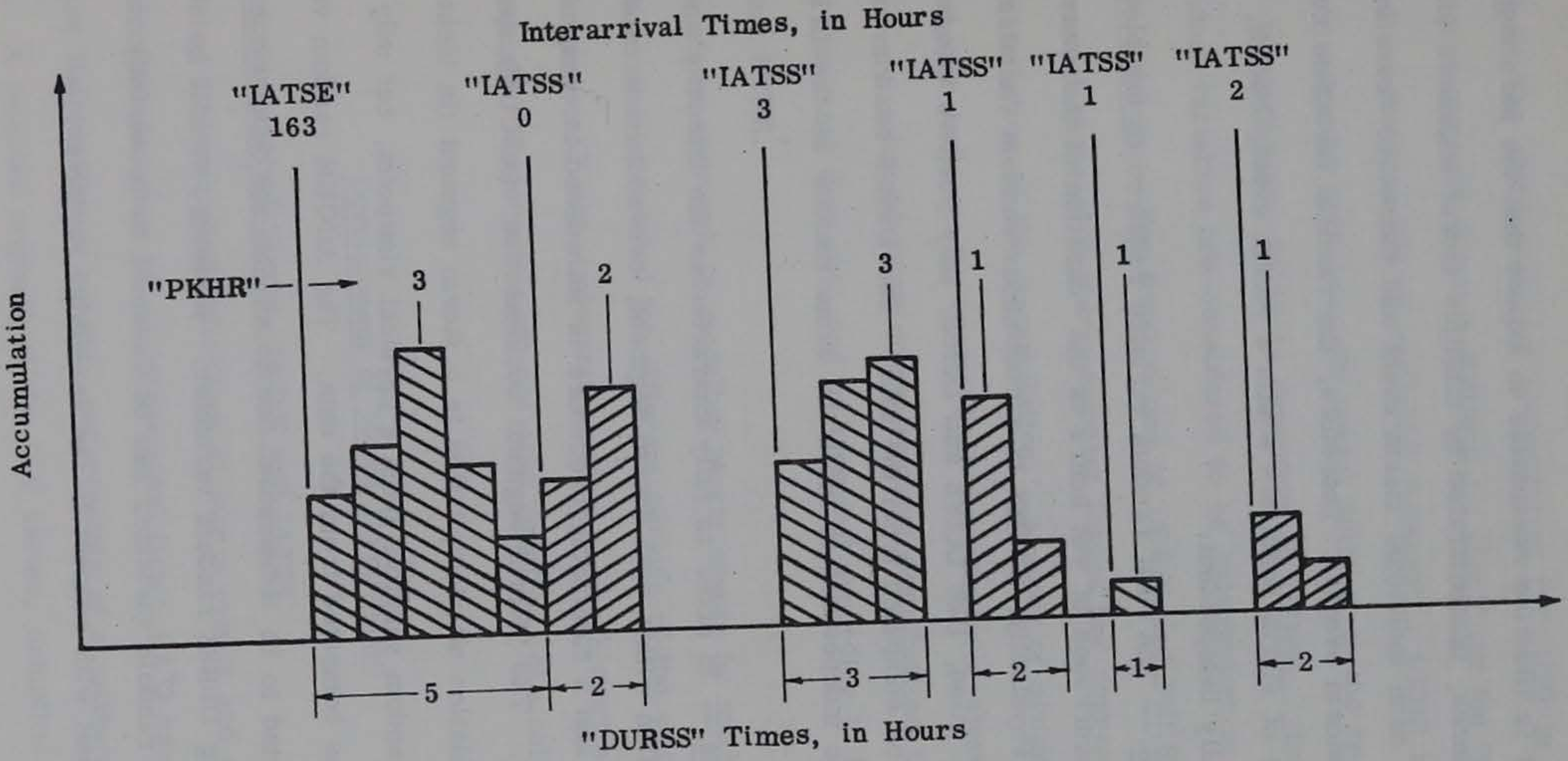

Figure 4. Typical Decomposition of a Storm Event into Storm Segments

events. It is likewise reasonable to expect that the persistence of wet hour sequences, demonstrated by multiple storm segments (or NSSSE), is internal to each individual storm event and cannot be "carried-over" from preceding storm events. Therefore, the random variables representing the number of storm segments within a storm event, NSSSE, are expected to be serially independent.

DURSS.-- The final random variable required to completely define the time occurrence of wet hours is the "duration of the storm segment" (DURSS). Physically, DURSS is a continuous random variable like IATSE and IATSS. Also, like IATSE and IATSS, only positive integer values (in hours) can be computed from the data. The DURSS random variables appear to be independent in much the same manner as the IATSS random variables.

ACCUM.-- In order to fully characterize the intensity and distribution of precipitation within each storm segment, two additional random variables are defined and a cataloging procedure is introduced to complete the storm event model. The "storm segment accumulation" (ACCUM) specifies the total accumulation of precipitation in a storm segment (in inches). It is a continuous random variable from a physical viewpoint, but only approximate values can be computed from the data. The ACCUM random variables cannot be expected to be independent due to an obvious dependence on the corresponding DURSS random variables. However, it will be shown later that ACCUM random variables can be assumed to be serially independent, and independent with respect to the remaining variables.

PKHR.-- The storm segment accumulation (ACCUM) is distributed over the storm segment duration (DURSS) by specifying the "peak hour" (PKHR) and accessing a file of empirical "shapes". PKHR is the location of the storm segment peak hour (in hours) relative to the beginning of the segment. By definition, PKHR is dependent on DURSS. However, the PKHR random variables are considered to be independent in other respects.

Shape Catalog.-- For fixed values of DURSS and PKHR, the single peak, unimodal shape of a storm segment leaves few degrees of freedom for the distribution of the accumulation. A study of historical storm segment shapes indicates no evidence of dependence of shape on ACCUM. Therefore, a catalog of mean storm segment distributions is assembled from the historical data set, and is accessed according to fixed values of DURSS and PKHR.

The above approach to modeling storm events by method of storm segments must be repeated for different periods of the year in order to model the seasonal non-stationarity evident in the historical data. Therefore, multiple "shape catalogs" are also required, one catalog for each period.

Development of Model Components

Modeling Interarrival Times, IATSE and IATSS

Using the preceding definitions of storm events and storm segments, the historical sequence of all interarrival times (IAT) can be computed from the Ralston Creek record, and consists of a mixture of IATSE and IATSS. A selected segment of the IAT series, compiled from the Ralston

Creek data, is presented in Table 1. The series consists of large values of IAT interspersed with persistent periods of small values of IAT that are associated with individual storm events containing more than one storm segment. The large values correspond to IATSE and the small values to IATSS. It is not difficult to set up a separation criterion that separates IAT into IATSE and IATSS. As defined herein, the "cutoff level" corresponds to a maximum value of IATSS, $(\mathrm{IATSS})_{\max}$. Therefore,

$$(\mathrm{IATSS})_{\max} = (\mathrm{IATSE})_{\min} - 1 \qquad 1.$$

since IATSE and IATSS are integer valued.

A noticeable seasonal difference in the empirical IAT series was observed between the winter and summer months. Although precipitation connected with cyclonic events (and the associated frontal activity) dominates throughout the year, the summer months contain numerous thunderstorm events of short duration and high intensity. Independent storm events can thus occur with shorter, but still independent values of IATSE separating them during the summer months. The appropriate levels, $(\mathrm{IATSS})_{\max}$, for different seasons of the year, were chosen by inspection of the data and consideration of the meteorological characteristics of the area throughout the year. Although this is a subjective technique, it was facilitated by computer constructions similar to Table 1 for each trial $(\mathrm{IATSS})_{\max}$ value. After inspection of the computer listings, separate $(\mathrm{IATSS})_{\max}$ values were selected for each of six different two-month periods within the year, representing the within-the-year non-stationarity which was apparent. The $(\mathrm{IATSS})_{\max}$ values are listed in Table 2. The

Table 1. **Selected Segment of Consecutive IAT's for $(\text{IATSS})_{\text{max}}$ Equal to 12 Hours**

→ 116/0, 0, 2, 0, 6, 0/18/1, 3, 1, 2, 1, 9, 0/361/0, 0, 0, 0, 0/38/2, 0, 0, 0, 1, 1, 0, 0/333/0, 0/58/2/144, 45 →

Note: Slashes separate adjacent values of IATSE and IATSS

Table 2. **Results of Exponential Function Fits for IATSE**

Period	$(\text{IATSS})_{\text{max}}$ or Cut-Off Level, c (hrs)	Sample Size	Sample Mean $\hat{\mu}$ (hrs)	Chi-Square Statistic	Confidence Limits, Chi-Square Statistic	
					90%	99%
Jan-Feb	12	303	144.61	7.25	13.4	20.1
Mar-Apr	12	428	99.32	6.70	13.4	20.1
May-Jun	6	607	69.78	14.69	9.2	15.1
Jul-Aug	6	491	91.74	2.77	10.6	16.8
Sep-Oct	9	370	114.27	7.65	12.0	18.5
Nov-Dec	12	316	138.73	10.98	13.4	20.1

two-month period was selected based on a trade-off between data analysis complexity and non-stationarity representation.

Using the above separation technique, the IATSE and IATSS values could be determined from the historical sequence of all IAT, resulting in a division of the data set into independent storm events. A storm event starting in a given seasonal period was considered to belong to that period even though it might end in the following period. IATSE values were considered to belong to that period containing the first hour of the interarrival time. The IATSE series was tested for independence by computing the serial correlations within each two-month period [Jenkins and Watts (1968), Eq. 5.3.33]. To avoid small-sample bias in computing the lag correlations, the sample mean and variance were computed using all IATSE values within each two-month by 33 year array. Also, the product terms within the covariance function were computed for each two-month period separately and then summed for each lag value over the 33 year span. The results (listed in Table 3) showed no significant indication of serial dependence in the IATSE series. All the confidence limits in Table 3 were computed using the normal distribution approximation for the correlation function. A maximum of 5 lags were computed since a greater number of lags would imply a search for dependence between storms more than one month apart. This degree of dependence was considered to be extremely unlikely considering the meteorological implications.

A shifted exponential probability density function was fit to each IATSE relative frequency histogram, the latter obtained by combining all 33 years of data for each two-month period. It was necessary to shift

Table 3. IATSE, NSSSE, IATSS, and DURSS Sample Serial Correlation Results

Lag	"IATSE"		"NSSSE"		"IATSS"		"DURSS"		Period
	Corr. Function	95% Conf. Limit, ±	Corr. Function	95% Conf. Limit, ±	Corr. Function	95% Conf. Limit, ±	Corr. Function	95% Conf. Limit, ±	
1	0.0737	0.121	0.0197	0.121	0.0881	0.091	-0.0439	0.075	Jan
2	0.0114	0.129	0.0146	0.129	0.0904	0.113	-0.0001	0.091	/
3	0.0152	0.139	0.0315	0.139	0.0053	0.137	0.0094	0.112	Feb
4	0.0276	0.152	0.0052	0.152	0.1526	0.168	-0.0864	0.137	
5	0.0049	0.168	0.0936	0.168	0.2034	0.207	0.0539	0.168	
1	-0.0443	0.101	0.0255	0.101	0.0708	0.068	0.0449	0.058	Mar
2	-0.0627	0.105	0.0499	0.105	0.0144	0.081	0.0274	0.068	/
3	0.0082	0.111	0.1403	0.111	0.0100	0.097	0.0173	0.081	Apr
4	0.0248	0.116	0.0564	0.116	-0.0204	0.115	-0.0536	0.097	
5	0.0858	0.123	0.0832	0.123	0.0244	0.136	-0.0654	0.115	
1	0.0146	0.083	0.0910	0.083	0.0615	0.089	0.0459	0.068	May
2	-0.0600	0.086	-0.0180	0.086	-0.0643	0.114	-0.0299	0.089	/
3	-0.0321	0.089	0.0654	0.089	-0.0003	0.147	0.0255	0.114	Jun
4	0.0679	0.092	0.0411	0.092	0.0850	0.193	0.0084	0.147	
5	-0.0550	0.095	-0.0035	0.095	0.0598	0.263	0.0480	0.193	
1	-0.0185	0.093	0.0845	0.093	-0.0498	0.130	-0.0083	0.091	Jul
2	0.0061	0.097	-0.0079	0.097	0.0021	0.183	0.1636	0.130	/
3	0.0285	0.101	0.0719	0.101	-0.1863	0.260	0.0131	0.183	Aug
4	-0.0119	0.106	0.0929	0.106	0.0265	0.365	0.1862	0.260	
5	0.0180	0.111	0.0599	0.111	0.1148	0.577	-0.0759	0.365	
1	-0.0335	0.109	-0.0207	0.109	0.1562	0.084	0.0675	0.072	Sep
2	-0.0001	0.115	0.0440	0.115	0.0306	0.099	-0.0238	0.084	/
3	0.0448	0.121	-0.0002	0.121	0.0057	0.115	-0.0163	0.099	Oct
4	-0.0170	0.130	-0.0199	0.130	0.0247	0.134	0.0348	0.114	
5	-0.0293	0.139	0.0865	0.139	-0.0623	0.156	-0.0509	0.134	
1	-0.0420	0.118	0.1098	0.118	0.0272	0.081	0.0090	0.068	Nov
2	0.0156	0.126	0.0806	0.126	0.0557	0.096	0.0188	0.081	/
3	-0.0555	0.135	0.1005	0.135	-0.0133	0.116	0.0440	0.096	Dec
4	0.0541	0.146	0.1789	0.146	0.0617	0.140	-0.0100	0.116	
5	-0.0354	0.161	0.0156	0.161	0.0317	0.169	-0.0917	0.140	

each density function by an amount equivalent to the cutoff level, $(\text{IATSS})_{max}$, since IATSE must be greater than $(\text{IATSS})_{max}$ by Equation 1. The shifted exponential density function is given below.

$$f(x) = \left[1/(\mu - c)\right] \exp\left[-(x - c)/(\mu - c)\right], \qquad \text{where } x > c, \mu > c \qquad 2.$$

In Equation 2, x is a value of IATSE, μ is the expected value of IATSE (estimated by the sample mean), and c is the cutoff level, $(\text{IATSS})_{max}$, previously defined. Values of μ were estimated from the data for each of the two-month periods, and are listed in Table 2. Chi-square goodness-of-fit tests [Lindgren and McElrath (1969), page 140] were performed and are also presented in Table 2. The chi-square tests indicate good fits in all instances. The IATSE frequency histograms and fitted exponential functions are included in Appendix B, as Figures B.1 through B.6. The results for Jan-Feb and Jul-Aug are presented as examples in Figure 5. Of course, using discretized data to estimate parameters of a continuous distribution results in some error; however, this error is held to be negligible since such large sample sizes are used in the estimation.

Independence in the IATSS random variables is more difficult to argue. However, a detailed examination of the historical data yields no apparent pattern in the IATSS values. It will also be recalled that storm segments are "surges of rainfall" resulting from the passage of one or more storm cells. From a physical viewpoint, there appears to be no consistent pattern of storm cell passage from a fixed observation point on the surface; therefore, significant serial correlation in IATSS seems improbable. A serial correlation study was performed in a manner similar

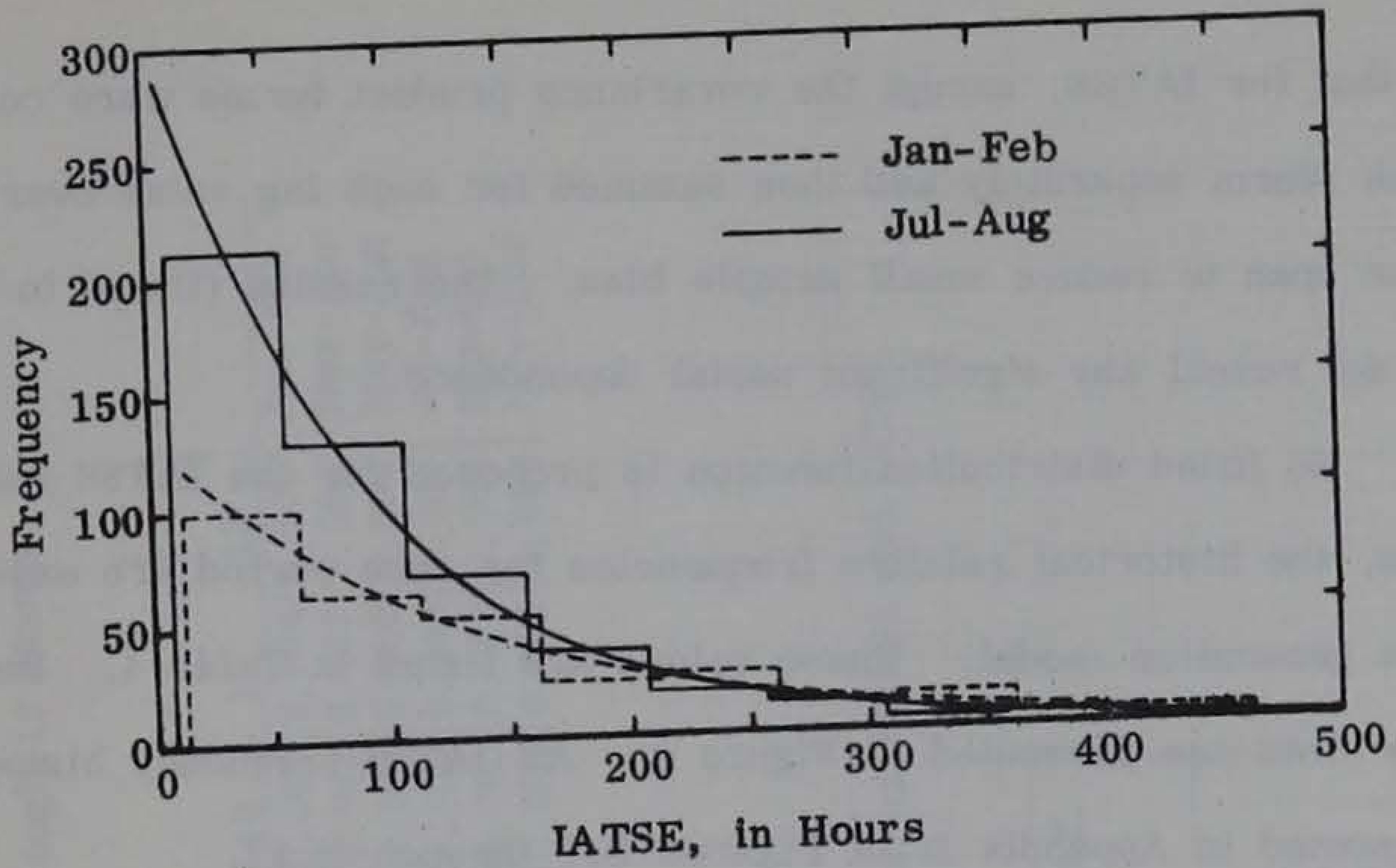

Figure 5. Example IATSE Fitted Shifted Exponental Functions

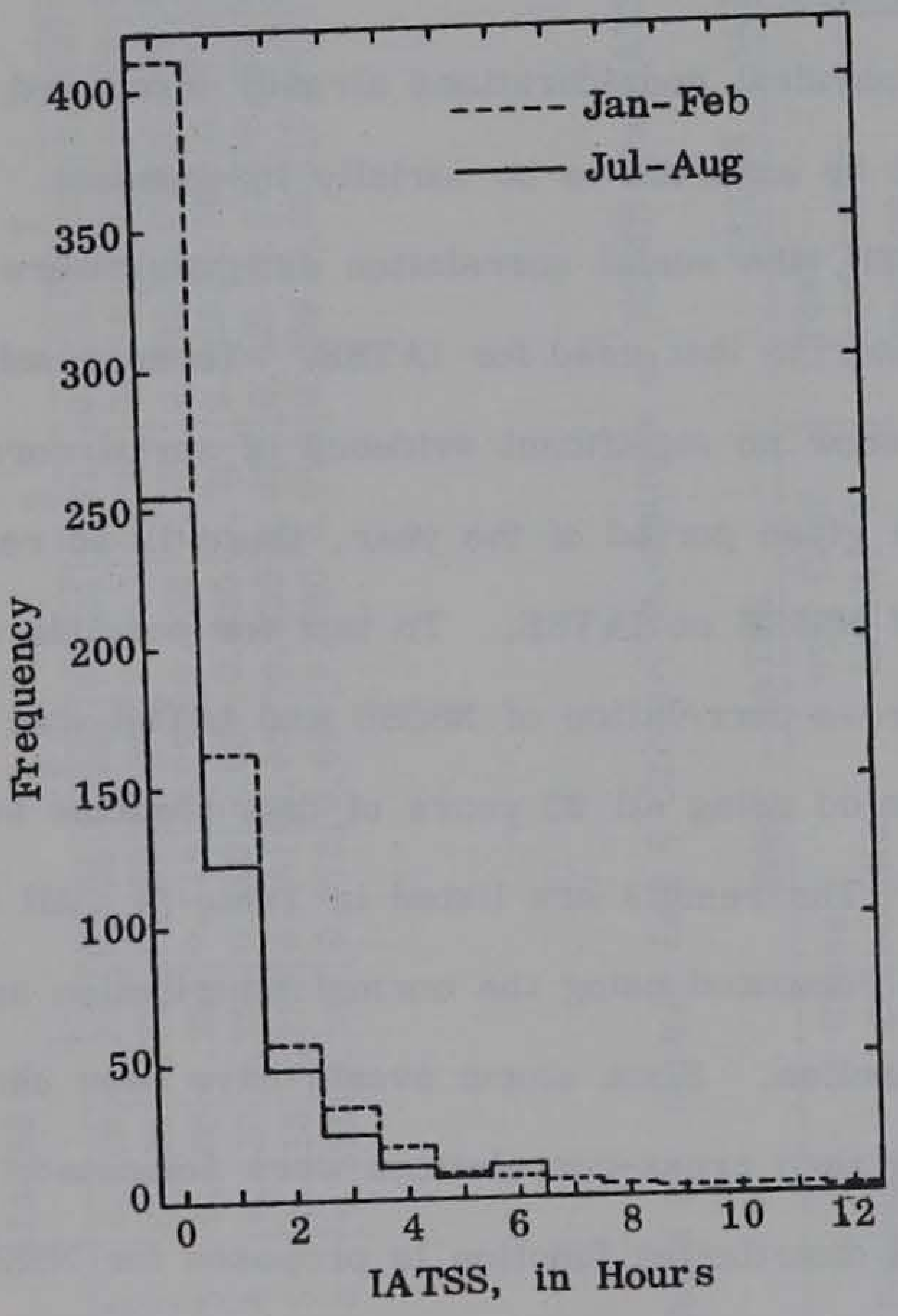

Figure 6. Example IATSS Frequency Histograms

to that for IATSE, except the covariance product terms were computed for each storm separately and then summed for each lag value over the 33 year span to reduce small sample bias. The results (listed in Table 3) do not reveal any significant serial dependence.

No fitted distribution function is proposed for the IATSS values; therefore, the historical relative frequencies for each period are used in the data generation model. These values are listed in Table 4. Representative plots are presented in Figure 6. All IATSS frequency histograms are presented in Appendix B as Figures B.7 through B.12.

Modeling NSSSE

Due to physical considerations already discussed, the NSSSE random variables can be expected to be serially independent. To test the independence of NSSSE, the serial correlation estimates were calculated in an identical manner to that used for IATSE. These results are included in Table 3 and show no significant evidence of serial correlation.

Within a given period of the year, there is no reason to suspect a dependence of NSSSE on IATSE. To test for possible cross-correlation, the sample cross-correlation of NSSSE and IATSE was computed for each two-month period using all 33 years of data [Jenkins and Watts (1968), Eq. 8.1.10]. The results are listed in Table 5. All confidence limits in Table 5 were computed using the normal distribution approximation for the correlation function. Since storm events have been shown to be independent, only lag zero cross-correlations were computed.

No fitted distribution function is proposed for NSSSE. Therefore, the generation of NSSSE values in the model is accomplished using the

Table 4. Relative IATSS Frequencies by Period, for Values of 0 Through 12 Hours

	IATSS = 0	1	2	3	4	5	6	7	8	9	10	11	12	
1	0.569	0.225	0.079	0.047	0.026	0.013	0.011	0.008	0.006	0.004	0.004	0.004	0.003	Jan-Feb
2	0.530	0.218	0.080	0.052	0.040	0.017	0.019	0.014	0.006	0.004	0.007	0.007	0.005	Mar-Apr
3	0.468	0.255	0.114	0.053	0.038	0.037	0.035	0.000	0.000	0.000	0.000	0.000	0.000	May-Jun
4	0.530	0.254	0.100	0.050	0.025	0.017	0.025	0.000	0.000	0.000	0.000	0.000	0.000	Jul-Aug
5	0.518	0.229	0.081	0.050	0.030	0.032	0.021	0.018	0.009	0.013	0.000	0.000	0.000	Sep-Oct
6	0.571	0.217	0.073	0.049	0.030	0.015	0.009	0.013	0.008	0.006	0.005	0.001	0.003	Nov-Dec

Table 5. Sample Lag 0 Cross-Correlations of NSSSE and IATSE, and of DURSS and IATSS

	NSSSE - IATSE		DURSS - IATSS	
Period	Cross-Correlation Function	95% Conf. Limit, ±	Cross-Correlation Function	95% Conf. Limit, ±
Jan-Feb	0.0460	0.114	-0.0152	0.079
Mar-Apr	0.0312	0.097	0.0278	0.060
May-Jun	0.0384	0.081	-0.0286	0.075
Jul-Aug	-0.0285	0.090	0.0730	0.106
Sep-Oct	-0.0372	0.104	-0.0712	0.075
Nov-Dec	0.1466	0.112	-0.0324	0.071

historical relative frequencies. These values are listed in Table 6 for each of the six two-month periods. Representative plots are included in Figure 7. All NSSSE frequency histograms are presented in Appendix C as Figures C.1 through C.6. The maximum historical value of NSSSE is 21. Reproduction of extreme values of NSSSE (greater than 21) is of no interest in light of the purpose to which the model is to be applied (modeling short to moderate length high intensity storms).

Modeling DURSS

Physically, serial dependence in DURSS and the dependence of DURSS on IATSS appear to be possible, but not likely to occur. Serial dependence in DURSS is unlikely due to the apparent lack of dependence between storm segments. The serial correlation study was accomplished using the same computational techniques as those used for IATSS (designed to avoid small sample bias). The serial correlation estimates are included in Table 3. No significant dependence is revealed. The sample lag zero cross-correlation of DURSS and IATSS was computed for each two-month period using all 33 years of data. The results, included in Table 5, show no significant dependence between the two. Due to the lack of serial dependence in DURSS and IATSS, and the lack of zero lag cross-correlation between the two, cross-correlation computations for lag values greater than zero were not considered.

Like IATSS, no fitted distribution function is proposed for DURSS. The historical relative frequencies listed in Table 7 are used in the modeling process. The maximum historical value of DURSS is 14 hours; therefore, the relative frequencies terminate at a value of DURSS equal

Table 6. Relative NSSSE Frequencies by Period, for Values of 1 Through 21

	NSSSE =										
	1	2	3	4	5	6	7	8	9	10	11
Jan-Feb	0.231	0.234	0.199	0.095	0.081	0.049	0.039	0.026	0.007	0.013	0.016
Mar-Apr	0.203	0.189	0.185	0.131	0.094	0.061	0.035	0.023	0.023	0.021	0.005
May-Jun	0.417	0.247	0.137	0.073	0.046	0.036	0.023	0.012	0.003	0.003	0.000
Jul-Aug	0.505	0.253	0.120	0.063	0.022	0.026	0.002	0.004	0.002	0.002	0.000
Sep-Oct	0.411	0.184	0.116	0.073	0.060	0.043	0.030	0.032	0.011	0.011	0.005
Nov-Dec	0.218	0.208	0.155	0.120	0.095	0.054	0.051	0.035	0.016	0.019	0.006

	12	13	14	15	16	17	18	19	20	21
Jan-Feb	0.010	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Mar-Apr	0.014	0.002	0.002	0.004	0.000	0.005	0.000	0.000	0.000	0.002
May-Jun	0.000	0.002	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.000
Jul-Aug	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sep-Oct	0.003	0.003	0.000	0.008	0.003	0.000	0.003	0.000	0.000	0.005
Nov-Dec	0.016	0.006	0.000	0.003	0.000	0.000	0.000	0.000	0.000	0.000

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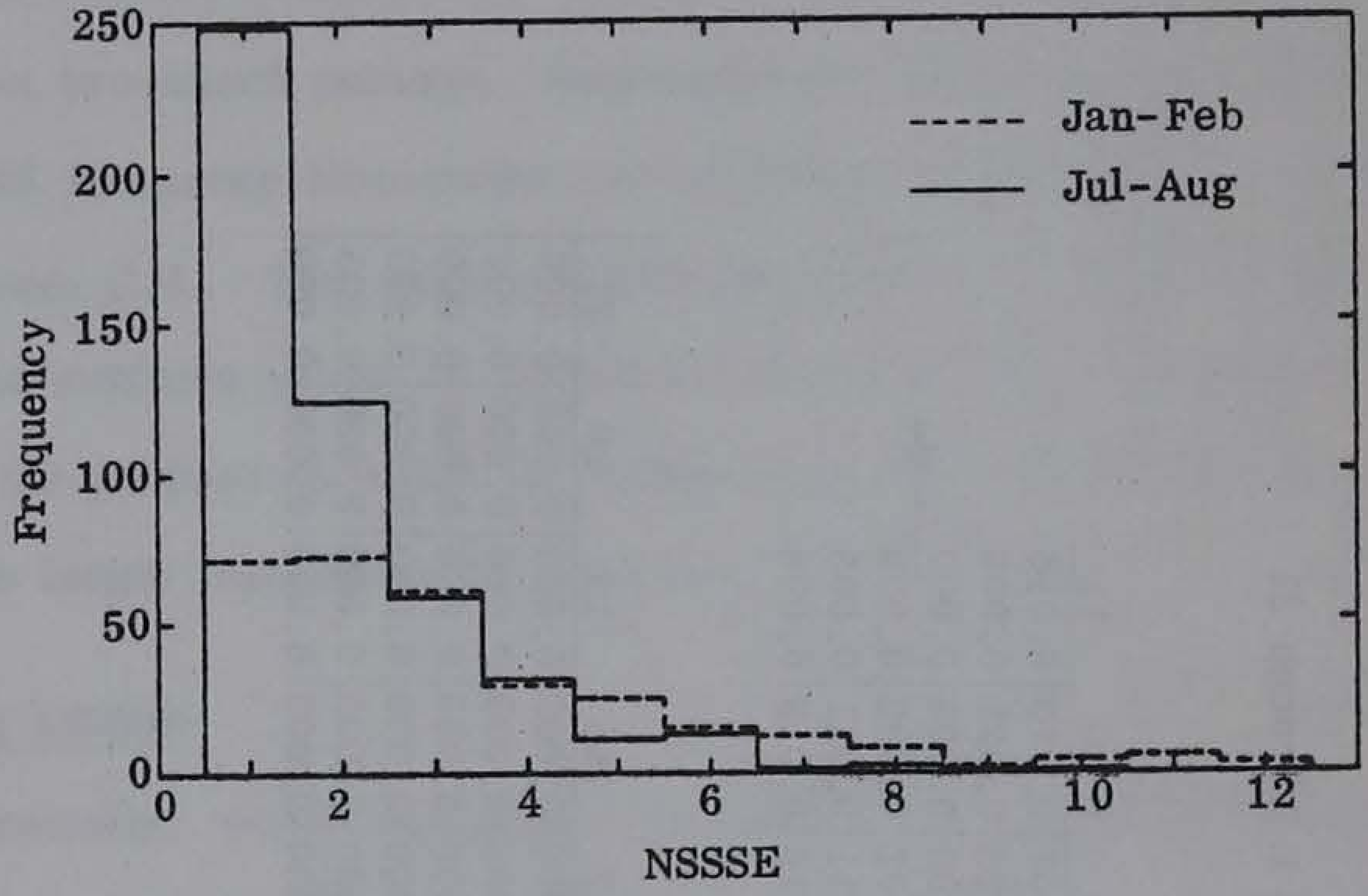


Figure 7. Example NSSSE Frequency Histograms

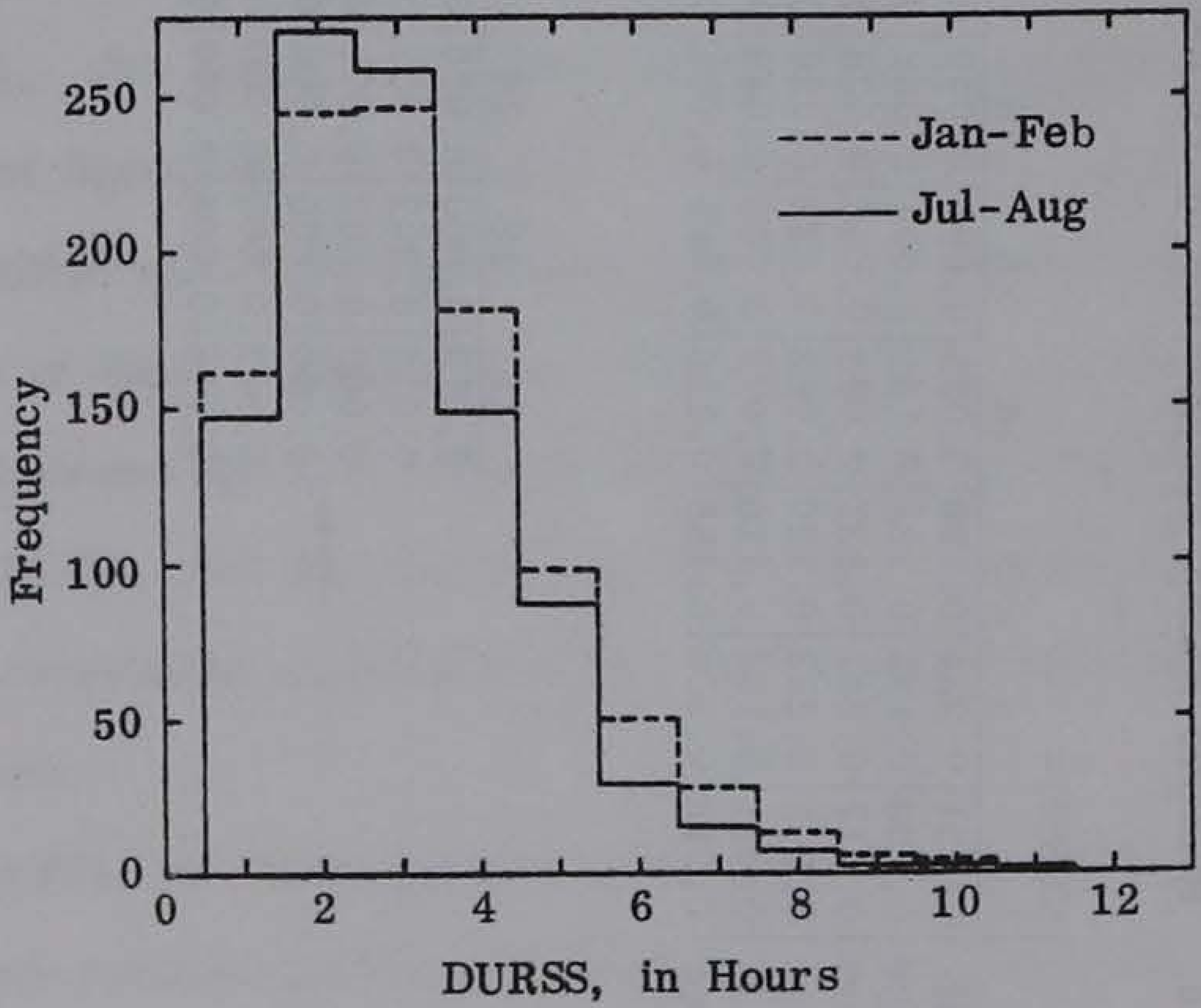


Figure 8. Example DURSS Frequency Histograms

Table 7. Relative DURSS Frequencies by Period, for Values of 1 Through 14 Hours

	DURSS =													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Jan-Feb	0.158	0.236	0.235	0.176	0.095	0.048	0.027	0.013	0.006	0.004	0.001	0.000	0.000	0.000
Mar-Apr	0.172	0.247	0.221	0.153	0.102	0.053	0.032	0.015	0.004	0.002	0.001	0.000	0.001	0.000
May-Jun	0.188	0.269	0.291	0.158	0.092	0.045	0.015	0.012	0.002	0.001	0.000	0.000	0.000	0.000
Jul-Aug	0.152	0.281	0.265	0.153	0.090	0.031	0.015	0.007	0.002	0.002	0.001	0.000	0.000	0.000
Sep-Oct	0.175	0.247	0.243	0.175	0.078	0.046	0.019	0.009	0.003	0.002	0.002	0.000	0.000	0.001
Nov-Dec	0.158	0.261	0.220	0.167	0.090	0.055	0.030	0.012	0.003	0.003	0.001	0.000	0.000	0.000

to 14 hours. Extreme values of DURSS are of no interest in the model for the same reason stated earlier for NSSSE. All DURSS frequency histograms are included in Appendix C as Figures C.7 through C.12. Representative plots are included in Figure 8.

With the exception of IATSE, the time occurrence random variables, IATSS, NSSSE, and DURSS, are to be modeled by use of the historical relative frequencies. Since these relative frequencies are unfilled and unsmoothed, some irregularities occur in the extreme value portions of the distributions. For example, the DURSS relative frequency distributions have several gaps in the upper ranges of DURSS. For DURSS values equal to 12, the lack of historical occurrences prevents the modeling of storm segments of this duration. This is a common problem, of varying degree, with all of the historical distributions used in the model. However, this problem is considered to be minor since it involves only extreme values that are not of major interest from the viewpoint of the primary objective. For this reason, the gaps and irregularities in the historical distributions are tolerated in order to avoid the complications of smoothing and distribution fits.

Modeling ACCUM

Independence is important in permitting the development of a simple and efficient data generation model. However, ACCUM is obviously dependent on DURSS. This is not a serious complication assuming that no further dependence exists. Sample serial correlations of ACCUM were computed using the same techniques outlined for earlier for IATSS and DURSS. The results are listed in Table 8. The confidence limits were computed

Table 8. Storm Segment (ACCUM) and Storm Event Accumulation Sample Serial Correlation Results

Period	Lag	Storm Segment (ACCUM)		Storm Event	
		Corr. Function	95% Conf. Limit, ±	Corr. Function	95% Conf. Limit, ±
Jan / Feb	1	0.226	0.075	0.069	0.121
	2	0.201	0.091	0.020	0.129
	3	0.181	0.113	-0.043	0.139
	4	-0.030	0.137	0.125	0.152
	5	0.271	0.168	-0.064	0.168
Mar / Apr	1	0.144	0.058	-0.011	0.101
	2	0.094	0.068	0.079	0.105
	3	0.040	0.081	0.040	0.110
	4	-0.049	0.097	0.091	0.116
	5	0.030	0.115	0.019	0.123
May / Jun	1	0.069	0.068	0.021	0.083
	2	0.082	0.089	0.024	0.086
	3	0.117	0.115	0.021	0.089
	4	0.042	0.147	0.017	0.092
	5	-0.014	0.193	0.039	0.095
Jul / Aug	1	0.065	0.091	-0.040	0.093
	2	-0.040	0.130	-0.002	0.097
	3	0.055	0.183	0.002	0.101
	4	0.201	0.260	-0.004	0.106
	5	0.034	0.365	0.075	0.111
Sep / Oct	1	0.155	0.072	-0.005	0.109
	2	0.003	0.085	0.003	0.115
	3	0.017	0.099	-0.029	0.121
	4	0.095	0.115	-0.004	0.130
	5	0.161	0.134	0.074	0.139
Nov / Dec	1	0.267	0.068	0.067	0.118
	2	0.148	0.081	0.003	0.126
	3	0.065	0.096	-0.031	0.135
	4	0.238	0.115	0.072	0.146
	5	-0.094	0.140	-0.028	0.161

Table 9. ACCUM-DURSS Sample Cross-Correlation Results

Period	Corr. Function	95% Conf. Limit
Jan-Feb	0.494	0.063
Mar-Apr	0.535	0.049
May-Jun	0.509	0.052
Jul-Aug	0.436	0.064
Sep-Oct	0.501	0.059
Nov-Dec	0.440	0.058

using the normal distribution approximation for the correlation function. Low, but significant, correlation levels were computed for the first two lags during the winter months. This is not totally unexpected in view of the meteorological conditions encountered during midwest winters. Storm cells associated with winter precipitation events tend to be more uniform and lower in intensity. Polar air mass encroachment from the north tends to depress any strong frontal activity southward, out of the region. Thunderstorm cells are not present to produce the wide variation in precipitation intensity encountered during the summer months. This increase in uniformity within storm events during the winter months results in the low, but significant, levels of positive correlation which are held to be spurious. For modeling purposes, these correlation levels are considered to be negligible since the design level storm events occur during the summer months. Also, if serial dependence were included in the model, it is doubtful that the small improvement (due to low levels of correlation) would be worth the considerable effort required.

The sample serial correlations for the total storm event accumulations were calculated using the IATSE and NSSSE serial correlation computation techniques. These results are included in Table 8. As expected (in view of previous storm event independence arguments), these results do not indicate significant dependence.

The only important dependence in ACCUM detected was in cross-correlation with DURSS. The computation method used was identical to that used for the DURSS-IATSS cross-correlation study. These correlation results are presented in Table 9. The confidence limits were computed using the normal distribution approximation. The dependence between ACCUM and DURSS is preserved in the model by assembling a set of fitted conditional distributions. One distribution is required for each value of DURSS in each period of the year. Three popular functions were chosen as possible candidates, the Weibull, the gamma, and the lognormal [Grace and Eagleson (1966) and Yevjevich (1972)]. The first two were rejected as grossly inadequate, primarily due to an inability to fit the extremely heavy-tailed sample distributions. An additional important factor was the potential lack of efficiency in data generation. Since a total of 84 distribution fits are required (14 values of DURSS times 6 periods of the year), a simple generation capability is mandatory. The Weibull appeared to be acceptable in generation but gave an extremely poor fit. The gamma failed in fit and, in addition, was exceedingly complex, requiring a prohibitive amount of generation time in the model. The lognormal gave acceptable fits and permitted extremely fast data generation. The lognormal density function is given below.

$$f(x) = [1/(x\sigma\sqrt{2\pi})] \exp[-(\ln(x) - \mu)^2/(2\sigma^2)] \qquad \text{where } x > 0 \qquad 3.$$

In equation 3, x is a value of ACCUM, μ is the mean of ln(x) (estimated by the sample mean), and σ^2 is the variance of ln(x) (estimated by the sample variance).

The maximum DURSS value to be modeled is 14 hours (maximum of record); however, insufficient sample data exists for parameter estimation of ln(ACCUM) beyond DURSS equal to 5. Therefore, the sample means of ln(x) and sample variances of ln(x) were plotted and extrapolated to obtain parameter estimates of ln(ACCUM) for DURSS values greater than 5. Figures 9 and 10 illustrate these extrapolations for the sample means. Extrapolation of the sample variances is illustrated in Figure 11. Unexpectedly, the sample variances were found to converge toward a single value for all six periods of the year before small sample bias caused a rapid scattering of the data points. This convergence is evident up to DURSS equal to 5. Convergence was assumed to continue for increasing values of DURSS, based on the historical evidence. Figure 11 indicates that the variance decreases for increasing DURSS for all six periods of the year. Two envelope curves mark, approximately, the upper and lower bounds of the data points for values of DURSS equal to or less than 5. The curves were drawn by eye to include all the points, except for one outlying point at DURSS equal to 4. It will be noted that points along the lower bound correspond to the winter months while those along the upper bound correspond to the summer months. Higher values of variance are associated with the summer months due to the presence of highly variable thunderstorm precipitation. The convergence in variance can be attributed to the greater uniformity in precipitation intensity for large values of DURSS. This implies that strong thunderstorm cells are not associated with long duration storm segments; therefore, long summer storm segments more closely resemble their winter counterparts than do short duration storm segments. It is logical to conclude that this resemblance will become stronger with increasing values of DURSS. For the above reasons, a single variance extrapolation (for DURSS greater than 5) is used for all periods of the year.

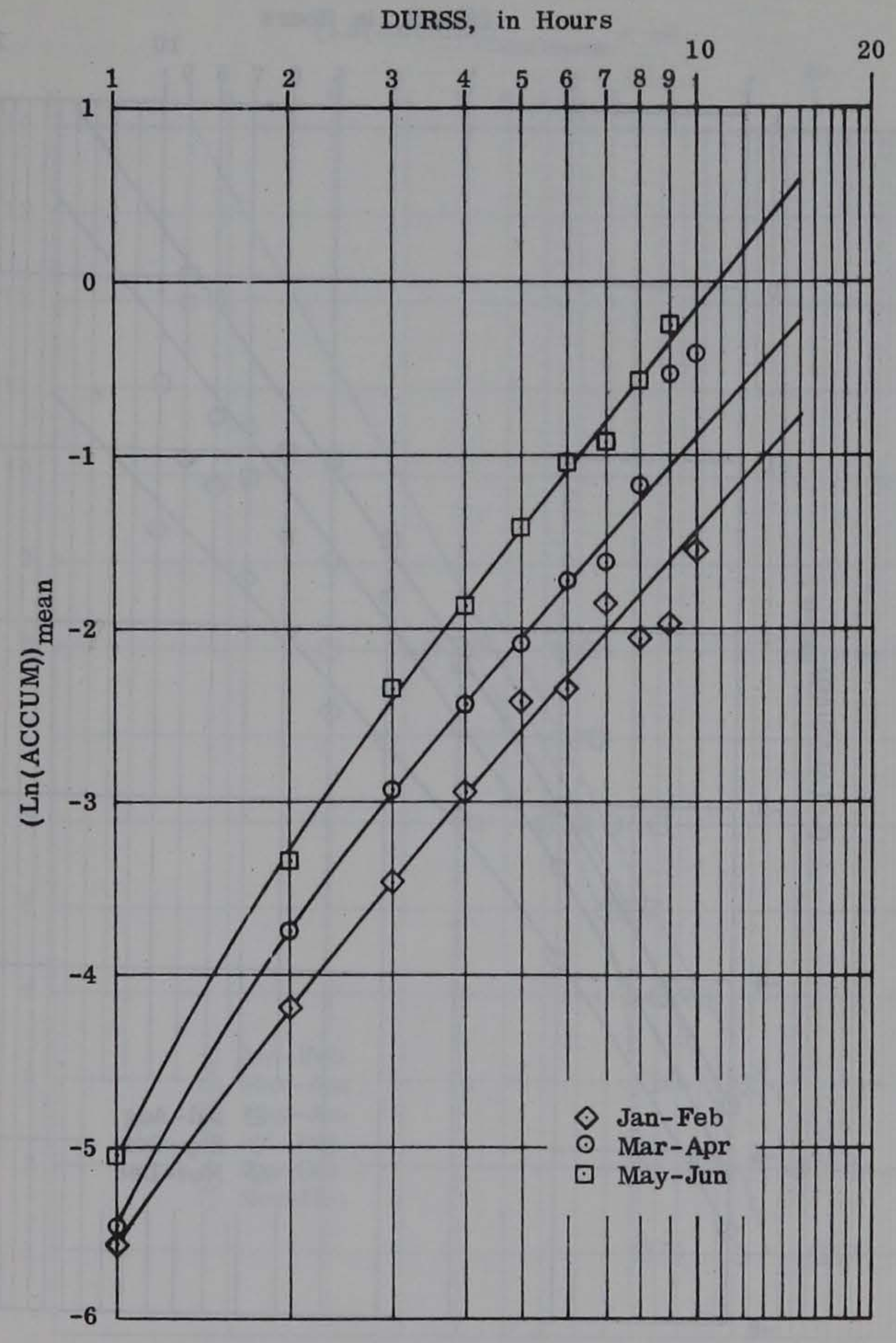


Figure 9. Sample Means of Ln(ACCUM), Periods 1, 2, and 3

DURSS sample cumulative distributions for all six periods are superimposed and included as Figure 12. These distributions indicate that approximately 92% of all storm segments are of 1 to 5 hours duration. Therefore, only 8% of all storm segments are involved in the extrapolation estimate of variance, and these are of low interest due to the large values of DURSS. To investigate the probable maximum error involved in the extrapolation, the envelope curves in Figure 11 were extended to DURSS equal 8. For values of DURSS equal to 6, 7, and 8, the lognormal density functions were plotted for each period of the year using the extrapolated variance, and the upper and lower envelope values of variance. A typical example of these plots is included as Figure 13. A visual comparison of these curves indicates that any error involved in the extrapolation is of a low order of magnitude. Therefore, any resulting error will be neglected since the associated storm segments are of low interest and occur only 8% of the time. Table 10 lists the sample means and variances used in the model.

Lognormal function fits to ACCUM were completed for DURSS values of 1 through 5, for each of the six periods of the year. The resulting fits to the ACCUM frequency histograms are included in Appendix D as Figures D.1 through D.30. Representative plots are included in Figure 14. A chi-square goodness-of-fit test was conducted for each lognormal function fit, and the results listed in Table 11. Taken individually, many of the fits do not appear to be outstanding. However, the large range of shapes the lognormal distribution must assume, in order to achieve all of the fits in a satisfactory manner, is impressive. From this viewpoint, the lognormal fit to historical ACCUM values is considered exceptional. To

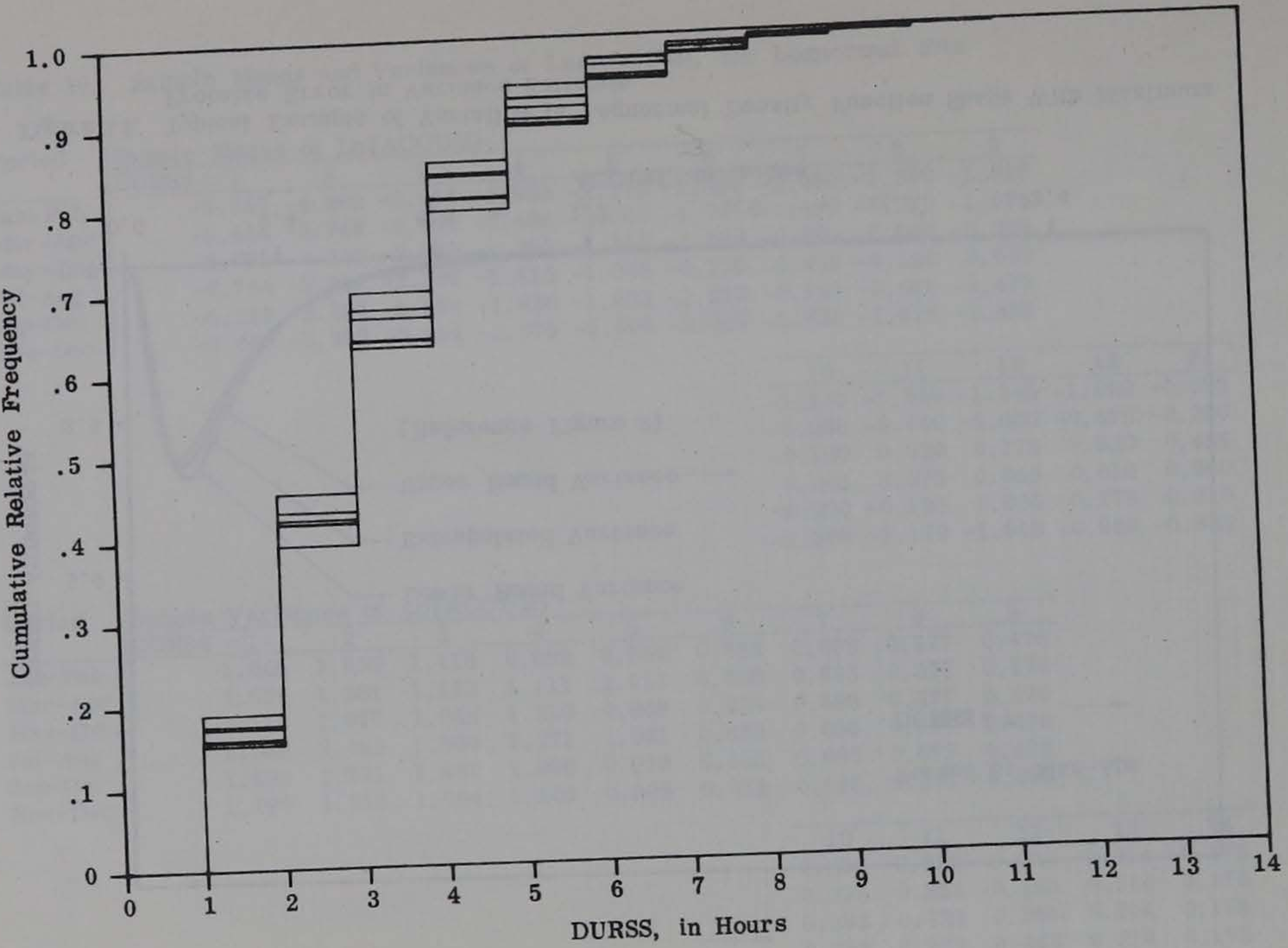


Figure 12. DURSS Sample Cumulative Distributions for All 6 Periods

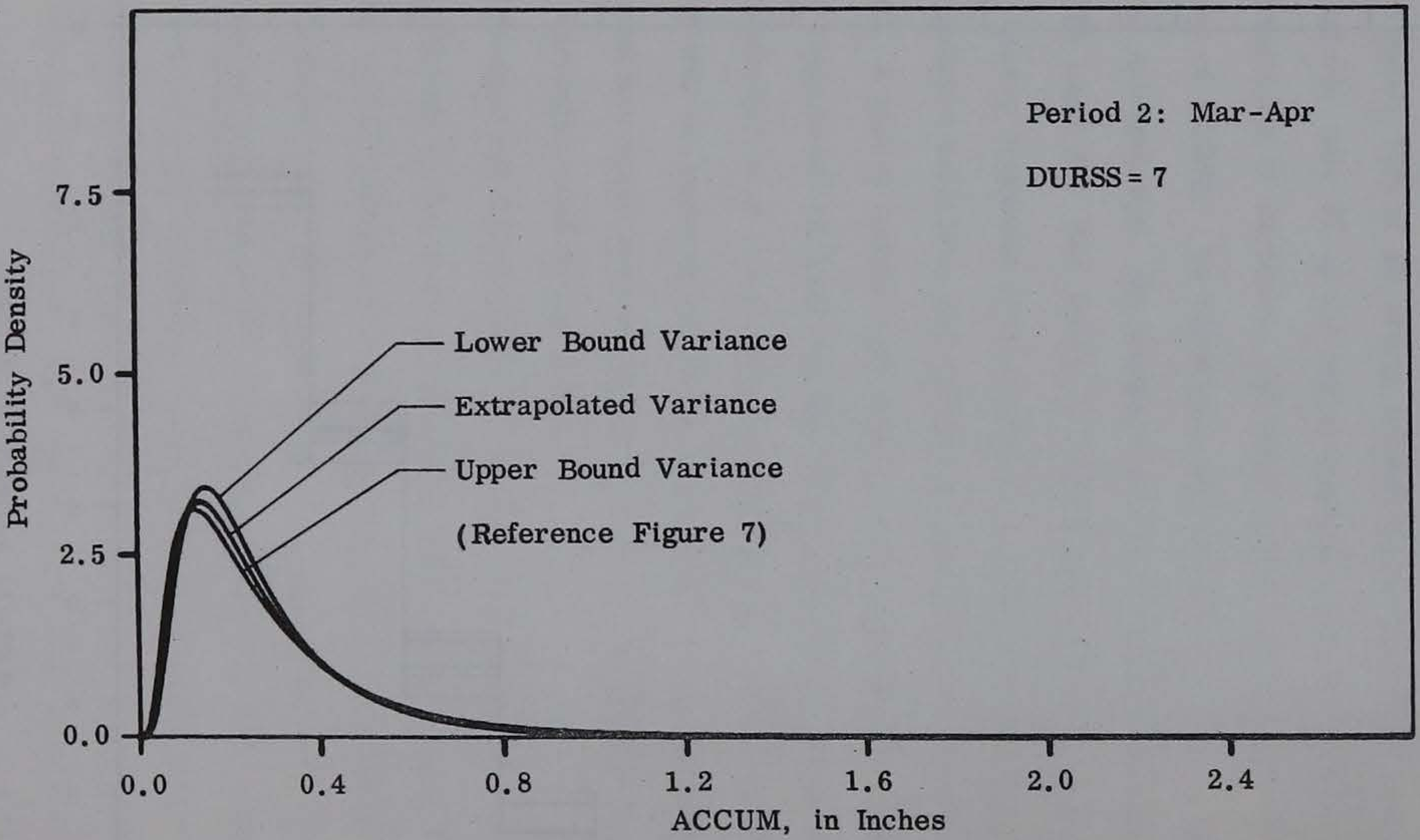
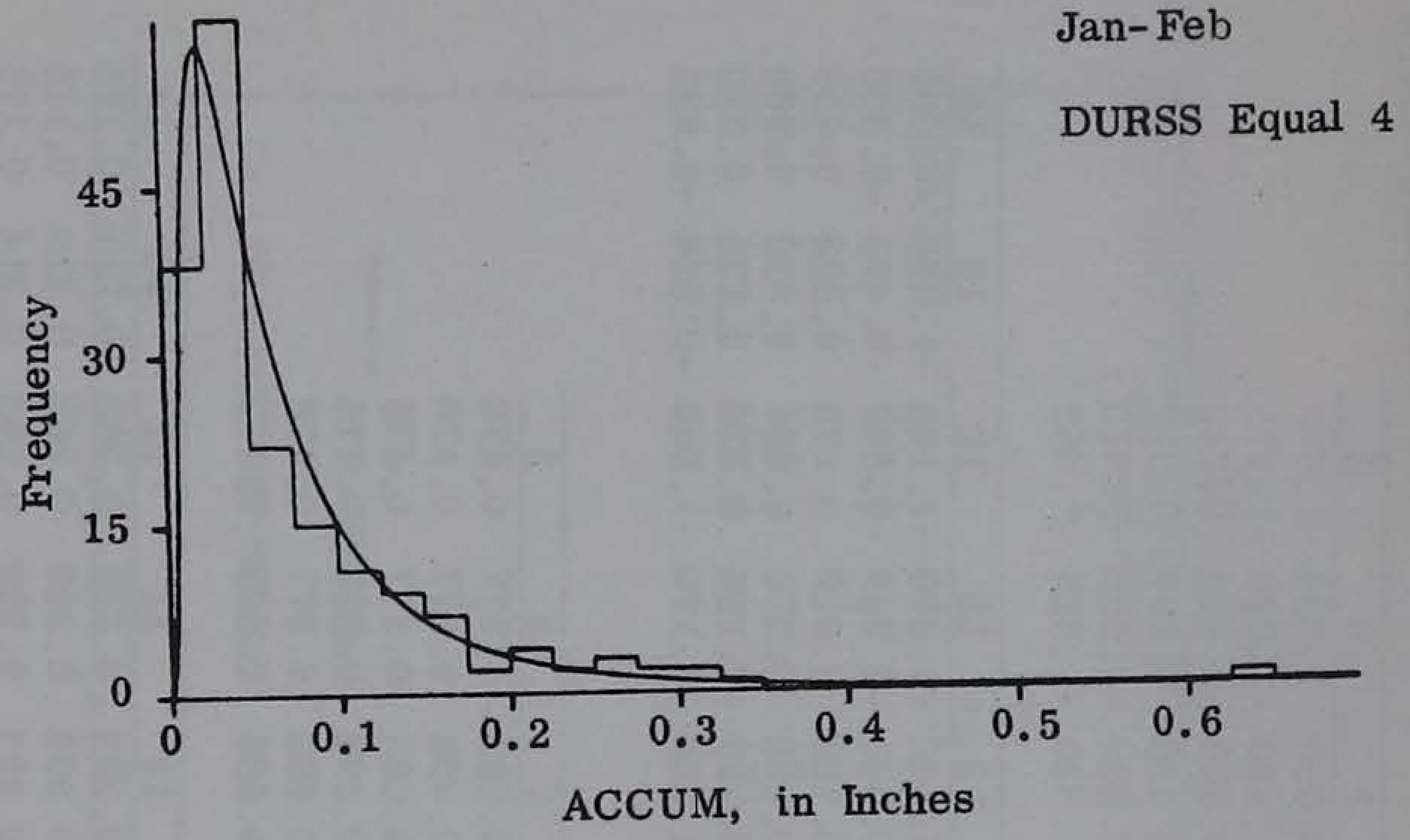


Figure 13. Typical Example of Variation in Lognormal Density Function Shape With Maximum Probable Error in Variance Estimate

Table 10. Sample Means and Variances of Ln(ACCUM), for Lognormal Fits

Period	Sample Means of Ln(ACCUM)													
	DURSS = 1	2	3	4	5	6	7	8	9	10	11	12	13	14
Jan-Feb	-5.587	-4.203	-3.458	-2.958	-2.143	-2.280	-2.080	-1.800	-1.615	-1.440	-1.280	-1.145	-1.020	-0.890
Mar-Apr	-5.454	-3.748	-2.922	-2.434	-2.093	-1.745	-1.490	-1.270	-1.075	-0.900	-0.740	-0.600	-0.475	-0.350
May-Jun	-5.051	-3.340	-2.349	-1.881	-1.413	-1.080	-0.800	-0.560	-0.340	-0.160	0.020	0.175	0.320	0.455
Jul-Aug	-4.744	-3.019	-2.207	-1.513	-1.048	-0.730	-0.425	-0.150	0.080	0.285	0.475	0.650	0.810	0.960
Sep-Oct	-5.115	-3.382	-2.594	-1.836	-1.633	-1.210	-0.930	-0.690	-0.475	-0.290	-0.125	0.030	0.175	0.310
Nov-Dec	-5.463	-3.903	-3.094	-2.679	-2.504	-2.050	-1.820	-1.625	-1.455	-1.300	-1.170	-1.040	-0.930	-0.825

Period	Sample Variances of Ln(ACCUM)													
	DURSS = 1	2	3	4	5	6	7	8	9	10	11	12	13	14
Jan-Feb	1.045	1.035	1.119	0.899	0.884	0.835	0.695	0.577	0.476	0.393	0.322	0.263	0.214	0.175
Mar-Apr	1.056	1.381	1.193	1.111	1.012	0.835	0.695	0.577	0.476	0.393	0.322	0.263	0.214	0.175
May-Jun	2.118	1.977	1.642	1.316	0.949	0.835	0.695	0.577	0.476	0.393	0.322	0.263	0.214	0.175
Jul-Aug	2.368	2.462	1.564	1.271	1.061	0.835	0.695	0.577	0.476	0.393	0.322	0.263	0.214	0.175
Sep-Oct	1.525	1.921	1.461	1.006	0.979	0.835	0.695	0.577	0.476	0.393	0.322	0.263	0.214	0.175
Nov-Dec	1.190	1.318	1.094	1.104	0.909	0.835	0.695	0.577	0.476	0.393	0.322	0.263	0.214	0.175



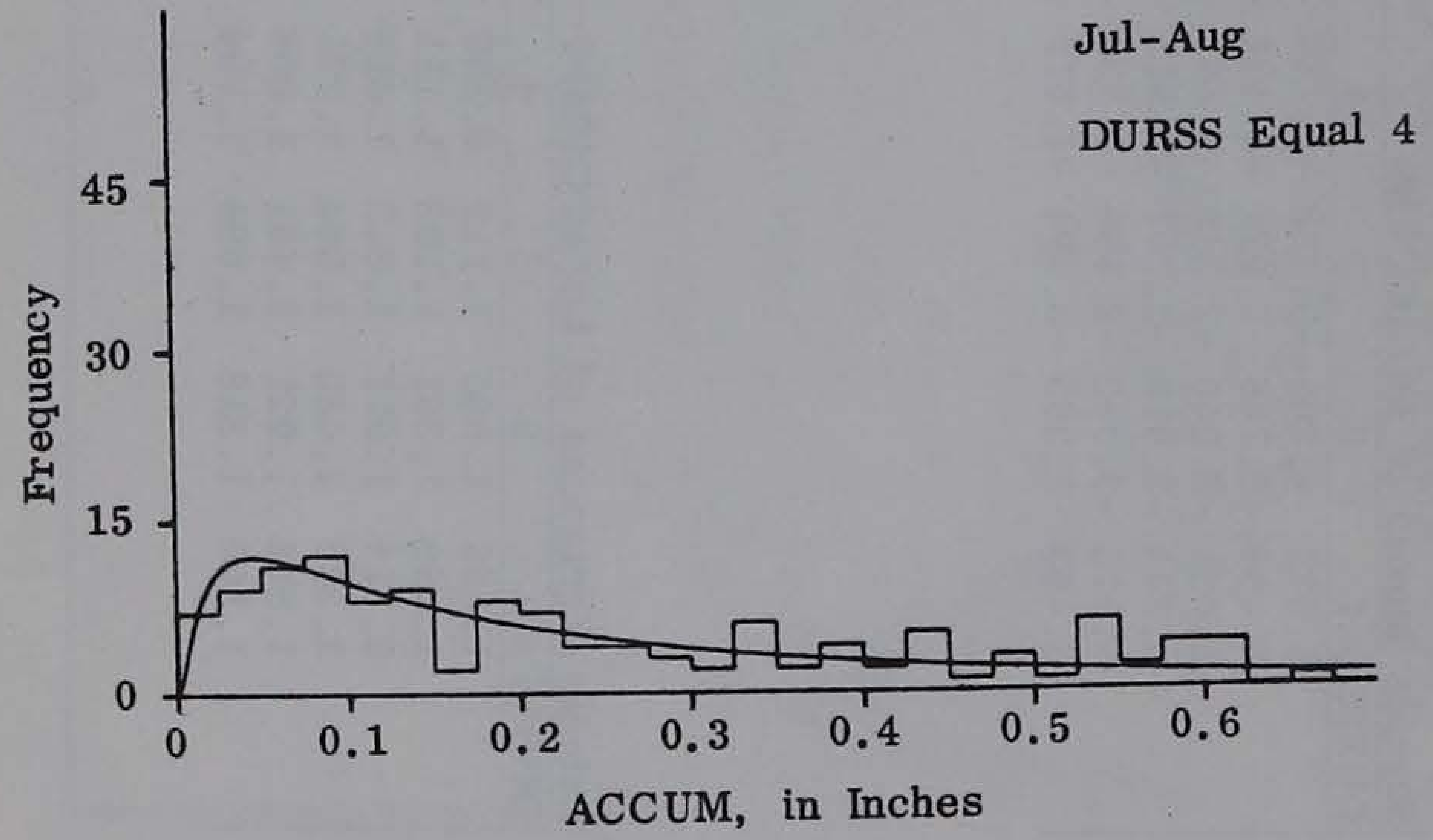


Figure 14. Example ACCUM Frequency Histograms and Fitted Lognormal Functions

Table 11. Chi-Square Tests, Lognormal Distribution Fits

Period	DURSS in Hours	Chi-Square Statistic	99% Conf. Limit	95% Conf. Limit
Jan / Feb	1	26.9	34.8	28.9
	2	37.8	34.8	28.9
	3	15.2	34.8	28.9
	4	13.3	34.8	28.9
	5	24.5	34.8	28.9
Mar / Apr	1	34.5	34.8	28.9
	2	19.3	34.8	28.9
	3	18.8	34.8	28.9
	4	27.4	34.8	28.9
	5	14.0	34.8	28.9
May / Jun	1	39.4	34.8	28.9
	2	25.4	34.8	28.9
	3	29.6	34.8	28.9
	4	26.4	34.8	28.9
	5	13.1	34.8	28.9
Jul / Aug	1	19.2	34.8	28.9
	2	33.1	34.8	28.9
	3	32.7	34.8	28.9
	4	28.9	34.8	28.9
	5	31.6	34.8	28.9
Sep / Oct	1	15.6	34.8	28.9
	2	15.5	34.8	28.9
	3	30.3	34.8	28.9
	4	14.7	34.8	28.9
	5	16.8	34.8	28.9
Nov / Dec	1	24.1	34.8	28.9
	2	18.3	34.8	28.9
	3	44.0	34.8	28.9
	4	6.2	34.8	28.9
	5	13.2	34.8	28.9

illustrate the variety of lognormal shapes, Figures D.31 through D.36 display all 84 functions used in the model.

Modeling PKHR

It has been demonstrated that the passage of storm cells is a highly random process when viewed from a single location. This has been used to support the independence of storm segments. The independence of storm segments is also strongly supported by the serial independence of IATSS, DURSS, and ACCUM. As a result, there is no difficulty in expecting the PKHR random variables to be serially independent also. Physically, no argument can be made for the dependence of PKHR on ACCUM for a given value of DURSS. Observation of the historical data also results in this same conclusion. By definition, PKHR must be less than or equal to DURSS; therefore, PKHR is mechanically dependent on DURSS. This dependence is maintained in the model by using conditional distributions.

The historical relative frequencies were chosen for use in the modeling process, requiring one relative frequency distribution for each period of the year, for each value of DURSS. PKHR relative frequencies are listed in Table 12 for DURSS values of 2 through 7. Representative plots are included as Figure 15. Due to insufficient sample size, a single relative frequency distribution is used for DURSS equal to 8. Data from all periods of the year are required to produce the single distribution. No serious error should result since the seasonal variation is relatively small for long duration storm segments. For DURSS values greater than 8, an approximate linear extrapolation of the DURSS equal to 8 PKHR distribution is used due to the lack of historical data. This process is illustrated in

Table 12. Relative PKHR Frequencies by Period, for DURSS Values of 1 Through 7 Hours

Period	DURSS	PKHR, in Hours						
	hrs	1	2	3	4	5	6	7
Jan / Feb	2	0.8423	0.1577					
	3	0.4542	0.4583	0.0875				
	4	0.1944	0.4333	0.3223	0.0500			
	5	0.1340	0.2784	0.3711	0.2165	0.0000		
	6	0.0408	0.2245	0.3469	0.2857	0.1020	0.0000	
	7	0.0357	0.1072	0.3571	0.2143	0.2143	0.0714	0.0000
Mar / Apr	2	0.8540	0.1460					
	3	0.4432	0.5069	0.0499				
	4	0.2400	0.4280	0.3120	0.0200			
	5	0.1377	0.3293	0.3713	0.1617	0.0000		
	6	0.1047	0.2209	0.2442	0.3372	0.0930	0.0000	
	7	0.0192	0.2115	0.2500	0.2308	0.1923	0.0962	0.0000
May / Jun	2	0.7747	0.2253					
	3	0.4130	0.5311	0.0559				
	4	0.1983	0.4526	0.3276	0.0215			
	5	0.1185	0.4222	0.2741	0.1778	0.0074		
	6	0.1061	0.3030	0.2879	0.1970	0.1060	0.0000	
	7	0.0000	0.2273	0.3182	0.2273	0.1364	0.0908	0.0000
Jul / Aug	2	0.7399	0.2601					
	3	0.4457	0.5233	0.0310				
	4	0.2282	0.4631	0.2819	0.0268			
	5	0.0805	0.4483	0.3218	0.1494	0.0000		
	6	0.1333	0.2333	0.3000	0.2333	0.1001	0.0000	
	7	0.0667	0.0000	0.4000	0.4000	0.0000	0.1333	0.0000
Sep / Oct	2	0.8269	0.1731					
	3	0.4086	0.5305	0.0609				
	4	0.2488	0.4179	0.3333	0.0000			
	5	0.0667	0.3222	0.4111	0.2000	0.0000		
	6	0.0943	0.1698	0.3774	0.2642	0.0943	0.0000	
	7	0.0455	0.2727	0.1818	0.3182	0.1364	0.0454	0.0000
Nov / Dec	2	0.8867	0.1133					
	3	0.3962	0.5423	0.0615				
	4	0.2690	0.3858	0.3350	0.0102			
	5	0.1132	0.2453	0.3868	0.2547	0.0000		
	6	0.0615	0.2462	0.4000	0.2154	0.0769	0.0000	
	7	0.0556	0.1944	0.1667	0.3611	0.1667	0.0555	0.0000

Note: DURSS = 1 is the degenerate case

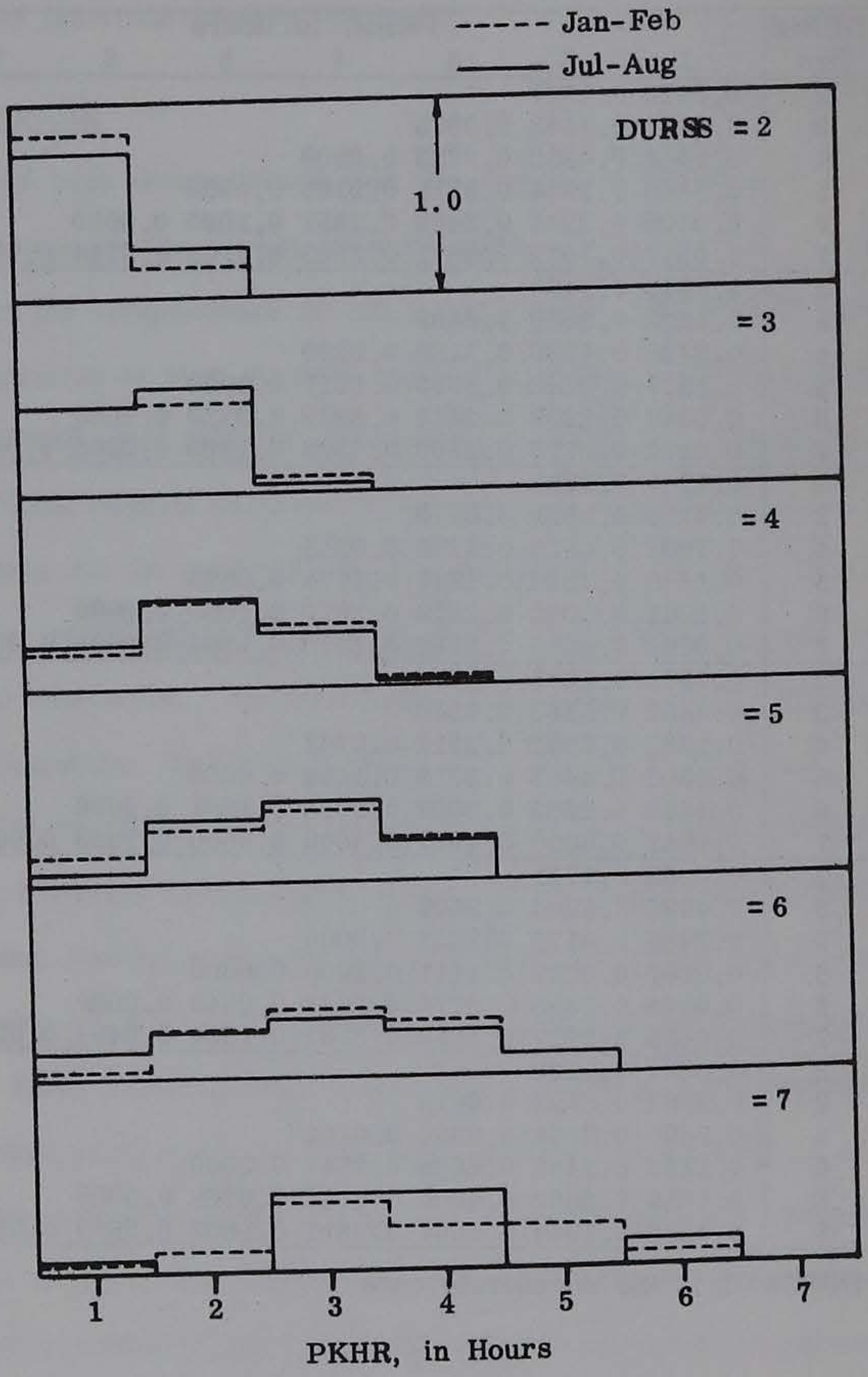


Figure 15. Example PKHR Relative Frequency Histograms

Figure 16. By referring to Table 12, it will be noted that there is very little difference in the relative frequencies for different periods of the year, except for high values of DURSS where small sample bias introduces variability. This agreement between periods of the year is also illustrated by Figure 15. For this reason, an example series of PKHR distributions (from the Jan-Feb period) is included in Figure 16 to show the typical progression of shapes with increasing values of DURSS. The extrapolation from the DURSS equal to 8 distribution maintains a third hour peak and distributes the relative frequencies as shown in Figure 16. This extrapolation best approximates the trends observed in the data. Table 13 lists the resulting PKHR relative frequencies corresponding to DURSS equal to 8 through 14. The lack of PKHR occurrences in the first and last two hours of the DURSS equal to 9 through 14 distributions is an accurate reflection of trends observed in the historical data.

Building the "Shape Catalog"

For a given value of DURSS and PKHR, the unimodal (single peak) shape of a storm segment allows a very simplified distribution of ACCUM over the storm segment hours. The approximately triangular hyetograph shapes appear to vary in a completely random fashion. For purposes of comparison, each empirical hyetograph shape was normalized by dividing each hourly intensity by ACCUM. By listing the normalized shapes in order of increasing ACCUM, holding DURSS and PKHR constant, it was determined that this remaining variability in the distribution of precipitation had no detectable relationship with the magnitude of ACCUM. Although dependence of shape on ACCUM was not generally evident, an occasional

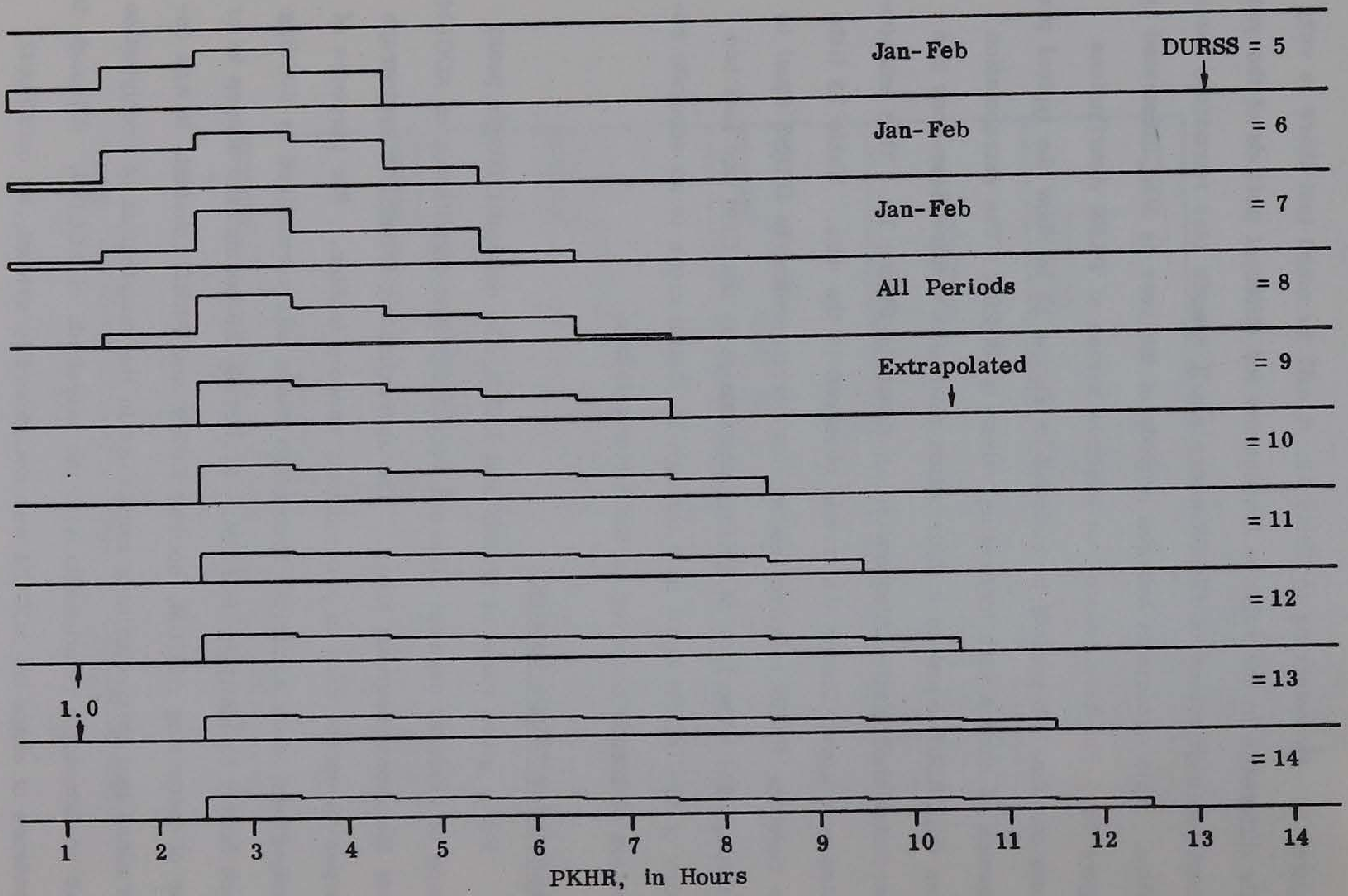


Figure 16. Illustration of the Extrapolation of the DURSS = 8 PKHR Relative Frequency Histogram

Table 13. Relative PKHR Frequencies for DURSS Values of 8 Through 14, for All Periods

DURSS hrs	PKHR, in Hours 1	2	3	4	5	6	7	8	9	10	11	12	13	14
8	0.0000	0.0930	0.3140	0.2330	0.1740	0.1630	0.0230	0.0000						
9	0.0000	0.0000	0.2797	0.2399	0.2000	0.1601	0.1204	0.0000	0.0000					
10	0.0000	0.0000	0.2331	0.2065	0.1799	0.1534	0.1268	0.1003	0.0000	0.0000				
11	0.0000	0.0000	0.1998	0.1808	0.1618	0.1428	0.1239	0.1049	0.0860	0.0000	0.0000			
12	0.0000	0.0000	0.1748	0.1606	0.1463	0.1321	0.1179	0.1036	0.0894	0.0753	0.0000	0.0000		
13	0.0000	0.0000	0.1554	0.1443	0.1333	0.1222	0.1111	0.1000	0.0890	0.0779	0.0669	0.0000	0.0000	
14	0.0000	0.0000	0.1399	0.1310	0.1221	0.1133	0.1044	0.0956	0.0867	0.0778	0.0690	0.0602	0.0000	0.0000

extreme value of ACCUM (associated with short to moderate values of DURSS) showed a very strong peak hour accumulation. This is physically appealing since high intensity rainfall associated with thunderstorm events has been shown to be extremely short-lived [Stall and Huff (1971)]. It was concluded that this occasional observation was of sufficient merit to include in the model (due to the expressed interest in thunderstorm events).

A catalog of the mean normalized hyetograph shapes was compiled by dividing the historical record of storm segment durations into three categories according to their relative importance and frequency of occurrence. Since 92% of all storm segments have DURSS values equal to or less than 5 hours, and are likely to be associated with thunderstorm events, this became the first and most important category. The above physical argument and observations led to a decision to store three shapes per period in the first category for each fixed value of DURSS and PKHR. This allowed the storage of mean hyetograph shapes based on the level of storm segment accumulation (ACCUM). Therefore, one mean shape was stored which represented the lower historical values of ACCUM. A second mean shape was stored to represent the middle ranges of ACCUM. The last mean shape stored represented the relatively few shapes corresponding to higher values of ACCUM. The ranges or levels of ACCUM over which these mean shapes were computed was determined by dividing the maximum historical value of ACCUM by 3. Therefore, the maximum accumulation value associated with the computation of the lowest level mean hyetograph shape was $(\mathrm{ACCUM})_{\mathrm{max}}/3$. The maximum value associated with the computation of the middle level mean shape was $2 \times (\mathrm{ACCUM})_{\mathrm{max}}/3$. The upper level mean hyetograph shape was computed using all the remaining historical shapes.

Only 6% to 8% of all storm segments have DURSS values of 6 through 8 which are used to form the second category. Therefore, due to the lower level of importance, one mean hyetograph shape was computed for each fixed value of DURSS, PKHR, and period of year. The final category covers DURSS values of 9 through 14. Only 1% to 2% of all storm segments fall in this category. Due to the lack of historical data and the relative unimportance, only one mean hyetograph shape was stored in the catalog for each fixed value of DURSS and PKHR. Some shapes not available in the historical data were filled in by eye based on the closest related historical shape. Shapes for DURSS equal to 12 were not included since storm segments of this length did not occur in the historical data and will not be generated. Table 14 summarizes the shape catalog and gives the number of shapes stored per category. The entire shape catalog is listed in Appendix D as Tables D.1 through D.12. When generating data in the model, the hyetograph shape (in the form of relative hourly accumulations) is pulled from storage by specifying DURSS, PKHR, and when required, period and ACCUM.

Application of the Precipitation Model Using the Digital Computer

Considerable effort has been made to describe the precipitation process in terms of independent random variables. The degree to which this is accomplished is reflected in the simplicity of the resulting computer model; and therefore, the efficiency of data generation. Independent random variables can be modeled very efficiently by generating values from

Table 14. Summary of Storm Segment Shape Catalog

Category	DURSS, in Hours	Comments	Number of mean shapes stored
1	2, 3, 4, 5	Store 3 mean hyetograph shapes (1 mean shape for each of 3 levels of ACCUM) per PKHR value, per period of the year	252
2	6, 7, 8	Store 1 mean hyetograph shape per PKHR value, per period of the year	108
3	9, 10, 11, 13, 14	Store 1 mean hyetograph shape per PKHR value	37
Note: For DURSS equal 1, shape is fully defined by ACCUM			Total Stored 397

the sample distribution or a fitted theoretical distribution. This is accomplished by the use of a random number generator. A large portion of the model developed herein consists of modeling independent random variables, which results in a remarkably efficient computer model, the details of which are discussed below.

Modeling the Time Occurrence Random Variables

The locations of storm events and storm segments in time are determined by the independent random variables IATSE, IATSS, NSSSE, and DURSS. Therefore, a single distribution is required to represent each random variable in each period of the year. With the exception of IATSE, the sample relative frequencies are read into computer storage (Tables 4, 5, and 7). A fitted exponential function represents the distribution of IATSE and requires less storage since only the six sample means and six lower cutoff levels are stored (Table 2). An added benefit is that IATSE values can be computed directly from the exponential distribution function, given a uniformly distributed random number from the interval zero to one. IATSE is generated from that model whose period contains the first hour of the interarrival time, which is in accordance with the way the data was analyzed. The generated IATSE value is truncated to the nearest hour, resulting in an average error in the discretization of 1/2 hour per about 100 hours average. Values of the remaining time occurrence variables are obtained by a search of the appropriate sample cumulative distribution using uniformly distributed random numbers. However, this search is greatly shortened since it begins at the lower end of the distribution where the probability is concentrated (refer to Appendices B and C).

The sequence of generating and reassembling values of these random variables to create storm events follows the exact reverse of the disassembly of the historical data in order to precisely model the precipitation process. The period in which a generated storm event occurs is determined by the period containing the first wet hour.

Modeling the Storm Segment Hyetograph

The intensity and distribution of precipitation within storm segments is determined by the random variables ACCUM and PKHR, and the shape catalog. The two random variables are not entirely independent and require the use of conditional distributions. Since the lognormal function is fitted to the ACCUM sample distributions, only the means and variances of the logarithms of the historical data are read into storage (Table 10). Values of ACCUM can then be computed directly using standard normally distributed random numbers produced by the random number generator. PKHR requires the storage of 78 sample distributions in the form of relative frequencies (Tables 12 and 13). Values are generated using uniformly distributed random numbers. The shape catalog requires the storage of 397 sample shapes in the form of normalized hourly intensities (Tables D.1 through D.12). The shapes are selected from storage by fixed values of DURSS, PKHR, ACCUM, and period, M, as required.

The Random Number Generator

The random number generator used is one originally developed by Marsaglia, et al, at McGill University, and is popularly called the "Super-Duper" [Marsaglia, MacLean, and Bray (1964)]. The basic generator is now widely used in published statistical software packages and is available at many computing facilities (including The University of Iowa) as an on-line subroutine. Several options are available at the call of a single program statement. These include a uniformly distributed random number from the interval zero to one, and a standard normal distributed random number, both of which are used in the precipitation model.

The popularity of the "Super-Duper" results from its ability to produce a series of random numbers with the desired properties at an extremely high speed of generation (approximately 15,000 per second for both the uniform and standard normal options). The generator requires two integer seed values, one for each of two internal generators which are combined to produce a single output.

The Computer Program

The precipitation model was expressed in terms of the Fortran IV language for use in conjunction with the IBM 360 digital computer at The University of Iowa. A program listing, including data, and a sample output are included in Appendix E as Tables E.1 and E.2. Figure 17 presents a simplified flow chart of the computer model.

After reading the distributions into storage, it is a simple matter to generate values from the distributions in the proper sequence to construct synthetic storm events. Briefly, this consists of generating an interarrival time to a storm event (IATSE), and then generating and locating the storm segments. This is repeated the desired number of times by the looping process illustrated in Figure 17. The only complex part of the procedure is determining the date of the storm event. In order to accomplish this, a multiple level time update system is used. This involves a year, List of Flow Chart Variables:

ACCUM(N)	- Nth storm segment precipitation accumulation, in inches.
DURSS(N)	- Duration of Nth storm segment, in hours.
IATSE	- Interarrival time to storm event, in hours.
IATSS(N-1)	- Interarrival time to Nth storm segment, in hours.
ISTART	- Random number generator seed (congruential generator).
JSTART	- Random number generator seed (shift register generator).
LL	- Incremental hourly counter referenced to beginning of storm event.
LENGTH	- Length of storm event, in hours.
LYR	- Last year of data generation.
M	- Period of year counter
MHRS(M)	- Total number of hours in period M.
N	- Incremental storm segment counter.
NBYR	- Year counter (initialized with first year of data generation).
NHOURS	- Accumulated time in hours from beginning of period, M.
NSSSE	- Number of storm segments in storm event.
PKHR(N)	- Peak hour of Nth storm segment, in hours.
RAIN(N, I)	- Hourly precipitation accumulations of the Nth storm segment, Ith hour, in inches.
TRAIN	- Total precipitation accumulation in storm event, in inches.

Flow Chart:

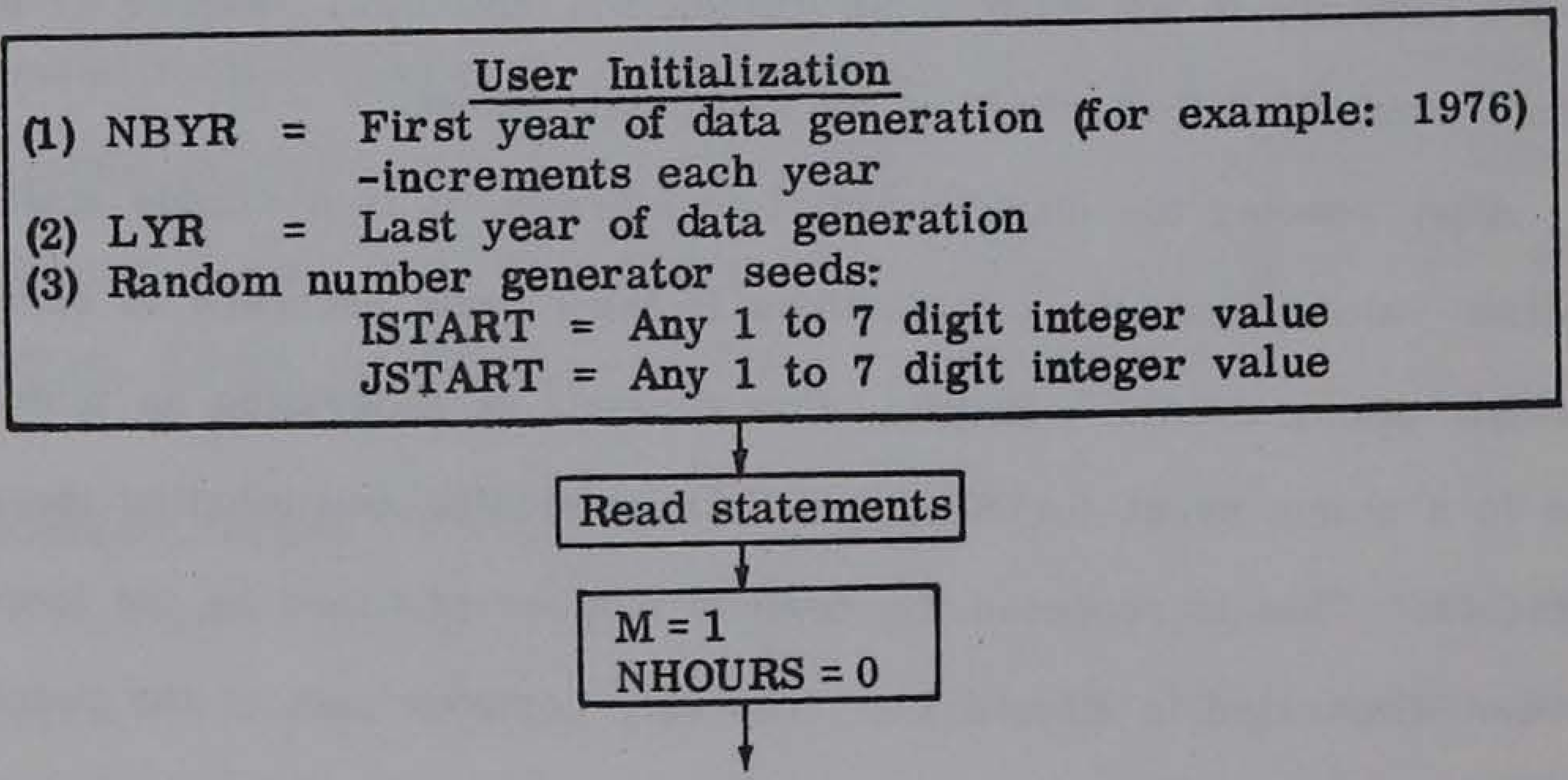


Figure 17. Digital Computer Model Flow Chart

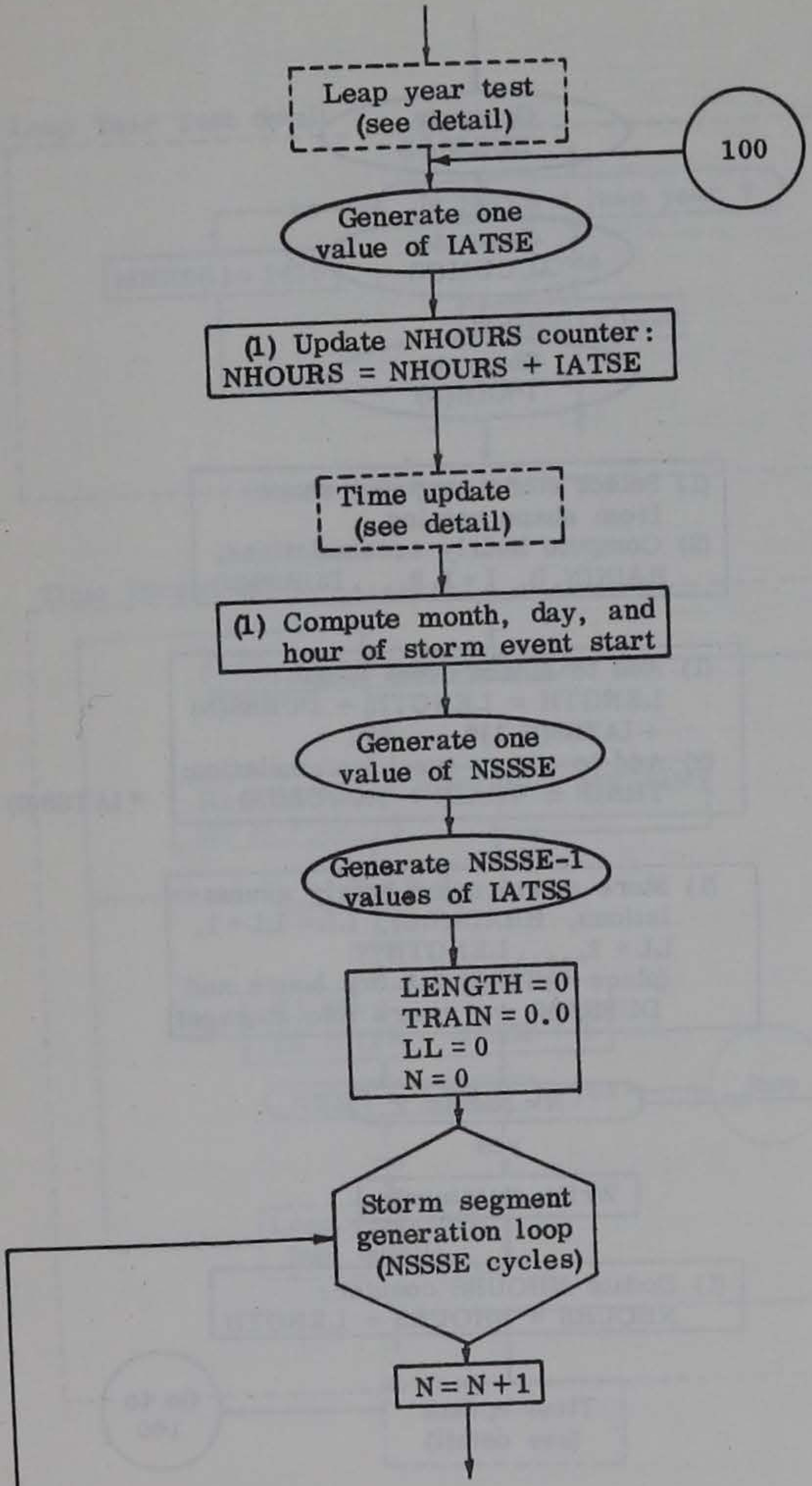


Figure 17 (cont'd.)

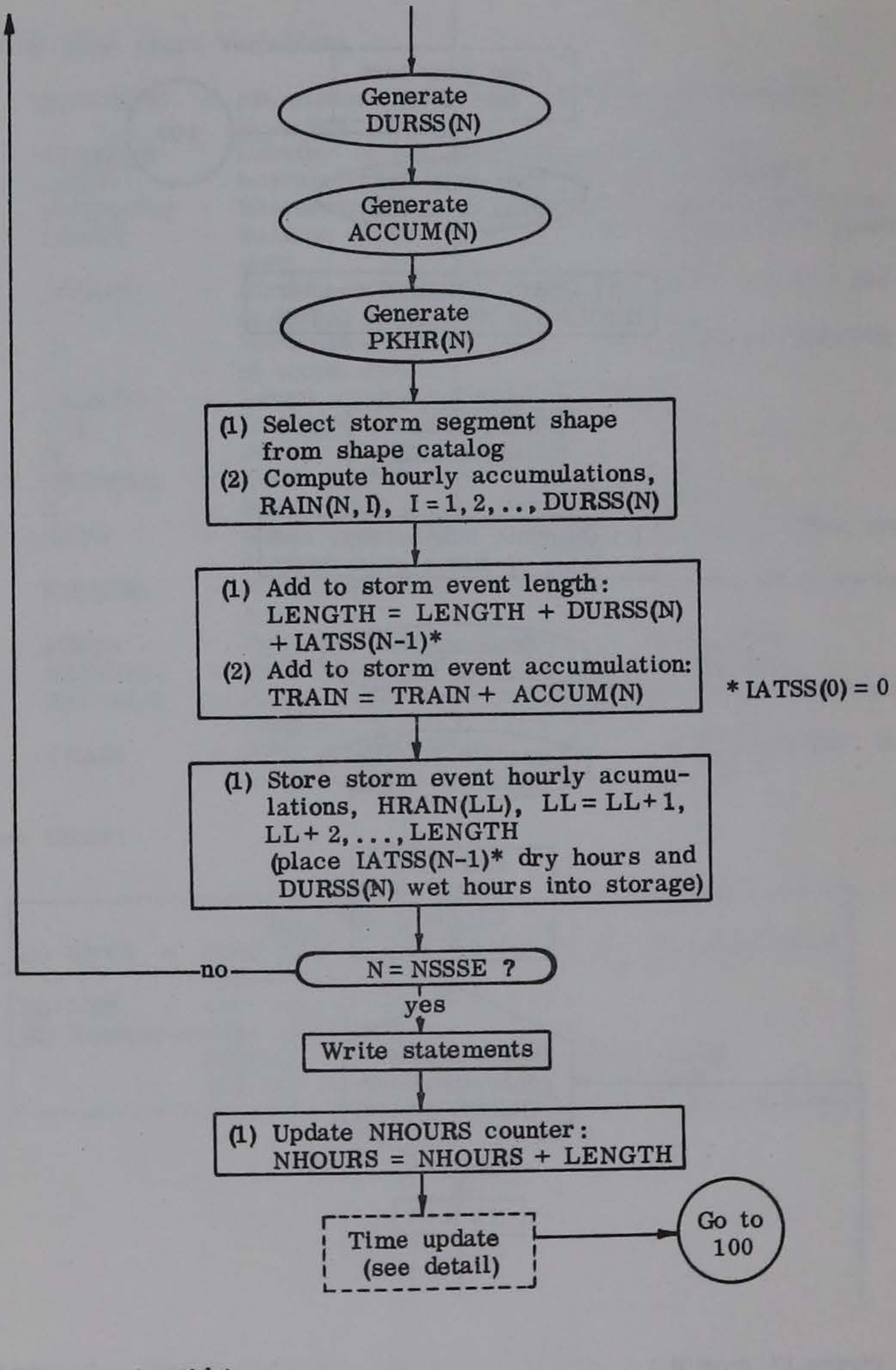
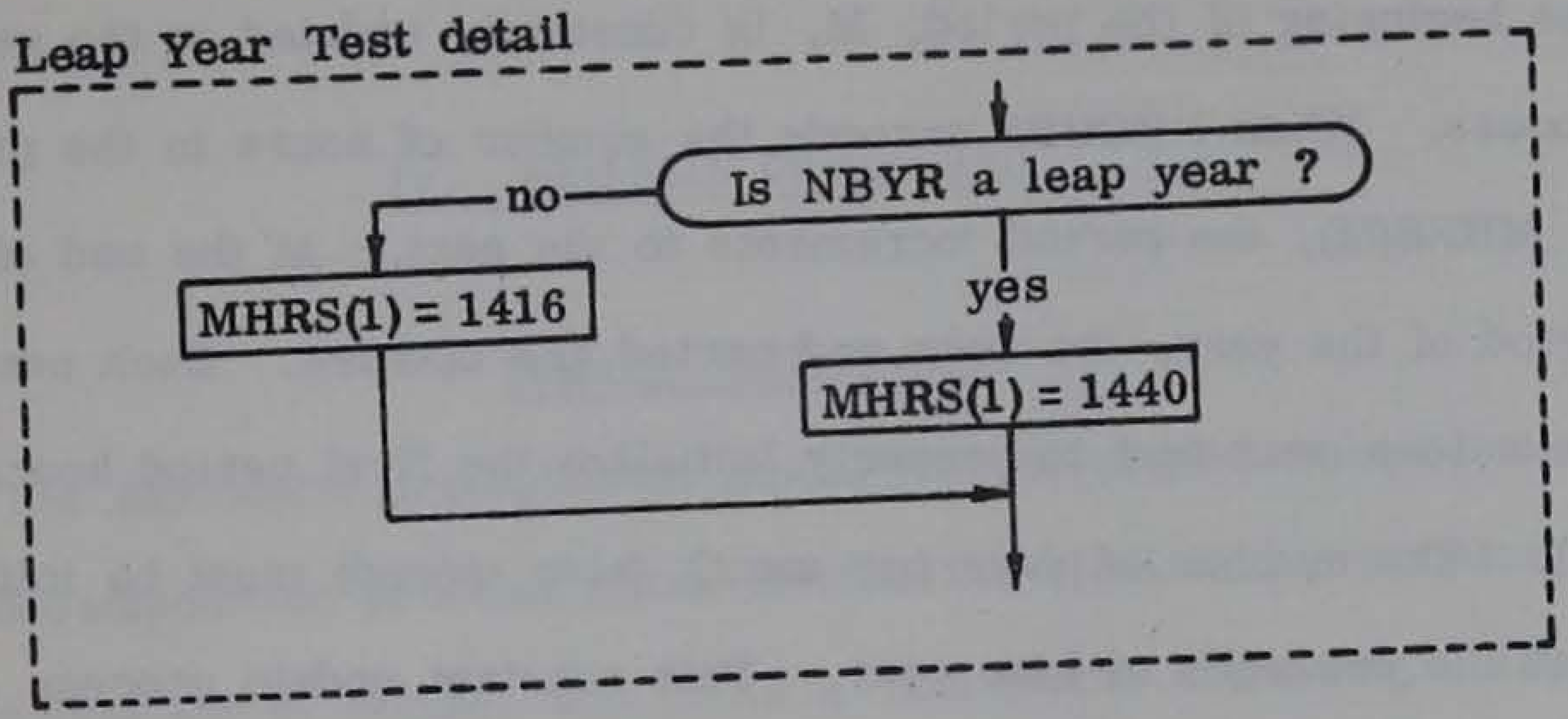


Figure 17 (cont'd.)



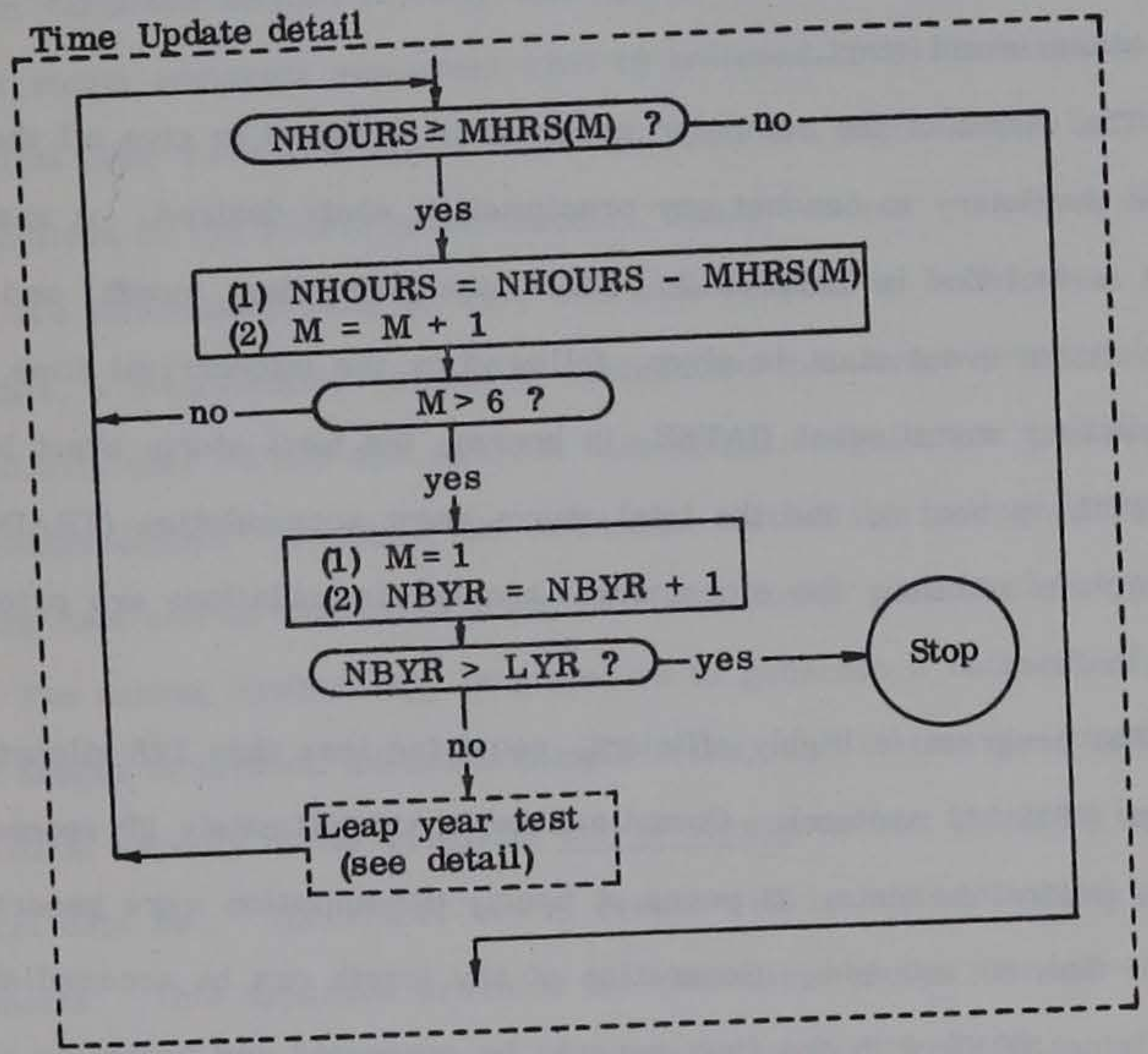


Figure 17 (cont'd.)

period, and hour update process. The number of hours, NHOURS, from the beginning of the period, M, is constantly updated in the generation process. When NHOURS exceeds the number of hours in the present period, MHRS(M), the period increments to the next. At the end of the last period of the year, the year and period are updated. Each new year requires a leap year test to properly initialize the first period hours, MHRS(1). The number of days per month (also stored) must be initialized to reflect the presence of leap year. This constant update process is required to enable the specification of the hour, day, month, and year of each storm event start.

The output of the computer program is designed to give all the information necessary to conduct any precipitation study desired. A sample output is included in Table E.2. First, the hour, day, month, and year of the storm event start is given, followed by the interarrival time from the previous storm event (IATSE, in hours), the total storm event length (LENGTH, in hours), and the total storm event accumulation (TRAIN, in inches). In addition, the storm event hourly accumulations are printed out in inches.

The program is highly efficient, requiring less than 128 kilobytes of storage (IBM 360 system). Compile time is approximately 20 seconds, and in generation tests, 33 years of hourly precipitation were generated in less than 30 seconds. Generation of any length can be accomplished by initializing NBYR with the first year to be generated and assigning to LYR the last year to be generated.

IV. ANALYSIS OF RESULTS

Testing Methodology

The stochastic precipitation model just developed makes use of a data decomposition process which divides the historical precipitation time series into storm events, and in turn, into storm segments. The various random variables defined to fully specify the location in time and the intensity of storm segments represent what is believed to be the essence of the historical time series of storm segments, and are represented by their distributions in the precipitation model. These random variables, in large part, are independent both serially and with respect to each other. To test this, a considerable amount of correlation tests were previously conducted with only DURSS and ACCUM displaying a significant dependence in cross-correlation. An important additional test of the independence assumptions can be conducted using the final model generated output.

The testing methodology proposed is to generate a data set of sufficient length to provide adequate sample sizes, and to test the important statistical aspects of the resulting <u>storm events</u> against those in the historical data set. Therefore, storm events will be tested instead of storm segments. This approach provides the best tests of the precipitation model since storm events are modeled in component form (i.e., storm segments). As a result, the storm segments, and their relationship to each other, must be precisely modeled to permit their proper assembly into storm events. Any undetected dependence in the random variables will almost certainly result in a lack of statistical agreement in the distributions of the historical and generated storm event durations and accumulations. A separate test of storm segment hyetograph shape (modeled by PKHR and the shape catalog) is not proposed since representative historical shapes are used directly in the model, with the primary purpose of providing a natural variety in the detailed precipitation structure.

The tests are conducted in two stages. A series of simple tests are conducted first to determine if the model is reproducing the basic aspects of the precipitation process. These aspects are:

(1) Number of storm events generated in each period of the year

(2) Storm event duration comparison

    a. Comparison of cumulative distributions

    b. Comparison of means and standard deviations

(3) Storm event accumulation comparison

    a. Comparison of cumulative distributions

    b. Comparison of means and standard deviations

The second stage of testing is stronger, and involves testing the depth versus duration relationship of storm events. Two comparisons are made which, in conjunction with the simple tests above, provide the necessary information on the applicability of the model. These are:

(1) Storm event cumulative depth-duration comparison

(2) Storm event depth-duration comparison for different frequency levels.

Data Generation Test Results

The above testing methodology was implemented by first generating a sample data set of 33 years length. A generated length equal to the historical record is advantageous since the sample sizes can be directly compared. In addition, based on experience with the historical record, a 33 year record length is entirely adequate in terms of sample size. The generated data were first separated into storm events using the procedure developed earlier for the historical data (including the same cutoff levels). The number of storm events occurring in each period of the year were compared to their historical counterparts and the results presented in Table 15. The close agreement in this simple statistic is very significant, since it implies that the variables IATSE, IATSS, NSSSE, and DURSS are being modeled properly. These variables, it will be recalled, entirely specify the time occurrence of precipitation and were assumed to be serially and mutually independent within each period of the year. IATSE controls the time between storm events, and IATSS, NSSSE, and DURSS directly determine the length of storm events. The primary variable determining the number of storm event occurrences is IATSE, with the remaining variables contributing to a lesser degree.

Storm Event Duration Comparison

The storm event duration distributions were computed for both the generated and historical data, and overplotted for direct comparison. These distribution comparisons are included in Appendix F as Figures F.1 through F.6. The distributions are virtually identical in each of the six periods of the year even though the historical distributions are significantly

Table 15. Comparison of the Number of Storm Events in 33 Years of Continuous Record, Historical Versus Generated

Period	Number of Storm Events		Absolute Deviation of Generated from Historical	% Deviation of Generated from Historical
	Historical Record	Generated Record		
Jan-Feb	306	292	-14	-4.6
Mar-Apr	428	404	-24	-5.6
May-Jun	607	597	-10	-1.6
Jul-Aug	491	480	-11	-2.2
Sep-Oct	370	376	6	1.6
Nov-Dec	318	299	-19	-5.9

Table 16. Results of Two-Sample Kolmogorov-Smirnov Tests (Historical Versus Generated Duration, Depth, and Depth-Duration Distributions)

Period	Duration		Depth		Depth-Duration	
	K-S Statistic	K-S 95% Conf. Lmt.	K-S Statistic	K-S 95% Conf. Lmt.	K-S Statistic	K-S 95% Conf. Lmt.
Jan-Feb	0.062	0.248	0.090	0.248	0.092	0.215
Mar-Apr	0.040	0.248	0.037	0.248	0.105	0.215
May-Jun	0.035	0.248	0.050	0.248	0.065	0.215
Jul-Aug	0.050	0.248	0.060	0.248	0.100	0.215
Sep-Oct	0.063	0.248	0.060	0.248	0.085	0.215
Nov-Dec	0.068	0.248	0.093	0.248	0.065	0.215

different between periods. A plot comparing two periods is included as Figure 18. The difference between the two sample cumulative distributions was tested using the Kolmogorov-Smirnov test [Lindgren and McElrath (1969), page 277]. These results, presented in Table 16, show no significant difference between the two.

The mean and standard deviation of the storm event durations were also computed for comparison in each period of the year. These values are listed in Table 17, and show very close agreement. It will be noted that the means differ by less than one hour for all periods of the year. A test of the equality of the means was conducted by using the normal approximation to the distribution of the means [Hogg and Craig (1970)]. These results are also listed in Table 17, and show no significant differences.

The results of the above tests, coupled with the aforementioned agreement in the number of storm event occurrences, lends support to the assumptions of independence in the time occurrence random variables IATSE, IATSS, NSSSE, and DURSS, and to the correctness of their representation.

Storm Event Accumulation Comparison

Next, the storm event accumulation distributions were computed for both the generated and historical data, and overplotted for direct comparison. These distribution comparisons are included in Appendix F as Figures F.7 through F.12. A plot comparing two periods is included as Figure 19. The results show very little difference between the distributions in each period of the year. The difference between the distributions was tested using the Kolmogorov-Smirnov test. These results, included in

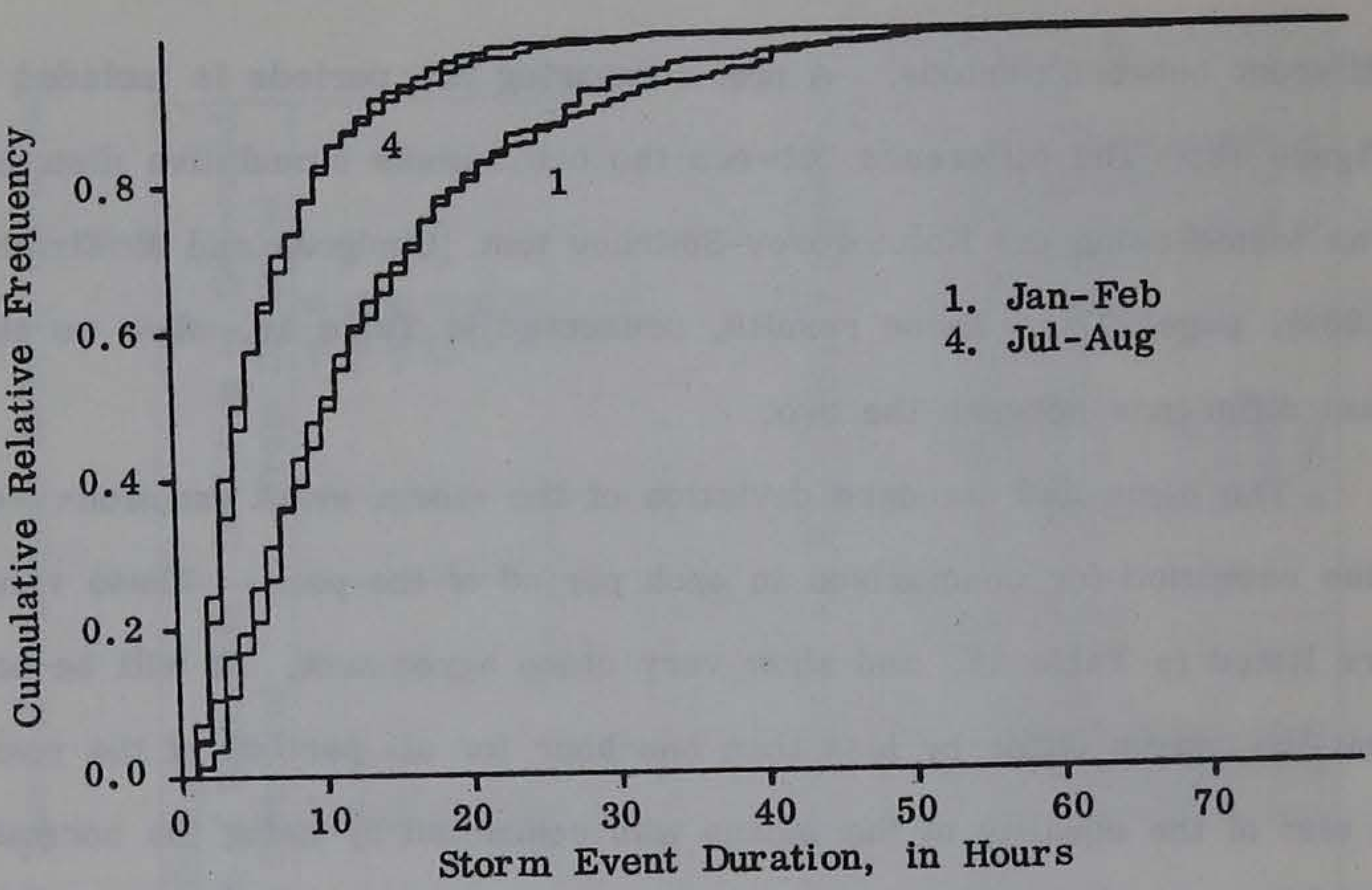


Figure 18. Historical and Generated Storm Event Duration Distributions, Comparison of Periods 1 and 4

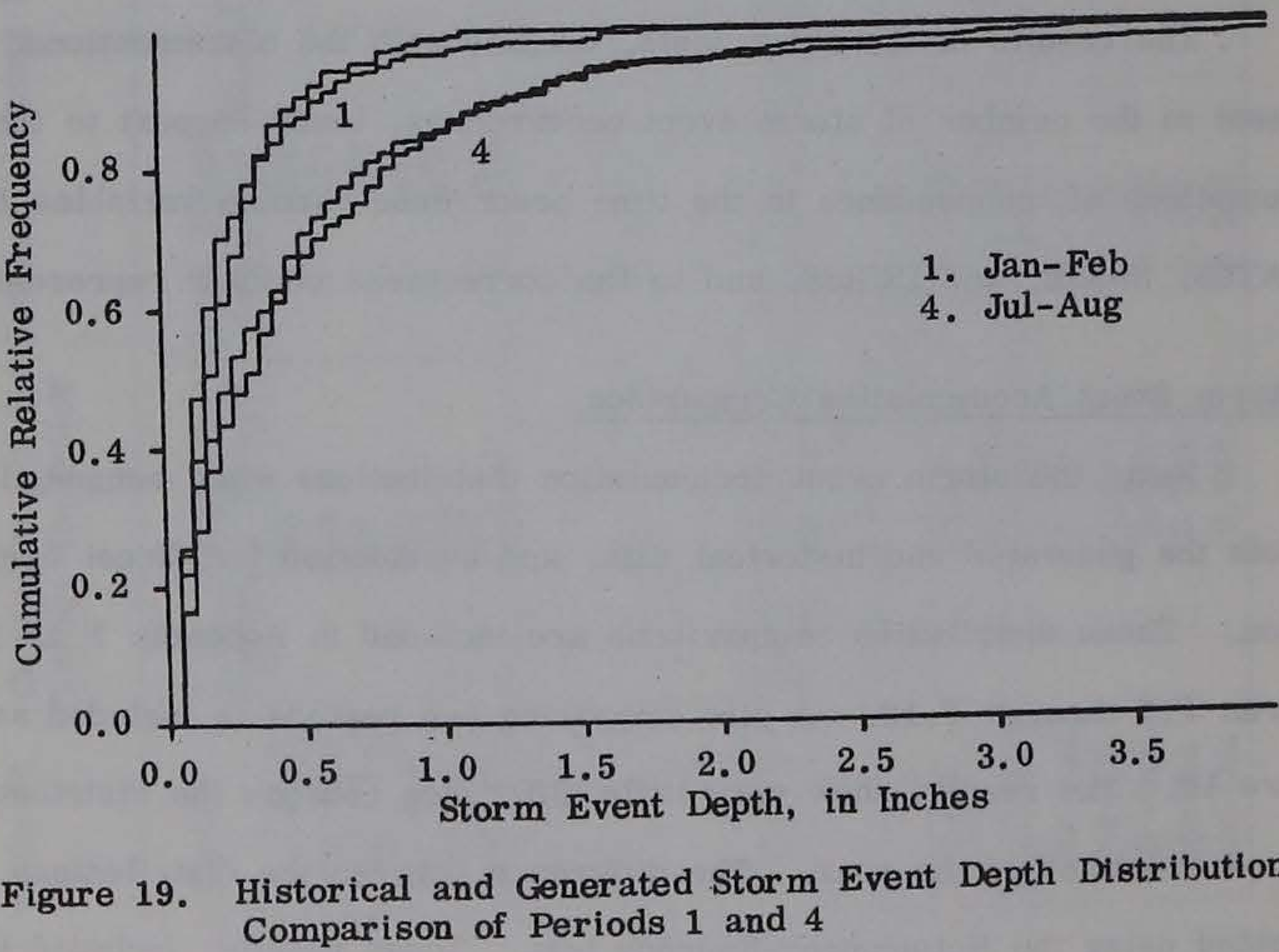


Figure 19. Historical and Generated Storm Event Depth Distributions, Comparison of Periods 1 and 4

Table 17. Comparison of Means and Standard Deviations of Storm Event Durations, Historical Versus Generated

Period	Historical Data, 33 Years		Generated Data, 33 Years		Deviation of Generated Mean from Historical	Test of Equality of the Means	
	Mean, in Hours	Std. Dev., in Hours	Mean, in Hours	Std. Dev., in Hours		Test Statistic	80% Conf. Interval
Jan-Feb	13.08	10.22	13.31	10.88	0.23	0.650	0.100-0.900
Mar-Apr	15.77	14.09	16.62	15.50	0.85	0.887	0.100-0.900
May-Jun	8.87	8.00	8.77	8.45	-0.10	0.380	0.100-0.900
Jul-Aug	6.80	6.00	6.46	5.64	-0.34	0.107	0.100-0.900
Sep-Oct	12.11	13.34	12.31	14.59	0.20	0.614	0.100-0.900
Nov-Dec	14.64	11.72	15.47	12.21	0.83	0.890	0.100-0.900

Table 18. Comparison of Means and Standard Deviations of Storm Event Accumulations, Historical Versus Generated

Period	Historical Data, 33 Years		Generated Data, 33 Years		Deviation of Generated Mean from Historical	Test of Equality of the Means	
	Mean, in Inches	Std. Dev., in Inches	Mean, in Inches	Std. Dev., in Inches		Test Statistic	75% Conf. Interval
Jan-Feb	0.221	0.307	0.211	0.226	-0.010	0.288	0.125-0.875
Mar-Apr	0.426	0.490	0.453	0.563	0.027	0.866	0.125-0.875
May-Jun	0.461	0.567	0.473	0.683	0.012	0.697	0.125-0.875
Jul-Aug	0.498	0.661	0.507	0.837	0.009	0.617	0.125-0.875
Sep-Oct	0.530	0.744	0.566	0.854	0.036	0.826	0.125-0.875
Nov-Dec	0.339	0.489	0.320	0.337	-0.019	0.250	0.125-0.875

Table 16, show no significant difference. The mean and standard deviation of the storm event accumulations were computed for comparison in each period of the year. These values are listed in Table 18, and show very close agreement. A test of the equality of the means was conducted by again using the normal approximation for the distribution of the means. These results are included in Table 18, again showing no significant differences.

The results of these tests and comparisons tend to support the contention that ACCUM is solely dependent on DURSS. Any significant undiscovered dependence of ACCUM on the other time occurrence variables would have likely caused greater differences between the historical and generated distributions. In addition, an implicit requirement of the lack of difference in the distributions is the proper modeling of the time occurrence random variables.

Storm Event Cumulative Depth-Duration Comparison

The storm event depth-duration distributions were computed and plotted for comparison, and are included in Appendix F as Figures F.13 through F.18. A representative plot, comparing two periods of the year, is included as Figure 20. Agreement in these distributions requires that storm events of a given length contribute the same portion of the total 33 year depth. The difference between the two sample distributions was tested using the Kolmogorov-Smirnov test. These results, which are included in Table 16, show no significant difference between the historical and generated distributions. Considering the severity of the test, agreement between the distributions is quite remarkable. The small differences that do occur

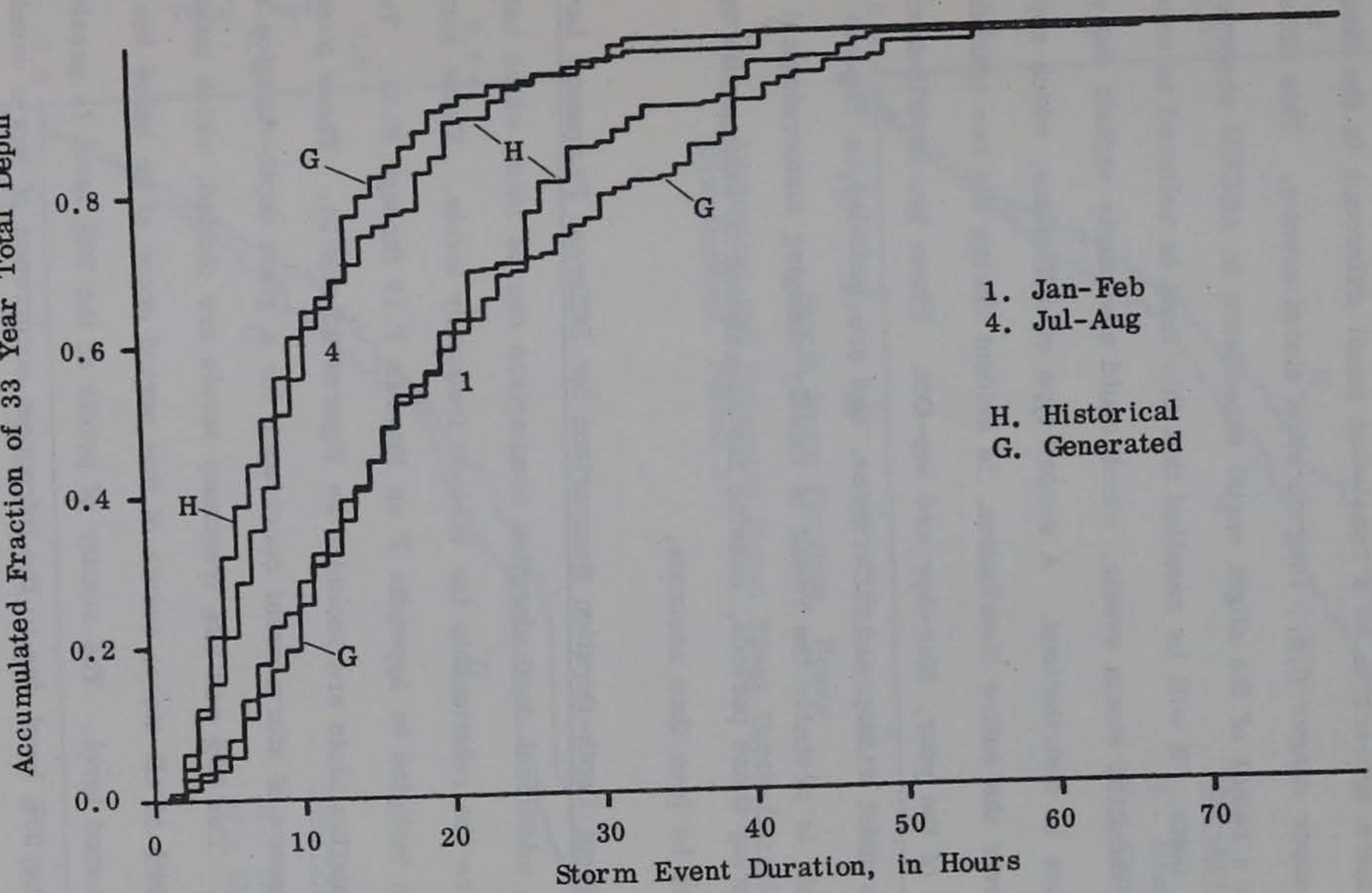


Figure 20. Historical and Generated Storm Event Depth-Duration Distributions, Comparison of Periods 1 and 4

perhaps can be explained in terms of model deficiencies. Throughout the year, there appears to be a consistent small difference in the distributions in the upper ranges (i.e., long duration storm events). This difference may be a result of the slight serial dependence in ACCUM observed in earlier tests. It will be recalled that this trait is believed to occur only in long duration storm events, which could adequately explain the observed difference in distributions. A second type of difference, which appears to occur over the entire distribution, is evident during the two transition periods of the year, Mar-Apr and Sep-Oct. These two distributions display the most widespread differences, and are included as Figures 21 and 22. This is probably the result of rapidly changing meteorological conditions during these periods, causing the assumption of stationarity in each period to be less than accurate.

Storm Event Depth-Duration Comparison for Different Frequency Levels

An additional depth-duration comparison can be made which better illustrates the relationship for various frequency levels. These comparisons are included in Appendix F as Figures F.19 through F.24. Two representative plots are included as Figures 23 and 24. These plots show the frequency of storm event occurrence for a given depth-duration relationship. The 90% and 99% frequency levels are plotted, which means that 90% or 99% of all storm events of that period occur at or below the appropriate plotted level. The scatter of points at the 99% level is greater than that at the 90% level due to the infrequent occurrence of storm events above the 99% level. The extent of agreement between the historical and generated data appears to be excellent. The small variation within a

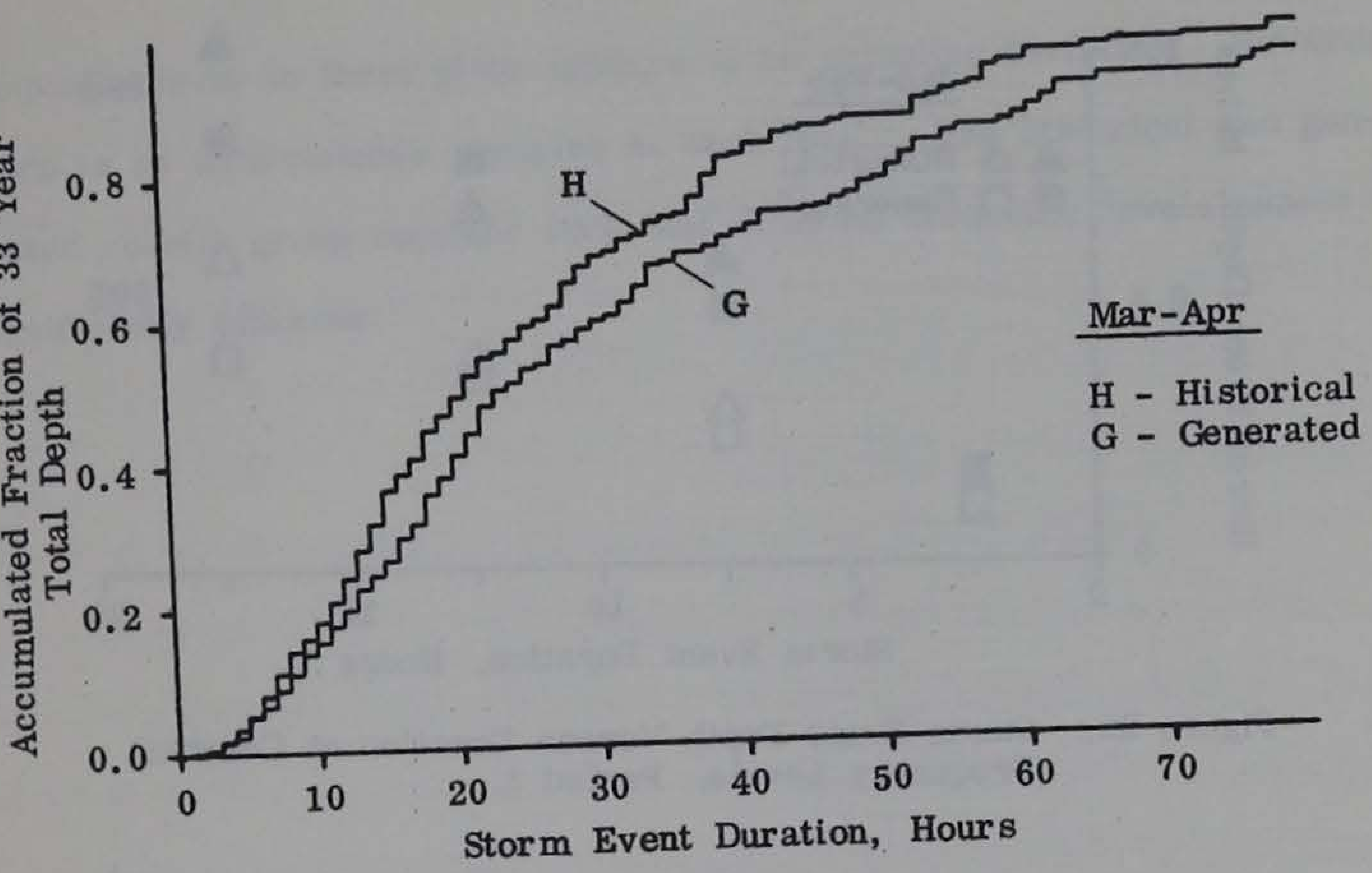


Figure 21. Historical and Generated Storm Event Depth-Duration Distributions, Period 2

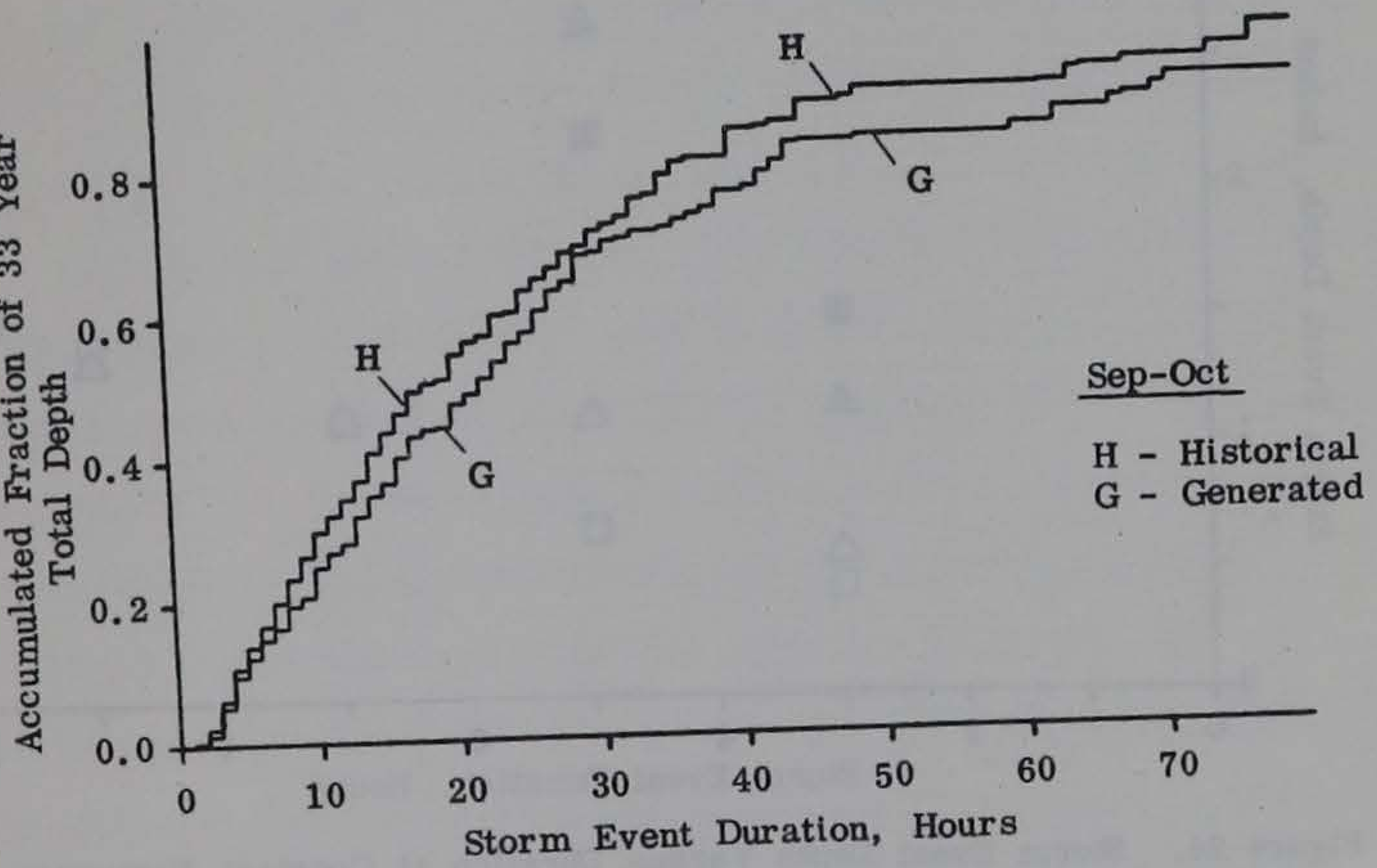


Figure 22. Historical and Generated Storm Event Depth-Duration Distributions, Period 5

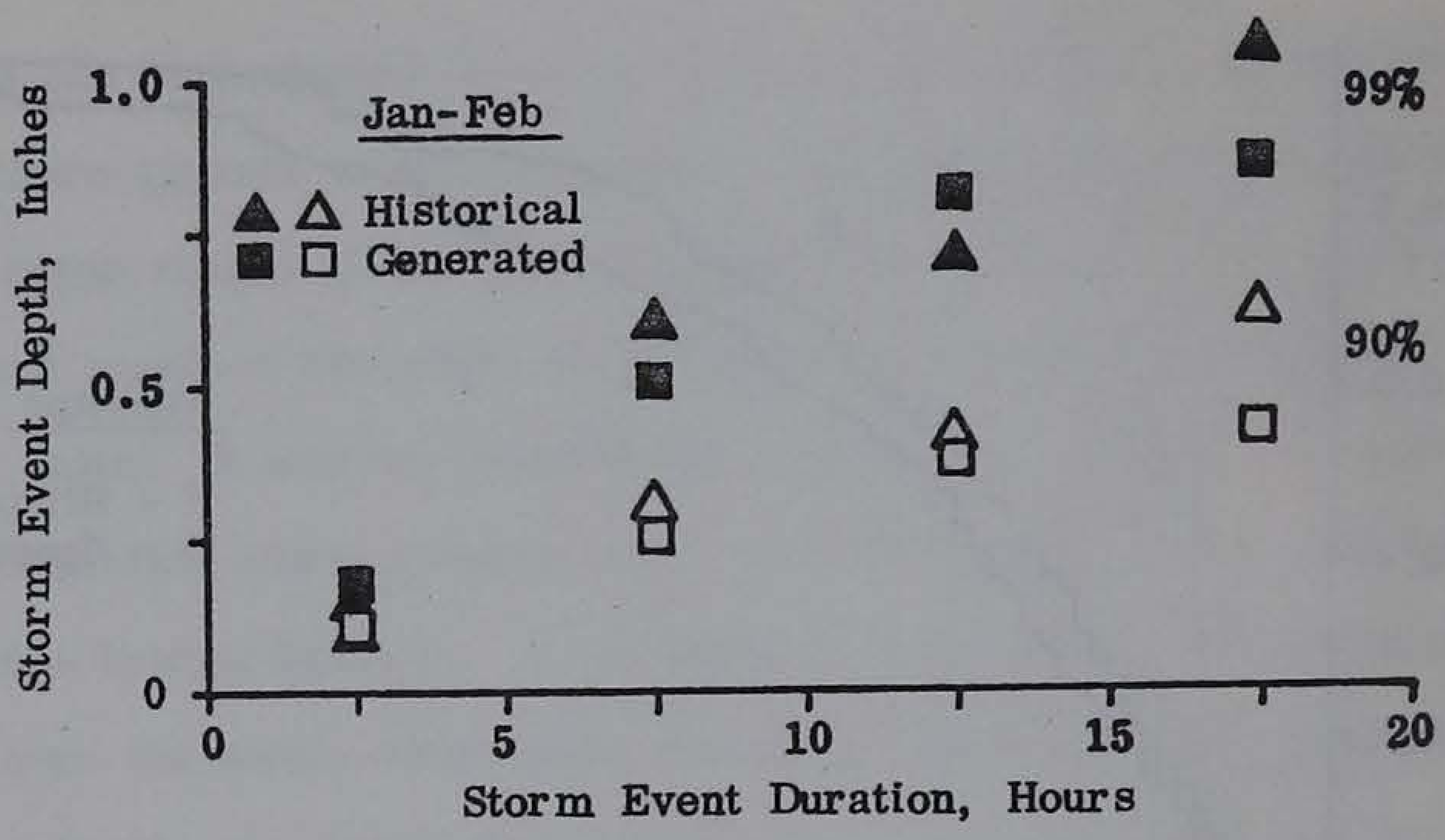


Figure 23. Storm Event Depth Versus Duration at Constant Frequency Levels, Period 1

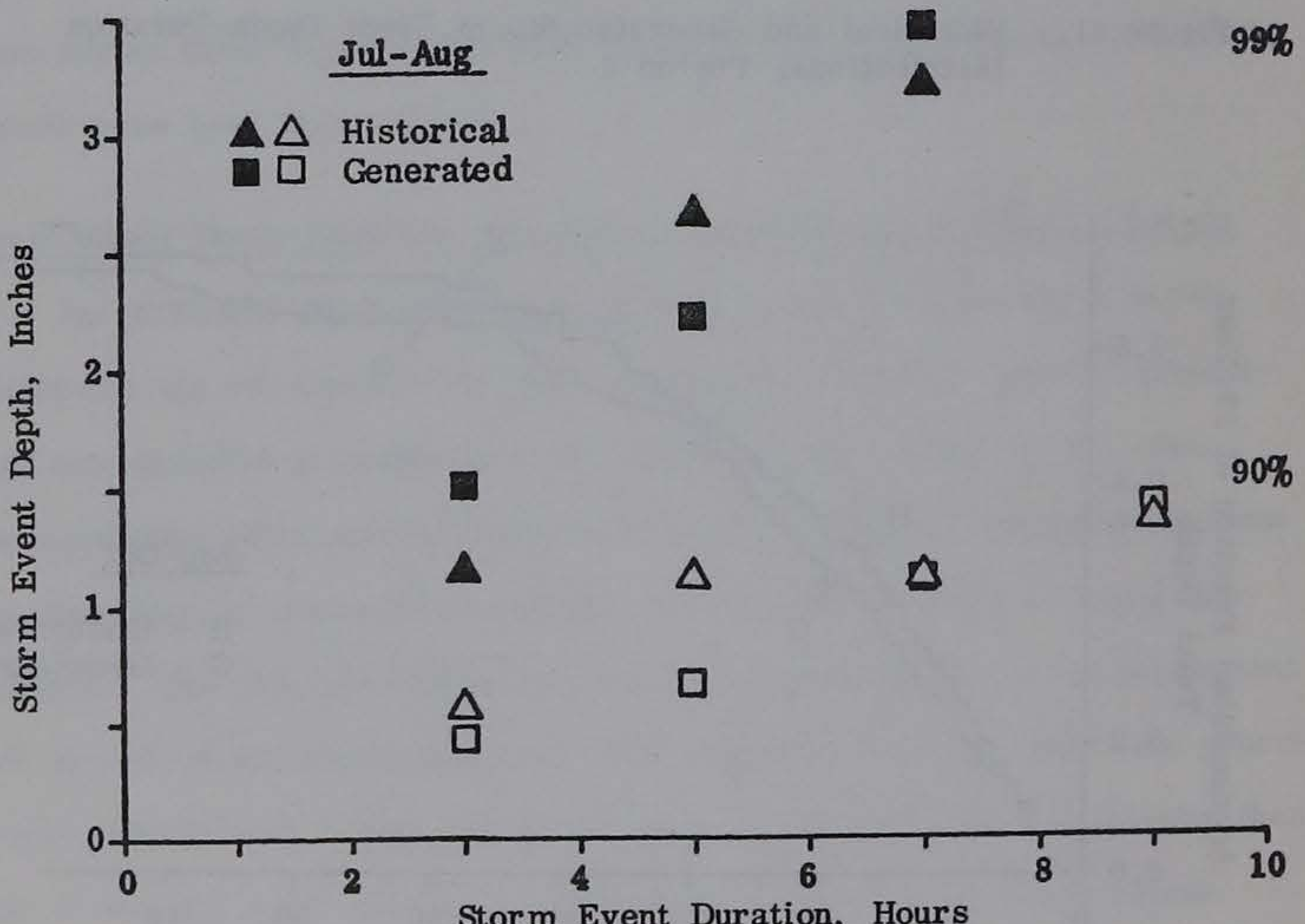


Figure 24. Storm Event Depth Versus Duration at Constant Frequency Levels, Period 4

frequency level in these plots appears to be sampling variation. However, there is an unmistakable grouping at each level. The historical and generated results group together such that different frequency levels appear significantly different.

V. CONCLUSIONS

Attainment of Objectives

Attainment of Primary Objective

The stochastic precipitation model just developed is primarily intended for use in the Ralston Creek flood hazard study. This primary purpose resulted in specific steps being taken in the model development to emphasize the model's ability to represent those periods of the year and types of storm events believed to be most important from a flooding viewpoint. Storm events emphasized are those that occur primarily during periods 3 and 4, corresponding to the summer season. Critical storm events are known to be those that contain severe thunderstorm cells which yield a short duration and high intensity rainfall. Emphasis of this type results in an indirect benefit that contributes to the primary objective. This benefit is the increased efficiency and simplicity resulting from the lack of need to generate extreme values of those model random variables (IATSS, NSSSE, and DURSS) specifying the time occurrence and persistence of precipitation within storm events. Only extreme values of ACCUM are neccessary to adequately model the storm events of interest. This is not to say that other periods of the year, and long storm events, are not adequately modeled. On the contrary, the extremely long historical record provides excellent sample distributions from which to generate values of IATSS, NSSSE, and DURSS during all periods of the year.

Representation of Extreme Events.-- Based on the success of the method of storm segments in the model development, and the depth-duration comparisons and tests in the results, the model should find successful application in the Ralston Creek study. The depth-duration comparisons indicate an accurate reproduction of the frequency of occurrence of storm events of a like depth-duration relationship. This agreement can only be observed for storm events of record where sample sizes are adequate. There is no way that an extrapolation of these conclusions can be made for extreme events of rare occurrence in the historical record, or for those yet to be observed. Comments can only be made in terms of levels of confidence, a subjective conclusion based on all the observations and results. The model has no knowledge beyond the historical record, but relies on statistical trends in the historical data to produce extreme events during data generation. There is an acceptable level of confidence that the model can produce extreme events that are representative of those that might occur.

Efficiency in Data Generation.-- Of equal importance is the efficiency of the model in data generation. Without a high level of efficiency in the digital computer application of the model, long term data generation cannot be adequately accomplished, and therefore, extreme storm events cannot be effectively analyzed. The precipitation model developed herein for digital computer application was tested under conditions representative of those it should encounter in application. The data generation efficiency seems to be adequate for any foreseeable use.

Attainment of Secondary Objective

Model Applicability at Other Locations.-- Stochastic precipitation modeling by the method of storm segments is a unique approach that holds considerable promise in other applications. The promise of success elsewhere rides with the independence of storm segments and the associated time occurrence random variables IATSS, NSSSE, and DURSS. The independence of storm events has already received some measure of acceptance elsewhere. The physical arguments supporting the independence of storm segments would seem to be applicable to most areas if the size and speed of storm cells are of the same order of magnitude as those experienced in the immediate vicinity of Ralston Creek. Squall lines (lines of thunderstorms) are one of the most ordered precipitation producing meteorological patterns, providing a good test of storm segment independence. An argument has already been made that this highly ordered structure produces a seemingly random pattern in the hourly precipitation accumulations recorded at a fixed point on the surface, resulting in the independence of storm segments. If this highly ordered structure results in independent storm segments at Ralston Creek, then there is reason to believe that independent storm segments will be encountered at other locations. If this is the case in future studies, then the method of storm segments can be applied in much the same manner as done herein.

Other applications will likely involve areas where the historical data set is of insufficient length to produce adequate sample distributions for use directly in data generation. In these cases, distribution fits may be required. This will create no problem in applying the storm segment method, and may even be desirable in order to generate extreme values of interest.

There are no inherent limitations to the use of the precipitation model in other locations, beyond those already discussed. Assuming a point precipitation model is required, and the time increment chosen is compatible with the meteorological conditions (producing independent storm segments), then the model should find a useful application. The fact that it is a point precipitation model will limit its use to watersheds of a few square miles or less. The maximum watershed size will be dependent on the local meteorological conditions. If these conditions are such that the precipitation is predominately widespread and uniform, then the maximum watershed size could be increased. If rainfall tends to be highly localized, such as that produced by thunderstorm events, then the watershed size would have to be limited in size such as the Ralston Creek watershed.

The time increment chosen must also be compatible with the watershed size. The time increment must be small enough to prevent excessive smoothing of the outflow hydrograph. Gentle topography and land use are not of direct concern with the exception of their influence on the time of concentration and rapidity of response of the watershed to precipitation inputs.

Localized influences on the precipitation process, such as those produced by mountainous terrain or urbanization, should not prevent use of the model as long as the data set used can be assumed to be stationary. Locations effected by tropical storms will probably require a separate model for those events due to their infrequent occurrence and unusual characteristics. Arid regions will pose special problems in scheduling the occurrence of storm events due to the strong persistence of dry periods. However, the method of storm segments still should be applicable assuming that the time occurrence of storm events can be specified by the appropriate model.

Model Applicability Using Other Time Increments.-- The success of the precipitation model developed herein is based on the definition of storm segments and their independence in relation to one another. It is possible that a radically different observation interval (i.e., different time increments) will upset this independence between storm segments by altering the mean number of storm cells observed per unit interval during wet periods. Therefore, to use a different time increment would require that the correlation studies be repeated for each of the model random variables to re-establish the independence of storm segments.

Model Deficiencies

No aspect of the precipitation model was judged deficient for the purpose for which it was developed. However, several areas could be considered deficient if other purposes (i.e., other than the Ralston Creek flooding hazard study) become important. If winter precipitation events, or those events which contain a large number of storm segments (long duration), become more important, then some consideration will have to be given to the slight serial dependence found in ACCUM for those cases. Based on test results during the two transition periods (Mar-Apr and Sep-Oct), the two-month equal length divisions of the year may be less than ideal for the modeling of seasonal non-stationarity. If a greater modeling accuracy in these two periods becomes desirable, a different system of division, perhaps using unequal lengths, may be appropriate. Other areas of potential deficiency will probably arise as new uses of the model are proposed. It is obviously impossible to develop a practical model suitable for every conceivable use. Therefore, any new uses proposed will require a detailed study to determine if model modifications are needed.

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APPENDIX A

DATA ACQUISITION AND PREPARATION

Ralston Creek Watershed

The watershed of the north branch of Ralston Creek is adjacent to Iowa City on the east and lies north of Rochester road between Iowa City and West Branch. It is roughly three and one-half miles long in an easterly and westerly direction and seven-eights of a mile wide (see Figure A.1). The main stream flows in a westerly direction to a streamflow gaging station which is located near the southwest corner of the watershed. The main stream has a total length of about four miles in which the total fall is 140 ft.

The westerly portion of the watershed may be described as strongly rolling to rough, and the easterly portion is gently rolling. The average slope of the ground surface is approximately 500 ft per mile. According to the soil survey of Johnson County, Iowa, the soil of the watershed is Clinton silt loam which is derived by weathering from loess. Approximately 40 percent of the area is under cultivation, 40 percent is in pasture, and 20 percent is in timber, brush, and orchard. A very small portion is urbanized, but this is expected to increase dramatically in the coming years. The pattern of cultivation has not varied seriously during the period of record. A high percentage of the pasture and woodland has contributed to a fairly constant land use due to the rough topography along the southern part of the watershed. In fact, the variation in typical crops has proved so small that only infrequent field surveys have been required. Both the topography and the cover have remained remarkably constant for a third of a century. The likelihood of substantial urbanization in the near future indicates the end of this situation, though only the rougher portion

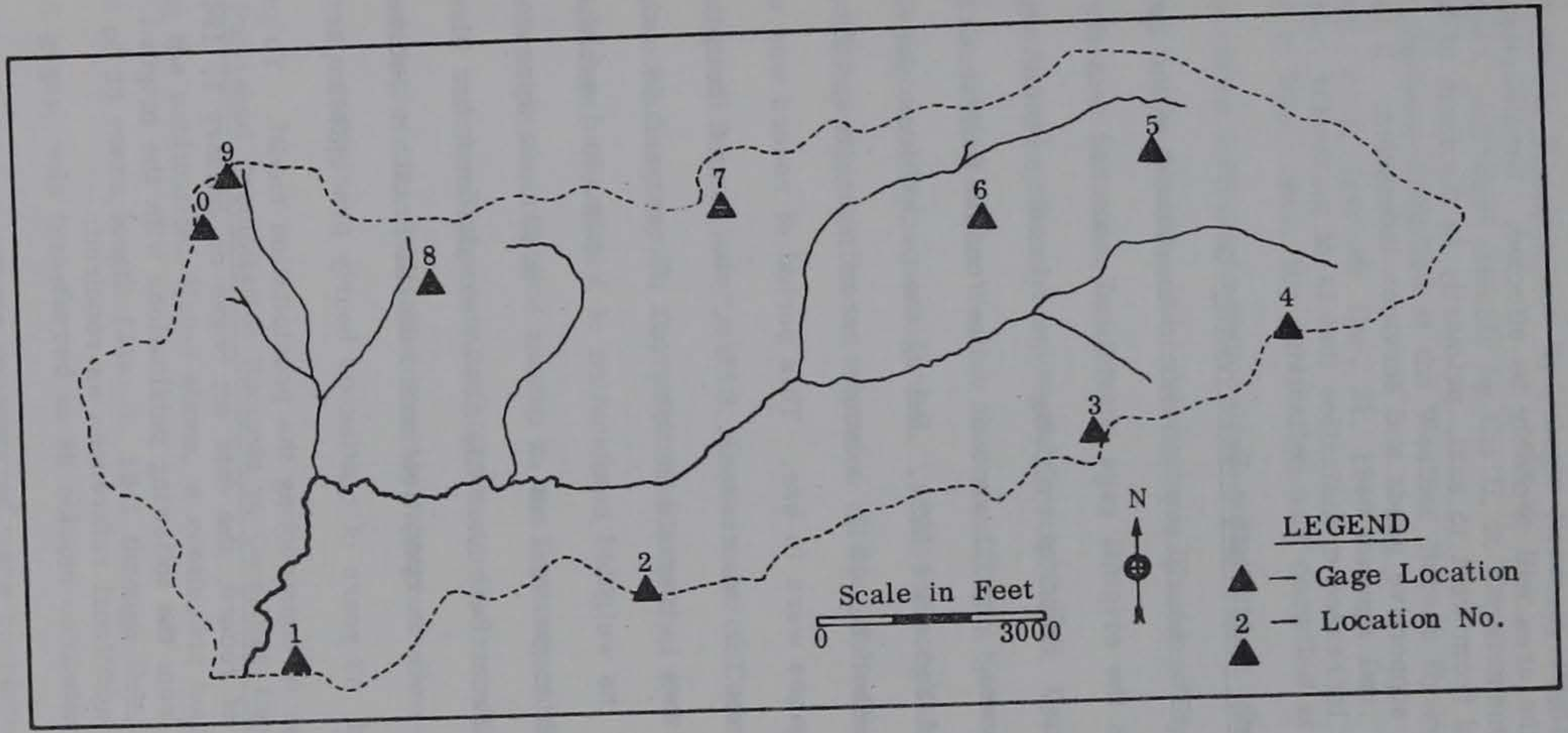

Figure A.1. Ralston Creek North Branch Watershed Precipitation Gage Locations of the area will probably be effected. Urbanization is expected to proceed from west to east, primarily in the form of housing developments and supportive goods and services industries. It is this promise of rapidly increased urbanization that is of particular interest.

Hourly Precipitation Data Sources

The hourly precipitation data utilized in the model were obtained from the original gage charts and published data derived from these charts. Standard weighing-type recording precipitation gages and nonrecording gages have been in use on the Ralston Creek North Branch watershed since 1924. During the period from June 8, 1924 through December 20, 1940, a single recording gage and from 5 to 7 nonrecording gages were in use. This period of record was not included in the data set for two reasons. First, the record from the single recording gage was incomplete in numerous places, and second, later records require the weighted combination of 5 gages and would therefore result in a nonhomogeneous set of data if both periods were combined.

From December 21, 1940 through December 31, 1973, 5 recording gages were in operation on the North Branch watershed. From this period, 33 years of continuous hourly precipitation record was assembled for use in constructing the precipitation model. To provide an even 33 years of record, the data set began on January 1, 1941. The data were taken from the following publications with the original gage charts providing additional references as required:

(1) "Daily and Hourly Precipitation Hydrologic Network, Region 4: Upper Mississippi", published monthly by the U. S. Department of Agriculture Weather Bureau, compiled at the Weather Bureau Hydrologic Office, Iowa City, Iowa, (period: Dec. 21, 1940 through Dec. 31, 1945). Note: Beginning in May, 1941, the publication was compiled at the Weather Bureau Office Hydrologic Unit, Kansas City, Mo. Also, the above publication is the forerunner of the next publication, "Hydrologic Bulletin", compiled at the same location.

(2) "Hydrologic Bulletin, Hourly and Daily Precipitation, Upper Mississippi District", compiled at the Weather Bureau Office, Kansas City, Missouri, published monthly, (period: Jan. 1, 1946 through Jul. 31, 1948). Note: This publication is an extension of the publication immediately above.

(3) "Climatological Data - Iowa", U. S. Department of Commerce, Weather Bureau, Washington, D. C., published monthly, (period: Aug. 1, 1948 through Sept. 30, 1951).

(4) "Hourly Precipitation Data - Iowa", U. S. Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Data Service, Asheville, N. C., published monthly, (period: Oct. 1, 1951 through Dec. 31, 1973).

Transfer of Published Precipitation Records to Computer Card Format

Utilizing the publications listed above, a continuous hourly precipitation record of 33 years length (Jan. 1, 1941 through Dec. 31, 1973), for each of 5 gages, was transferred to 80 column computer card coding forms. At this time, any errors encountered were corrected. Next, standard 80 column length computer cards were punched from these forms, with the data exhibiting the following characteristics:

(1) The entire data set, 33 years in length, consisted of hourly precipitation records resulting from 5 weighing-bucket recording gages, all within the Ralston Creek North Branch watershed.

(2) Throughout the 33 year history, four different location configurations resulted due to changes in gage location. In order to pinpoint the different locations in time, a coding system was devised consisting of the 10 single integer digits, 1, 2, ...9, 0. These numbers denote the 10 gage locations occurring since the first installation in 1924. The corresponding map locations for the 10 map codes are shown on Figure A.1. Column 80 on the computer cards was set aside for the map location code.

(3) Five cards, one for each recording gage, were required for each wet-day record. A wet-day was defined as at least one hour of nonzero rainfall on one or more of the five gages in one calendar day. Each card lists the date and gage number in columns 73 through 79; columns 73-74 for the day, 75-76 for the month, and 77-78 for the year. Column 79 was reserved for the gage number, always 1 through 5. By referring to Table A.1, and Figure A.1, the gage locations can be determined at any given time within the 33 year period.

(4) The hourly precipitation record was recorded in columns 1 through 72, allowing 3 columns per hour, beginning with the 12 midnight to 1 a.m. hour in columns 1 through 3. The data was recorded in inches, as published, and in integer form permitting the recording of a maximum

of 8.87 inches as 887 in the 3 column width allowed. The value 999, as well as 888, was set aside for signaling purposes as explained below.

(5) Throughout the historical record, numerous cases of missing or "bad" data were encountered, necessitating some form of coding to signal the location of this problem. The number 999 was chosen to denote: "nonzero precipitation exsists, but is unknown for this hour". Therefore, if one or more of the five gages was not operating during a given storm period, a string of 9's would be substituted during the hours rainfall was known, or thought to have occurred. The number 888 was set aside for those few cases where the record of a complete day was missing and absolutely no information was available to estimate the intensity or distribution of the precipitation. In this case three 8's were entered at the beginning and end of the day's record, with the rest remaining blank.

(6) Often the total precipitation accumulation of a storm was known, but its distribution was not known. In this case the total precipitation accumulation was entered, preceded immediately by one or more hours of code 999. Total storm accumulations were not carried over from one day to the next, thus necessitating the splitting of the total precipitation accumulation for a storm occurring on two or more calendar days. Therefore, within a given day the total storm accumulation was placed in the final hour of the storm, or weighted and split between two consecutive days with the total accumulation for the first day placed in the last hour of the day and the remaining portion at the end of the storm on the following day. This allowed (by machine computation) the distribution of the rainfall accumulation over all 999 coded hours, including the hour

containing the total amount. The distribution of the total accumulation takes place over all preceding 999 coded hours within that day until a nonzero hour or the first hour of the day is reached. Therefore, the distribution could also take place over slack, zero rainfall periods within the storm without the necessity of using the 999 code. The most important requirement is that the hour immediately preceding the total must be a 999 hour, zero not being allowed since the total accumulation would then be incorrectly interpreted as a one hour accumulation.

(7) Unlike the 999 code, the 888 code was not considered a program code requiring special computations. This code was used only as a signal that data was completely missing. That is, all five gages were not operating.

Treatment of Incorrect or Missing Data

As already mentioned, incorrect or missing data was encountered during the transfer of published data to computer card form. This necessitated the coding process already explained. These lapses in data were handled as follows:

(1) In the process of copying the data onto the coding forms, any obvious faults in the data, or short lapses, were corrected or filled by eye where easy to do so without chance of significant error. Therefore, some cases of missing data calling for the 999 code were filled immediately by estimate, based on data from the remaining gages in operation. The magnitude of the missing data problem was significant as all gages at one time or another experienced varying degrees of malfunction. Fortunately, except for a small handful of cases requiring the 888 code,

there was always at least one gage operating within the watershed allowing a reasonably accurate data-fill.

(2) The 888 code cases were eliminated by using nearby precipitation gages. In all cases the "Morse" and "Oasis" gages located a few miles from the watershed provided sufficient data to complete the record. The precipitation characteristics were estimated by observing the intensity and time distribution of the precipitation at these two gages.

(3) Following the manual transfer of data to the coding forms, the data was punched onto computer cards as already described. After the cards were punched, they were verified using a standard card verifying machine.

(4) Following card verification, a short computer program was used to check for coding and punching errors. The resulting output, including the precipitation list, was scanned and corrections made. All runs, including recorded corrections on the output sheets, were saved for future reference.

Missing Data Fill and Gage Combination Procedures

In order to facilitate the processing and eventual combining of the corrected raw data resulting from the above steps, a computer program was constructed to first fill in all missing data based on exsisting data:

(1) The first function of the computer program was to fill in missing data as denoted by the 999 code. The program was designed to read into storage one day's data and operate in hourly time increments to fill in the missing data. Thus, the fill-in process progressed hour by hour and each missing hour of data was estimated based on the data from the remaining gages in operation. Due to the close proximity of the gages

(see Figure A.1), any of several weighing schemes could be used to fill in any given missing hour with essentially the same results. On occasion, storms occurred which hit only one area of the watershed. Therefore, a weighing scheme that would give heavy weight to operating gages in closest proximity was chosen to give good fill-in properties for "off-center" storm occurrences. The weighing factor chosen was one which varied depending on the inverse square of the distance between the inoperative gage and each of the remaining gages in operation. For off-center storms, this gives a high weight to the closest gage. For relatively uniform storms, the weighing scheme gives comparable results to any linear scheme. Here we let X_{ij} be the distance between the inoperative gage, i, and any other operating gage, j. And if D_j is the precipitation hourly accumulation of an operating gage, and D_i is the precipitation accumulation of the gage to be filled, then the weighing equation can be written as follows:

$$D_i = \frac{1}{F_i} \sum_j \frac{1}{X_{ij}^2} D_j \quad , \qquad i \neq j = 1, 2, 3, 4, 5 \qquad \text{A.1.}$$

where

$$F_i = \sum_j \frac{1}{X_{ij}^2}$$

(2) If a total storm precipitation accumulation is encountered following the last 999 code within the storm period, then an additional routine is called to distribute this amount over the preceding 999 coded hours including the hour on which the total is listed. But before this step is completed, the fill-in routine above is performed. Thus, the fill-in step gives the desired rainfall distribution, but not necessarily the

desired total storm accumulation. In order to determine the hourly accumulations, the total accumulation is distributed over the same hours filled in previously, without disturbing the relative intensity of one hour as compared to another within the same storm event.

(3) In order to complete the data fill-in procedure, the linear distance between gages is required for use in the weighing equation, A.1. These are supplied as linear distance matrices which are symetrical matrices relating the map distance in inches between each of the gages as read from a large watershed map. Four different matrices are required, one for each of the four gage location configurations listed in Table A.1. These four matrices are included as Table A.2.

(4) After all missing data was filled, the resulting complete 33 year data record from each of the five gages was combined into a single record using the standard Thiessen method. The Thiessen weights for the different gage configurations encountered over the 33 year period are presented in Table A.1.

(5) The final single record output was presented in printout form and recorded on magnetic tape. The final hourly accumulations were computed to 3 decimal places. Although the original data was to 2 decimal places, the filling and combining process required the introduction of 3 decimal places to avoid rainfall loss due to round-off.

Final Data Presentation

In planning future statistical studies of the historical record, it was determined that it would be more desirable to have a complete 33 calendar year data record, including all the dry days. Therefore, the

Table A.1. Gage Location Numbers and Thiessen Weights

Gage No.	Location No.*	Thiessen Weight	Effective Date
1	2	0.211	12/21/40
2	4	0.259	
3	7	0.216	
4	8	0.213	
5	9	0.101	
1	2	0.230	7/7/45
2	4	0.142	
3	6	0.279	
4	8	0.248	
5	9	0.101	
1	2	0.222	7/1/59
2	4	0.138	
3	6	0.285	
4	8	0.212	
5	0	0.143	
1	2	0.213	7/1/64
2	3	0.160	
3	6	0.272	
4	8	0.212	
5	0	0.143	

* see Figure A.1.

Table A.2. Rain Gage Linear Distance Matrix, in Map Inches

12/21/40 - 7/6/45

	j \ i	Inoperative Gage				
		1	2	3	4	5
Operative Gage	1	0	15.15	8.70	8.35	13.05
	2	15.15	0	12.70	18.75	23.55
	3	8.70	12.70	0	6.55	10.95
	4	8.35	18.75	6.55	0	5.15
	5	13.05	23.55	10.95	5.15	0

7/7/45 - 6/31/59

	j \ i	Inoperative Gage				
		1	2	3	4	5
Operative Gage	1	0	15.15	10.90	8.35	13.05
	2	15.15	0	7.40	18.75	23.55
	3	10.90	7.40	0	11.85	16.40
	4	8.35	18.75	11.85	0	5.15
	5	13.05	23.55	16.40	5.15	0

Table A.2 (cont'd)

7/1/59 - 6/31/64

	j \ i	Inoperative Gage				
		1	2	3	4	5
Operative Gage	1	0	15.15	10.90	8.35	12.75
	2	15.15	0	7.40	18.75	24.15
	3	10.90	7.40	0	11.85	17.10
	4	8.35	18.75	11.85	0	5.45
	5	12.75	24.15	17.10	5.45	0

7/1/64 - 12/31/73

	j \ i	Inoperative Gage				
		1	2	3	4	5
Operative Gage	1	0	10.40	10.90	8.35	12.75
	2	10.40	0	5.75	15.00	20.45
	3	10.90	5.75	0	11.85	17.10
	4	8.35	15.00	11.85	0	5.45
	5	12.75	20.45	17.10	5.45	0

computer program used to combine the five gage records was also designed to output onto magnetic tape the entire 33 year combined record, including all days of the year. Card output consisted only of the wet-day combined record since this was intended for file purposes and was not used in the model construction procedures. The following steps outline the form and format of these two different outputs:

(1) A 1200 ft standard magnetic tape was acquired for the total combined record output. The computer program was designed to output the precipitation data in the format, (24F5.3, 3I2). Therefore, the logical record length was 126, that is, 126 bytes per LRECL, per day. The format, 24F5.3, allows 24 hourly accumulations of 3 decimal places each for each day of record, while the format, 3I2, provides space for the day, month, and year. Block size factor was arbitrarily chosen to be 20. Therefore, each block was 20 x 26 = 2520 bytes long. Using this format, exactly 33 years of record (Jan. 1, 1941 through Dec. 31, 1973) was read onto the tape as the first data set. The tape file number is SC0398 and the data set name assigned was "WRAIN".

(2) In order to provide a more permanent record, the wet-day record was read from the tape record above, and punched onto cards with the format, (12F6.3, 3I2, 1X, '1', /, 12F6.3, 3I2, 1X, '2'). Thus, 2 cards were necessary for each wet-day of record. The first card lists the a.m. hours (columns 1-72), and date (day, month, and year in columns 73-78), and after skipping column 79, the card number, 1, in column 80. The second card has identical format and lists the 12 p.m. hours, the data, and finally the card number, 2.

APPENDIX B

INTERARRIVAL TIME DISTRIBUTIONS

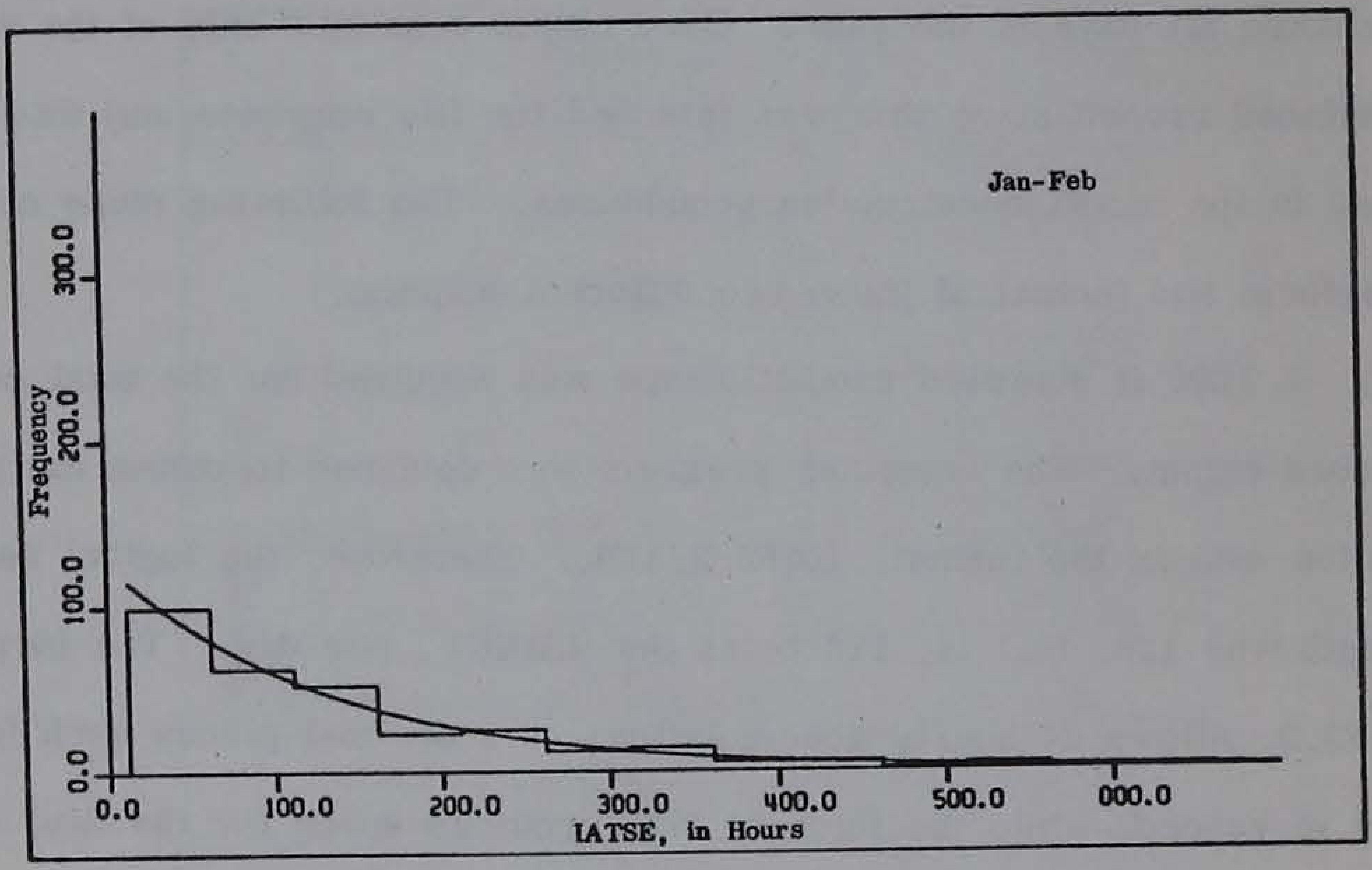

Figure B.1. IATSE Frequency Histogram and Fitted Exponential Function, Period 1

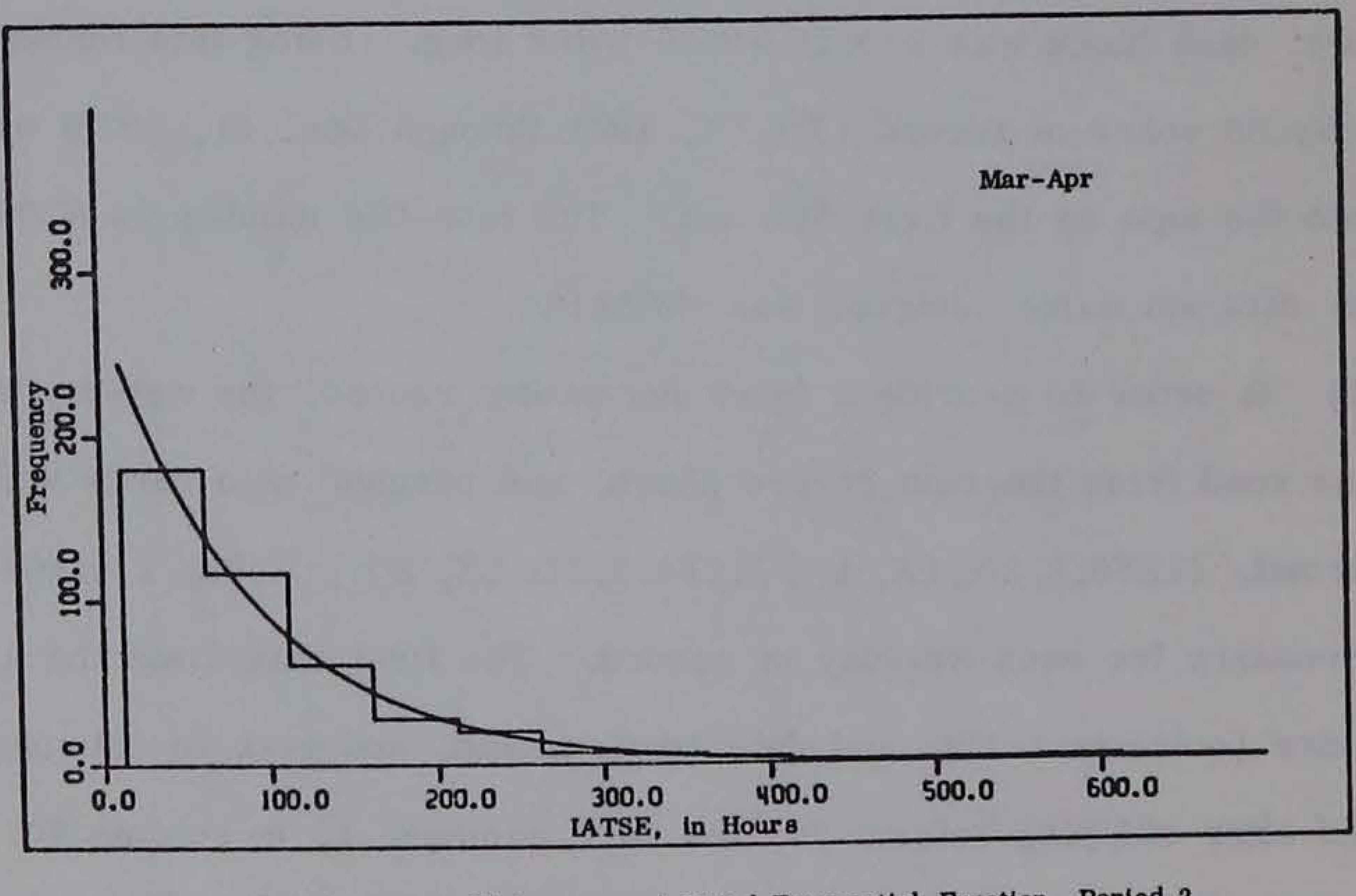

Figure B.2. IATSE Frequency Histogram and Fitted Exponential Function, Period 2

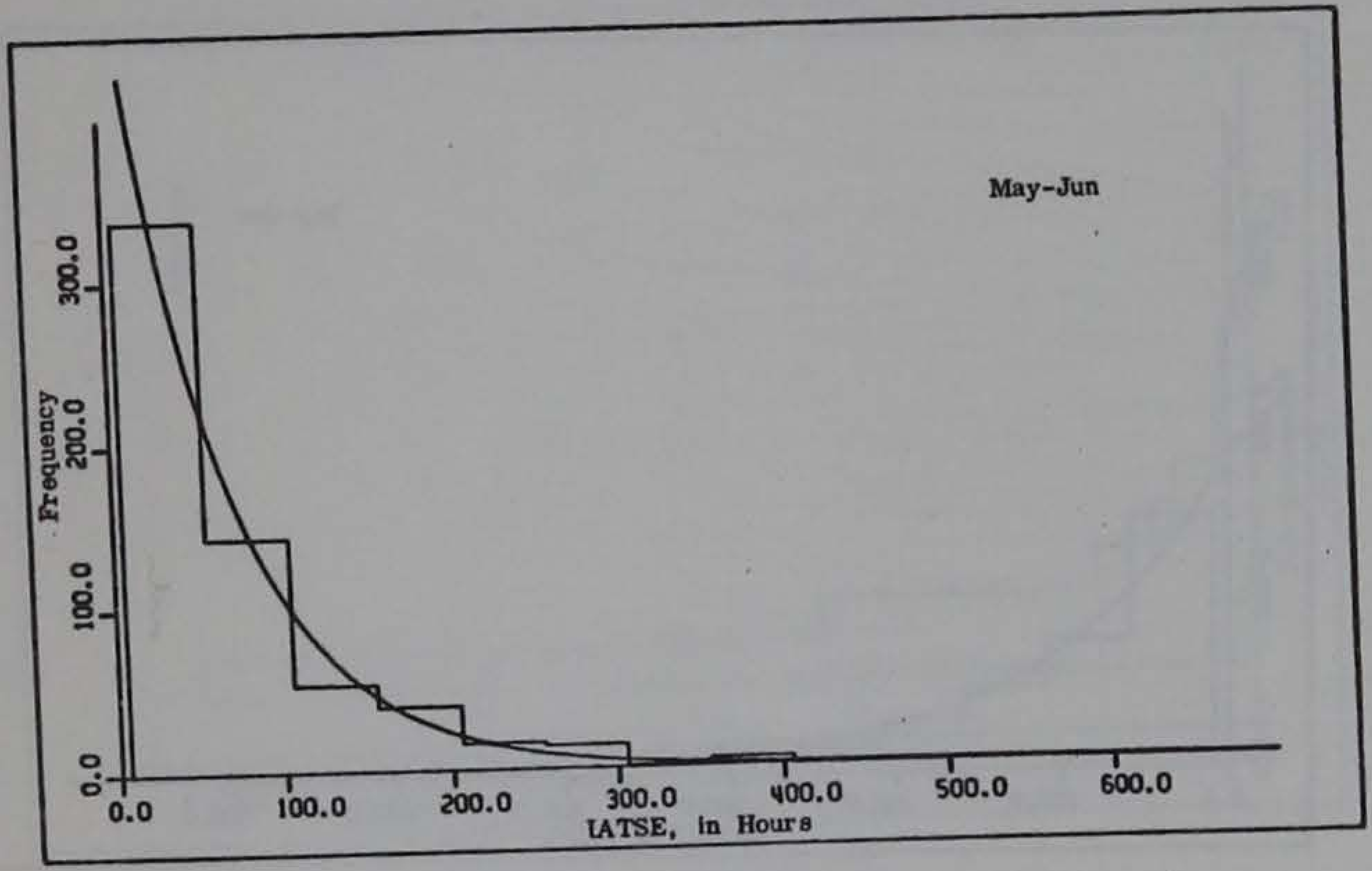

Figure B.3. IATSE Frequency Histogram and Fitted Exponential Function, Period 3

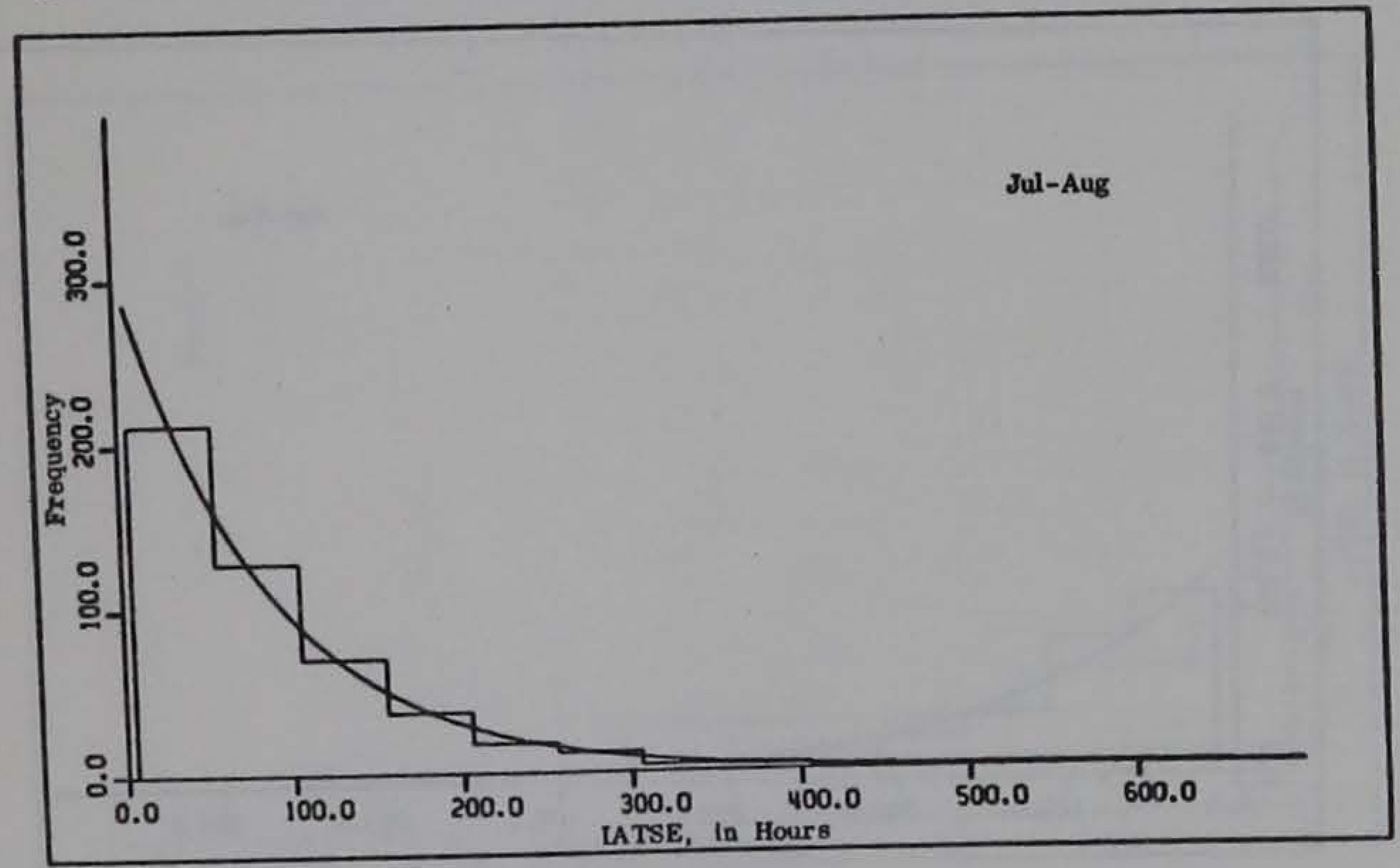

Figure B.4. IATSE Frequency Histogram and Fitted Exponential Function, Period 4

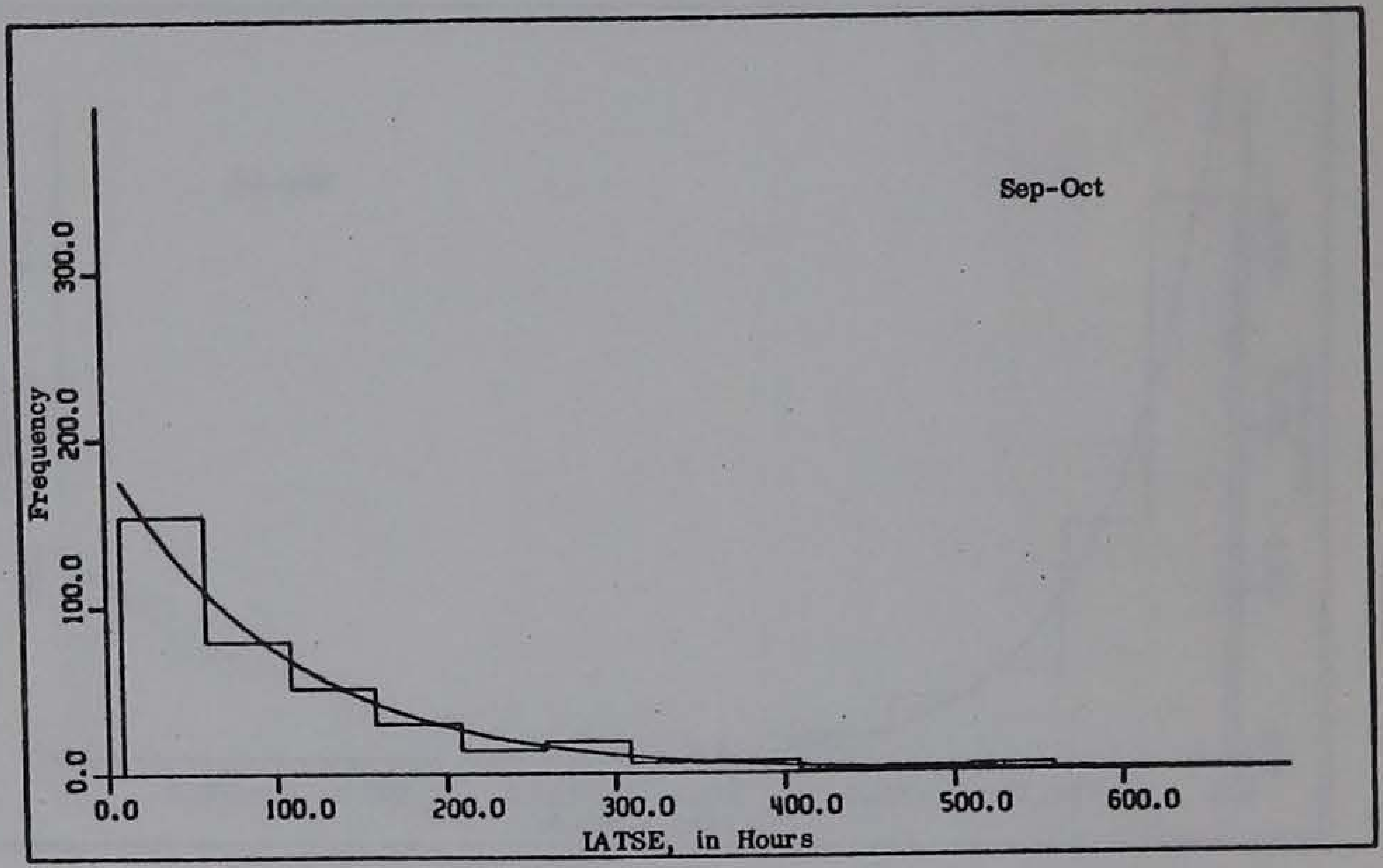

Figure B.5. IATSE Frequency Histogram and Fitted Exponential Function, Period 5

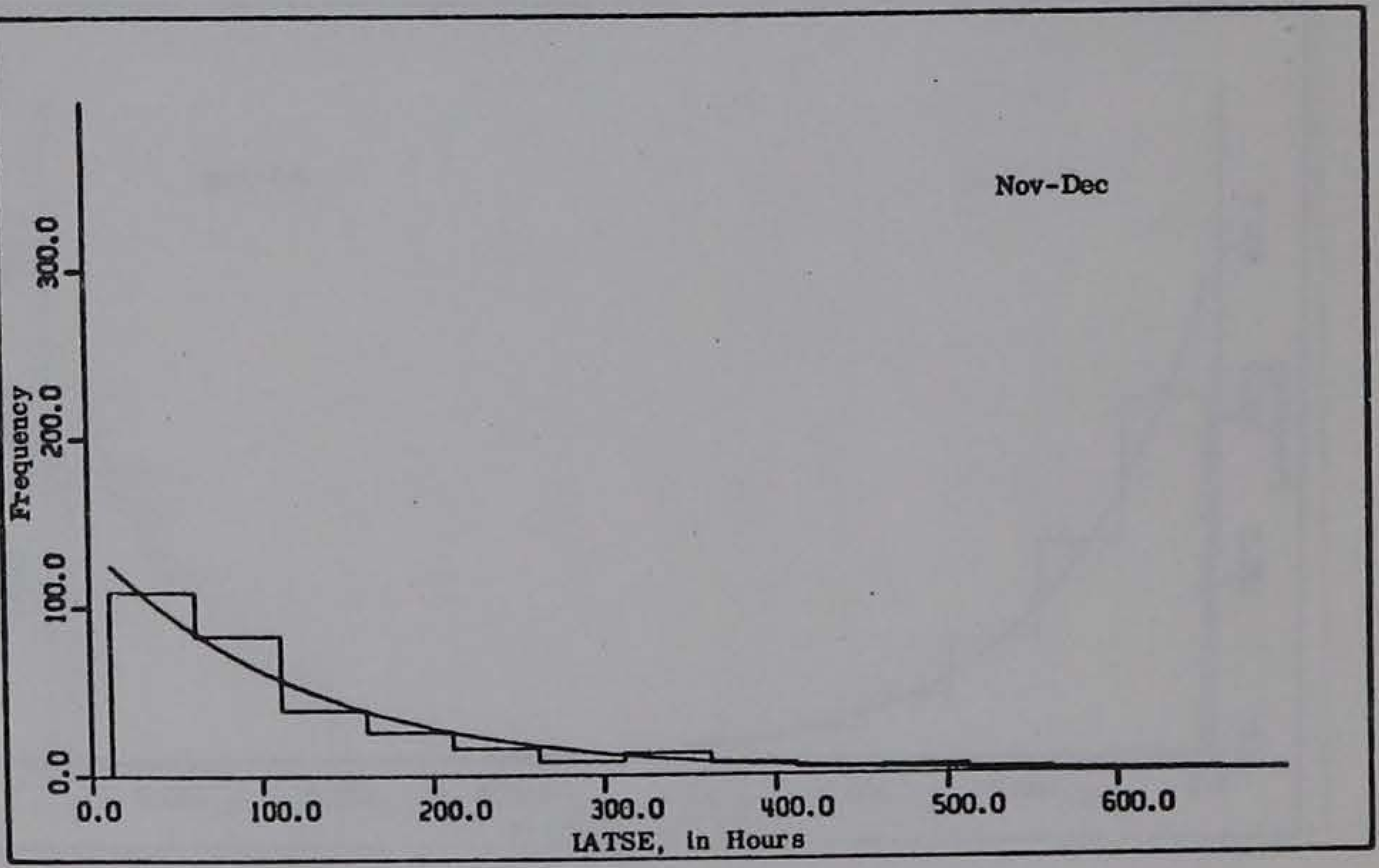

Figure B.6. IATSE Frequency Histogram and Fitted Exponential Function, Period 6

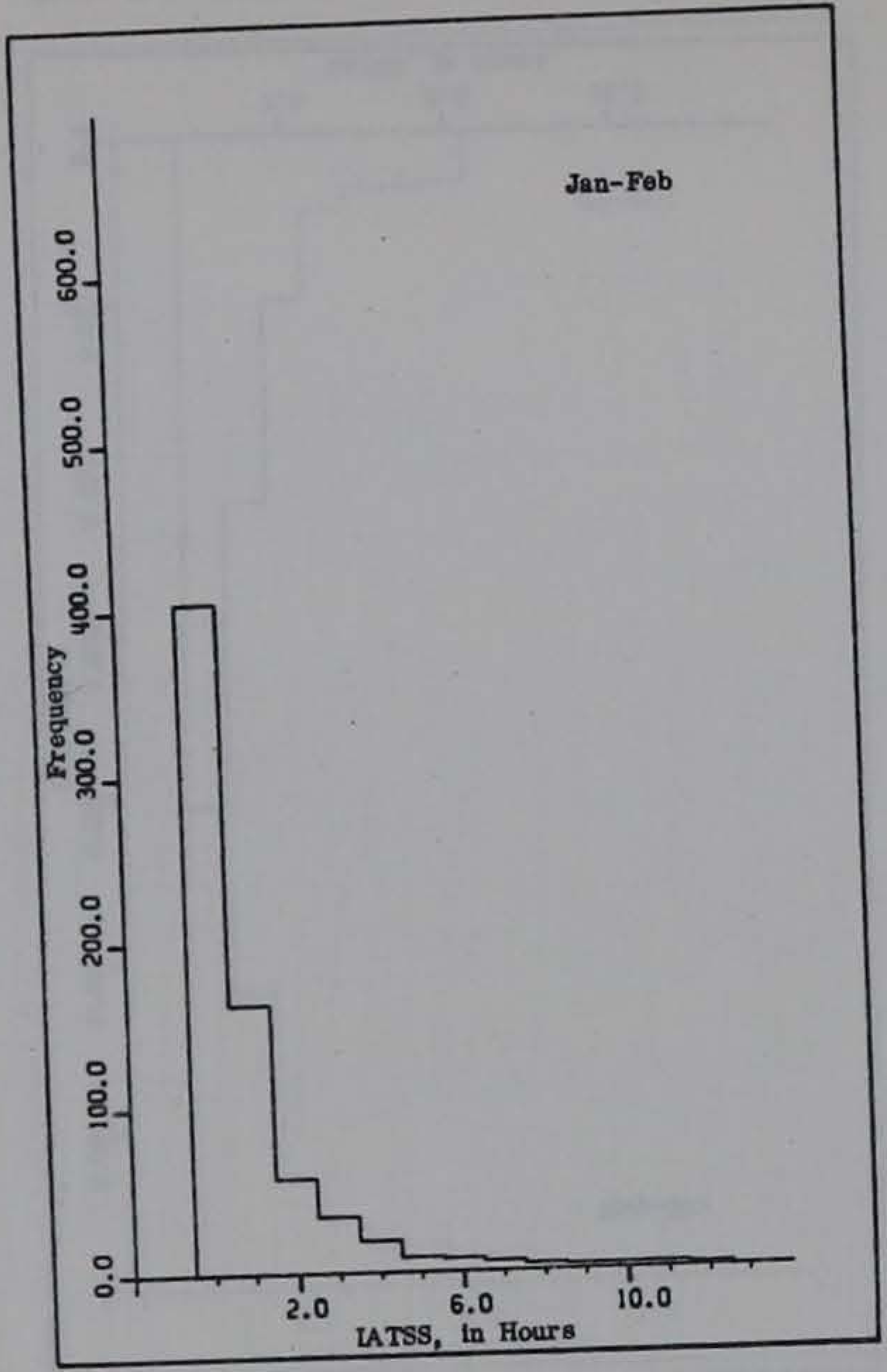

Figure B.7. IATSS Frequency Histogram, Period 1

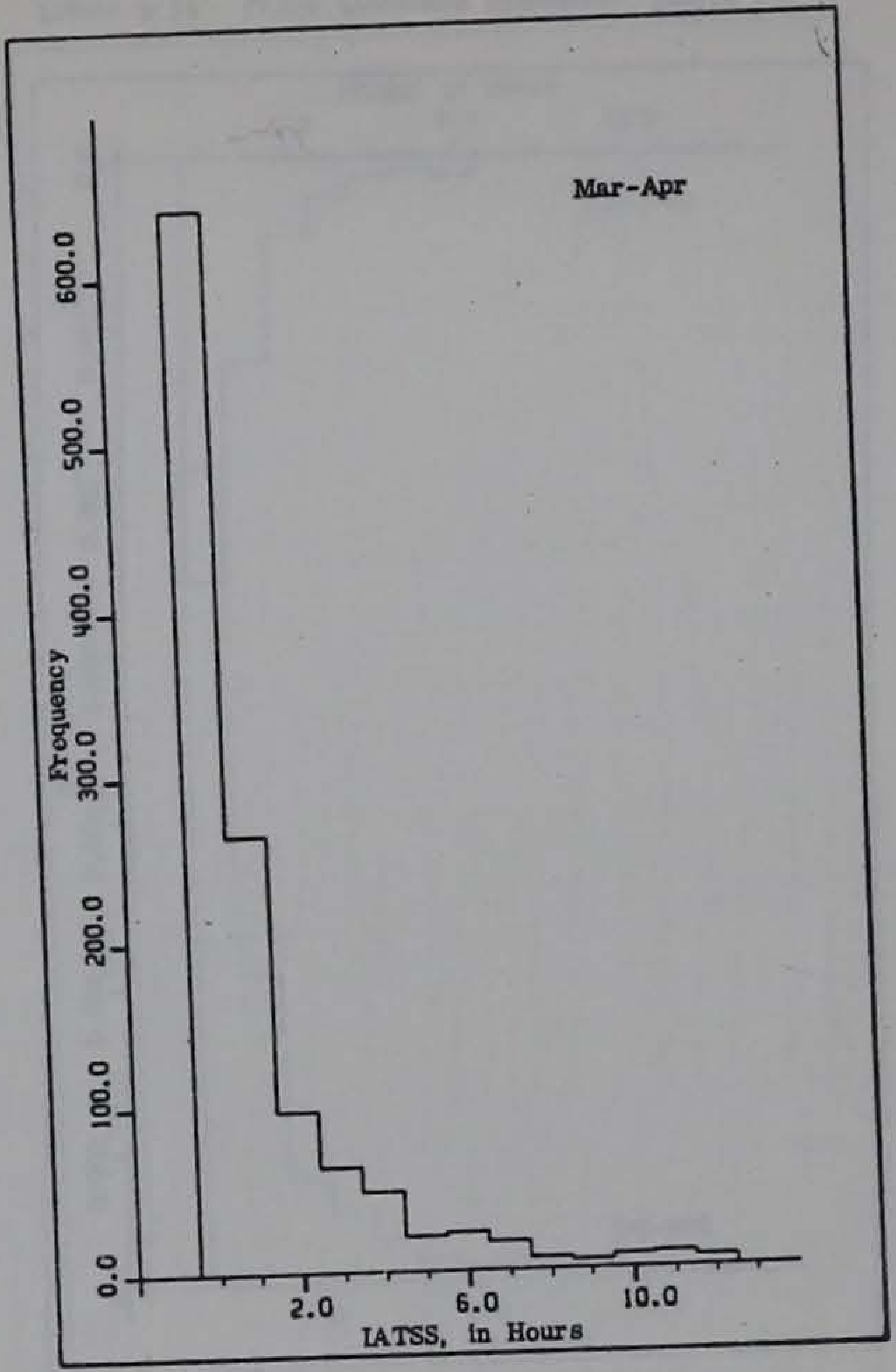

Figure B.8. IATSS Frequency Histogram, Period 2

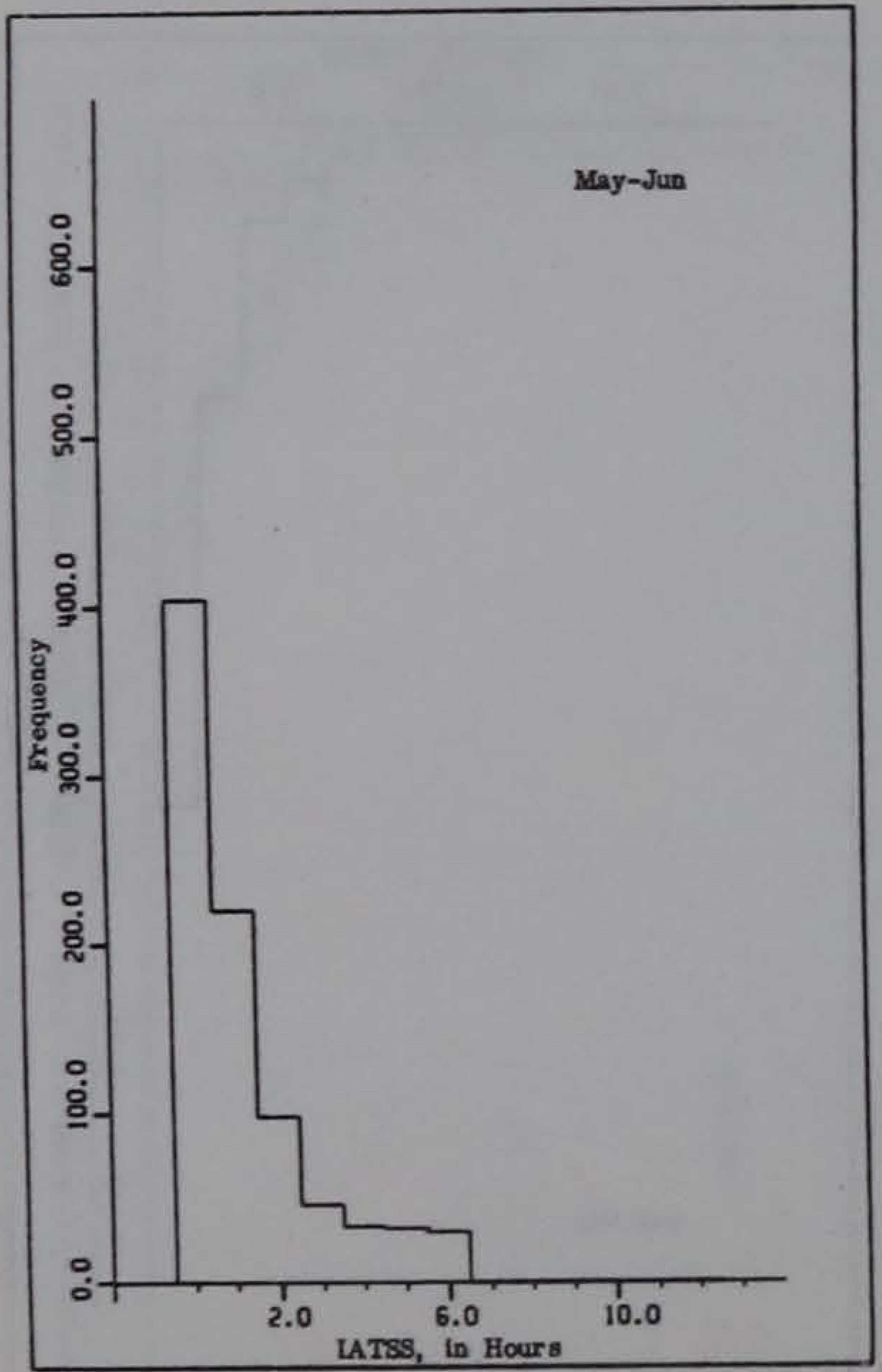

Figure B.9. IATSS Frequency Histogram, Period 3

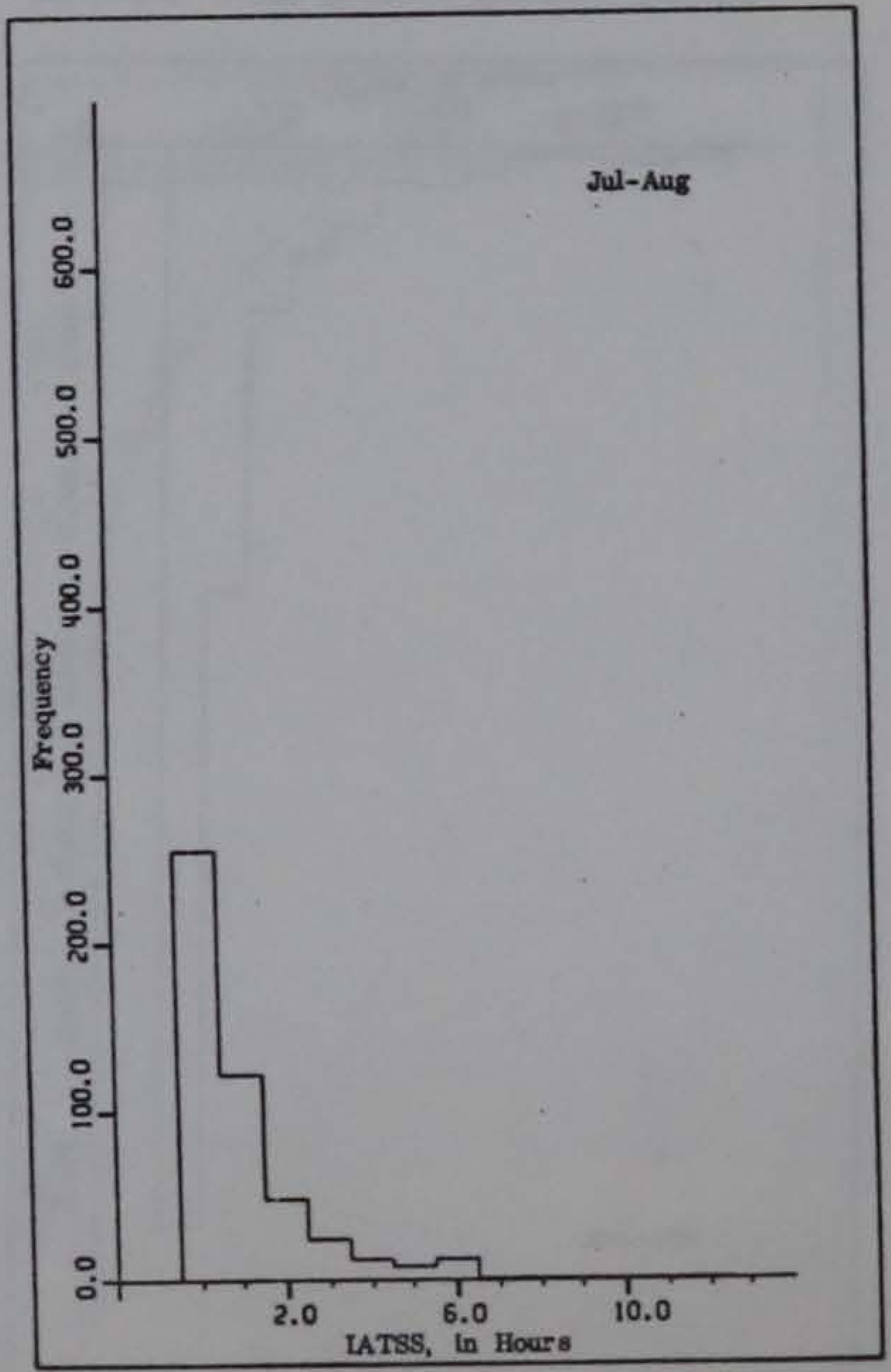

Figure B.10. IATSS Frequency Histogram, Period 4

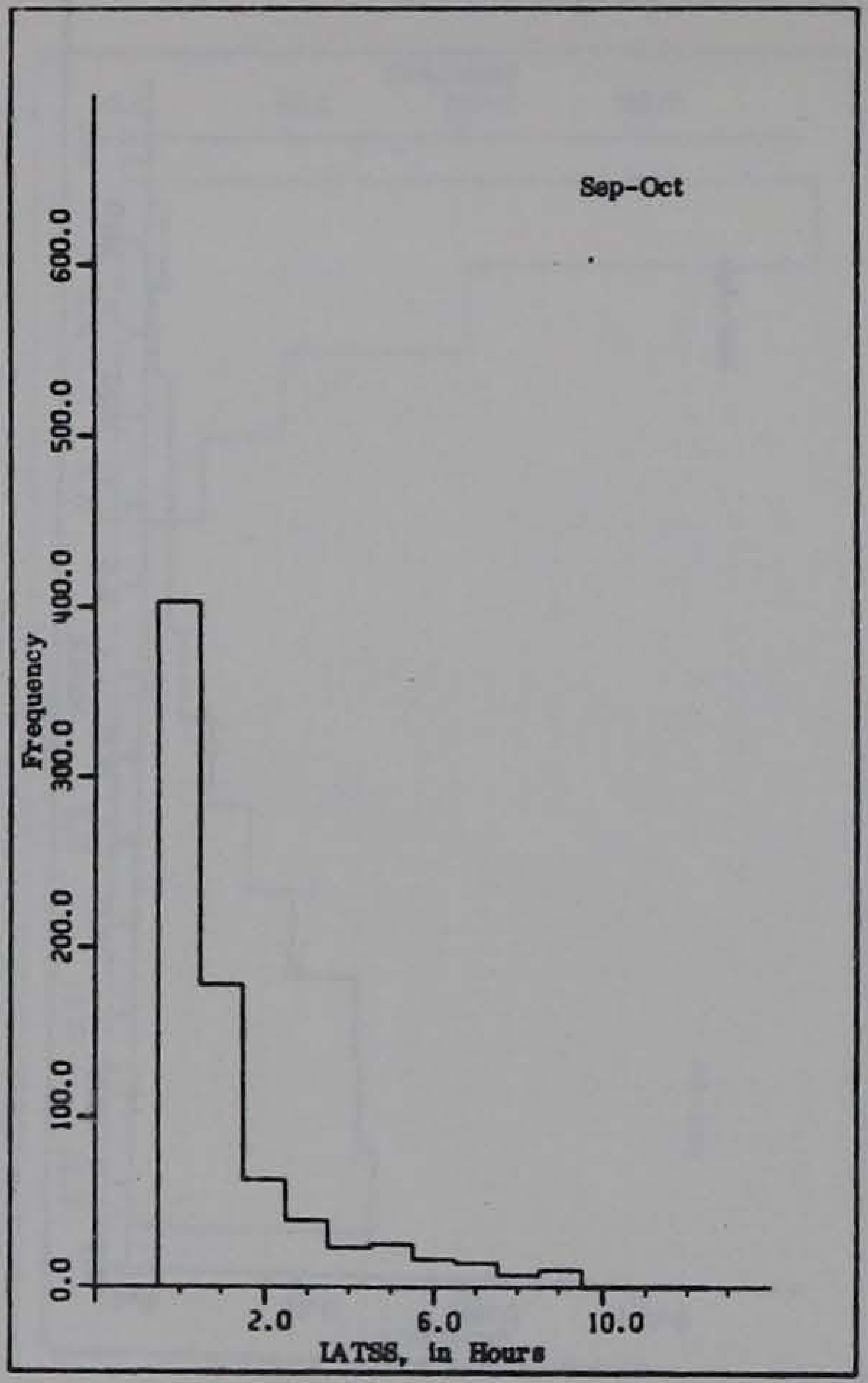

Figure B.11. IATSS Frequency Histogram, Period 5

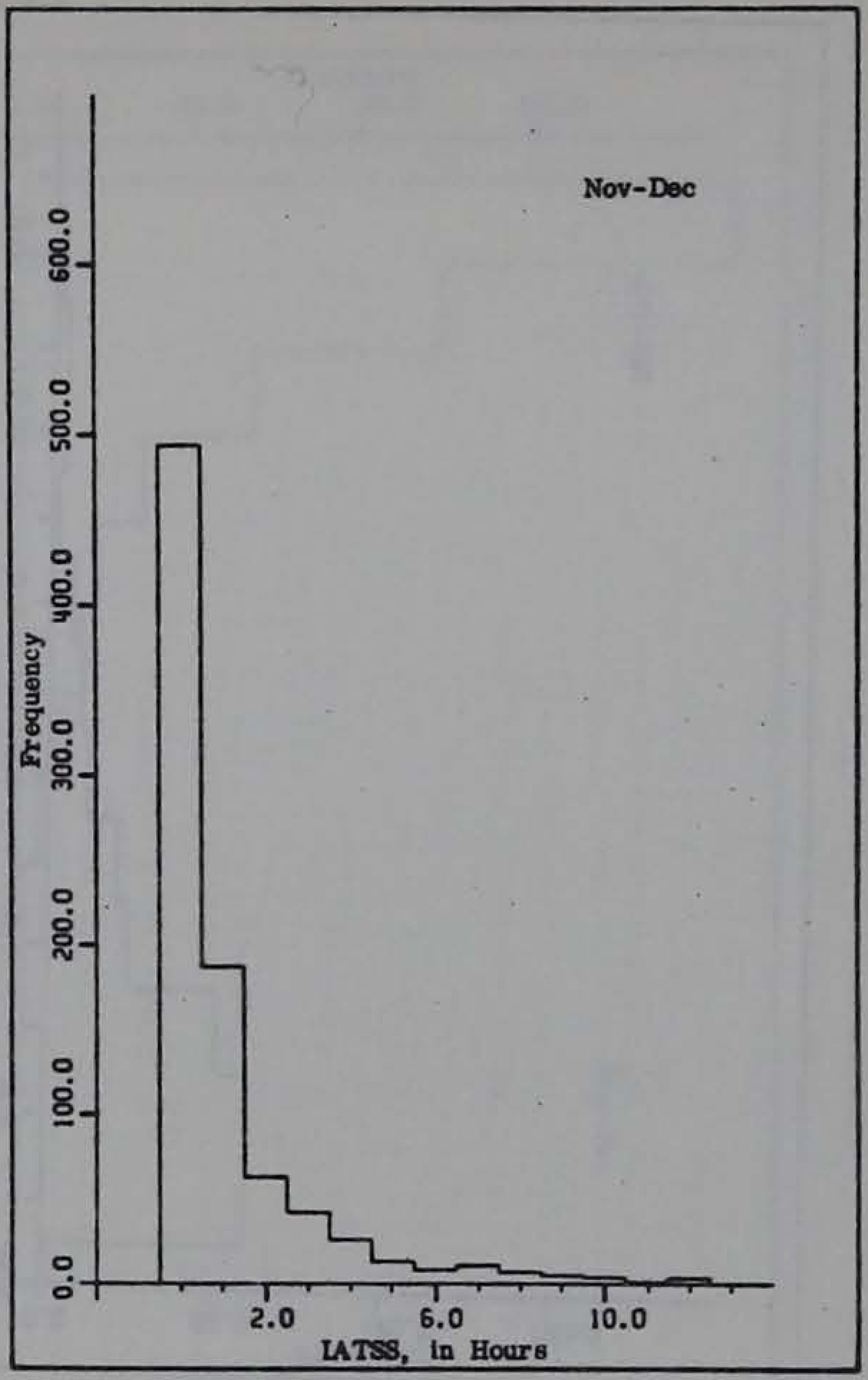

Figure B.12. IATSS Frequency Histogram, Period 6

APPENDIX C

NSSSE AND DURSS HISTOGRAMS

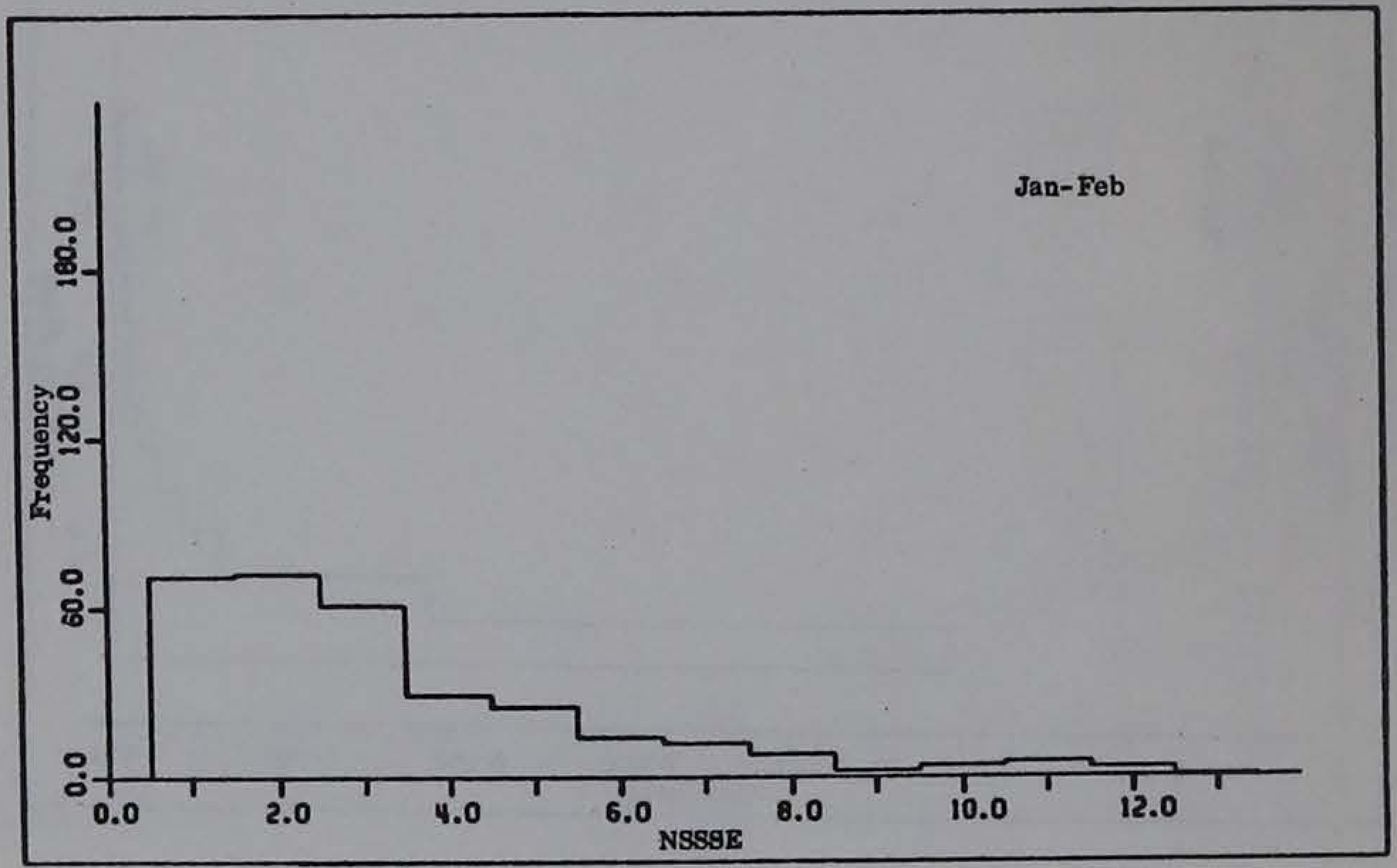

Figure C.1. NSSSE Frequency Histogram, Period 1

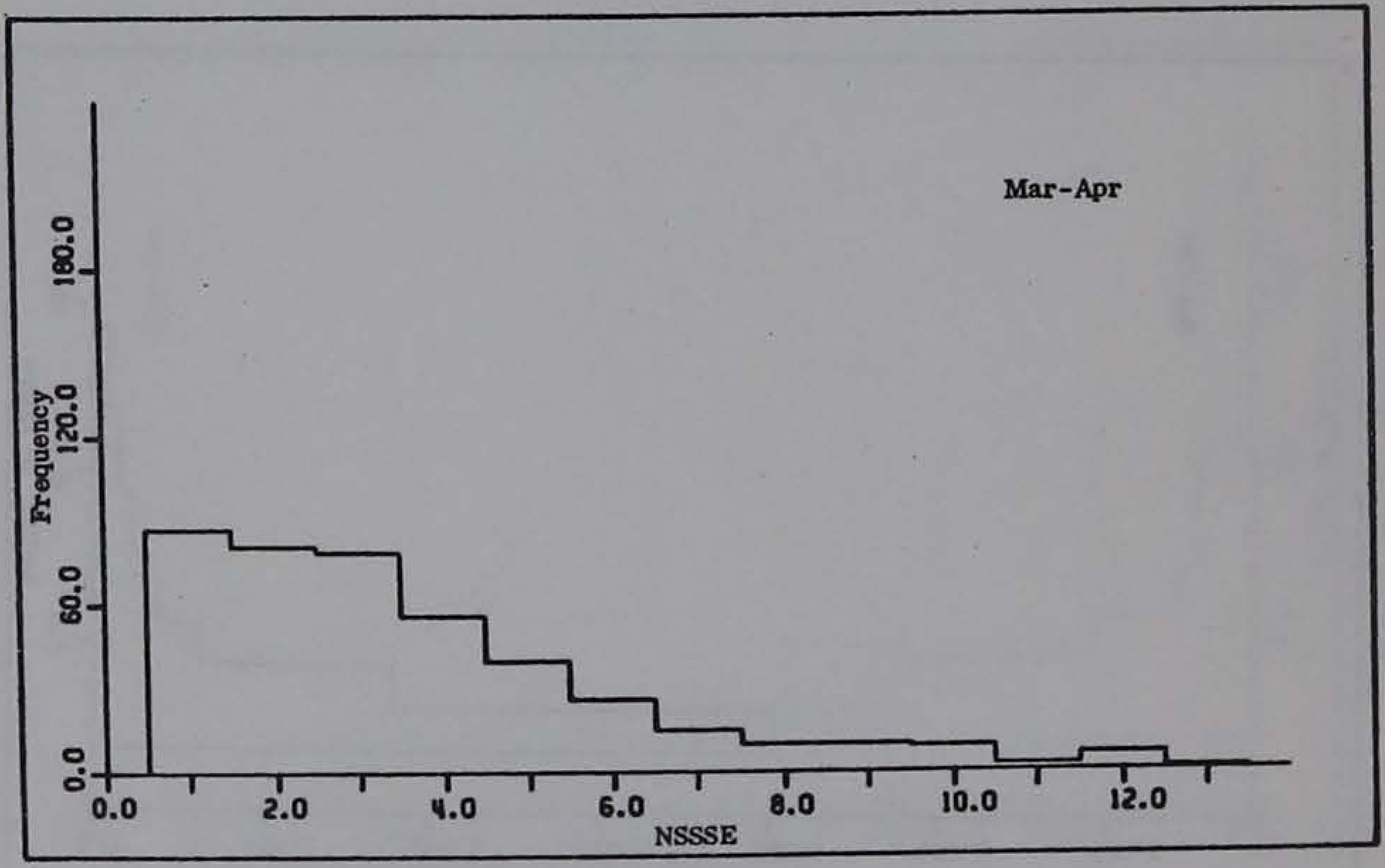

Figure C.2. NSSSE Frequency Histogram, Period 2

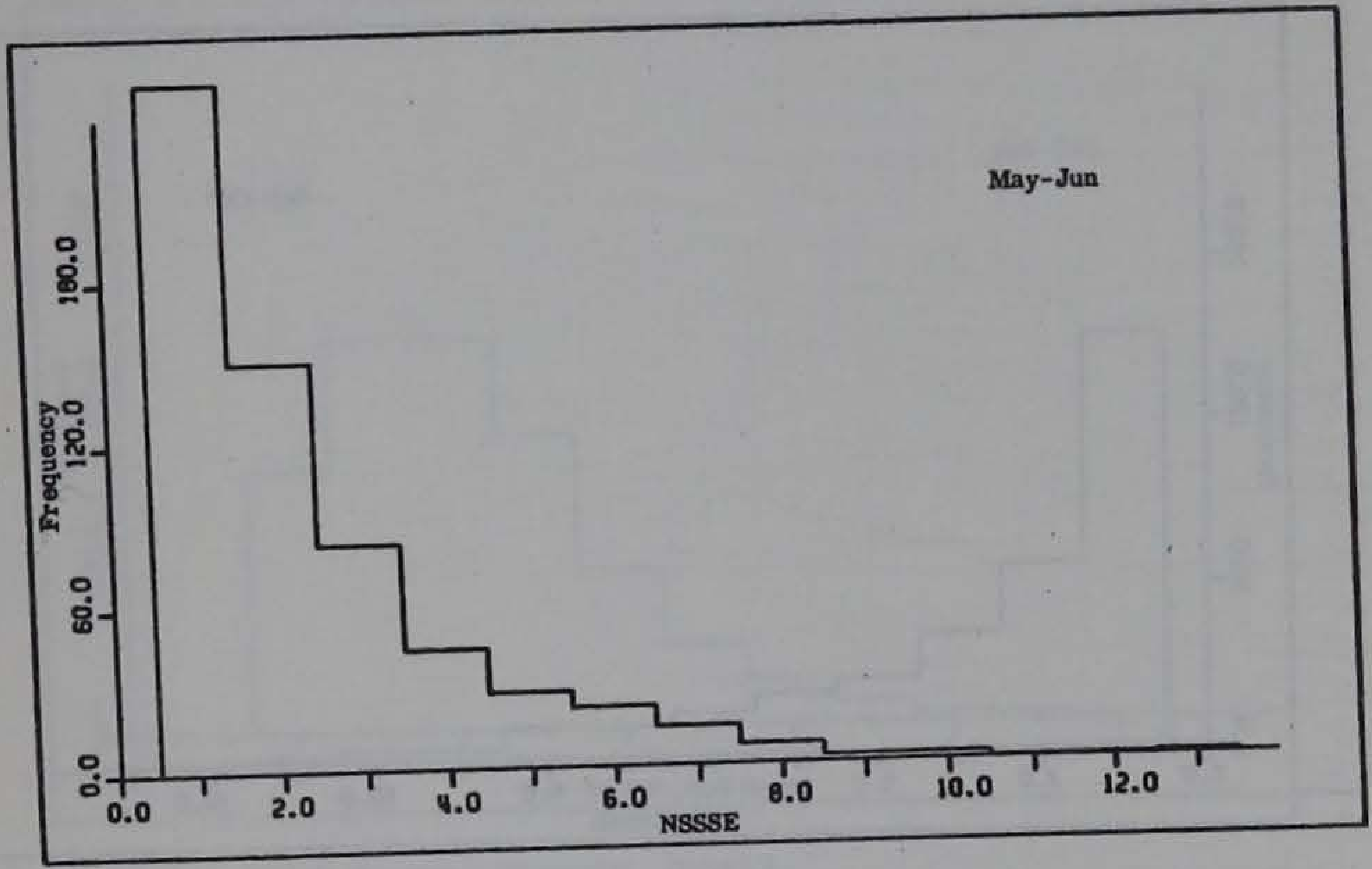

Figure C.3. NSSSE Frequency Histogram, Period 3

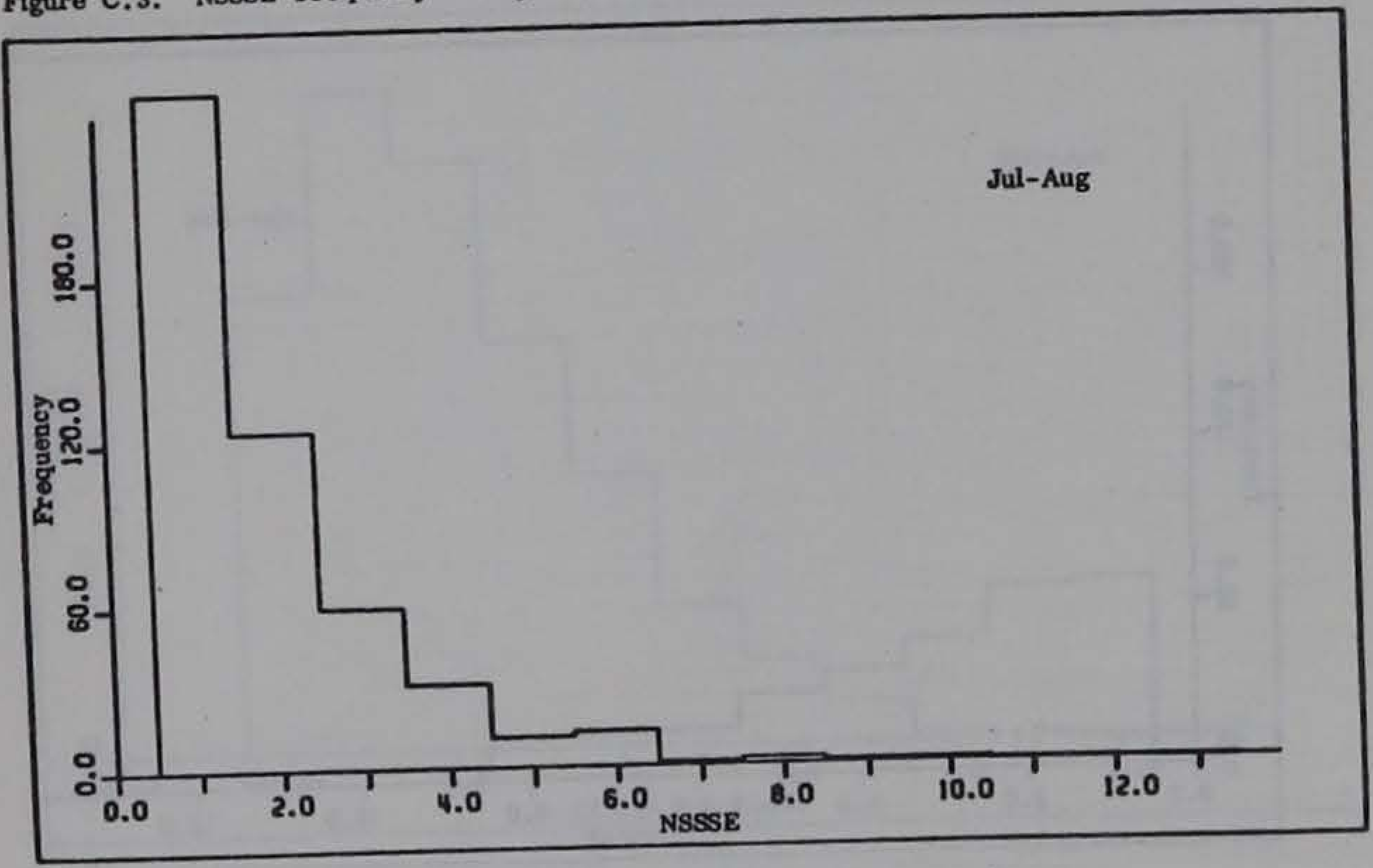

Figure C.4. NSSSE Frequency Histogram, Period 4

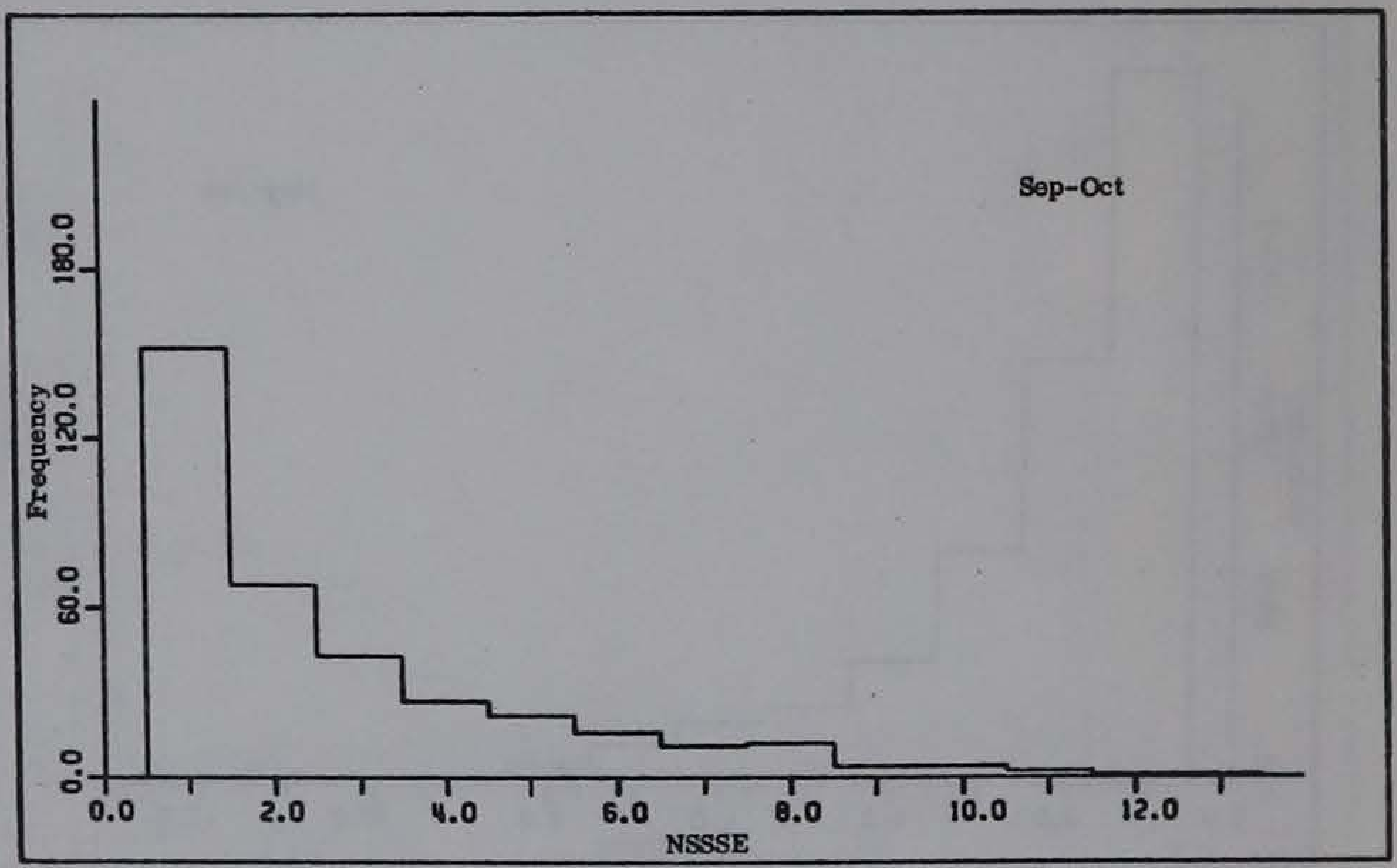

Figure C.5. NSSSE Frequency Histogram, Period 5

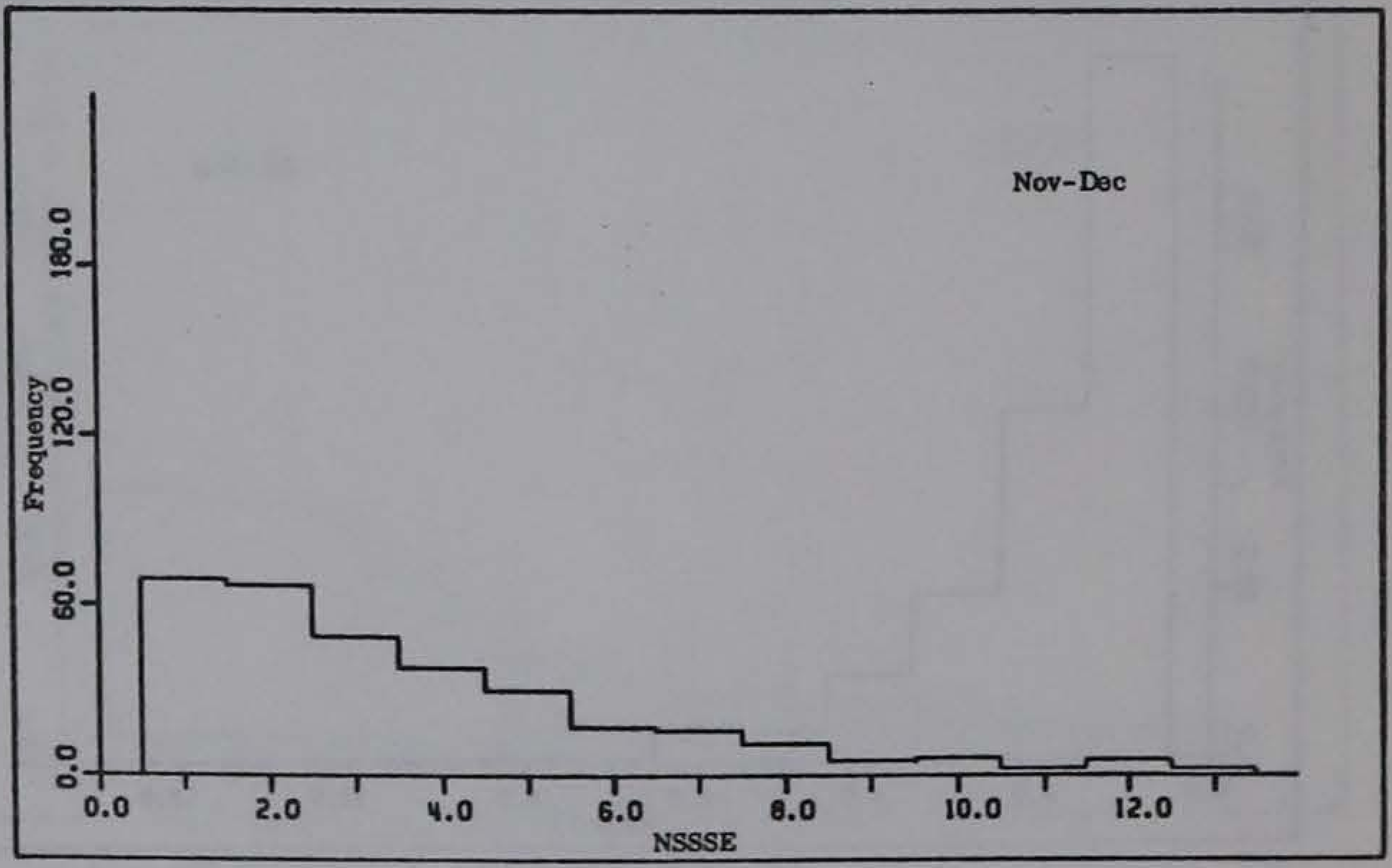

Figure C.6. NSSSE Frequency Histogram, Period 6

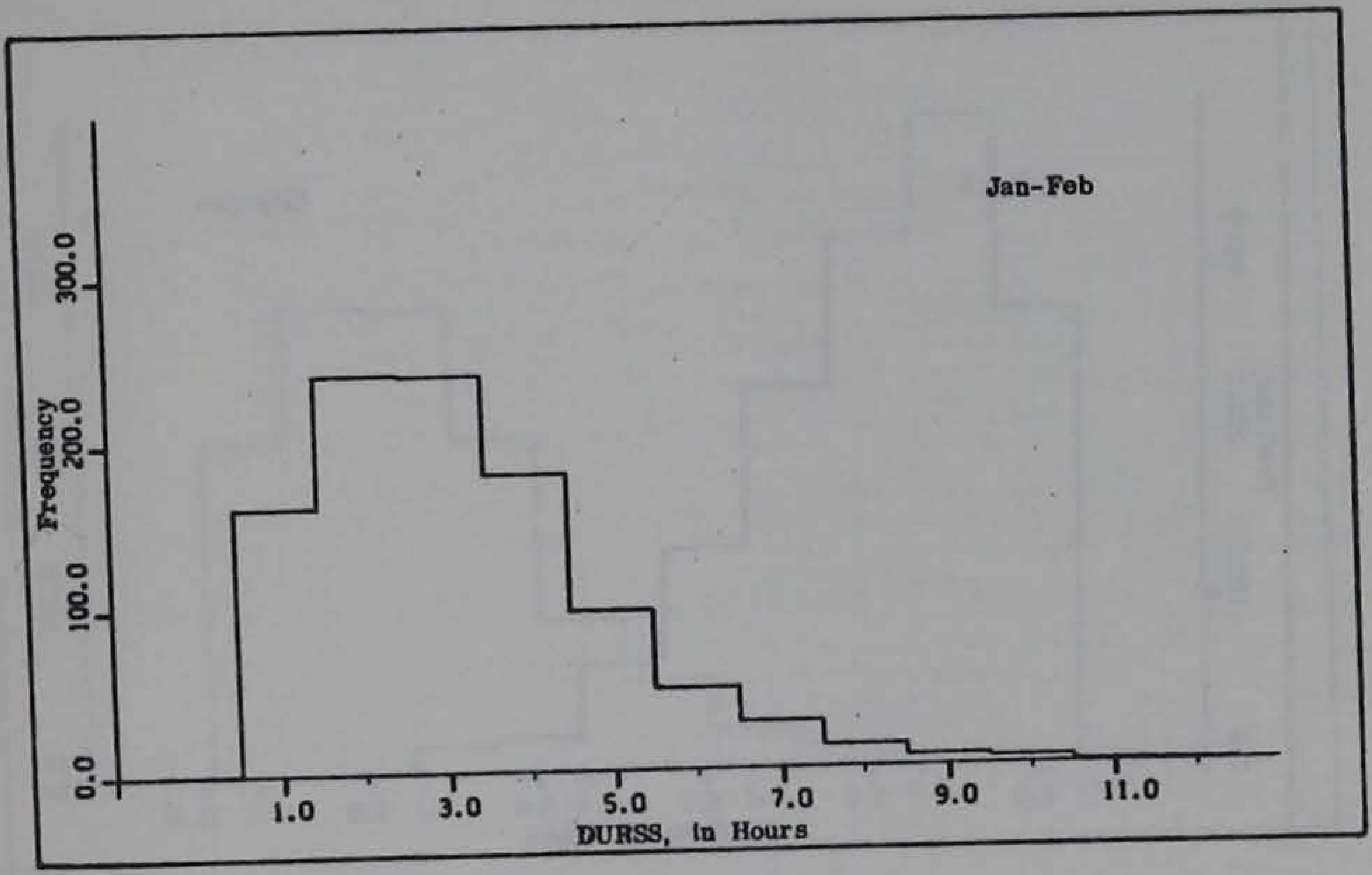

Figure C.7. DURSS Frequency Histogram, Period 1

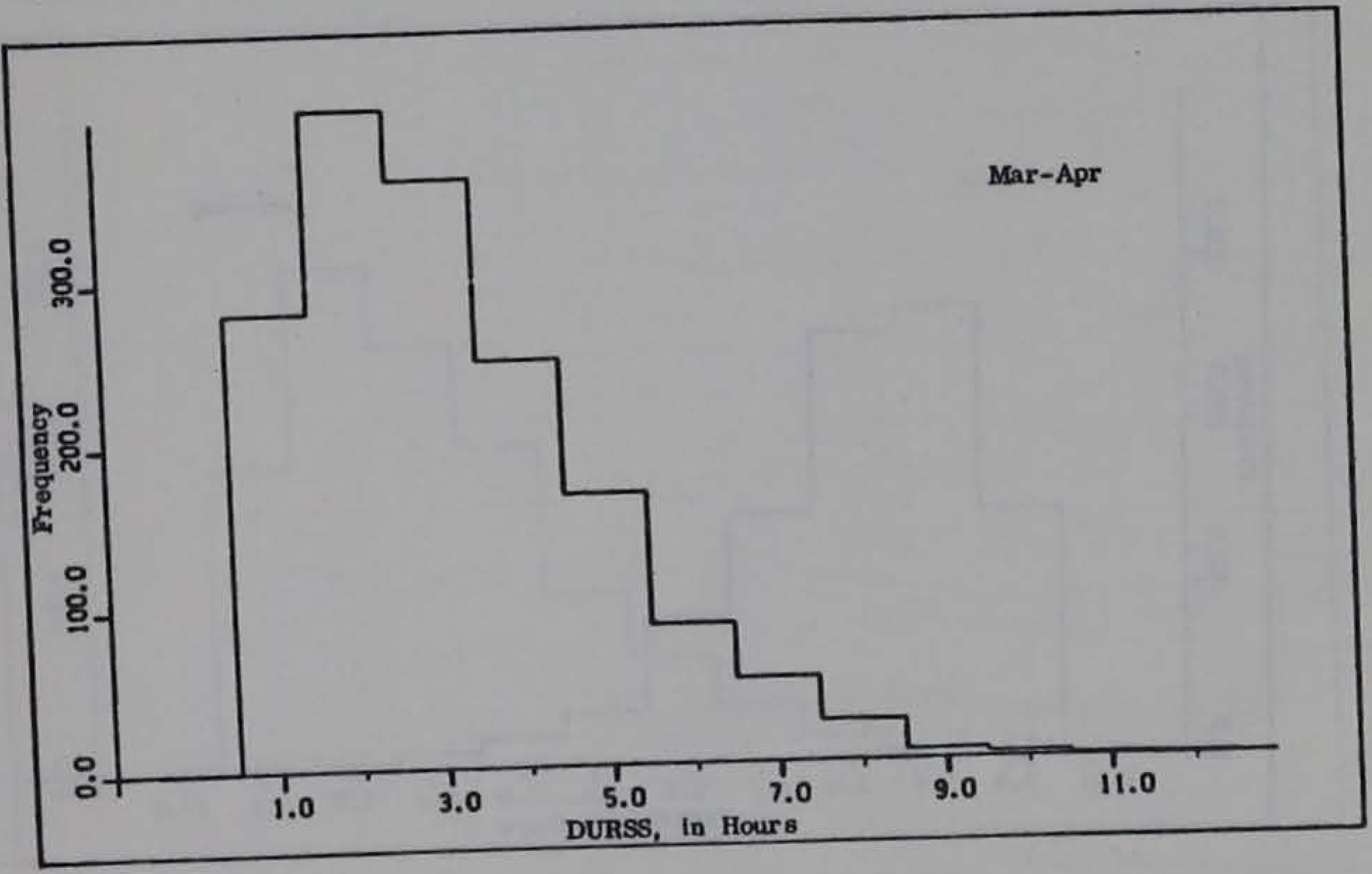

Figure C.8. DURSS Frequency Histogram, Period 2

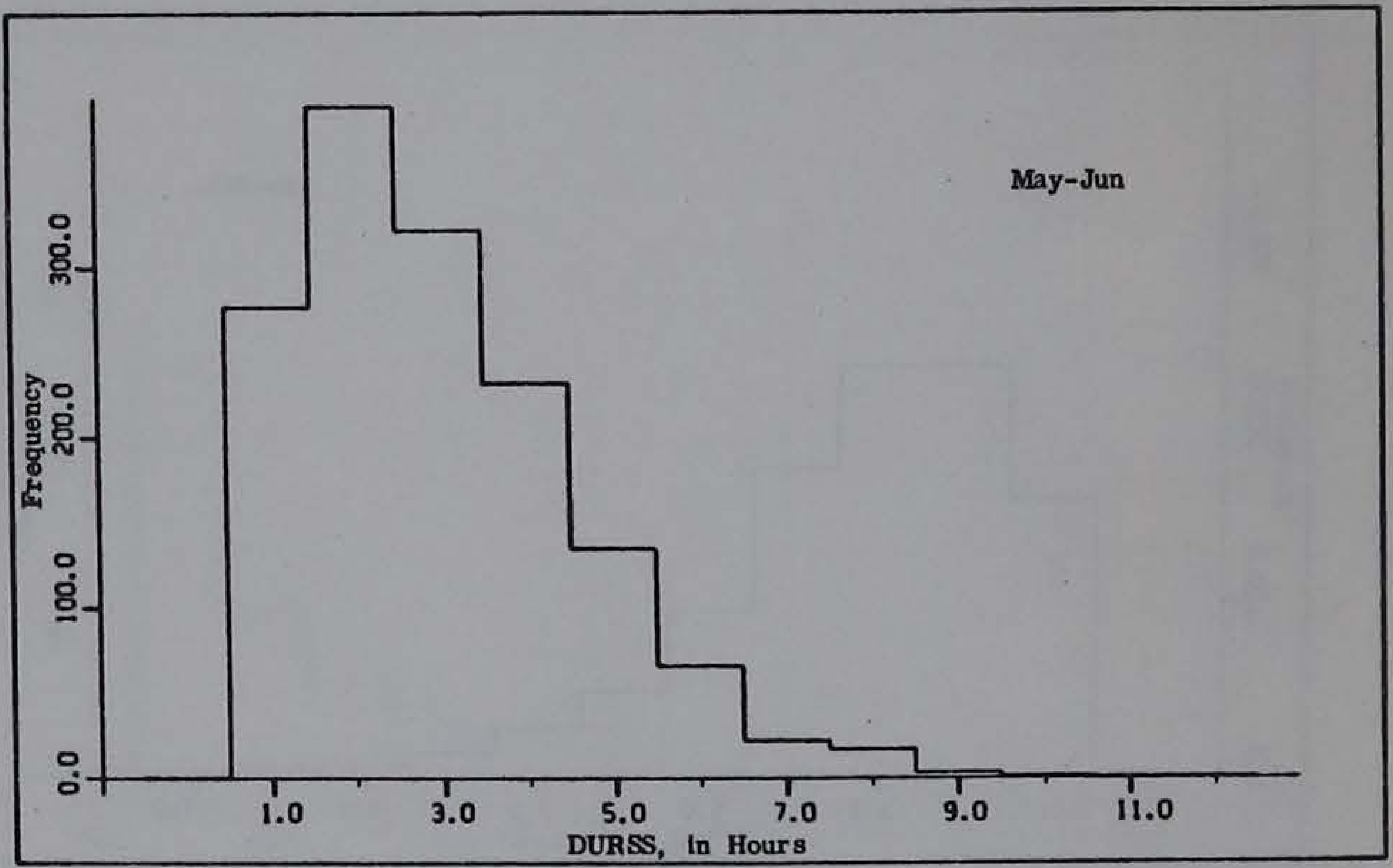

Figure C.9. DURSS Frequency Histogram, Period 3

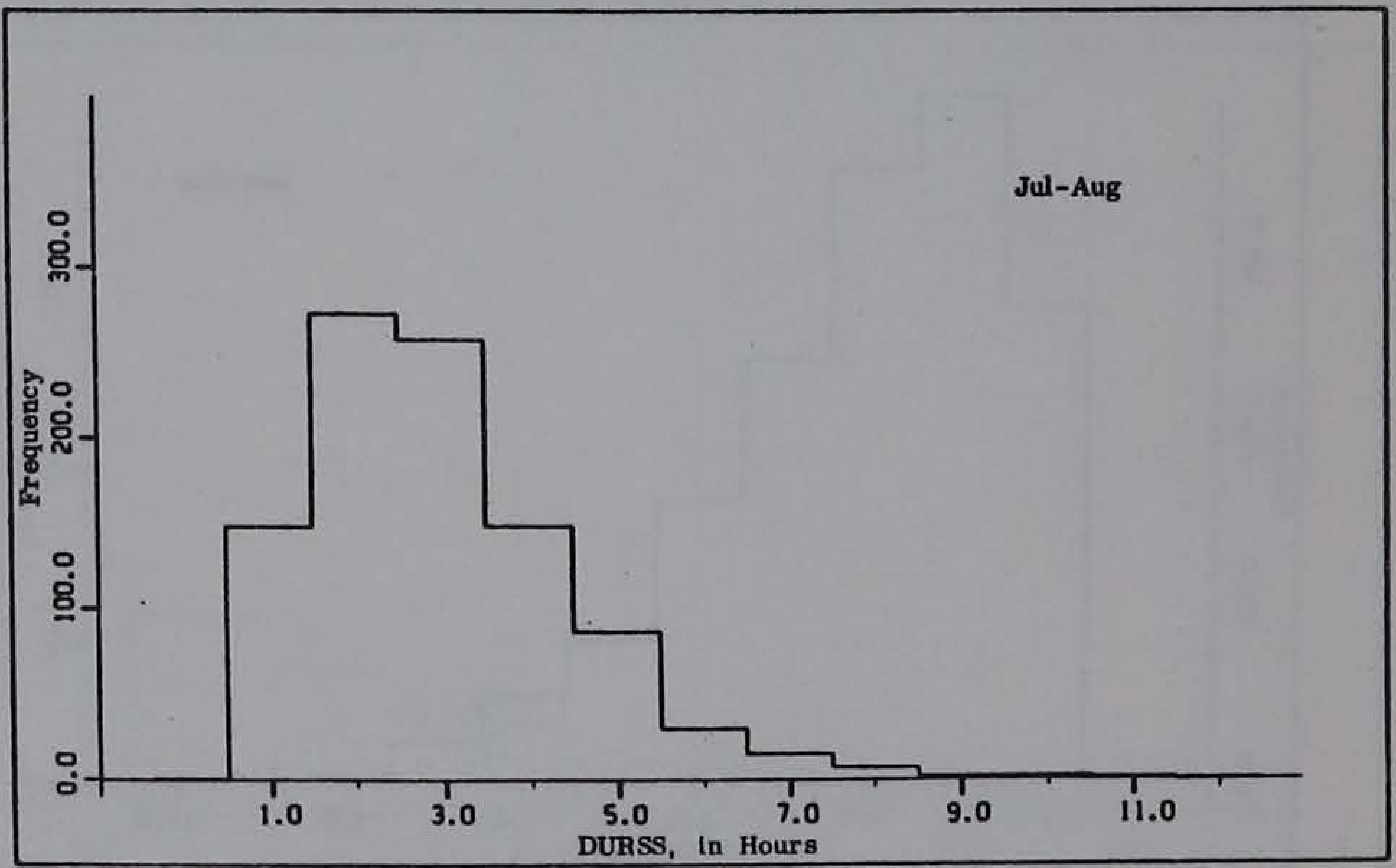

Figure C.10. DURSS Frequency Histogram, Period 4

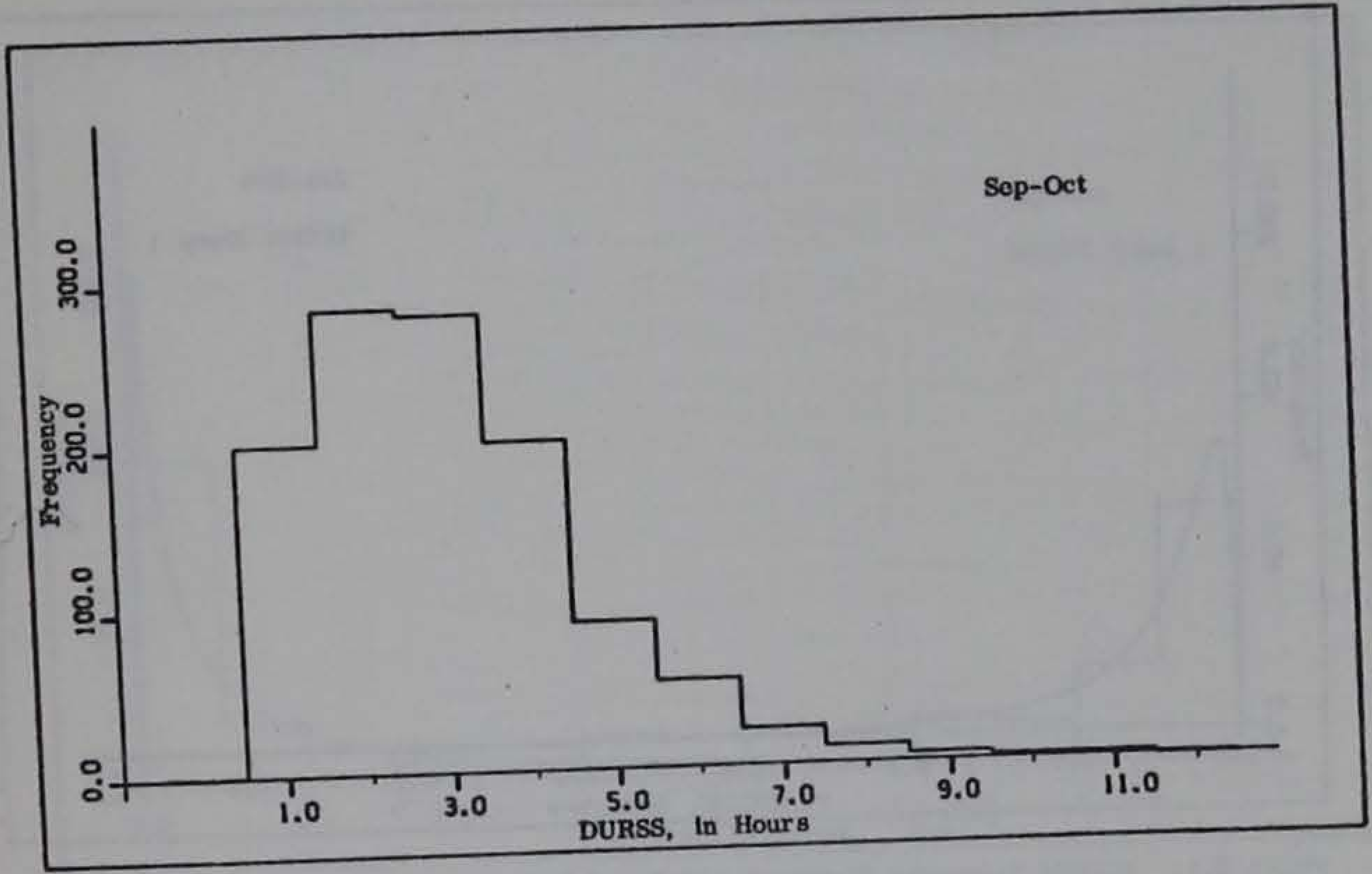

Figure C.11. DURSS Frequency Histogram, Period 5

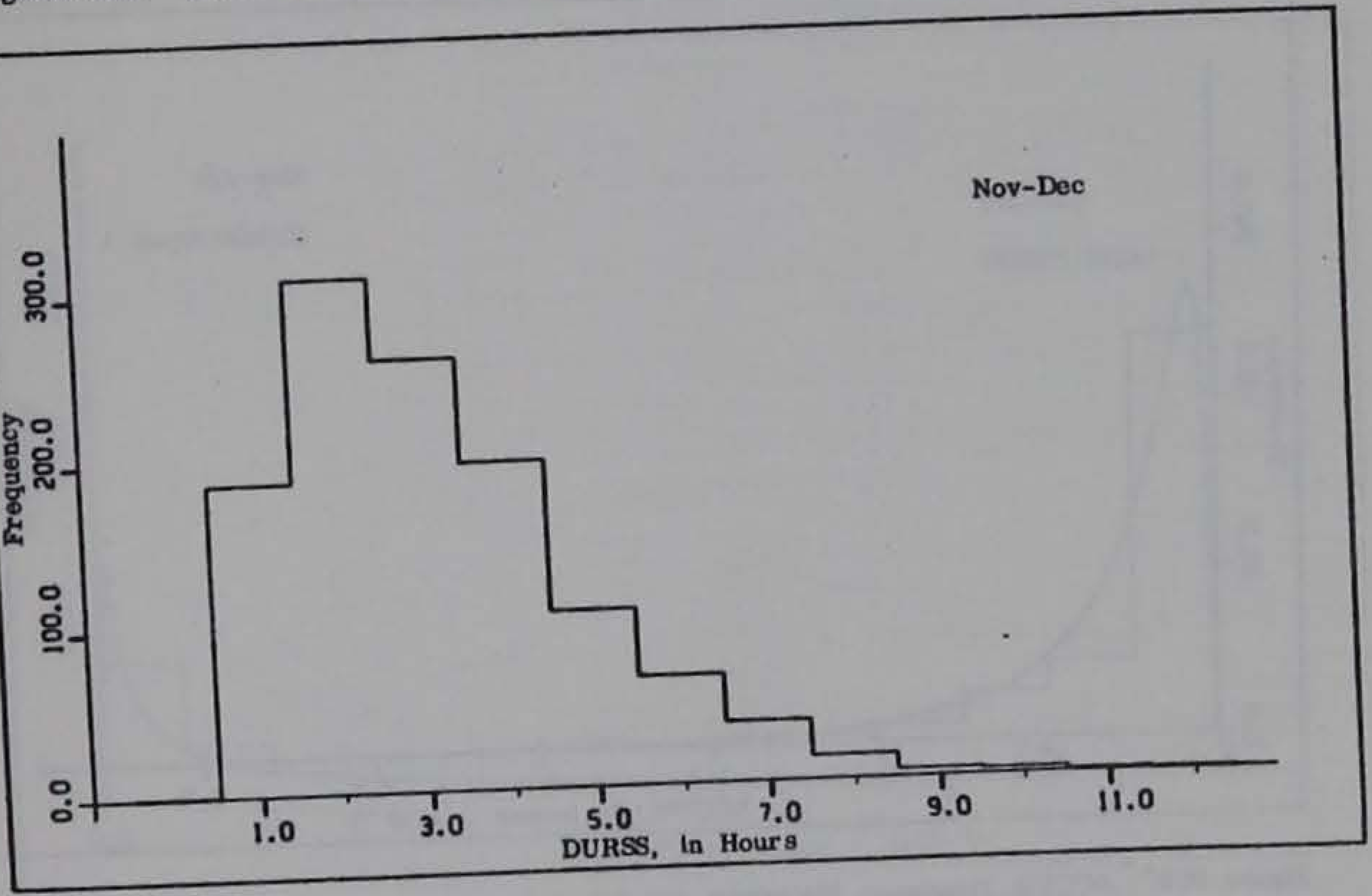

Figure C.12. DURSS Frequency Histogram, Period 6

APPENDIX D

ACCUM DISTRIBUTIONS AND SHAPE CATALOG

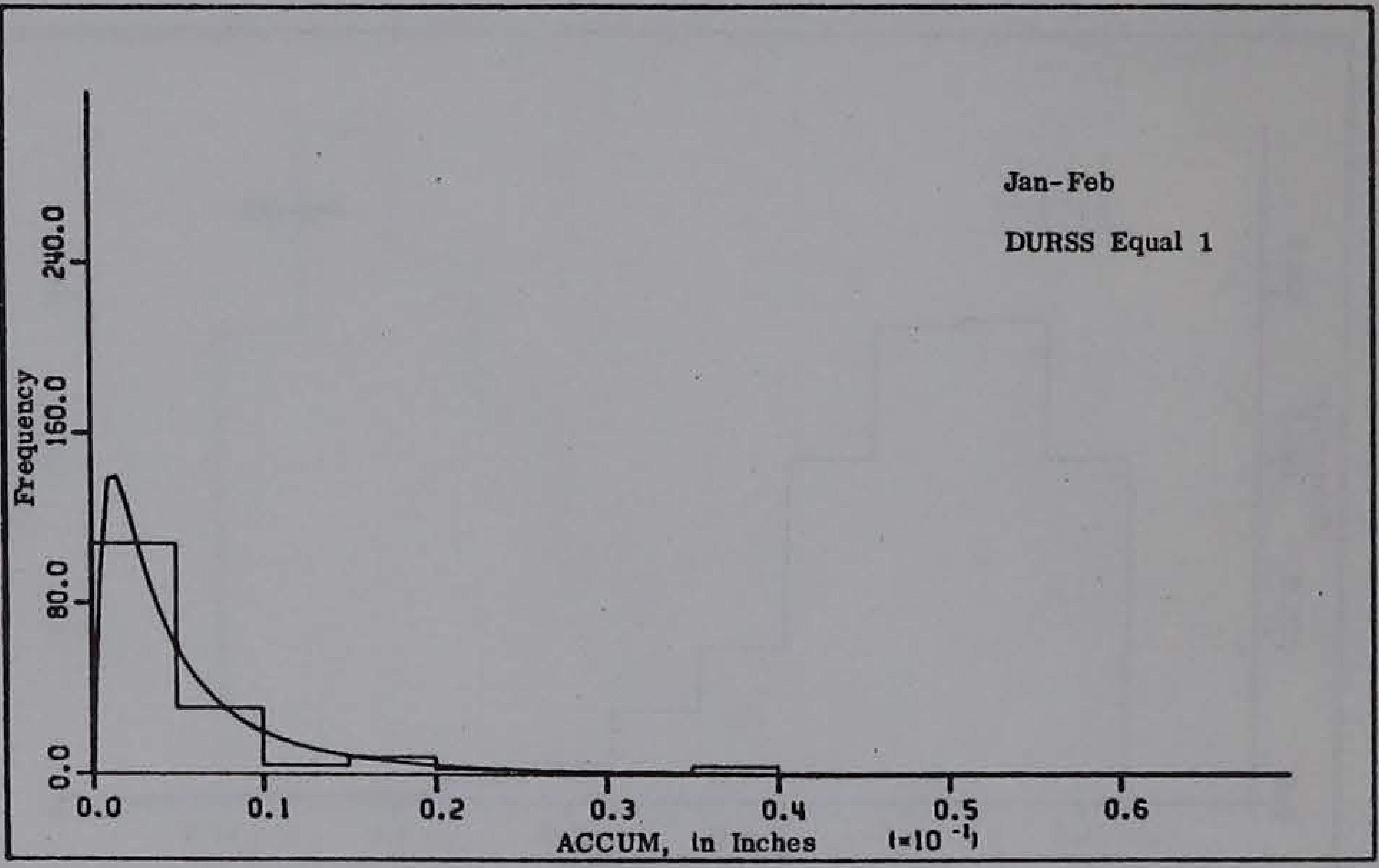

Figure D.1. ACCUM Frequency Histogram and Fitted Lognormal Function, Period 1, DURSS Equal 1

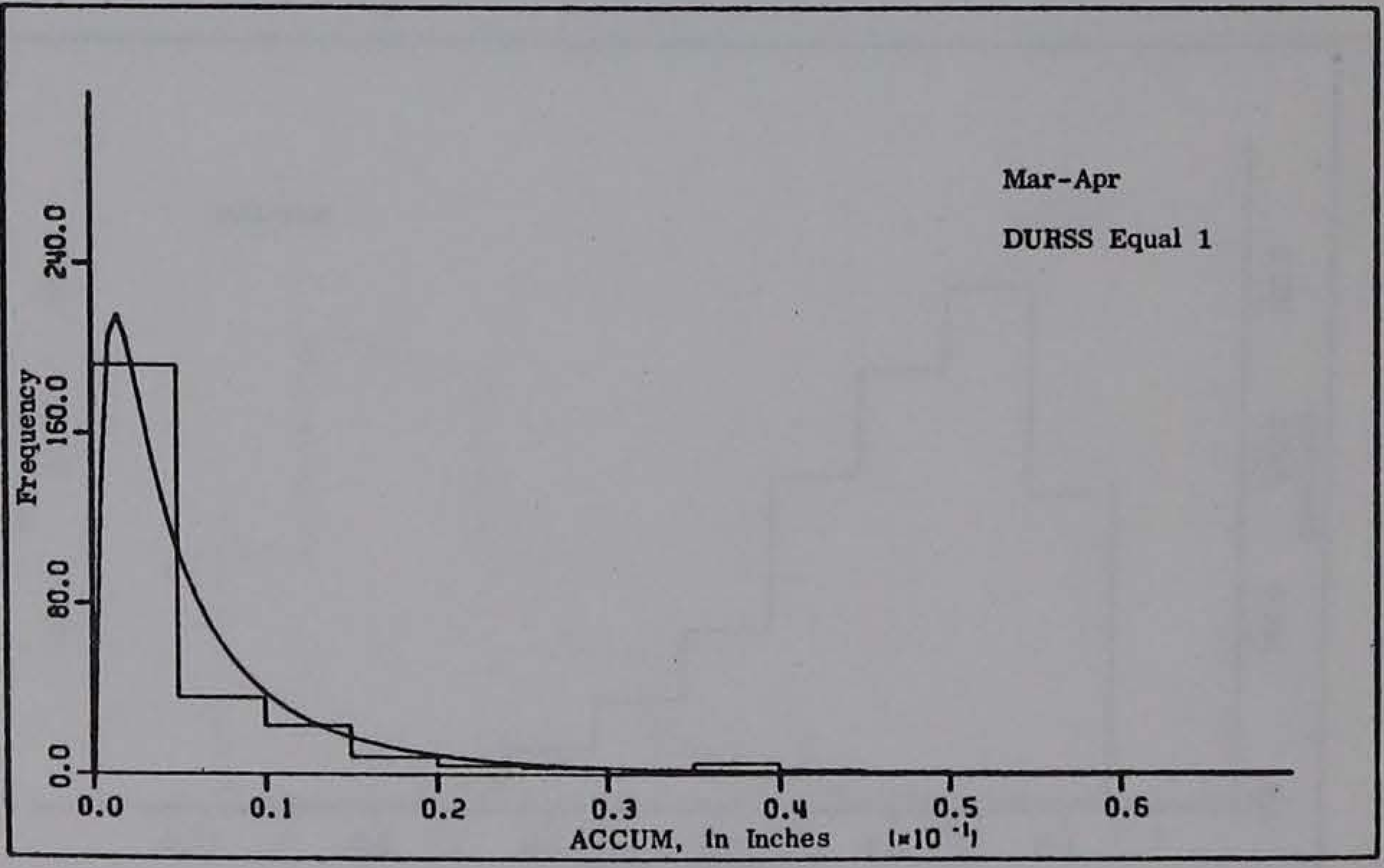

Figure D.2. ACCUM Frequency Histogram and Fitted Lognormal Function, Period 2, DURSS Equal 1

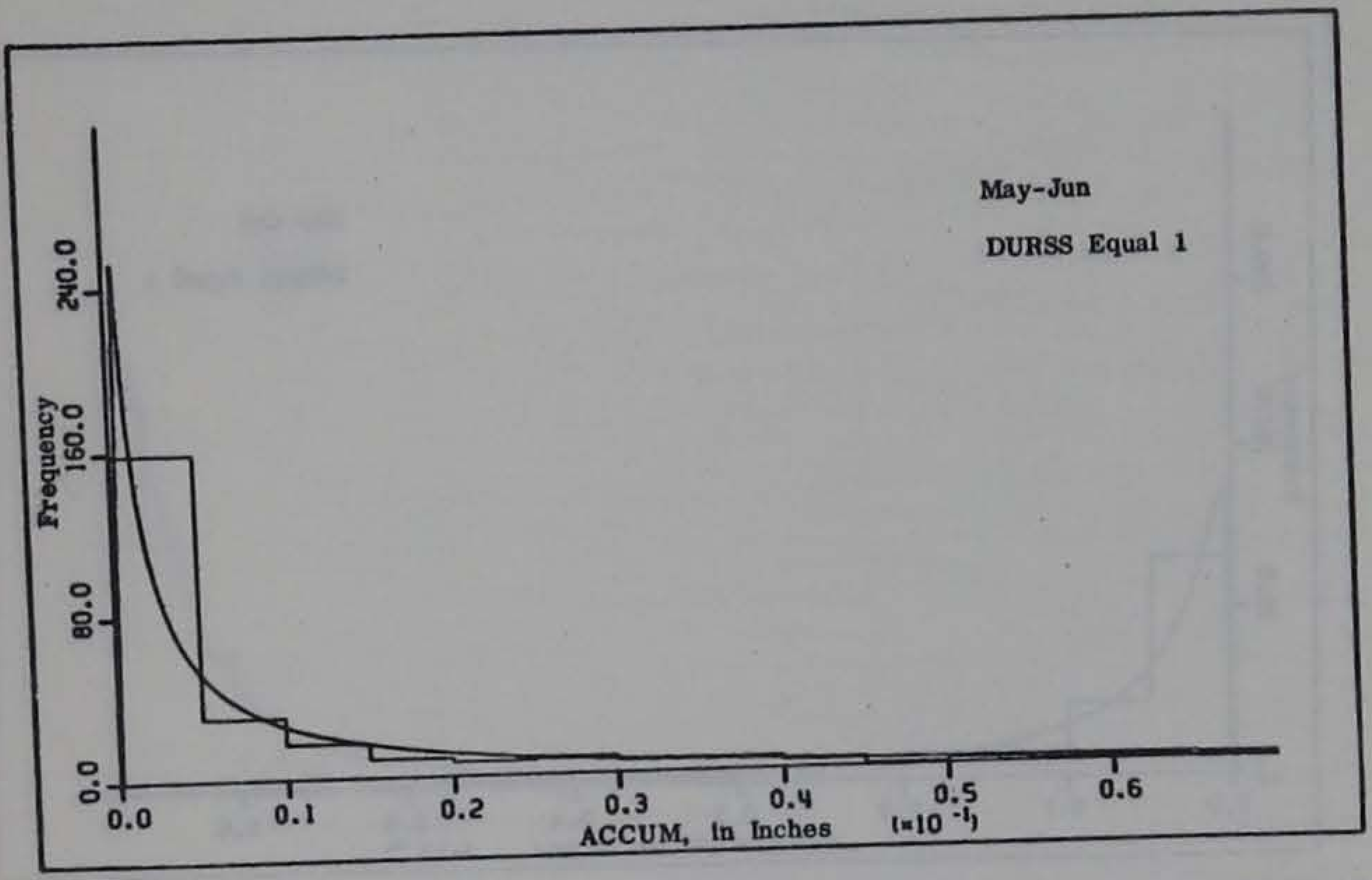

Figure D.3. ACCUM Frequency Histogram and Fitted Lognormal Function, Period 3, DURSS Equal 1

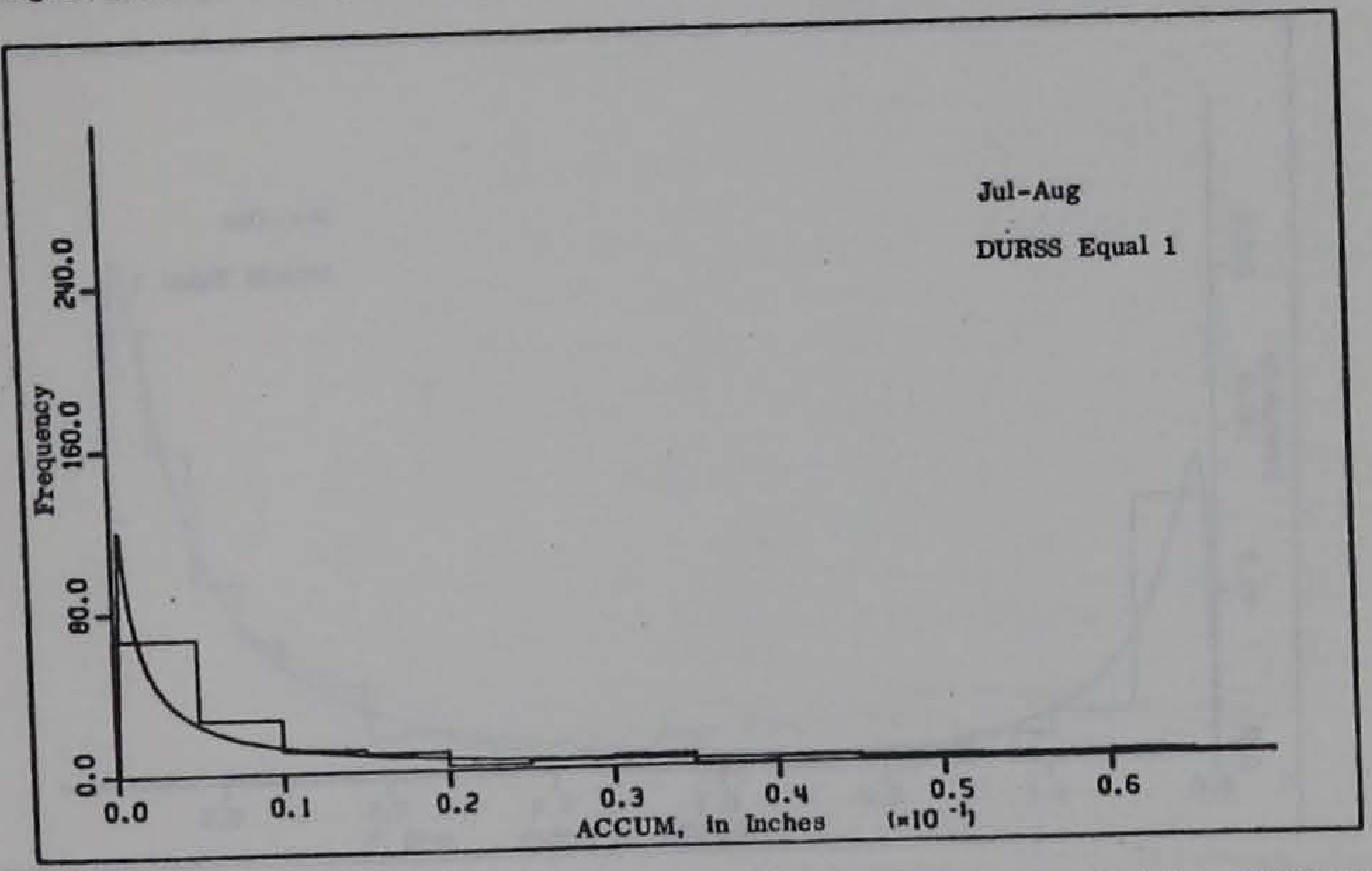

Figure D.4. ACCUM Frequency Histogram and Fitted Lognormal Function, Period 4, DURSS Equal 1

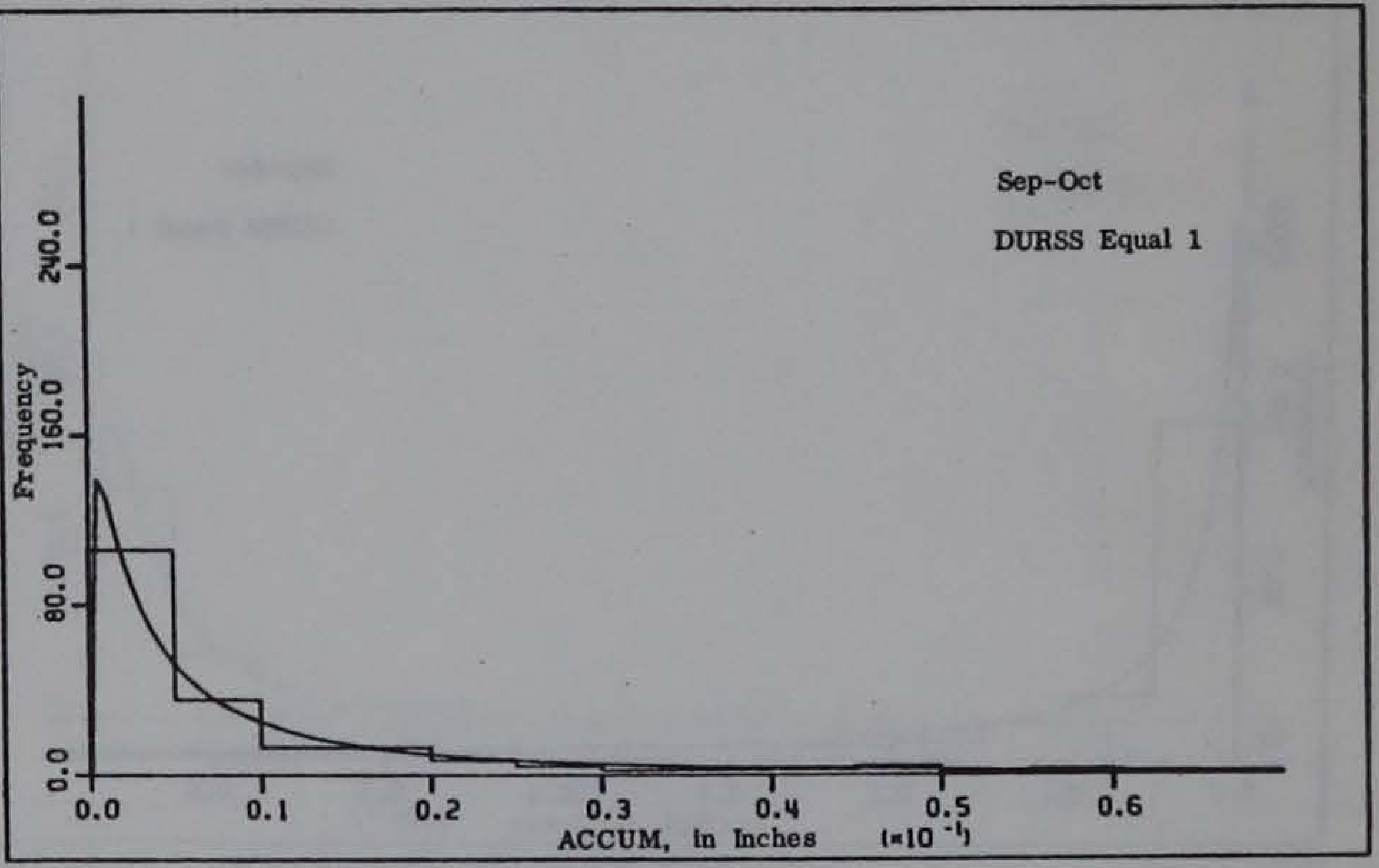

Figure D.5. ACCUM Frequency Histogram and Fitted Lognormal Function, Period 5, DURSS Equal 1

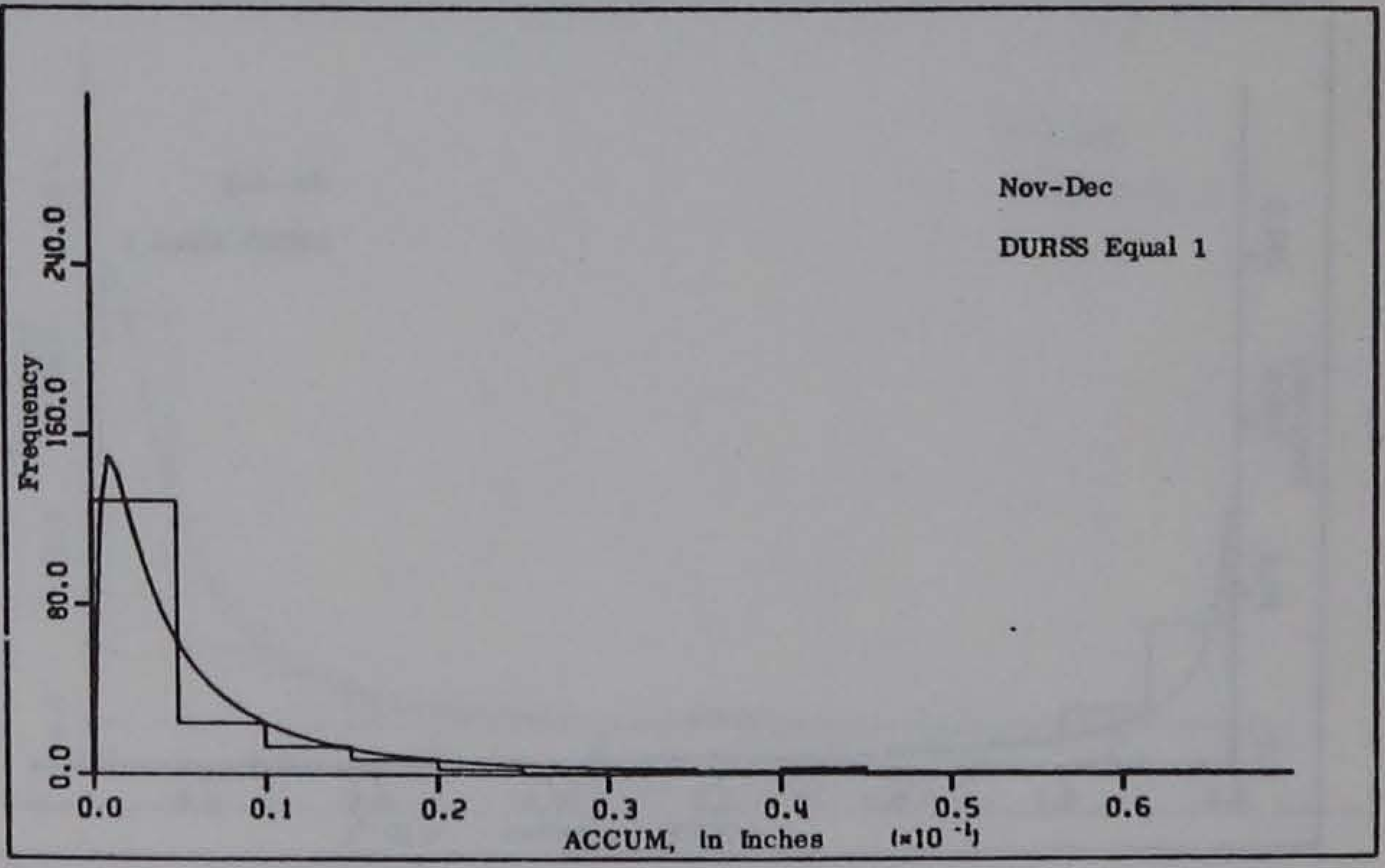

Figure D.6. ACCUM Frequency Histogram and Fitted Lognormal Function, Period 6, DURSS Equal 1

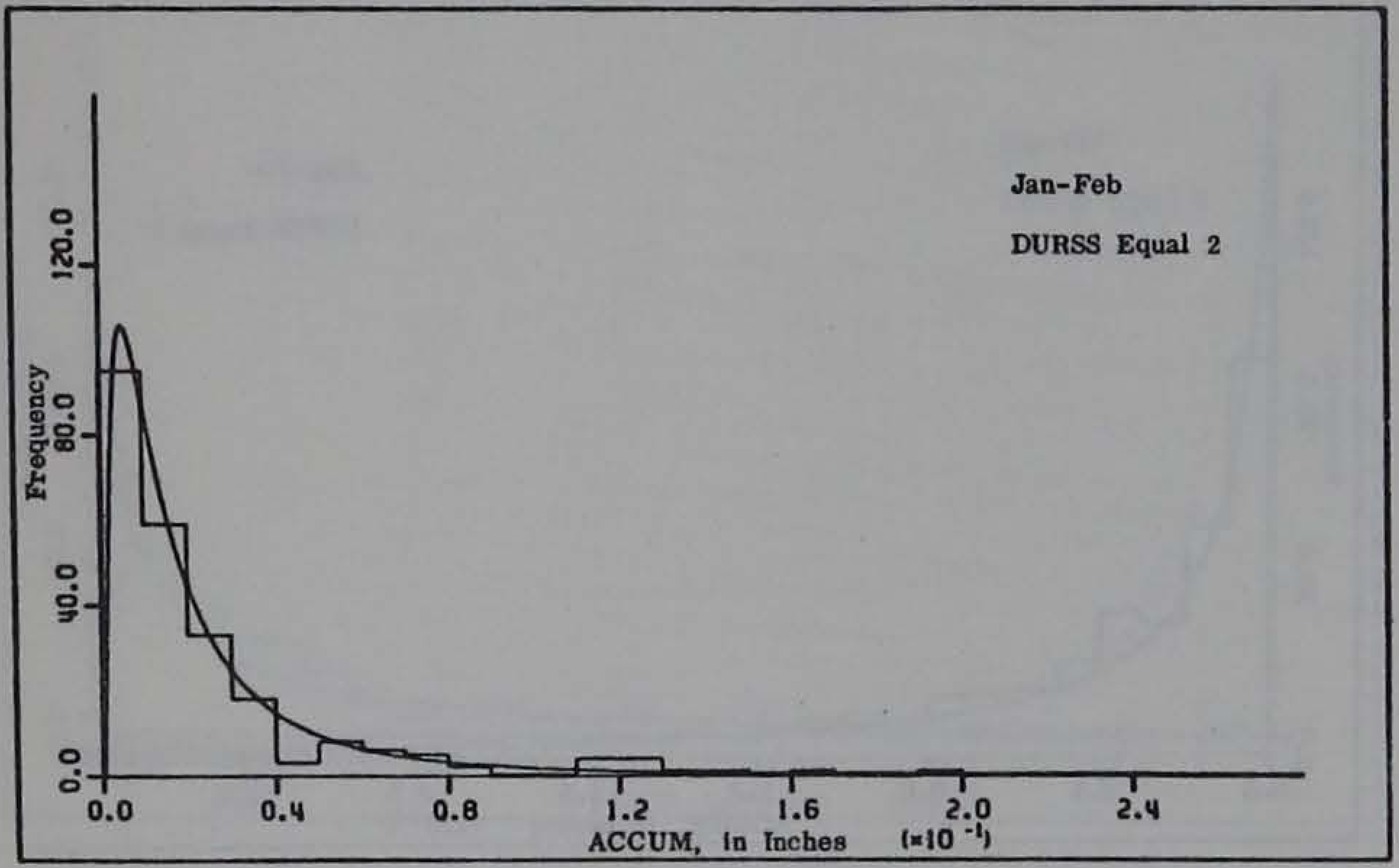

Figure D.7. ACCUM Frequency Histogram and Fitted Lognormal Function, Period 1, DURSS Equal 2

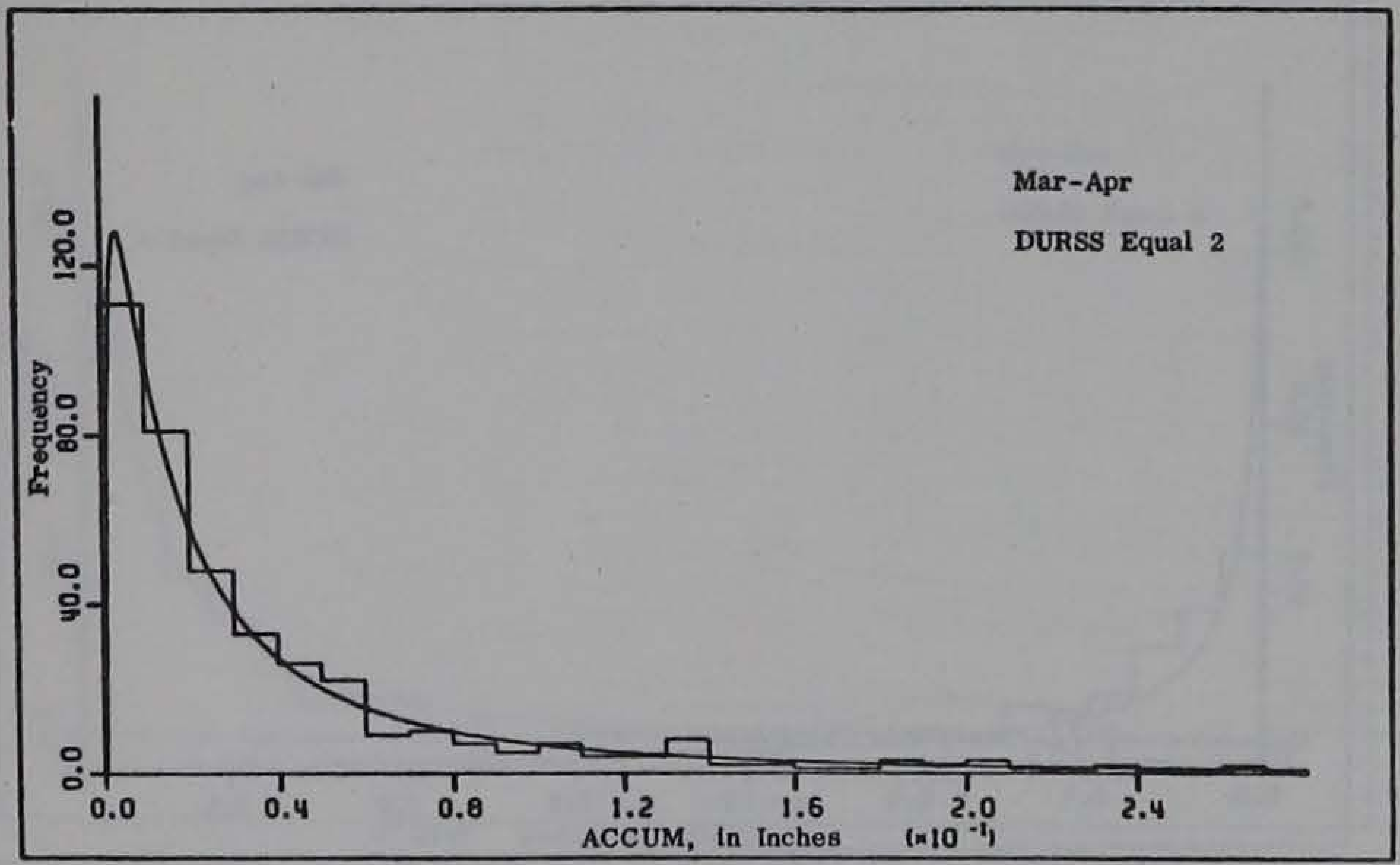

Figure D.8. ACCUM Frequency Histogram and Fitted Lognormal Function, Period 2, DURSS Equal 2

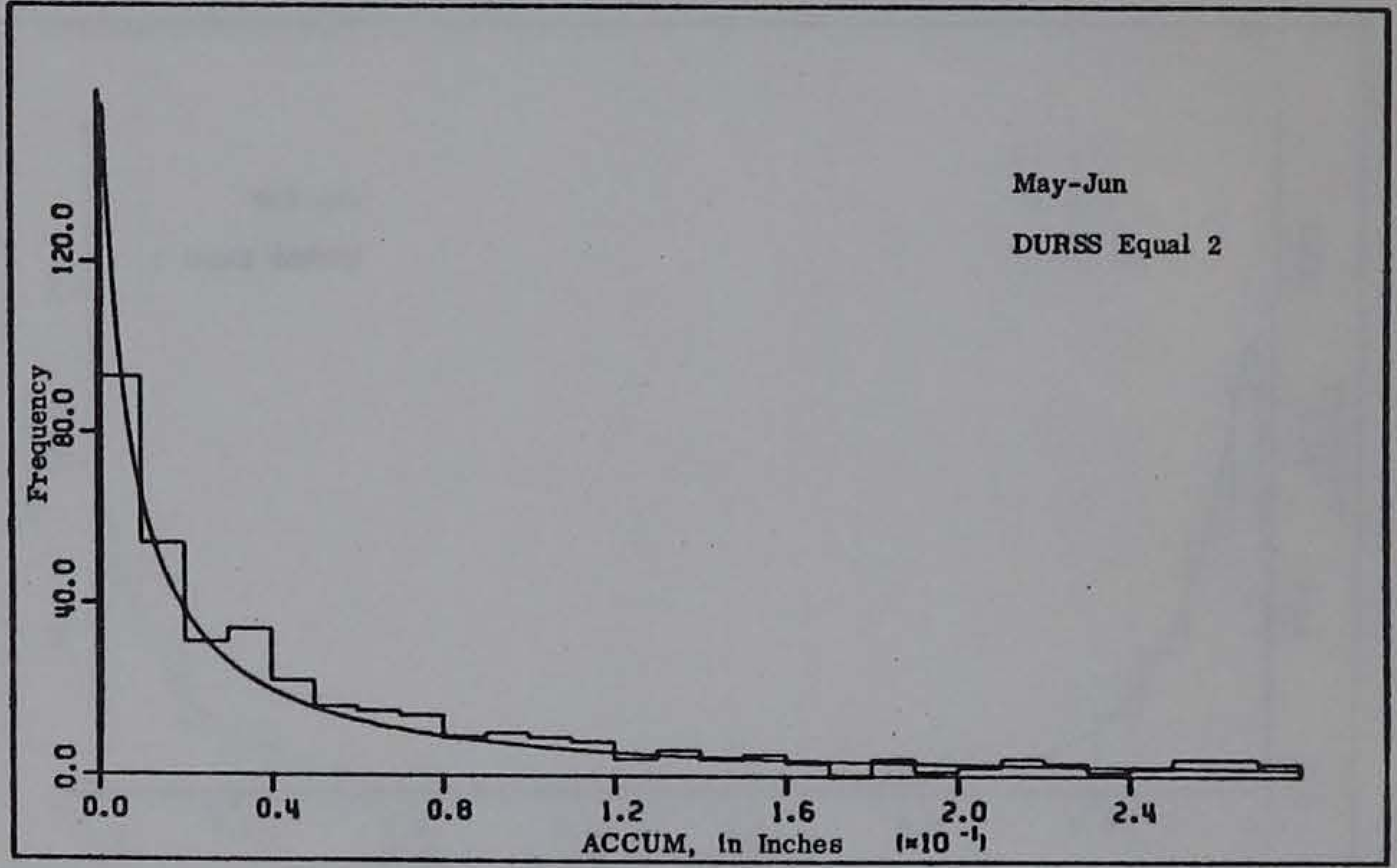

Figure D.9. ACCUM Frequency Histogram and Fitted Lognormal Function, Period 3, DURSS Equal 2

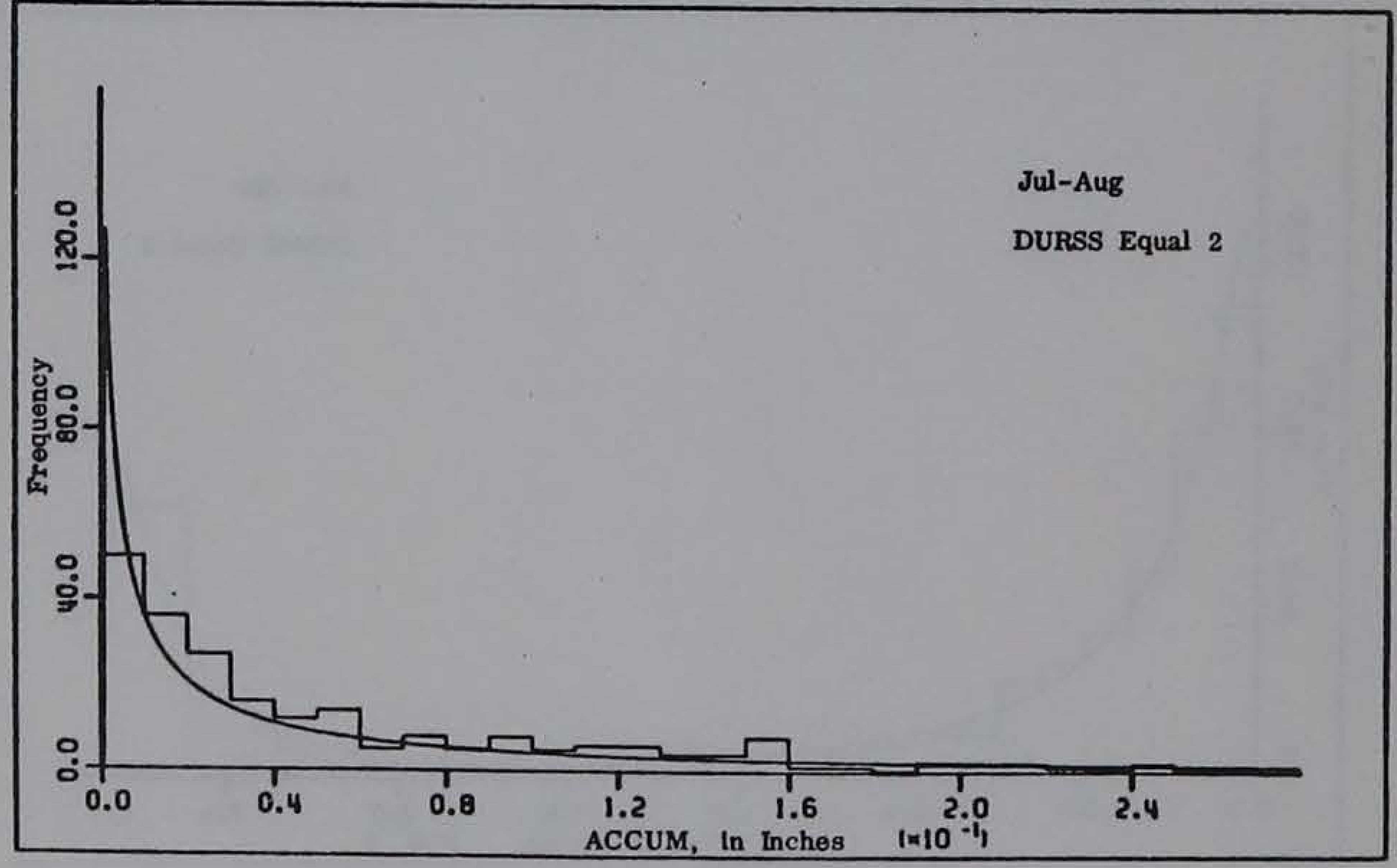

Figure D.10. ACCUM Frequency Histogram and Fitted Lognormal Function, Period 4, DURSS Equal 2

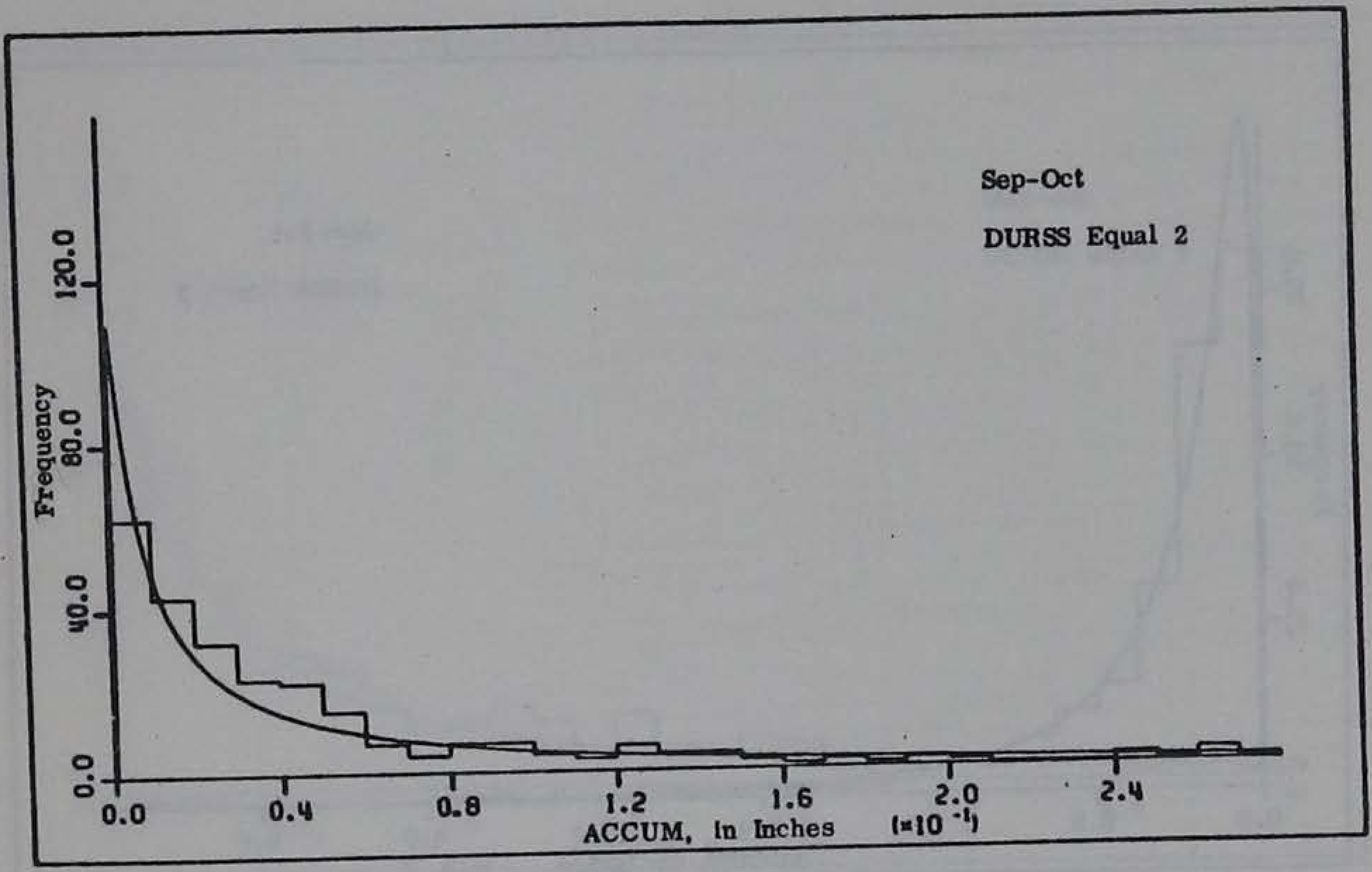

Figure D.11. ACCUM Frequency Histogram and Fitted Lognormal Function, Period 5, DURSS Equal 2

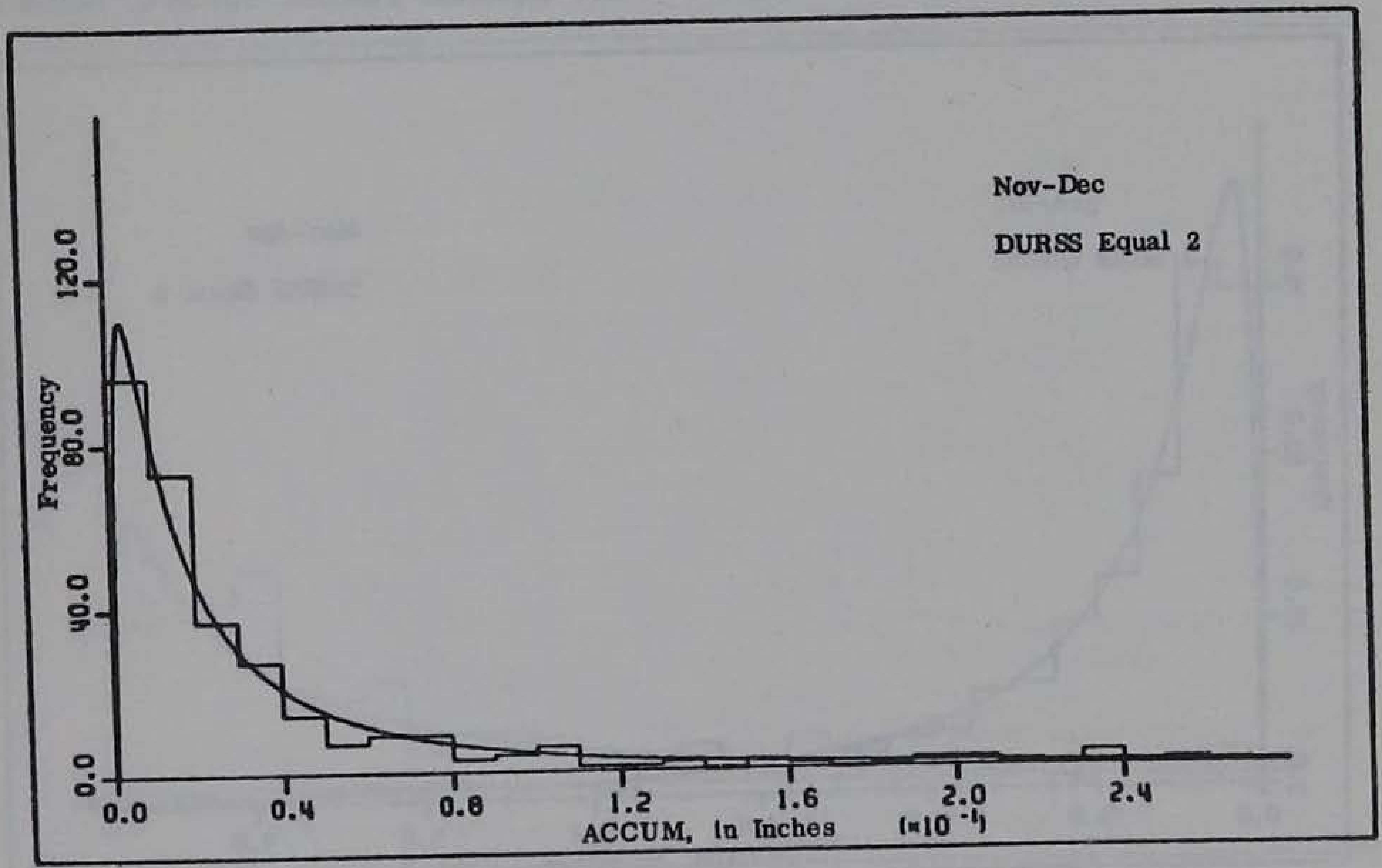

Figure D.12. ACCUM Frequency Histogram and Fitted Lognormal Function, Period 6, DURSS Equal 2

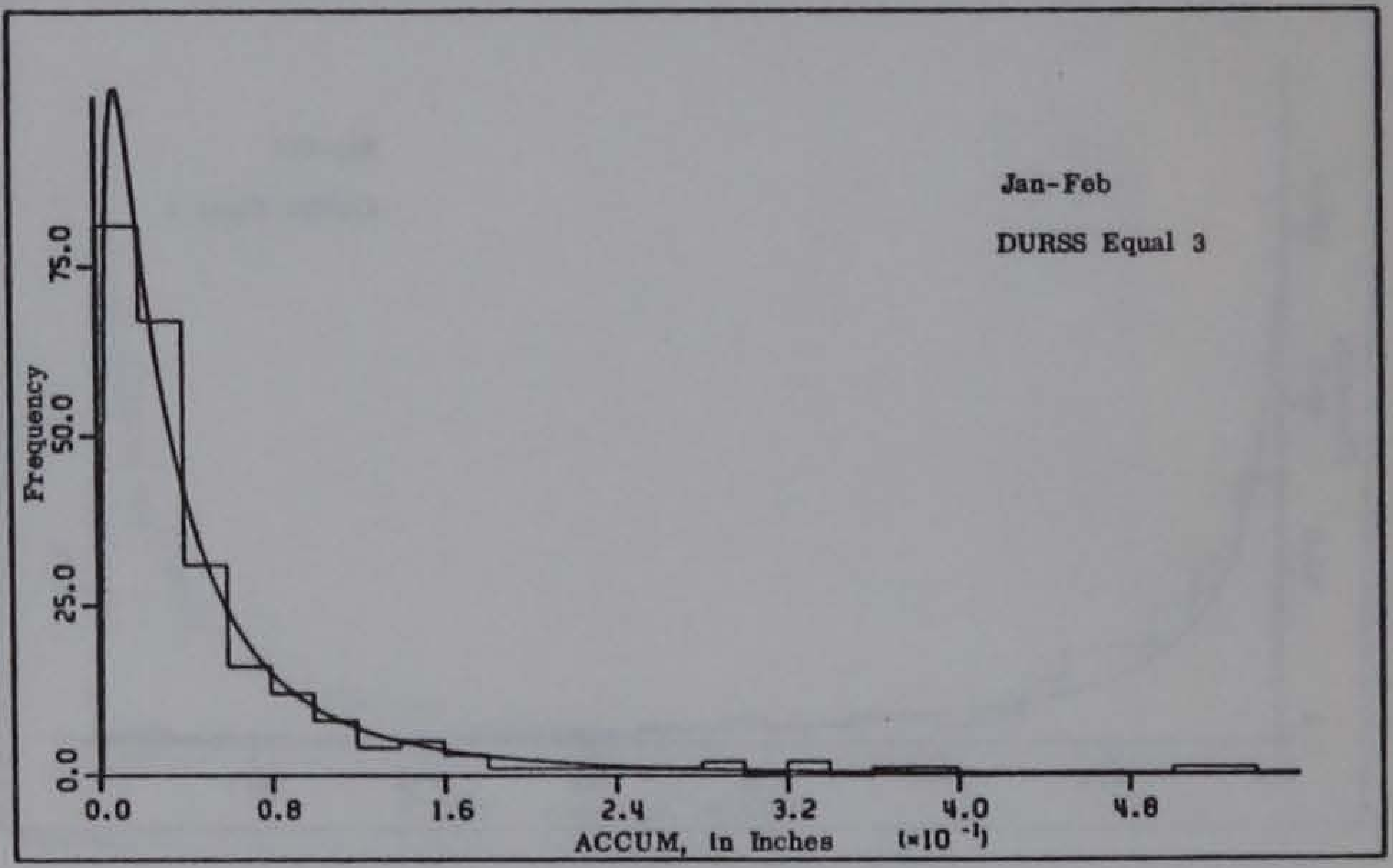

Figure D.13. ACCUM Frequency Histogram and Fitted Lognormal Function, Period 1, DURSS Equal 3

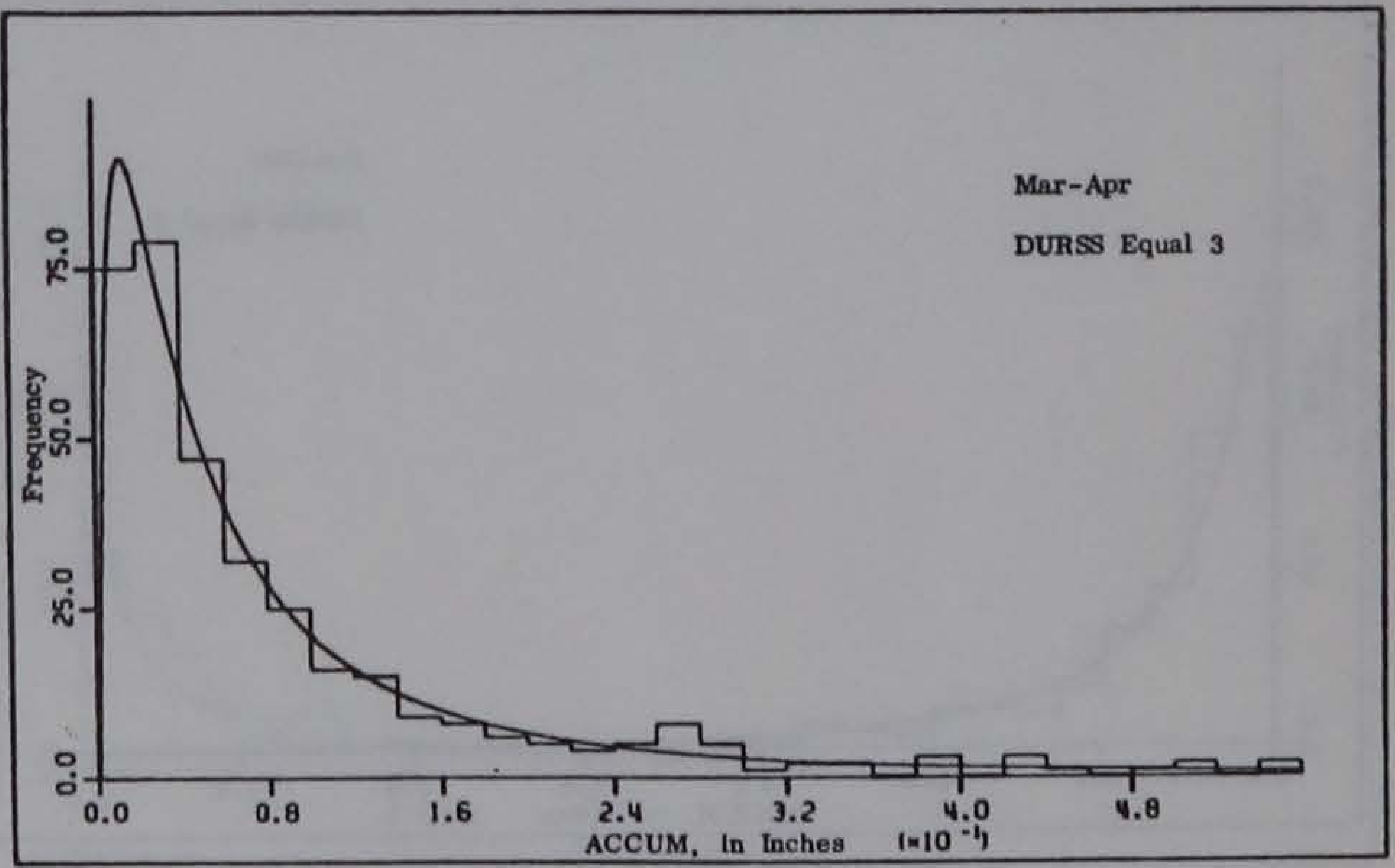

Figure D.14. ACCUM Frequency Histogram and Fitted Lognormal Function, Period 2, DURSS Equal 3

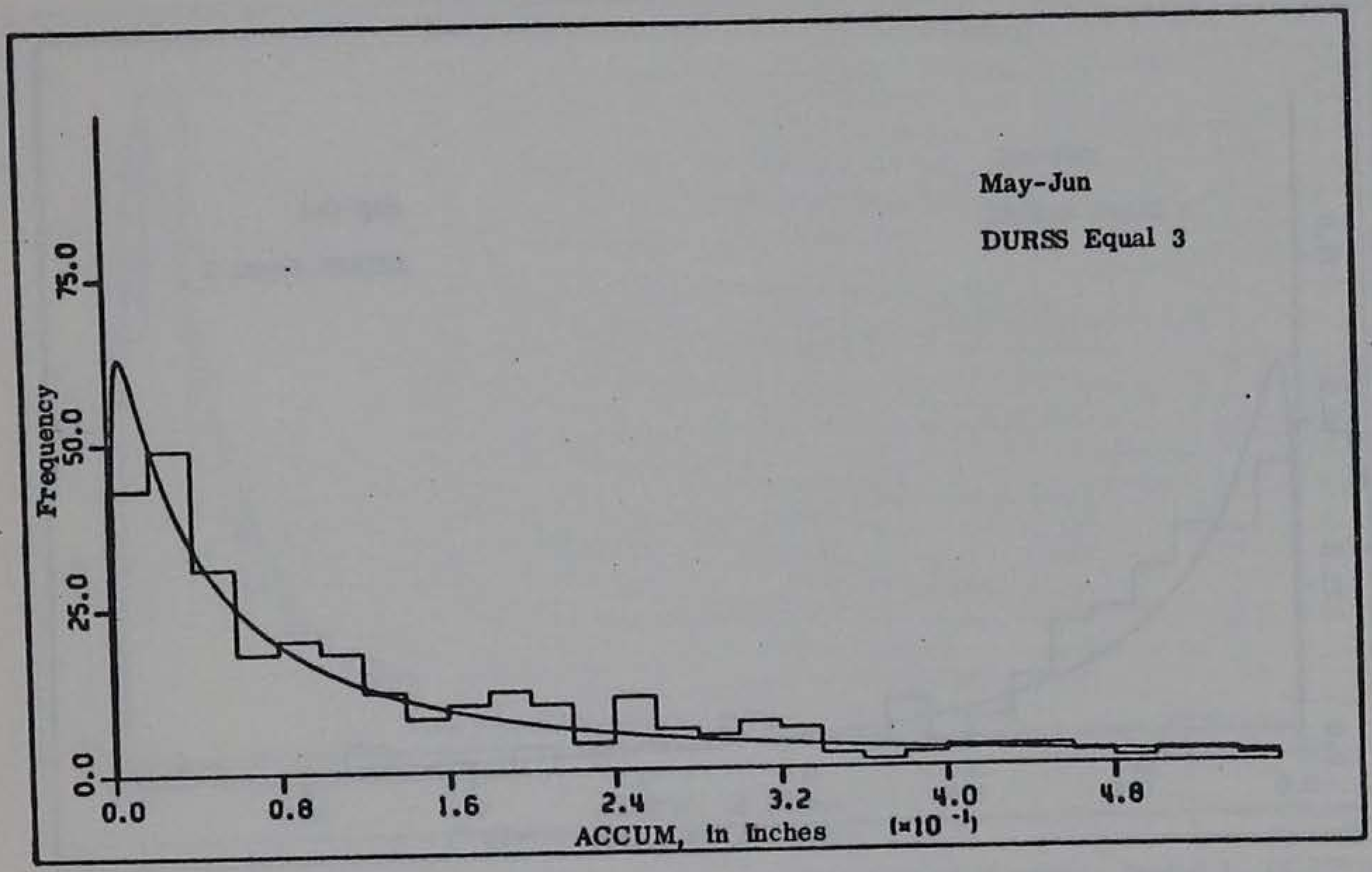

Figure D.15. ACCUM Frequency Histogram and Fitted Lognormal Function, Period 3, DURSS Equal 3

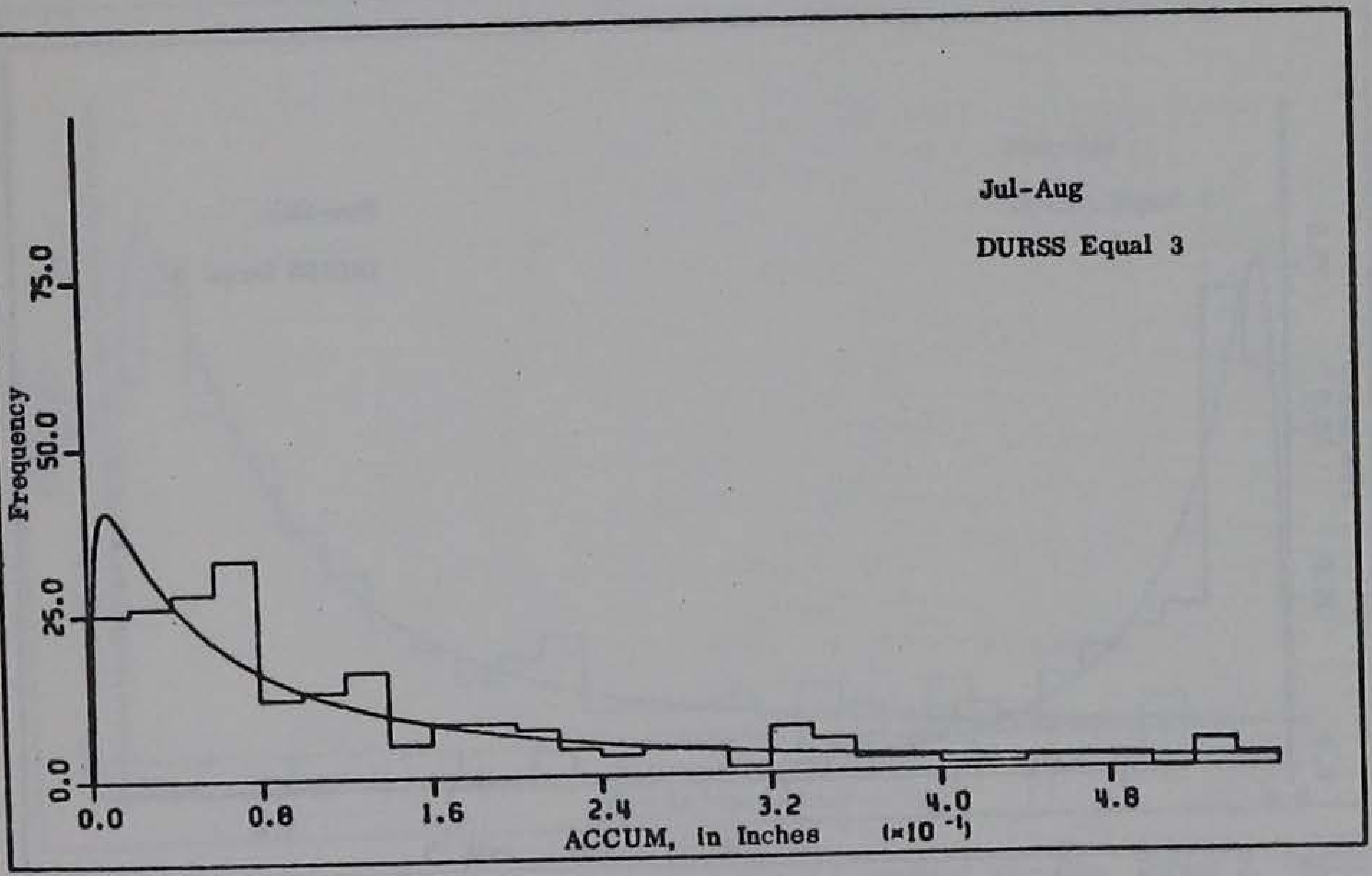

Figure D.16. ACCUM Frequency Histogram and Fitted Lognormal Function, Period 4, DURSS Equal 3

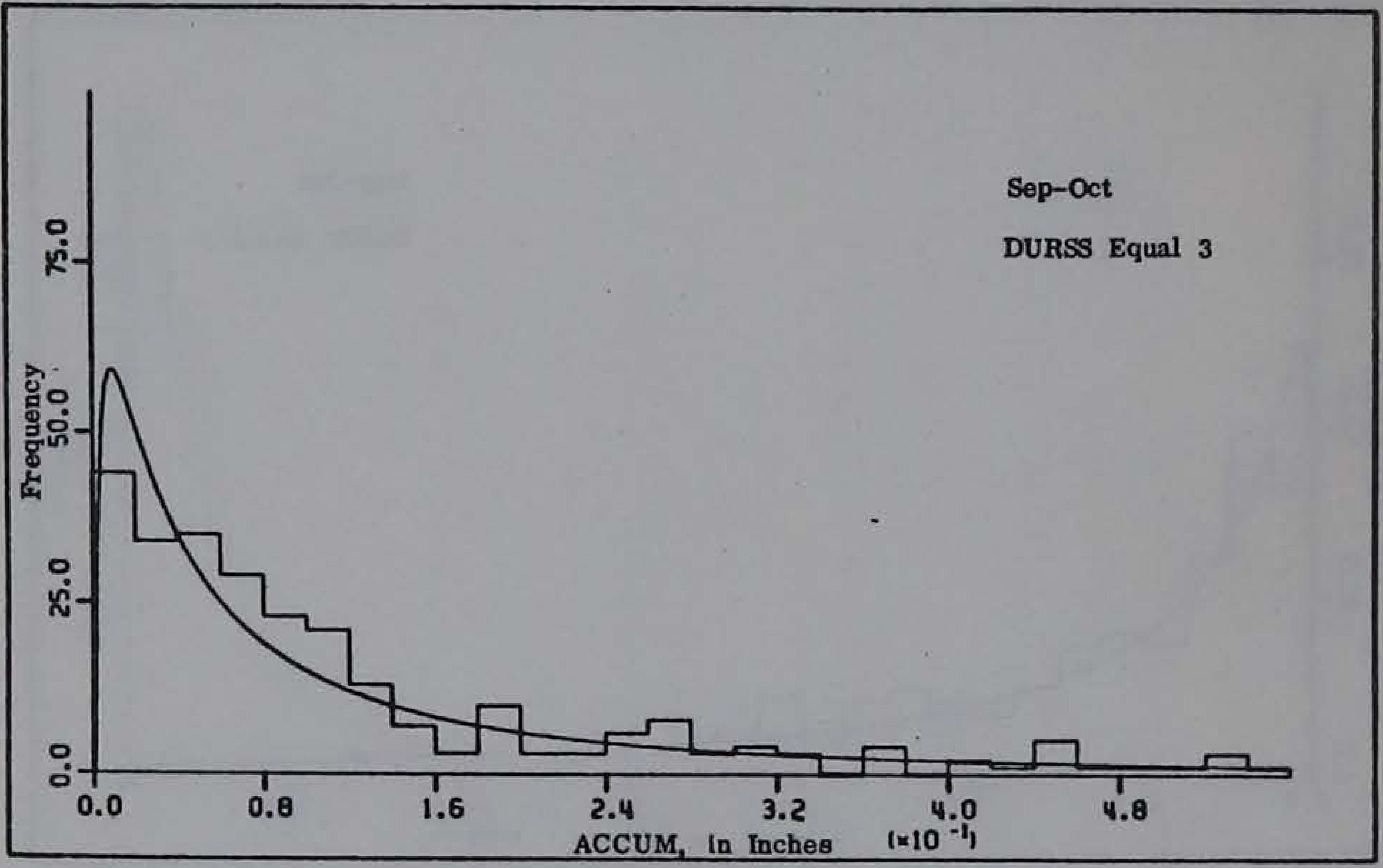

Figure D.17. ACCUM Frequency Histogram and Fitted Lognormal Function, Period 5, DURSS Equal 3

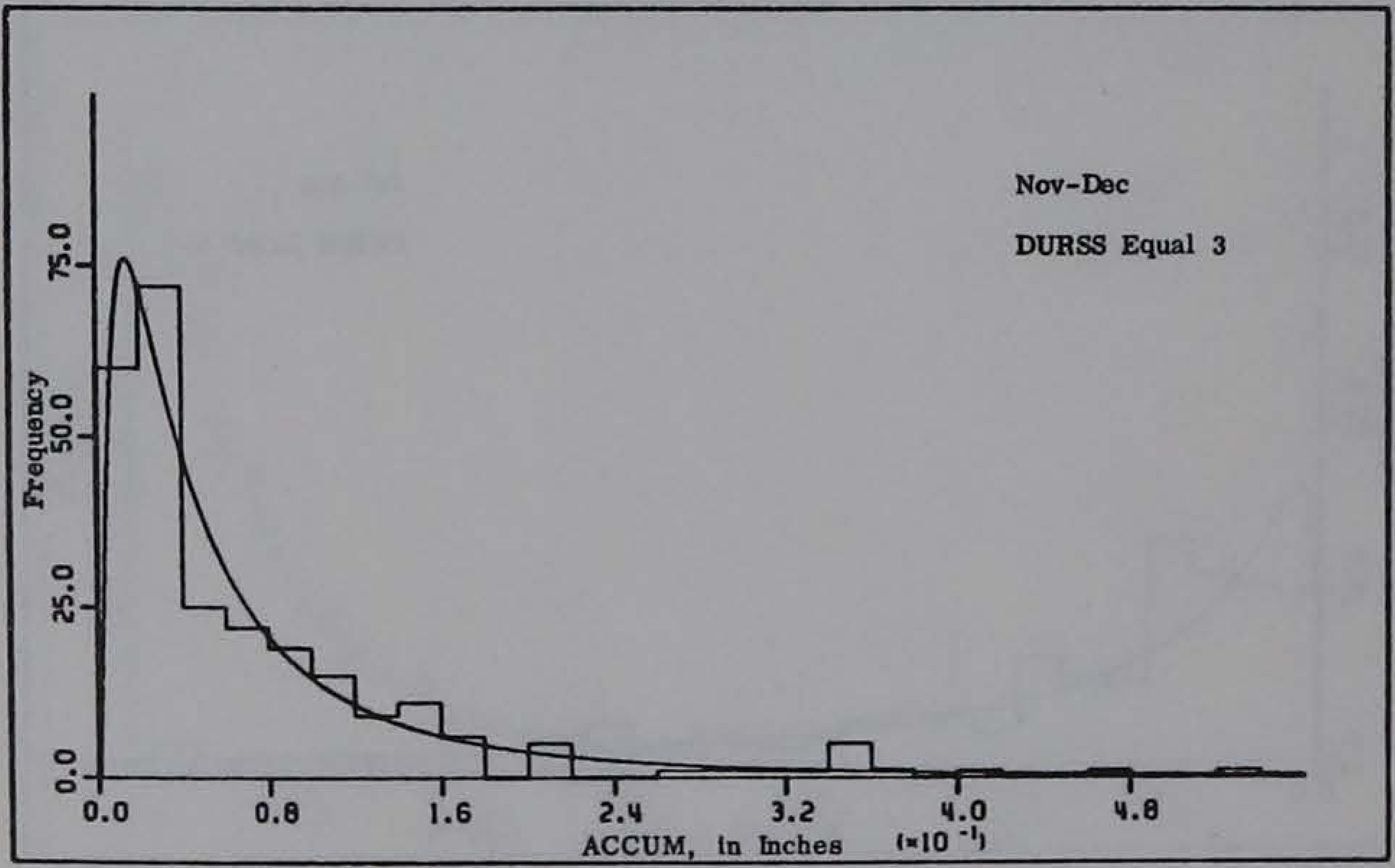

Figure D.18. ACCUM Frequency Histogram and Fitted Lognormal Function, Period 6, DURSS Equal 3

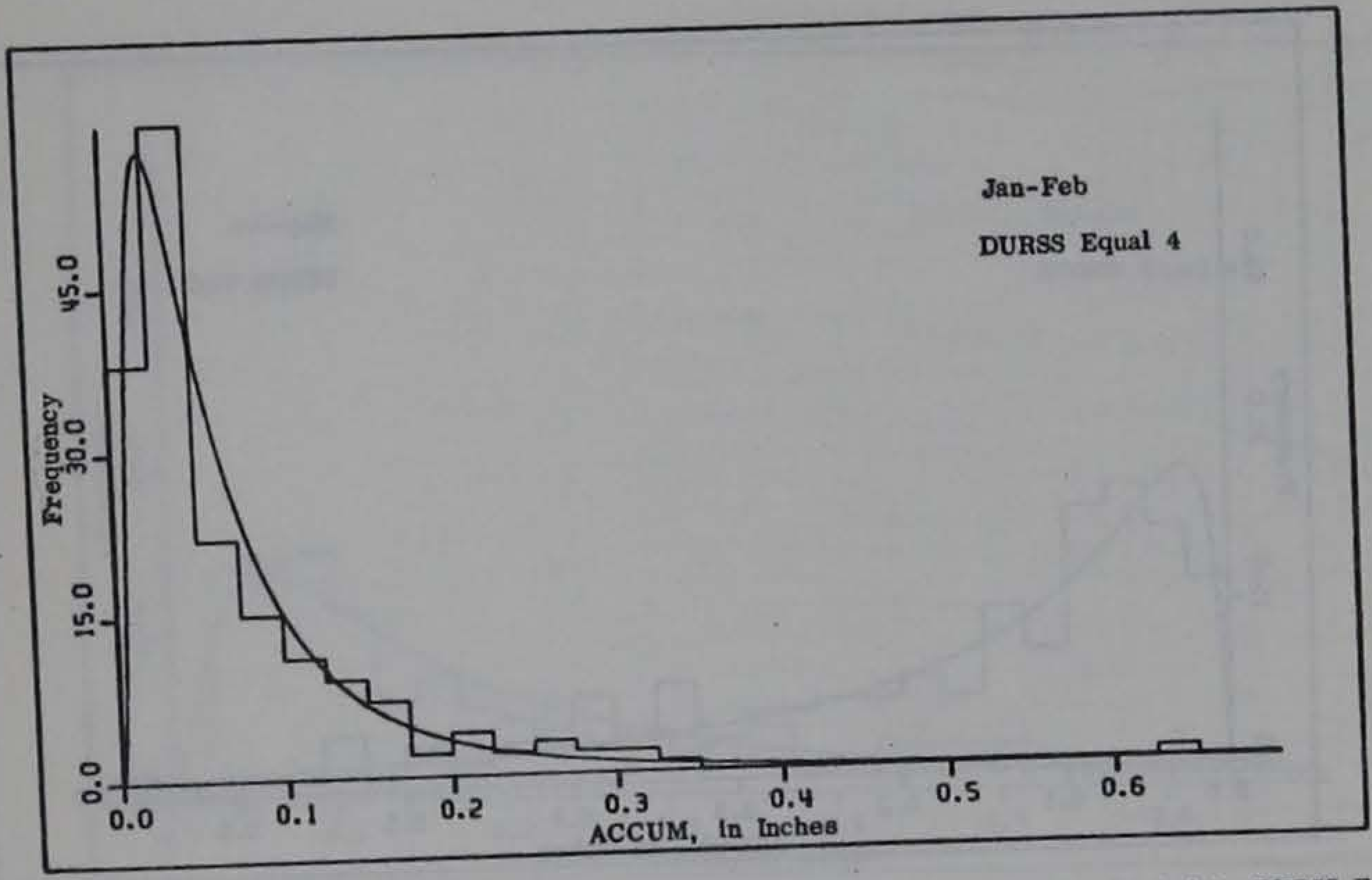

Figure D.19. ACCUM Frequency Histogram and Fitted Lognormal Function, Period 1, DURSS Equal 4

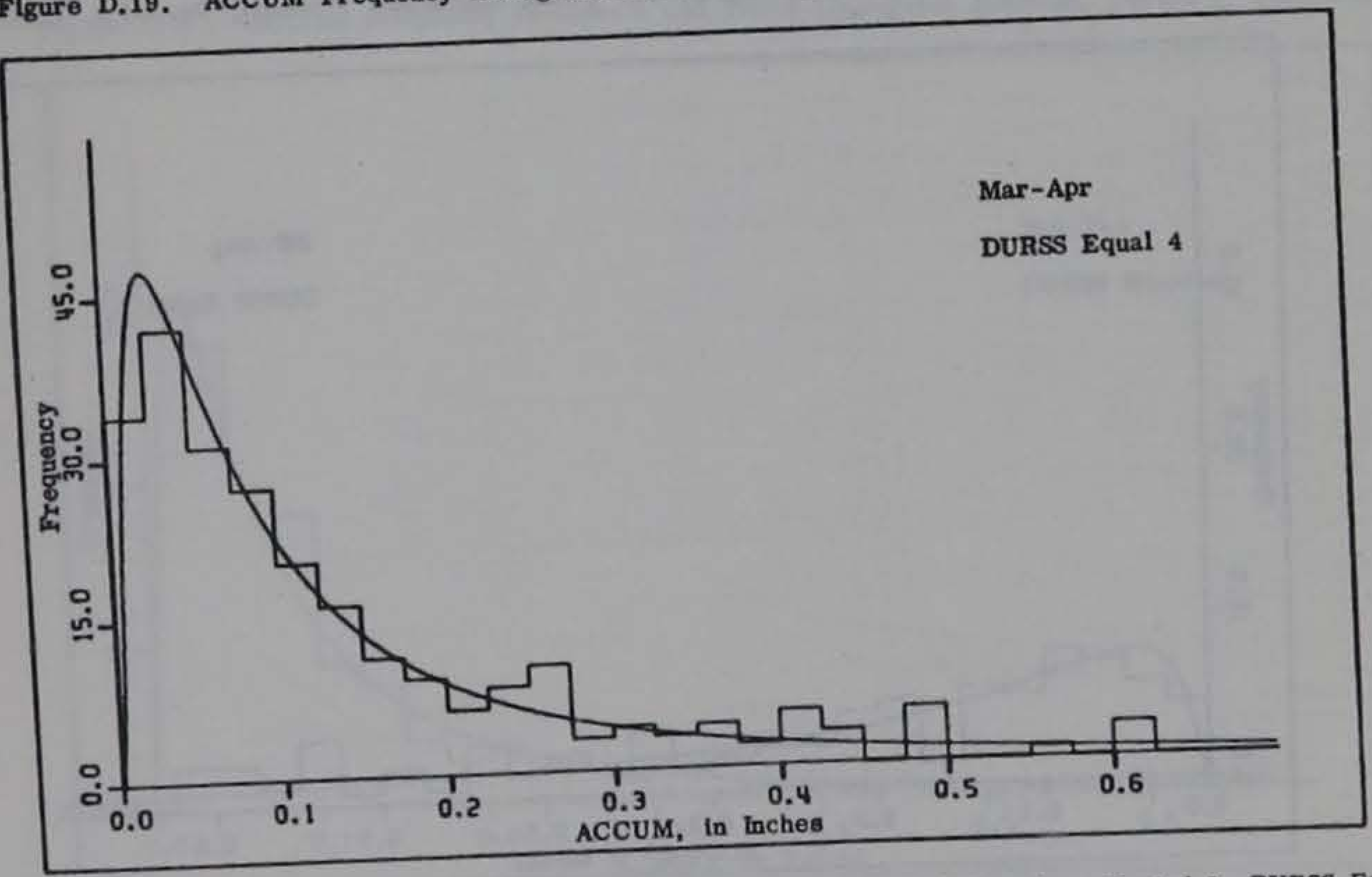

Figure D.20. ACCUM Frequency Histogram and Fitted Lognormal Function, Period 2, DURSS Equal 4

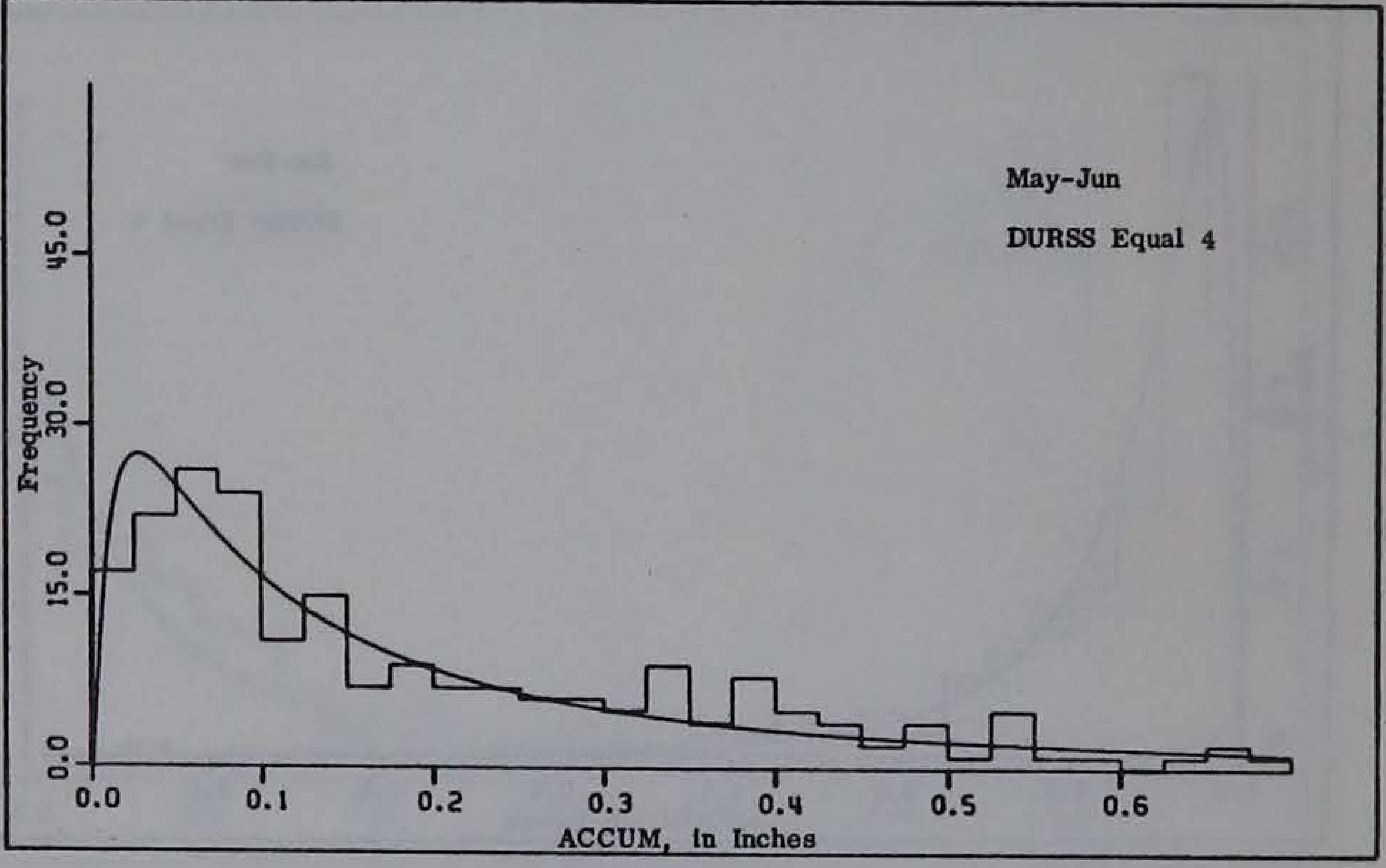

Figure D.21. ACCUM Frequency Histogram and Fitted Lognormal Function, Period 3, DURSS Equal 4

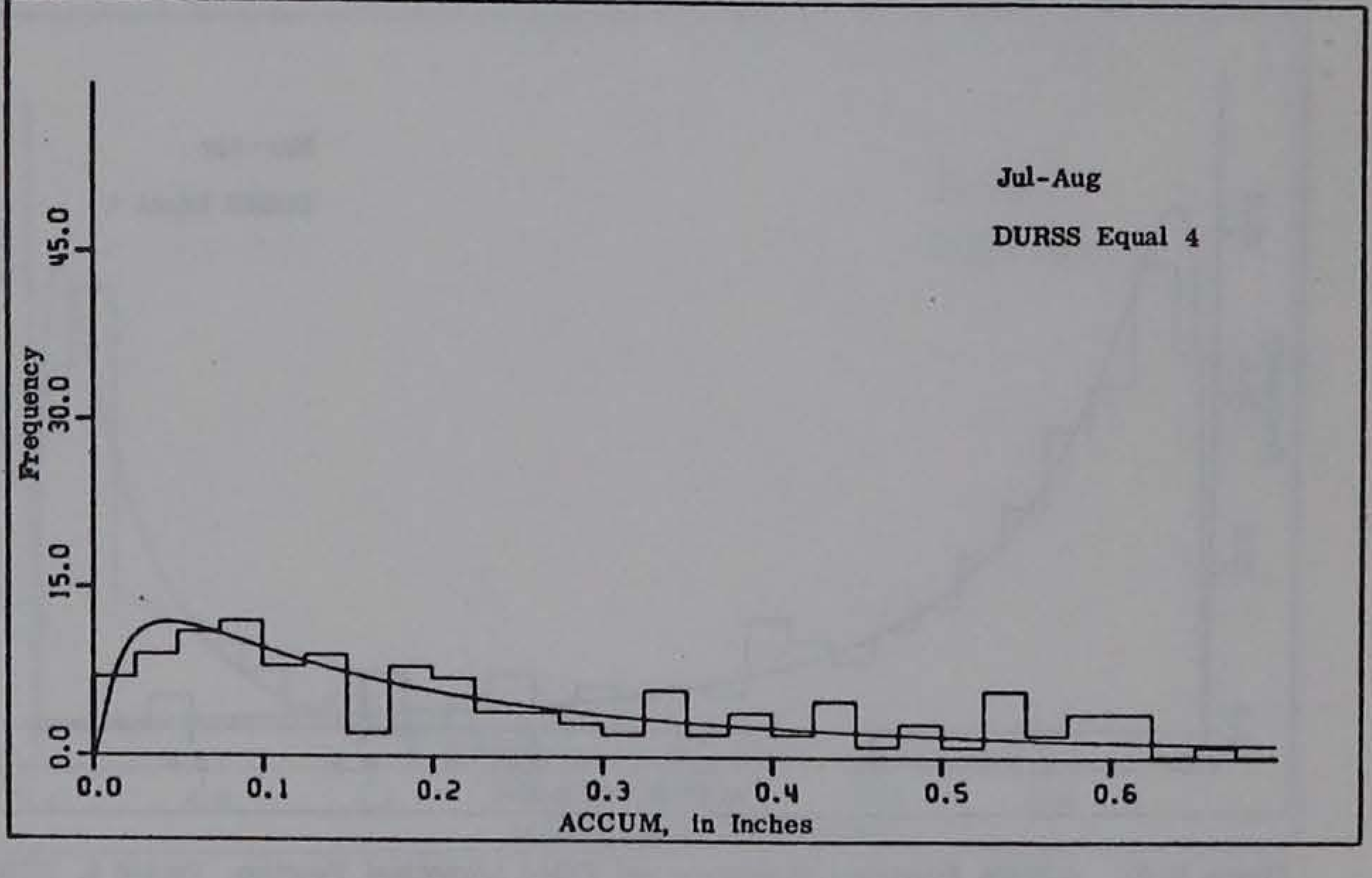

Figure D.22. ACCUM Frequency Histogram and Fitted Lognormal Function, Period 4, DURSS Equal 4

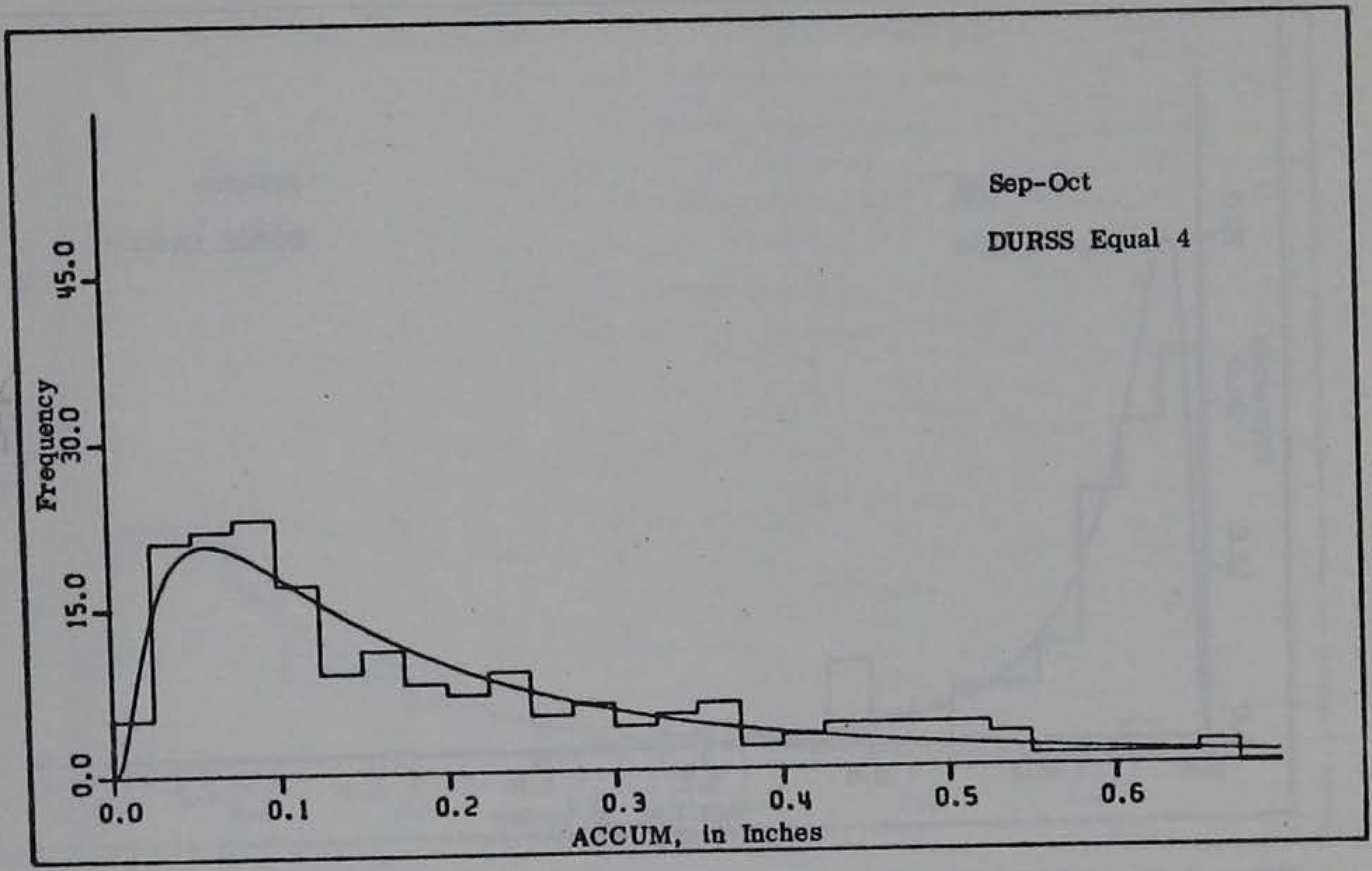

Figure D.23. ACCUM Frequency Histogram and Fitted Lognormal Function, Period 5, DURSS Equal 4

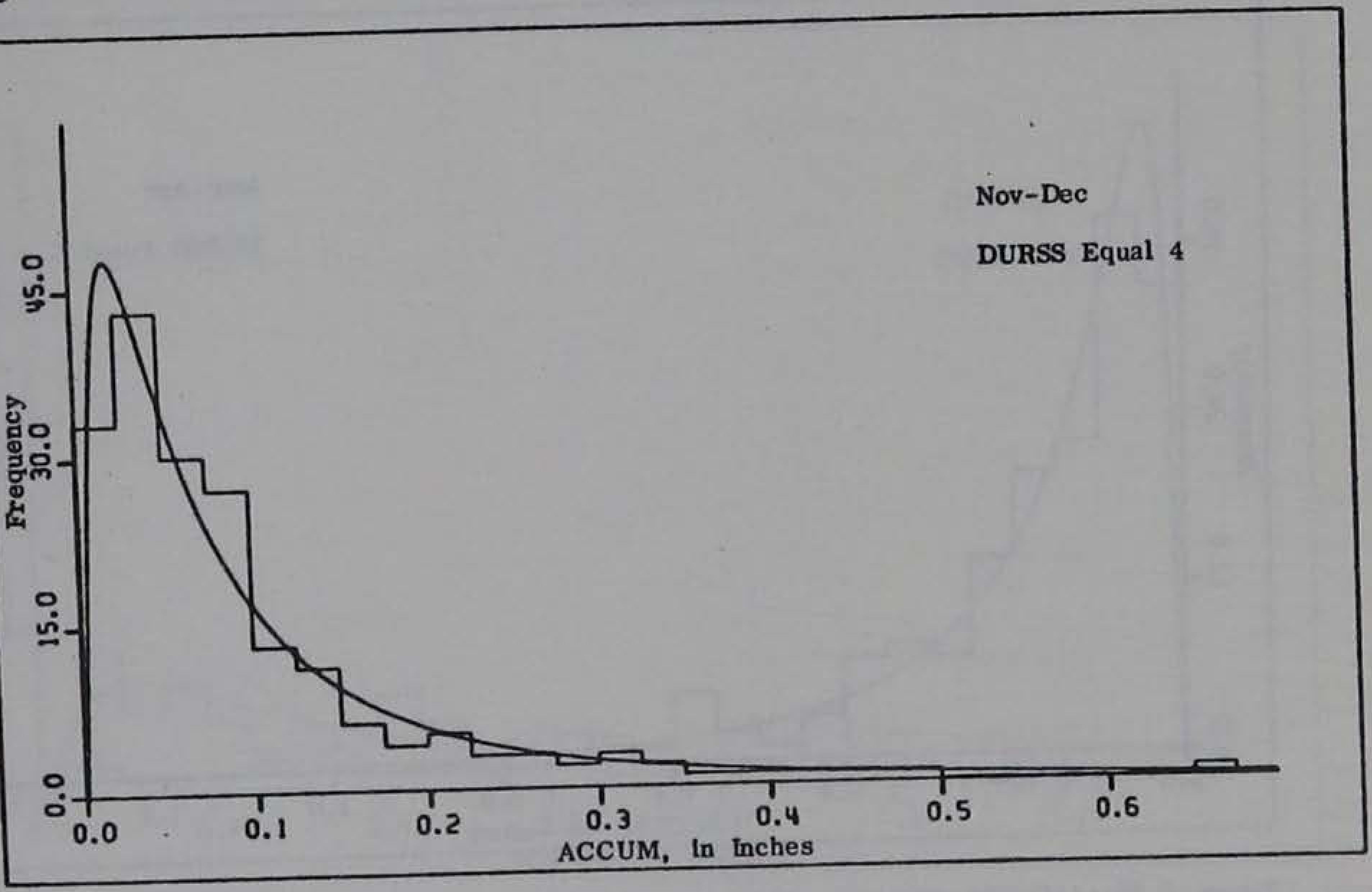

Figure D.24. ACCUM Frequency Histogram and Fitted Lognormal Function, Period 6, DURSS Equal 4

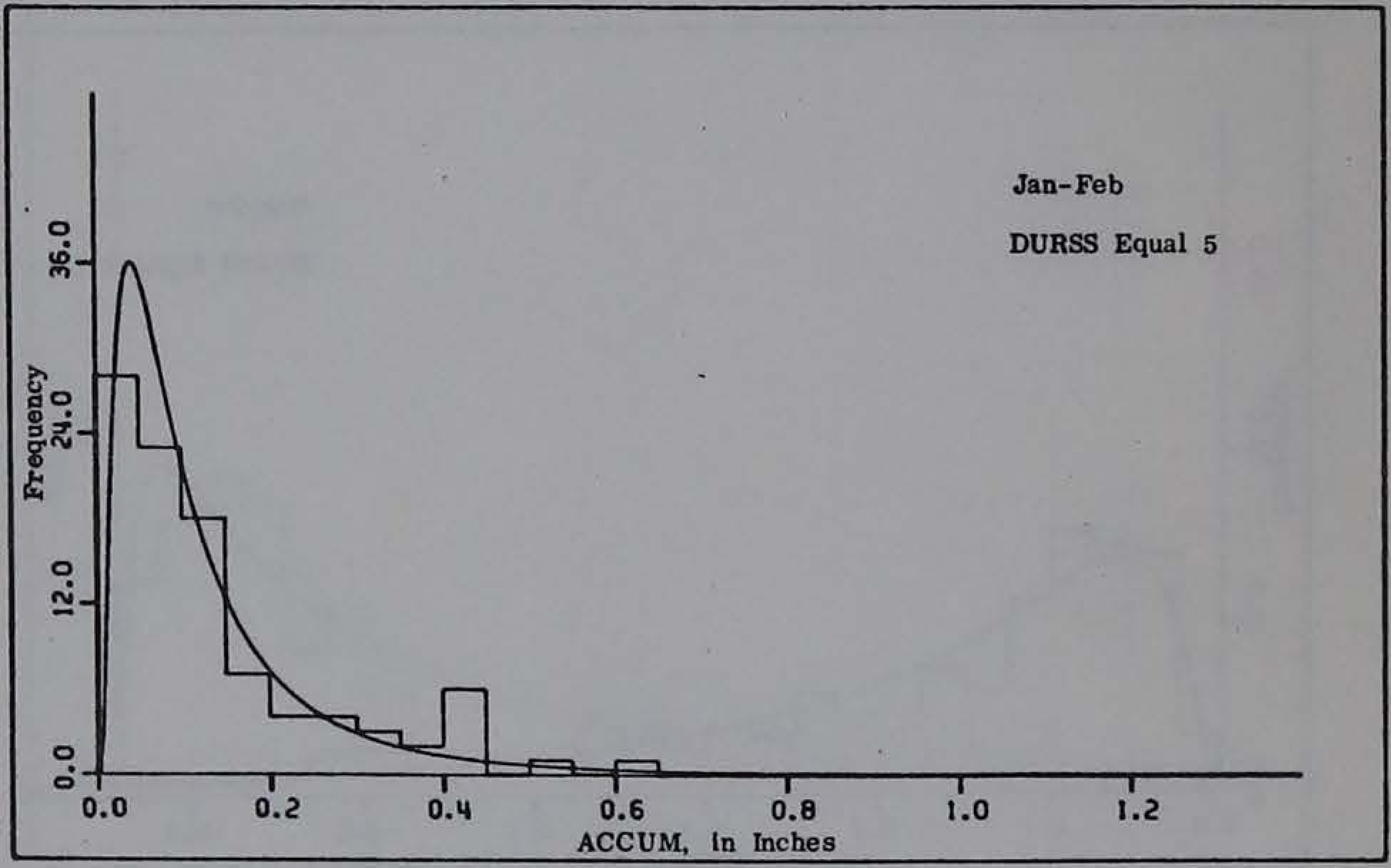

Figure D.25. ACCUM Frequency Histogram and Fitted Lognormal Function, Period 1, DURSS Equal 5

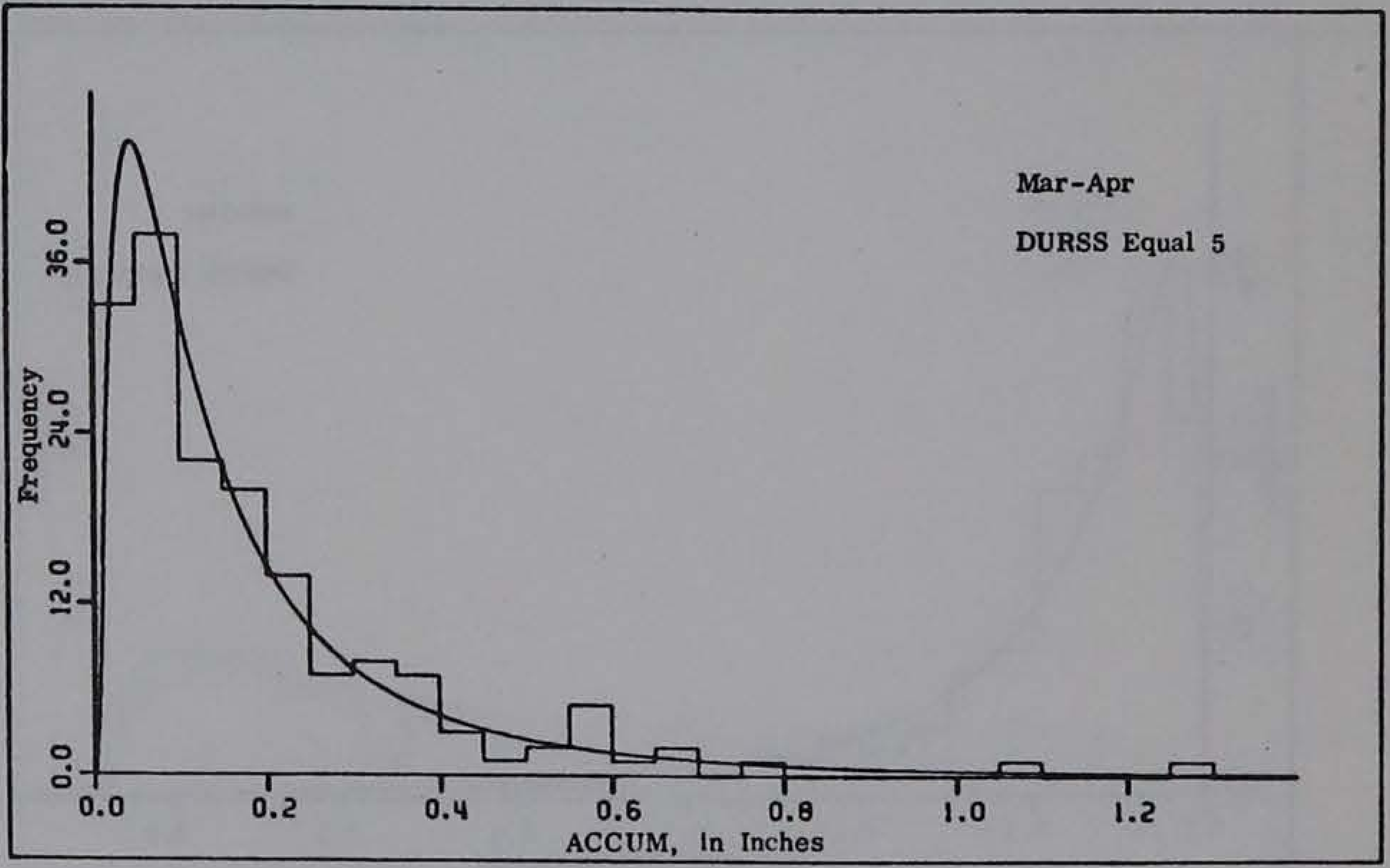

Figure D.26. ACCUM Frequency Histogram and Fitted Lognormal Function, Period 2, DURSS Equal 5

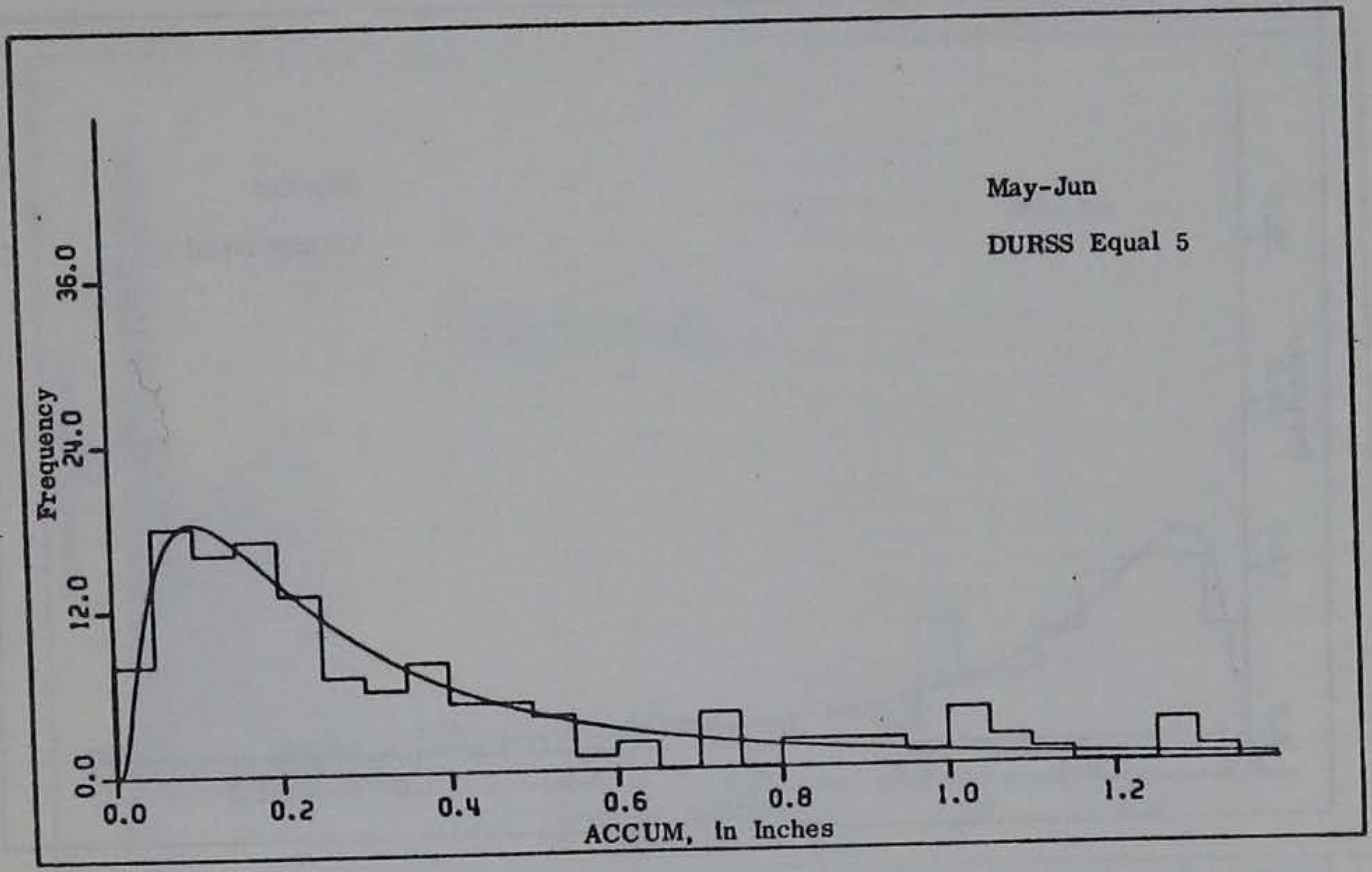

Figure D.27. ACCUM Frequency Histogram and Fitted Lognormal Function, Period 3, DURSS Equal 5

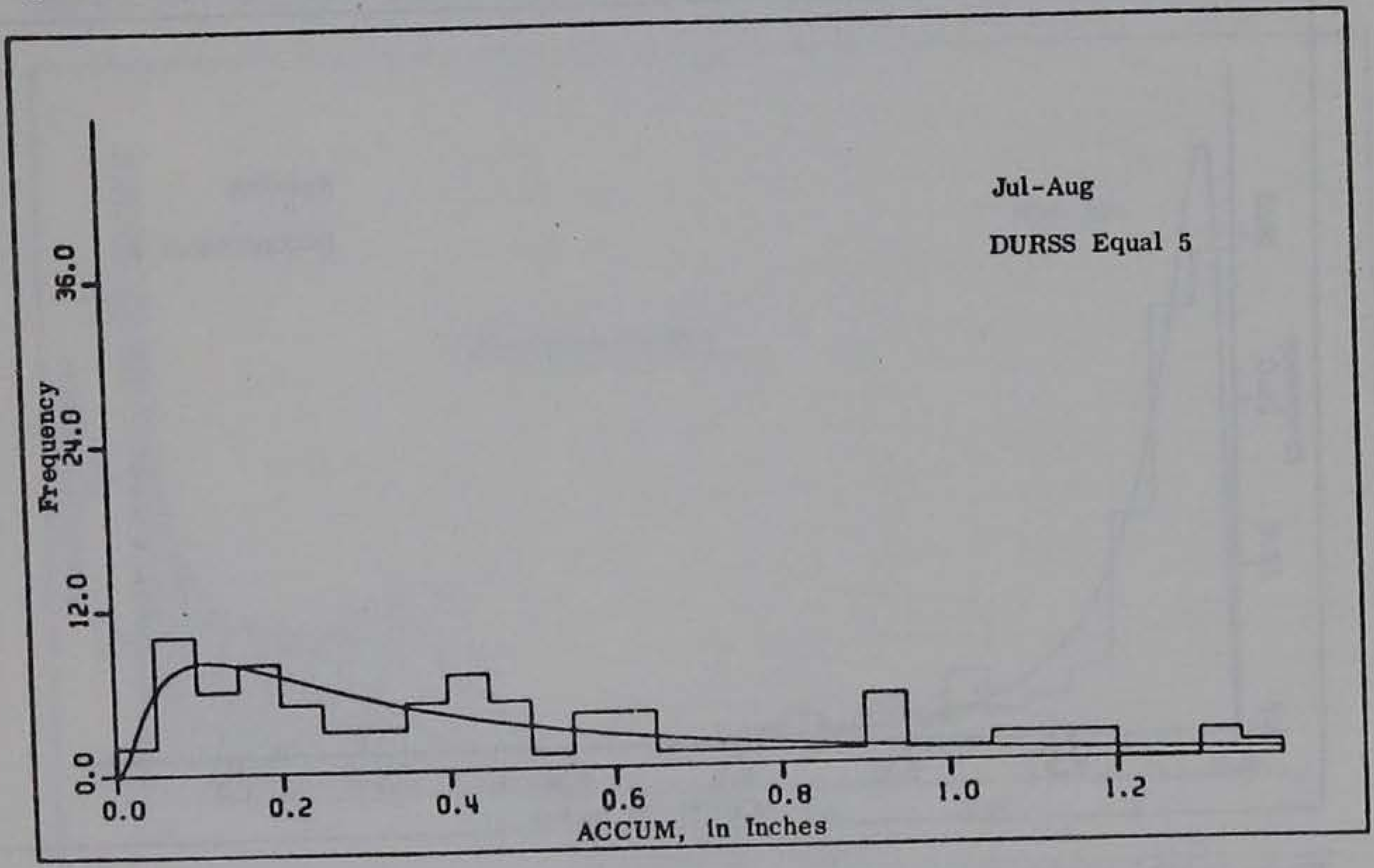

Figure D.28. ACCUM Frequency Histogram and Fitted Lognormal Function, Period 4, DURSS Equal 5

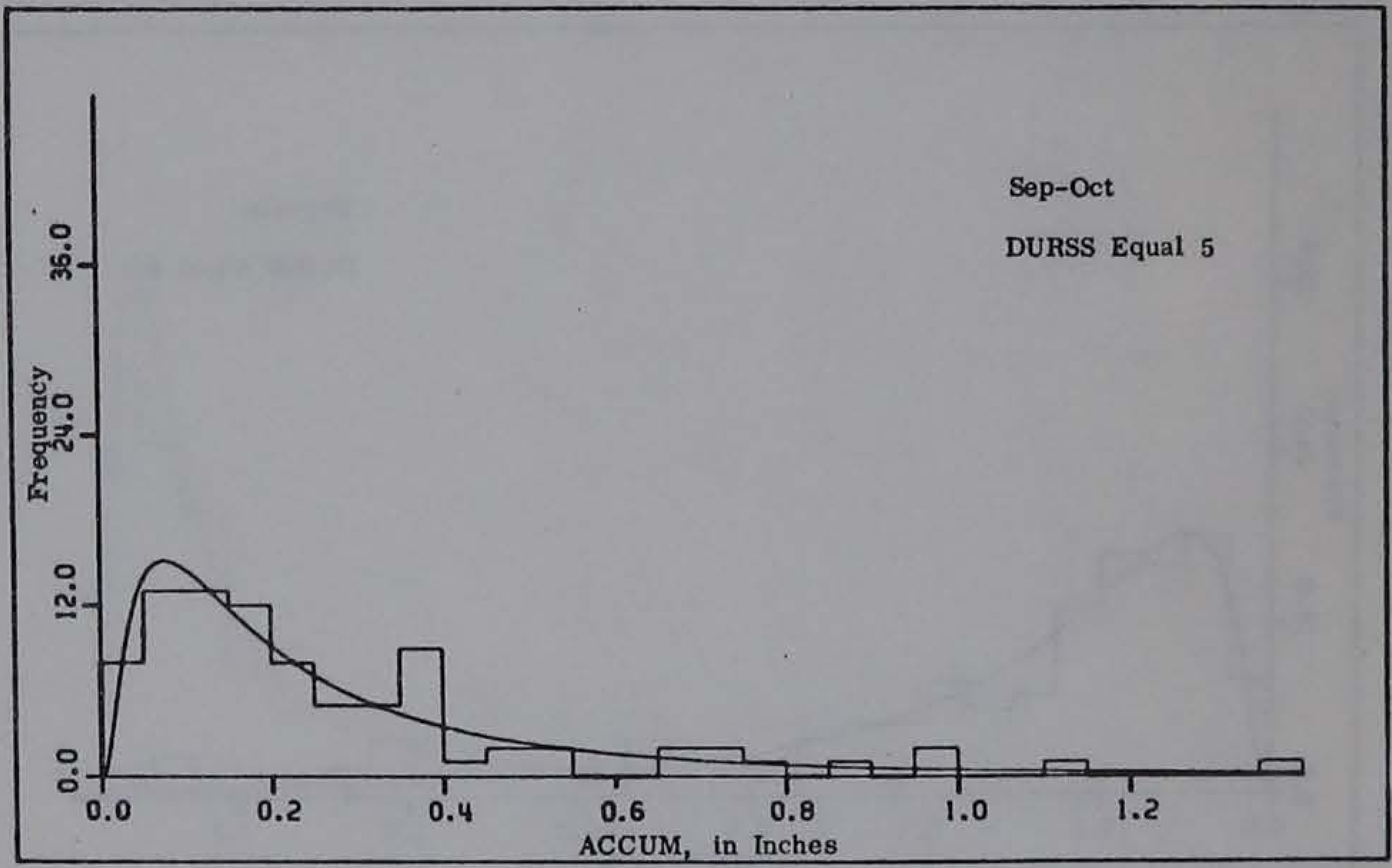

Figure D.29. ACCUM Frequency Histogram and Fitted Lognormal Function, Period 5, DURSS Equal 5

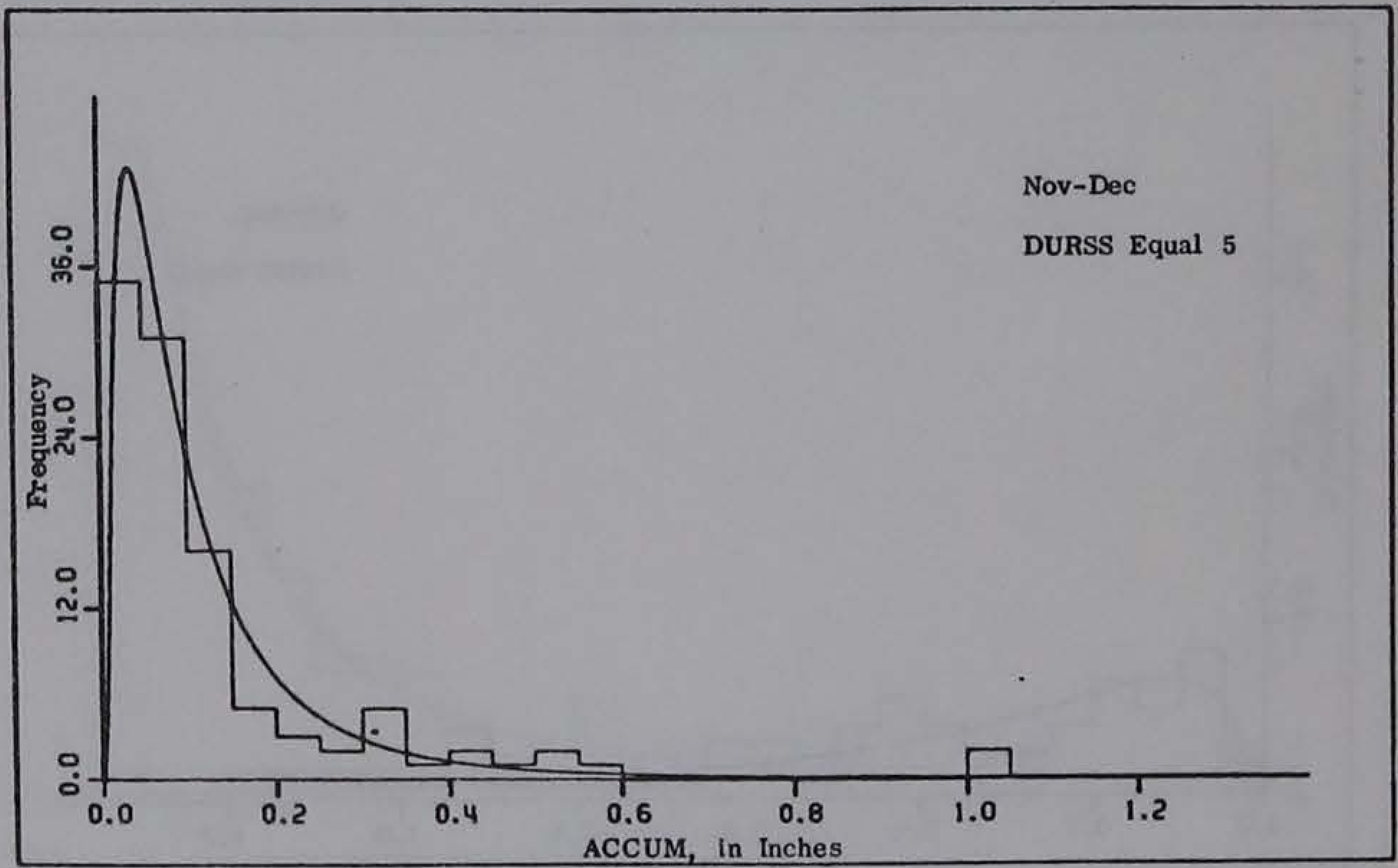

Figure D.30. ACCUM Frequency Histogram and Fitted Lognormal Function, Period 6, DURSS Equal 5

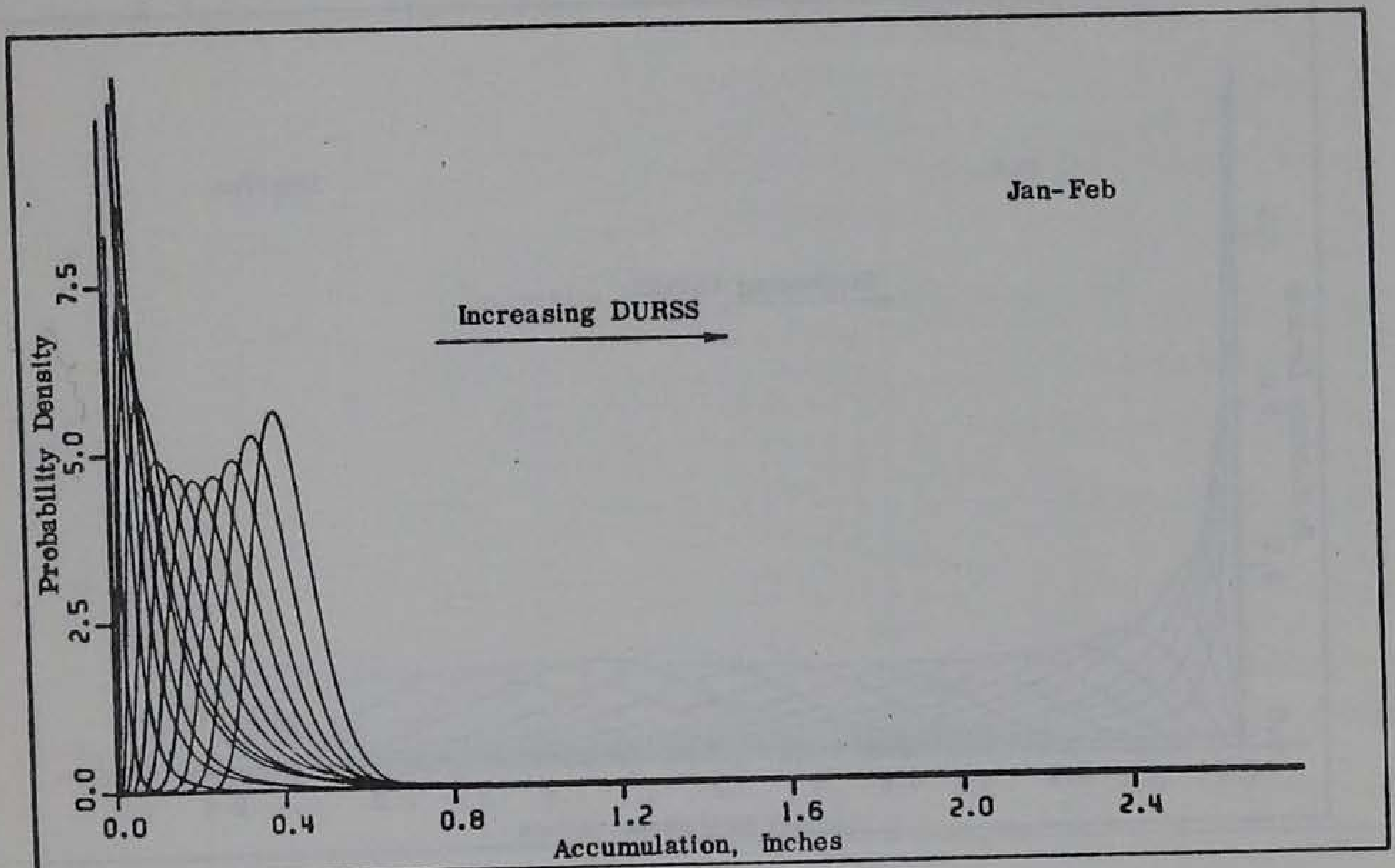

Figure D.31. Lognormal Density Functions, DURSS Equal 1 Through 14, Period 1

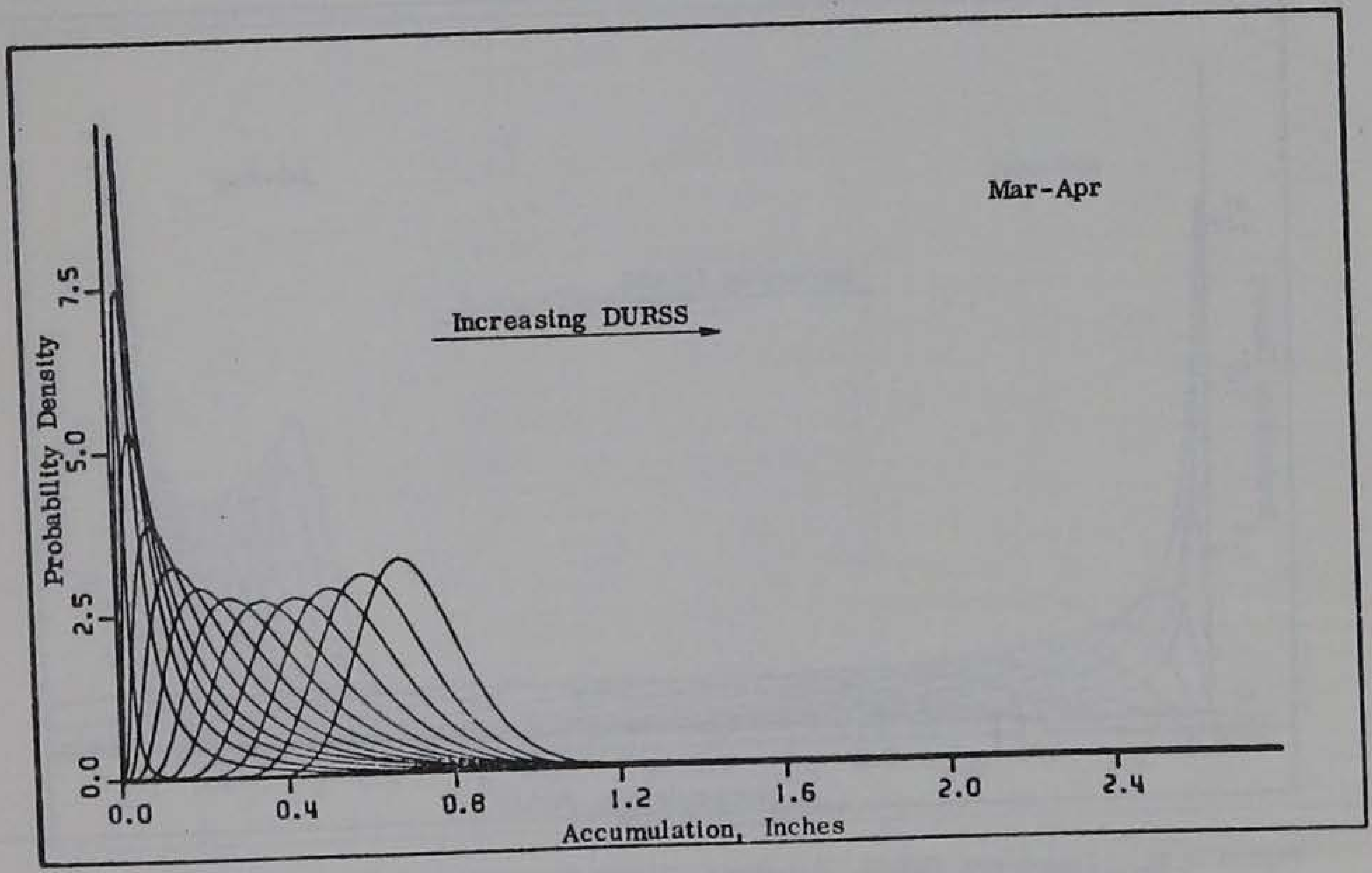

Figure D.32. Lognormal Density Functions, DURSS Equal 1 Through 14, Period 2

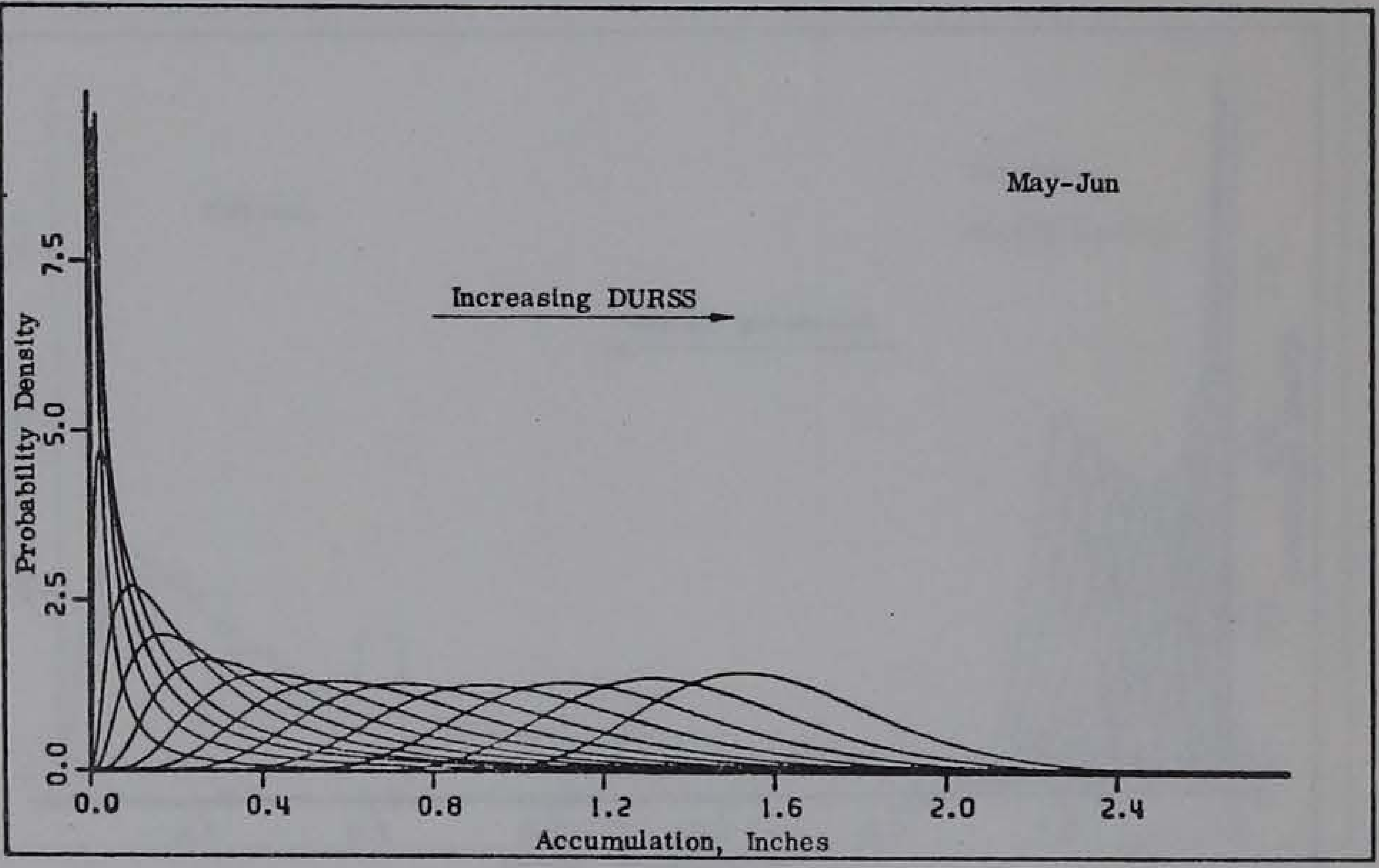

Figure D.33. Lognormal Density Functions, DURSS Equal 1 Through 14, Period 3

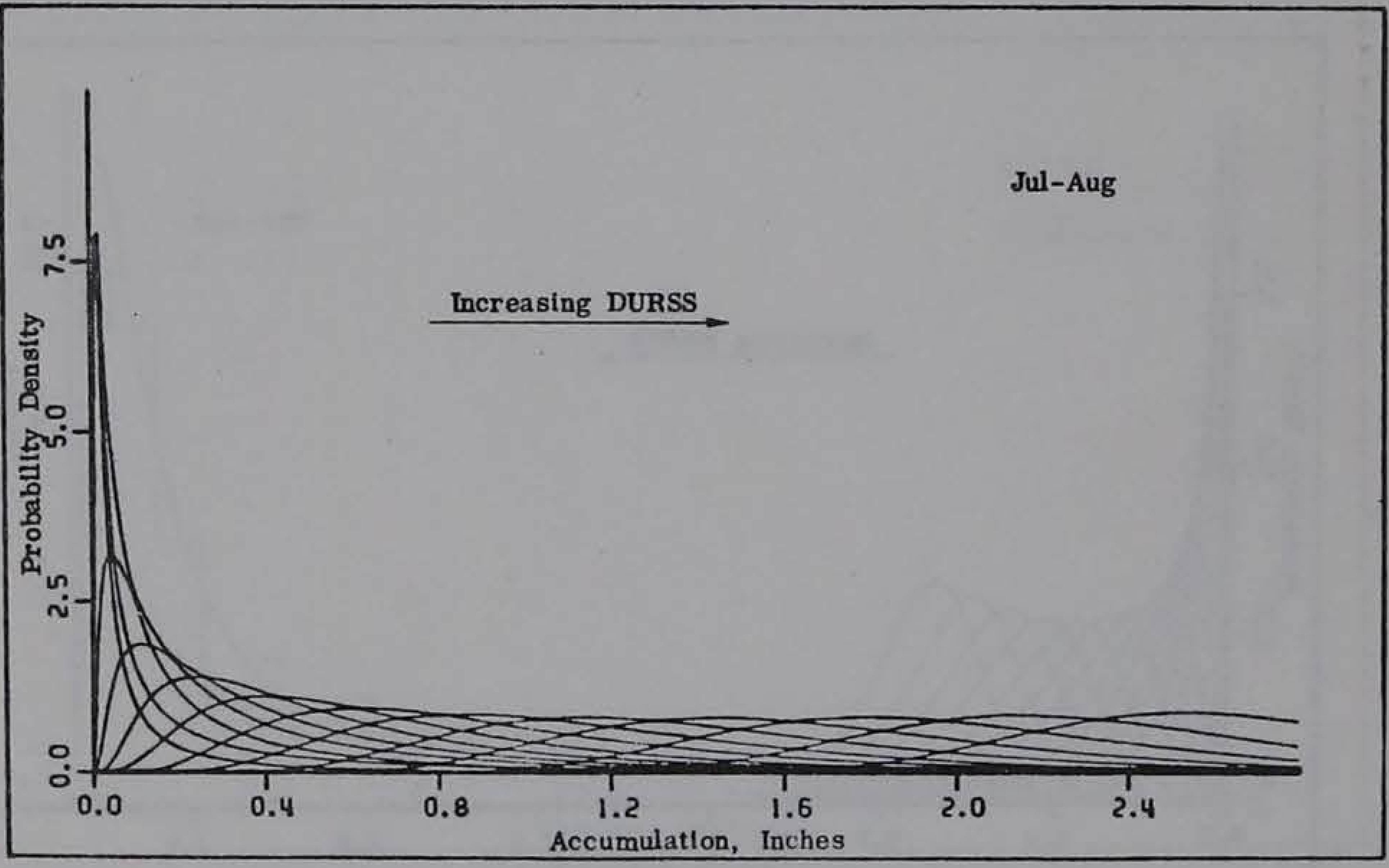

Figure D.34. Lognormal Density Functions, DURSS Equal 1 Through 14, Period 4

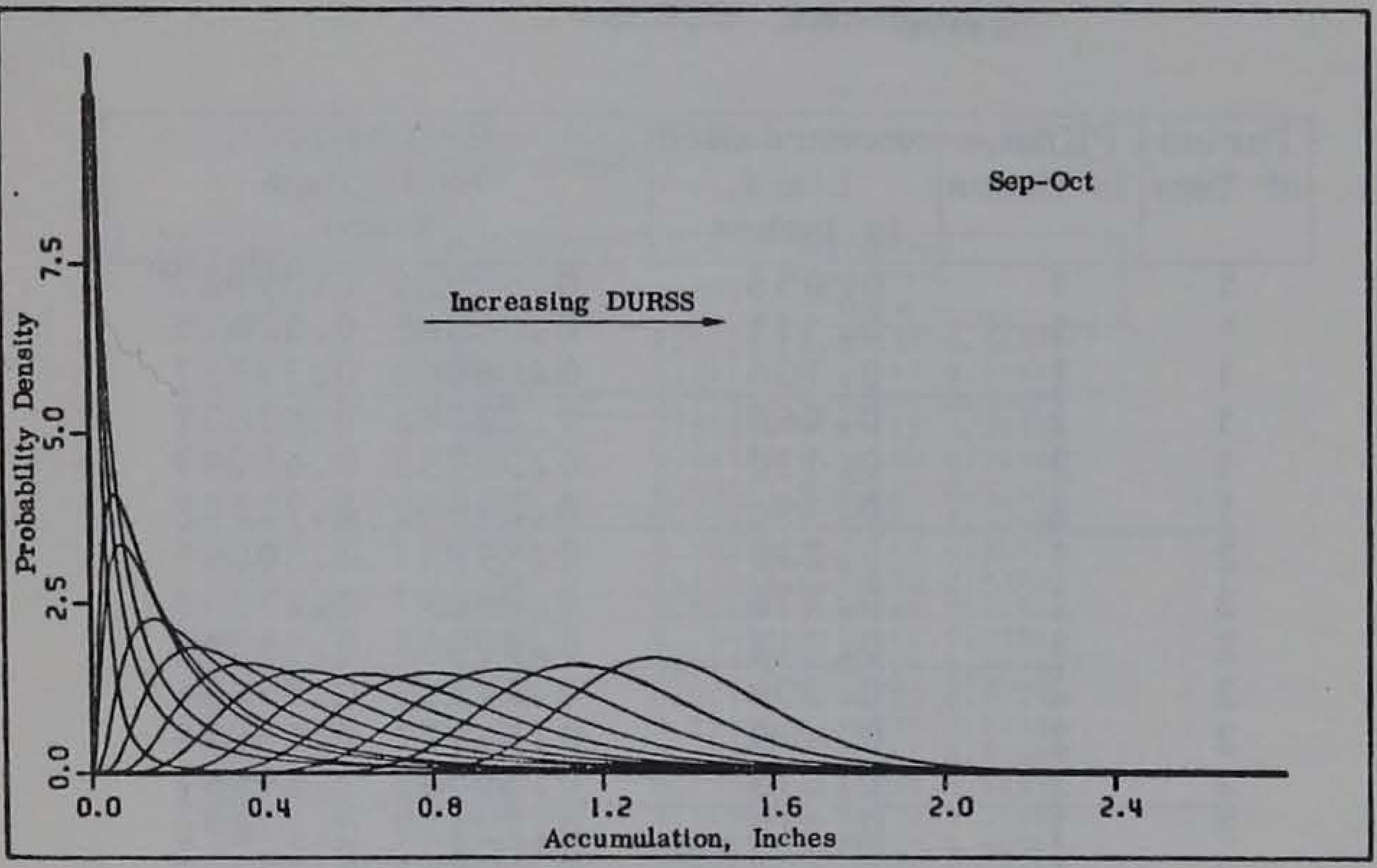

Figure D.35. Lognormal Density Functions, DURSS Equal 1 Through 14, Period 5

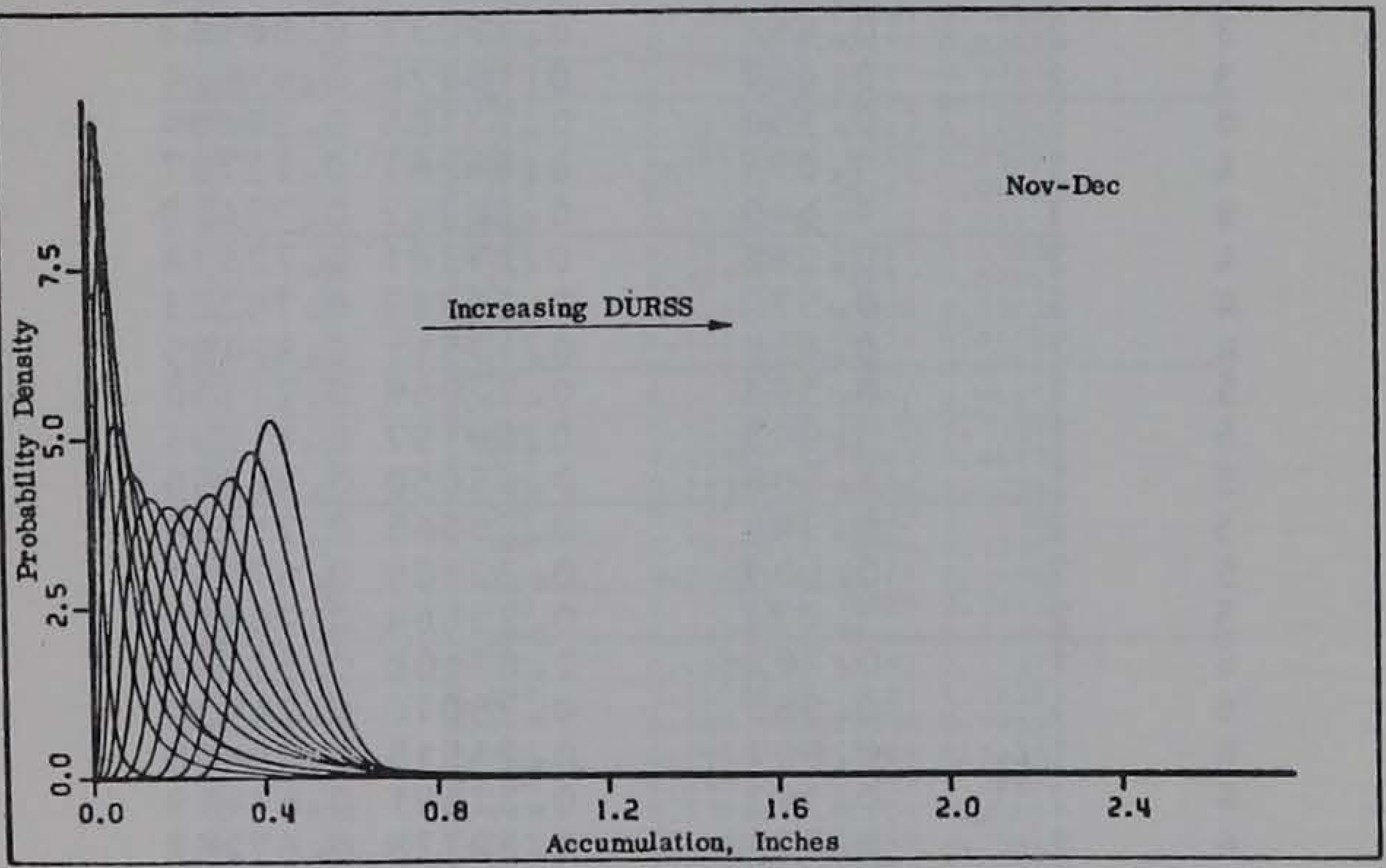

Figure D.36. Lognormal Density Functions, DURSS Equal 1 Through 14, Period 6

Table D.1. Storm Segment Shape Catalog of Mean Normalized Hyetographs, DURSS = 2

Period of Year	PKHR, in Hours	Accumulation Limit, in Inches	Normalized Hyetograph Shape
1	1	0.055	0.67536 0.32462
1	1	0.111	0.66565 0.33435
1	1	0.166	0.68863 0.31137
1	2	0.065	0.32362 0.67637
1	2	0.130	0.30753 0.69247
1	2	0.195	0.27692 0.72308
2	1	0.238	0.69953 0.30046
2	1	0.476	0.78637 0.21363
2	1	0.714	0.80952 0.19048
2	2	0.204	0.24566 0.75434
2	2	0.409	0.44151 0.55849
2	2	0.613	0.30343 0.69657
3	1	0.310	0.72129 0.27870
3	1	0.620	0.76693 0.23307
3	1	0.930	0.72030 0.27970
3	2	0.229	0.28518 0.71482
3	2	0.458	0.19037 0.80963
3	2	0.687	0.18376 0.81624
4	1	0.550	0.73105 0.26894
4	1	1.099	0.88263 0.11737
4	1	1.649	0.90397 0.09603
4	2	0.286	0.27381 0.72618
4	2	0.572	0.25767 0.74233
4	2	0.858	0.17511 0.82489
5	1	0.503	0.72068 0.27930
5	1	1.005	0.88197 0.11803
5	1	1.508	0.65650 0.34350
5	2	0.344	0.28665 0.71334
5	2	0.689	0.32489 0.67511
5	2	1.033	0.23684 0.76316
6	1	0.182	0.67608 0.32391
6	1	0.365	0.75070 0.24930
6	1	0.547	0.71515 0.28485
6	2	0.161	0.32881 0.67119
6	2	0.321	0.32738 0.67262
6	2	0.482	0.24481 0.75519

Table D.2. Storm Segment Shape Catalog of Mean Normalized Hyetographs, DURSS = 3

Period of Year	PKHR, in Hours	Accumulation Limit, in Inches	Normalized Hyetograph Shape		
1	1	0.169	0.52286	0.30737	0.16977
1	1	0.338	0.53178	0.35507	0.11315
1	1	0.507	0.71821	0.19701	0.08477
1	2	0.177	0.24056	0.52782	0.23161
1	2	0.353	0.23137	0.50307	0.26555
1	2	0.530	0.42077	0.52261	0.05661
1	3	0.049	0.19429	0.27489	0.53082
1	3	0.098	0.15394	0.36131	0.48474
1	3	0.147	0.19048	0.37415	0.43537
2	1	0.336	0.55458	0.30599	0.13942
2	1	0.672	0.76671	0.19762	0.03568
2	1	1.008	0.52778	0.46429	0.00794
2	2	0.232	0.20948	0.58758	0.20293
2	2	0.464	0.18170	0.58725	0.23106
2	2	0.696	0.20055	0.65542	0.14403
2	3	0.144	0.17846	0.32259	0.49895
2	3	0.289	0.12363	0.33973	0.53664
2	3	0.433	0.00693	0.39261	0.60046
3	1	0.322	0.64548	0.24451	0.11000
3	1	0.644	0.69792	0.22773	0.07434
3	1	0.966	0.76135	0.19131	0.04734
3	2	0.660	0.18639	0.64355	0.17005
3	2	1.319	0.19823	0.65787	0.14390
3	2	1.979	0.15109	0.82317	0.02573
3	3	0.380	0.12522	0.30265	0.57212
3	3	0.760	0.11509	0.12276	0.76215
3	3	1.140	0.08341	0.16343	0.75316
4	1	0.329	0.64182	0.26130	0.09687
4	1	0.659	0.67205	0.28367	0.04428
4	1	0.988	0.76942	0.17642	0.05416
4	2	0.589	0.19374	0.64787	0.15837
4	2	1.177	0.13762	0.78431	0.07807
4	2	1.766	0.25460	0.61504	0.13036
4	3	0.216	0.08292	0.30576	0.61131
4	3	0.431	0.01230	0.11066	0.87705
4	3	0.647	0.02782	0.06646	0.90572
5	1	0.296	0.62095	0.26535	0.11370
5	1	0.591	0.63940	0.29487	0.06574
5	1	0.887	0.78254	0.19406	0.02340
5	2	0.374	0.20108	0.61631	0.18259
5	2	0.748	0.19324	0.66896	0.13780
5	2	1.122	0.29655	0.53384	0.16961
5	3	0.090	0.15744	0.30826	0.53430
5	3	0.181	0.03957	0.19849	0.76194
5	3	0.271	0.05860	0.36762	0.57376
6	1	0.198	0.55565	0.29181	0.15253
6	1	0.397	0.58030	0.32376	0.09594
6	1	0.595	0.84135	0.13504	0.02361
6	2	0.208	0.24238	0.53756	0.22005
6	2	0.417	0.19320	0.53231	0.27449
6	2	0.625	0.24507	0.59547	0.15946
6	3	0.137	0.15332	0.29891	0.54777
6	3	0.274	0.12363	0.33973	0.53664
6	3	0.411	0.00730	0.24331	0.74939

Table D.3. Storm Segment Shape Catalog of Mean Normalized Hyetographs, DURSS = 4

Period of Year	PKHR, in Hours	Accumulation Limit, in Inches	Normalized Hyetograph Shape			
1	1	0.212	0.42922	0.27826	0.18684	0.10568
1	1	0.425	0.49091	0.34182	0.13091	0.03636
1	1	0.637	0.50392	0.19152	0.19152	0.11303
1	2	0.464	0.19367	0.45578	0.24240	0.10814
1	2	0.928	0.11663	0.50805	0.24879	0.12652
1	2	1.392	0.01006	0.91092	0.05819	0.02083
1	3	0.112	0.10367	0.22614	0.46513	0.20506
1	3	0.224	0.13625	0.23204	0.40472	0.22699
1	3	0.336	0.10344	0.21872	0.42682	0.25102
1	4	0.016	0.12143	0.17143	0.24285	0.46428
1	4	0.032	0.10049	0.14216	0.31372	0.44363
1	4	0.048	0.10442	0.16925	0.31590	0.41043
2	1	0.285	0.50029	0.27194	0.14523	0.08254
2	1	0.571	0.54663	0.30645	0.10852	0.03841
2	1	0.856	0.61916	0.26519	0.08528	0.03037
2	2	0.278	0.17424	0.48577	0.24764	0.09234
2	2	0.555	0.21902	0.47887	0.24542	0.05669
2	2	0.833	0.06533	0.62699	0.27571	0.03196
2	3	0.206	0.10995	0.24548	0.47759	0.16697
2	3	0.411	0.07348	0.22084	0.57242	0.13325
2	3	0.617	0.07603	0.23451	0.57913	0.11034
2	4	0.037	0.20000	0.20000	0.20000	0.40000
2	4	0.074	0.03644	0.19309	0.31042	0.46003
2	4	0.111	0.15350	0.20800	0.30601	0.33249
3	1	0.413	0.54939	0.26662	0.12140	0.06258
3	1	0.826	0.63295	0.27887	0.07630	0.01188
3	1	1.239	0.52984	0.33275	0.11236	0.02505
3	2	0.889	0.16024	0.56493	0.21434	0.06048
3	2	1.777	0.13944	0.74790	0.10660	0.00606
3	2	2.666	0.09415	0.51313	0.28245	0.11028
3	3	0.403	0.07583	0.24659	0.55584	0.12173
3	3	0.807	0.04669	0.18214	0.62322	0.14795
3	3	1.210	0.04739	0.29903	0.49861	0.15497
3	4	0.278	0.14719	0.16234	0.28355	0.40693
3	4	0.557	0.04427	0.13542	0.35937	0.46094
3	4	0.835	0.00359	0.08024	0.25269	0.66347
4	1	0.461	0.60193	0.27205	0.08802	0.03800
4	1	0.923	0.61435	0.29947	0.06396	0.02222
4	1	1.384	0.63542	0.28365	0.07370	0.00723
4	2	1.042	0.18446	0.57220	0.19720	0.04615
4	2	2.085	0.14175	0.68711	0.14698	0.02416
4	2	3.127	0.10028	0.67466	0.22136	0.00369
4	3	0.735	0.06821	0.21214	0.56583	0.15382
4	3	1.469	0.00357	0.05805	0.87233	0.06603
4	3	2.204	0.23730	0.28584	0.45009	0.02677
4	4	0.375	0.01847	0.04600	0.10378	0.83174
4	4	0.750	0.09489	0.09854	0.37044	0.43613
4	4	1.125	0.06844	0.14578	0.29600	0.48978
5	1	0.618	0.54598	0.27690	0.12335	0.05377
5	1	1.237	0.64839	0.26767	0.05916	0.02477
5	1	1.855	0.63342	0.28949	0.07655	0.00054
5	2	0.637	0.19227	0.50100	0.22444	0.08227
5	2	1.274	0.14555	0.59737	0.21639	0.04069
5	2	1.911	0.21191	0.67711	0.10914	0.00182
5	3	0.472	0.09090	0.22005	0.50290	0.18613
5	3	0.943	0.09158	0.18240	0.48019	0.24583
5	3	1.415	0.07250	0.20989	0.59178	0.12582
5	4	0.0	0.0	0.0	0.0	0.0
5	4	0.0	0.0	0.0	0.0	0.0
5	4	0.0	0.0	0.0	0.0	0.0
6	1	0.269	0.46435	0.28256	0.16755	0.08553
6	1	0.539	0.62139	0.27246	0.08810	0.01804
6	1	0.808	0.37129	0.30941	0.25124	0.06807
6	2	0.311	0.20184	0.45491	0.22162	0.12163
6	2	0.623	0.11663	0.50805	0.24879	0.12652
6	2	0.934	0.19800	0.58592	0.16494	0.03114
6	3	0.610	0.11586	0.22230	0.46550	0.19633
6	3	1.221	0.14427	0.23519	0.37887	0.24166
6	3	1.831	0.03004	0.38667	0.58165	0.00164
6	4	0.012	0.12143	0.17143	0.24285	0.46428
6	4	0.023	0.06667	0.06667	0.20000	0.66667
6	4	0.035	0.05714	0.17143	0.37143	0.40000

Table D.4. Storm Segment Shape Catalog of Mean Normalized Hyetographs, DURSS = 5

Period of Year	PKHR, In Hours	Accumulation Limit, In Inches	Normalized Hyetograph Shape				
1	1	0.145	0.38068	0.28467	0.15478	0.10434	0.07553
1	1	0.291	0.48819	0.23228	0.20079	0.05512	0.02362
1	1	0.436	0.33109	0.29256	0.22381	0.08871	0.06382
1	2	0.139	0.17311	0.37169	0.23370	0.15893	0.06256
1	2	0.277	0.12834	0.39948	0.27924	0.13102	0.06191
1	2	0.416	0.13890	0.45582	0.19128	0.12869	0.08530
1	3	0.168	0.08629	0.22072	0.42392	0.17932	0.08975
1	3	0.337	0.08346	0.16309	0.39669	0.25896	0.09779
1	3	0.505	0.09738	0.21495	0.36121	0.25796	0.06849
1	4	0.209	0.06840	0.13486	0.21421	0.40267	0.17986
1	4	0.417	0.15479	0.20539	0.21211	0.28255	0.14515
1	4	0.626	0.00479	0.07668	0.20607	0.40895	0.30351
1	5	0.0	0.0	0.0	0.0	0.0	0.0
1	5	0.0	0.0	0.0	0.0	0.0	0.0
1	5	0.0	0.0	0.0	0.0	0.0	0.0
2	1	0.214	0.39737	0.26774	0.15913	0.10191	0.07385
2	1	0.428	0.38958	0.33990	0.14838	0.06423	0.05790
2	1	0.642	0.30841	0.28193	0.21184	0.12305	0.07477
2	2	0.526	0.16233	0.41888	0.23275	0.12601	0.06004
2	2	1.052	0.09842	0.52789	0.27845	0.08405	0.01120
2	2	1.578	0.22940	0.45501	0.17681	0.11153	0.02725
2	3	0.417	0.07310	0.20855	0.42900	0.20882	0.08053
2	3	0.835	0.05897	0.20142	0.46404	0.24557	0.03001
2	3	1.252	0.01340	0.22386	0.65429	0.08749	0.02095
2	4	0.160	0.07133	0.15086	0.23069	0.38501	0.16210
2	4	0.320	0.02302	0.09046	0.18967	0.44146	0.25538
2	4	0.480	0.03595	0.16664	0.27641	0.41784	0.10316
2	5	0.0	0.0	0.0	0.0	0.0	0.0
2	5	0.0	0.0	0.0	0.0	0.0	0.0
2	5	0.0	0.0	0.0	0.0	0.0	0.0
3	1	0.350	0.59585	0.22902	0.11361	0.04129	0.02024
3	1	0.701	0.82007	0.13677	0.02621	0.01243	0.00450
3	1	1.051	0.56996	0.22232	0.10077	0.08534	0.02161
3	2	0.491	0.14758	0.46361	0.25176	0.10242	0.03462
3	2	0.982	0.15696	0.54013	0.20785	0.07651	0.01854
3	2	1.473	0.18267	0.58601	0.17196	0.03892	0.02045
3	3	0.326	0.06465	0.19728	0.48504	0.19081	0.06222
3	3	0.652	0.06619	0.17485	0.46825	0.22975	0.06097
3	3	0.978	0.03553	0.19168	0.57354	0.13475	0.06450
3	4	0.442	0.06266	0.10889	0.22300	0.43582	0.16963
3	4	0.885	0.06183	0.14408	0.34435	0.37073	0.07901
3	4	1.327	0.01711	0.05381	0.25773	0.63948	0.03186
3	5	0.365	0.06266	0.10889	0.16963	0.22300	0.43582
3	5	0.731	0.06183	0.07901	0.14408	0.34435	0.37073
3	5	1.096	0.00182	0.00547	0.00730	0.38139	0.60401
4	1	0.338	0.46049	0.33699	0.14212	0.04426	0.01614
4	1	0.675	0.52019	0.28936	0.15161	0.03386	0.00497
4	1	1.013	0.52912	0.41066	0.05232	0.00592	0.00197
4	2	0.463	0.14667	0.50714	0.23943	0.08255	0.02421
4	2	0.926	0.10390	0.54619	0.24706	0.08440	0.01845
4	2	1.389	0.15783	0.53540	0.21306	0.06722	0.02649
4	3	0.903	0.08413	0.22499	0.46490	0.17287	0.05311
4	3	1.807	0.00845	0.10566	0.55417	0.26490	0.06681
4	3	2.710	0.00406	0.24834	0.56125	0.18450	0.00185
4	4	0.877	0.03434	0.09283	0.24951	0.49583	0.12750
4	4	1.754	0.01111	0.07778	0.09333	0.42222	0.39556
4	4	2.631	0.06050	0.08900	0.25990	0.44140	0.14918
4	5	0.0	0.0	0.0	0.0	0.0	0.0
4	5	0.0	0.0	0.0	0.0	0.0	0.0
4	5	0.0	0.0	0.0	0.0	0.0	0.0
5	1	0.239	0.50022	0.25157	0.14662	0.07045	0.03114
5	1	0.479	0.25325	0.25325	0.23701	0.19481	0.06169
5	1	0.718	0.42274	0.28004	0.16814	0.08543	0.04364
5	2	0.680	0.15653	0.46570	0.23143	0.09482	0.05152
5	2	1.360	0.19494	0.48815	0.24521	0.06418	0.00752
5	2	2.040	0.12088	0.56846	0.22142	0.05816	0.03107
5	3	0.318	0.08852	0.23029	0.43462	0.17485	0.07171
5	3	0.636	0.03002	0.17949	0.50393	0.21514	0.07143
5	3	0.954	0.01283	0.17723	0.42573	0.26854	0.11567
5	4	0.333	0.05020	0.13116	0.23410	0.39054	0.19400
5	4	0.667	0.03665	0.06477	0.22211	0.51955	0.15693
5	4	1.000	0.02000	0.16500	0.24200	0.31400	0.25900
5	5	0.0	0.0	0.0	0.0	0.0	0.0
5	5	0.0	0.0	0.0	0.0	0.0	0.0
5	5	0.0	0.0	0.0	0.0	0.0	0.0
6	1	0.078	0.48563	0.23630	0.13363	0.08181	0.06262
6	1	0.157	0.45572	0.20843	0.17068	0.10699	0.05818
6	1	0.235	0.42312	0.24134	0.18807	0.12180	0.02566
6	2	0.338	0.15175	0.37015	0.26618	0.12864	0.08326
6	2	0.677	0.20801	0.46950	0.19948	0.07297	0.05002
6	2	1.015	0.14778	0.43842	0.33399	0.06108	0.01872
6	3	0.342	0.09215	0.21078	0.37474	0.21566	0.10667
6	3	0.683	0.05591	0.14537	0.49372	0.24078	0.06421
6	3	1.025	0.00195	0.01951	0.63610	0.26634	0.07610
6	4	0.196	0.07814	0.13089	0.22109	0.39544	0.17444
6	4	0.393	0.07849	0.12657	0.23678	0.39811	0.16005
6	4	0.589	0.04097	0.18505	0.20592	0.44009	0.12799
6	5	0.0	0.0	0.0	0.0	0.0	0.0
6	5	0.0	0.0	0.0	0.0	0.0	0.0
6	5	0.0	0.0	0.0	0.0	0.0	0.0

Table D.5. Storm Segment Shape Catalog of Mean Normalized Hyetographs, DURSS = 6

Period of Year	PKHR, in Hours	Normalized Hyetograph Shape					
		Hour → 1	2	3	4	5	6
1	1	0.43379	0.22268	0.14016	0.11530	0.06876	0.01930
1	2	0.16752	0.39907	0.24863	0.11143	0.04343	0.02992
1	3	0.13080	0.21554	0.36061	0.15464	0.09030	0.04811
1	4	0.05422	0.14085	0.21516	0.35589	0.17212	0.06176
1	5	0.02228	0.08208	0.16872	0.21234	0.32229	0.19229
2	1	0.34550	0.27185	0.21414	0.10491	0.04503	0.01857
2	2	0.13743	0.43148	0.23907	0.10401	0.06317	0.02485
2	3	0.07256	0.22210	0.39864	0.18091	0.08121	0.04458
2	4	0.04222	0.09366	0.22468	0.39019	0.18683	0.06242
2	5	0.06166	0.09134	0.12833	0.20758	0.37379	0.13730
3	1	0.49195	0.31293	0.13341	0.03262	0.01822	0.01087
3	2	0.18178	0.44725	0.22264	0.10035	0.03832	0.00967
3	3	0.04176	0.16806	0.43554	0.28453	0.05714	0.01297
3	4	0.03296	0.07822	0.20530	0.39622	0.23256	0.05474
3	5	0.01121	0.02504	0.10889	0.29889	0.44787	0.10810
4	1	0.57242	0.24089	0.07940	0.04876	0.03178	0.02675
4	2	0.17539	0.44261	0.23367	0.10220	0.03703	0.00910
4	3	0.05490	0.25118	0.49801	0.12754	0.05179	0.01658
4	4	0.01184	0.03835	0.19696	0.48022	0.20712	0.06551
4	5	0.03099	0.08163	0.10829	0.18880	0.46826	0.12205
5	1	0.43876	0.27691	0.16089	0.06784	0.04399	0.01161
5	2	0.13795	0.44104	0.20944	0.13741	0.06492	0.00922
5	3	0.09121	0.17662	0.43585	0.19069	0.07481	0.03083
5	4	0.04723	0.11166	0.20205	0.38143	0.17870	0.07894
5	5	0.03416	0.05786	C.10001	0.15171	0.50958	0.14668
6	1	0.36628	0.32940	0.15507	0.07184	0.04391	0.03349
6	2	0.12253	0.38336	0.20744	0.15960	0.10215	0.02491
6	3	0.04983	0.16241	0.38738	0.25321	0.11428	0.03288
6	4	0.05199	0.11545	0.23278	0.33817	0.18122	0.08039
6	5	0.02563	0.03814	0.07104	0.18443	0.41301	0.26774

Table D.6. Storm Segment Shape Catalog of Mean Normalized Hyetographs, DURSS = 7

Period of Year	PKHR, in Hours	Normalized Hyetograph Shape						
		Hour → 1	2	3	4	5	6	7
1	1	0.33721	0.31395	0.20930	0.03488	0.03488	0.03488	0.03488
1	2	0.14851	0.34970	0.17838	0.13223	0.09031	0.07414	0.02673
1	3	0.08074	0.16883	0.31134	0.22816	0.11541	0.06005	0.03548
1	4	0.05439	0.09597	0.19744	0.30768	0.17820	0.11664	0.04970
1	5	0.04951	0.06942	0.13034	0.22840	0.33977	0.13987	0.04268
1	6	0.07794	0.10779	0.10779	0.14510	0.17288	0.26679	0.12168
2	1	0.29282	0.21547	0.17127	0.12707	0.11602	0.07182	0.00552
2	2	0.18490	0.36617	0.20168	0.13220	0.07806	0.02325	0.01374
2	3	0.04212	0.16909	0.49855	0.18979	0.05528	0.03168	0.01349
2	4	0.02650	0.07714	0.21260	0.37375	0.16370	0.11250	0.03382
2	5	0.01116	0.04106	0.07850	0.15092	0.43001	0.20620	0.08214
2	6	0.02204	0.03853	0.11995	0.14931	0.19166	0.35209	0.12643
3	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	2	0.15249	0.49188	0.22296	0.05186	0.04023	0.02742	0.01315
3	3	0.02331	0.10330	0.53276	0.20761	0.09527	0.03073	0.00702
3	4	0.04726	0.08343	0.17227	0.30861	0.23086	0.09995	0.05762
3	5	0.02683	0.10703	0.15503	0.23298	0.34492	0.09920	0.03401
3	6	0.04289	0.11539	0.13905	0.14268	0.20515	0.29046	0.06436
4	1	0.51163	0.25000	0.08140	0.06977	0.04651	0.02907	0.01163
4	2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	3	0.02511	0.15990	0.45543	0.20619	0.11430	0.02828	0.01078
4	4	0.03802	0.09717	0.24846	0.33364	0.18376	0.07499	0.02395
4	5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	6	0.02355	0.06201	0.06201	0.07642	0.22054	0.32384	0.23160
5	1	0.33737	0.27509	0.14706	0.10900	0.07612	0.04325	0.01211
5	2	0.14424	0.36685	0.23733	0.09465	0.08490	0.05053	0.02149
5	3	0.06915	0.20716	0.34526	0.17869	0.13780	0.03527	0.02665
5	4	0.03442	0.09940	0.17296	0.37943	0.19226	0.08702	0.03451
5	5	0.06676	0.08578	0.12673	0.20227	0.34634	0.15095	0.02116
5	6	0.01715	0.04287	0.05788	0.24652	0.29904	0.33119	0.00536
6	1	0.23631	0.18823	0.14472	0.12663	0.10739	0.10739	0.08930
6	2	0.09143	0.44221	0.21960	0.10647	0.06676	0.04632	0.02722
6	3	0.13275	0.18298	0.26937	0.17002	0.11614	0.07835	0.05039
6	4	0.02981	0.11215	0.20141	0.32919	0.16744	0.11442	0.04558
6	5	0.03270	0.05252	0.09387	0.19234	0.29583	0.23258	0.10015
6	6	0.05278	0.05363	0.06327	0.12004	0.20758	0.37791	0.12478

Table D.7. Storm Segment Shape Catalog of Mean Normalized Hyetographs, DURSS = 8

Period of Year	PKHR, in Hours	Normalized Hyetograph Shape							
		Hour → 1	2	3	4	5	6	7	8
1	2	0.11382	0.25203	0.19512	0.19512	0.09756	0.09756	0.04065	0.00813
1	3	0.05563	0.16119	0.29713	0.19793	0.13967	0.08259	0.04441	0.02144
1	4	0.04287	0.06150	0.11499	0.28822	0.25986	0.13873	0.06238	0.03144
1	5	0.03604	0.05405	0.12613	0.20721	0.33333	0.15315	0.07207	0.01802
1	6	0.03333	0.06667	0.10000	0.16667	0.20000	0.23333	0.16667	0.03333
1	7	0.03333	0.06667	0.10000	0.13667	0.15667	0.20000	0.22333	0.08333
2	2	0.14025	0.28869	0.21796	0.12039	0.09288	0.05483	0.04777	0.03720
2	3	0.03158	0.19751	0.35926	0.20180	0.10765	0.07259	0.02080	0.00880
2	4	0.02950	0.07375	0.21513	0.34075	0.21963	0.07787	0.03208	0.01129
2	5	0.11291	0.12234	0.16229	0.17010	0.23275	0.09787	0.06338	0.03832
2	6	0.02873	0.06315	0.09739	0.13951	0.22499	0.30235	0.09795	0.04593
2	7	0.05128	0.05128	0.05128	0.05128	0.05128	0.07692	0.41026	0.25641
3	2	0.18622	0.45598	0.16707	0.10284	0.05900	0.01456	0.00856	0.00577
3	3	0.03646	0.12190	0.42439	0.22780	0.08088	0.05612	0.03248	0.01997
3	4	0.01321	0.06078	0.19187	0.38242	0.20194	0.10692	0.03734	0.00550
3	5	0.00974	0.08865	0.12264	0.17582	0.27817	0.19291	0.09688	0.03519
3	6	0.01324	0.06823	0.10591	0.21181	0.24236	0.26884	0.05397	0.03564
3	7	0.01324	0.03564	0.06823	0.10591	0.21181	0.24236	0.26884	0.05397
4	2	0.31311	0.34098	0.10984	0.07705	0.07705	0.06066	0.01148	0.00984
4	3	0.14105	0.28607	0.40342	0.11843	0.01892	0.01531	0.01378	0.00301
4	4	0.00990	0.08581	0.23432	0.30363	0.16832	0.09241	0.07591	0.02970
4	5	0.00971	0.07153	0.14400	0.29082	0.39599	0.07860	0.00702	0.00232
4	6	0.00302	0.00302	0.00906	0.10272	0.41390	0.43202	0.03323	0.00302
4	7	0.00902	0.01302	0.01906	0.10272	0.14000	0.29000	0.41202	0.01416
5	2	0.12403	0.37870	0.18963	0.13701	0.07858	0.04217	0.03583	0.01405
5	3	0.03583	0.12403	0.37870	0.18963	0.13701	0.07858	0.04217	0.01405
5	4	0.04333	0.08799	0.16813	0.31011	0.15792	0.13271	0.07263	0.02716
5	5	0.01556	0.03025	0.15557	0.22988	0.38090	0.13912	0.03081	0.01788
5	6	0.00209	0.05950	0.09290	0.10021	0.14614	0.39979	0.14405	0.05532
5	7	0.01209	0.04532	0.05950	0.09290	0.10021	0.14614	0.39979	0.14405
6	2	0.12832	0.28540	0.16814	0.15265	0.13938	0.05973	0.04425	0.02212
6	3	0.06404	0.21549	0.30942	0.19906	0.10492	0.06598	0.02601	0.01507
6	4	0.01114	0.09453	0.18572	0.29218	0.20667	0.13006	0.06397	0.01571
6	5	0.02226	0.05703	0.10483	0.17869	0.47108	0.08713	0.05766	0.02130
6	6	0.01088	0.01579	0.04866	0.17027	0.24097	0.34701	0.12934	0.03707
6	7	0.00704	0.02113	0.04225	0.05634	0.15493	0.23944	0.27465	0.20423

Table D.8. Storm Segment Shape Catalog of Mean Normalized Hyetographs, DURSS = 9

PKHR, in Hours	Normalized Hyetograph Shape								
	Hour								
	1	2	3	4	5	6	7	8	9
3	0.02695	0.12246	0.30358	0.22512	0.17740	0.07588	0.03884	0.02105	0.00873
4	0.02950	0.08649	0.15213	0.26544	0.20744	0.13190	0.08395	0.03431	0.00882
5	0.04175	0.06673	0.10970	0.15646	0.26875	0.20623	0.09710	0.04316	0.01011
6	0.02344	0.02948	0.07151	0.12776	0.20890	0.30668	0.12875	0.06366	0.03981
7	0.01911	0.02705	0.04038	0.08806	0.14951	0.22895	0.28517	0.14303	0.01874

Table D.9. Storm Segment Shape Catalog of Mean Normalized Hyetographs, DURSS = 10

PKHR, in Hours	Normalized Hyetograph Shape									
	Hour									
	1	2	3	4	5	6	7	8	9	10
3	0.00079	0.11624	0.32747	0.32065	0.17948	0.03332	0.01758	0.00210	0.00184	0.00052
4	0.02186	0.02186	0.15301	0.34426	0.30874	0.11202	0.01913	0.00820	0.00546	0.00546
5	0.00513	0.03729	0.06463	0.21567	0.27424	0.17434	0.10892	0.06338	0.03947	0.01693
6	0.02514	0.03455	0.08847	0.12701	0.21475	0.27871	0.11676	0.06442	0.03639	0.01381
7	0.00726	0.06167	0.06771	0.09311	0.17775	0.24426	0.32527	0.01330	0.00605	0.00363
8	0.00363	0.00726	0.06167	0.06771	0.09311	0.17775	0.24426	0.32527	0.01330	0.00605

Table D.10. Storm Segment Shape Catalog of Mean Normalized Hyetographs, DURSS = 11

PKHR, in Hours	Normalized Hyetograph Shape										
	Hour → 1	2	3	4	5	6	7	8	9	10	11
3	0.06103	0.13772	0.28951	0.20970	0.11737	0.07512	0.03756	0.03443	0.02661	0.00626	0.00469
4	0.03756	0.06103	0.13772	0.28951	0.20970	0.11737	0.07512	0.03443	0.02661	0.00626	0.00469
5	0.03443	0.03756	0.06103	0.13772	0.28951	0.20970	0.11737	0.07512	0.02661	0.00626	0.00469
6	0.00626	0.03443	0.03756	0.06103	0.13772	0.28951	0.20970	0.11737	0.07512	0.02661	0.00469
7	0.00469	0.00626	0.03443	0.03756	0.06103	0.13772	0.28951	0.20970	0.11737	0.07512	0.02661
8	0.00469	0.00626	0.02661	0.03443	0.03756	0.06103	0.13772	0.28951	0.20970	0.11737	0.07512
9	0.00469	0.00626	0.02661	0.03443	0.03756	0.06103	0.07512	0.13772	0.28951	0.20970	0.11737

Table D.11. Storm Segment Shape Catalog of Mean Normalized Hyetographs, DURSS = 13

PKHR, in Hours	Normalized Hyetograph Shape												
	Hour												
	1	2	3	4	5	6	7	8	9	10	11	12	13
3	0.03641	0.10922	0.20227	0.15453	0.14401	0.12460	0.07767	0.05583	0.04045	0.02023	0.01780	0.01133	0.00565
4	0.02023	0.03641	0.10922	0.20227	0.15453	0.14401	0.12460	0.07767	0.05583	0.04045	0.01780	0.01133	0.00565
5	0.01780	0.02023	0.03641	0.10922	0.20227	0.15453	0.14401	0.12460	0.07767	0.05583	0.04045	0.01133	0.00565
6	0.01133	0.01780	0.02023	0.03641	0.10922	0.20227	0.15453	0.14401	0.12460	0.07767	0.05583	0.04045	0.00565
7	0.00565	0.01133	0.01780	0.02023	0.03641	0.10922	0.20227	0.15453	0.14401	0.12460	0.07767	0.05583	0.04045
8	0.00565	0.01133	0.01780	0.02023	0.03641	0.04045	0.10922	0.20227	0.15453	0.14401	0.12460	0.07767	0.05583
9	0.00565	0.01133	0.01780	0.02023	0.03641	0.04045	0.05583	0.10922	0.20227	0.15453	0.14401	0.12460	0.07767
10	0.00565	0.01133	0.01780	0.02023	0.03641	0.04045	0.05583	0.07767	0.10922	0.20227	0.15453	0.14401	0.12460
11	0.00565	0.01133	0.01780	0.02023	0.03641	0.04045	0.05583	0.07767	0.10922	0.12460	0.20227	0.15453	0.14401

Table D.12. Storm Segment Shape Catalog of Mean Normalized Hyetographs, DURSS = 14

PKHR, in Hours	Normalized Hyetograph Shape									
	Hour									
	1	2	3	4	5	6	7	8	9	10
3	0.03398	0.10922	0.20227	0.15453	0.14401	0.12460	0.07767	0.05583	0.04045	0.02023
4	0.02023	0.03398	0.10922	0.20227	0.15453	0.14401	0.12460	0.07767	0.05583	0.04045
5	0.01780	0.02023	0.03398	0.10922	0.20227	0.15453	0.14401	0.12460	0.07767	0.05583
6	0.00243	0.01780	0.02023	0.03398	0.10922	0.20227	0.15453	0.14401	0.12460	0.07767
7	0.00243	0.00565	0.01780	0.02023	0.03398	0.10922	0.20227	0.15453	0.14401	0.12460
8	0.00243	0.00565	0.01133	0.01780	0.02023	0.03398	0.10922	0.20227	0.15453	0.14401
9	0.00243	0.00565	0.01133	0.01780	0.02023	0.03398	0.04045	0.10922	0.20227	0.15453
10	0.00243	0.00565	0.01133	0.01780	0.02023	0.03398	0.04045	0.05583	0.10922	0.20227
11	0.00243	0.00565	0.01133	0.01780	0.02023	0.03398	0.04045	0.05583	0.07767	0.10922
12	0.00243	0.00565	0.01133	0.01780	0.02023	0.03398	0.04045	0.05583	0.07767	0.10922

PKHR, in Hours	Hour			
	11	12	13	14
3	0.01780	0.01133	0.00565	0.00243
4	0.01780	0.01133	0.00565	0.00243
5	0.04045	0.01133	0.00565	0.00243
6	0.05583	0.04045	0.01133	0.00565
7	0.07767	0.05583	0.04045	0.01133
8	0.12460	0.07767	0.05583	0.04045
9	0.14401	0.12460	0.07767	0.05583
10	0.15453	0.14401	0.12460	0.07767
11	0.20227	0.15453	0.14401	0.12460
12	0.12460	0.20227	0.15453	0.14401

APPENDIX E

COMPUTER PROGRAM LISTING AND OUTPUT

Table E.1. Computer Program Listing

```
C***************************************************************************************
C
C     RALSTON CREEK HOURLY INCREMENT PRECIPITATION MODEL
C
C***************************************************************************************
C
C
C     USER INITIALIZATION:
C
C        NBYR=     FIRST YEAR OF DATA GENERATION (FOR EXAMPLE: 1976)
C        LYR=      LAST YEAR OF DATA GENERATION
C        ISTART=   ANY 1 TO 7 DIGIT INTEGER SEED VALUE
C        JSTART=   ANY 1 TO 7 DIGIT INTEGER SEED VALUE
C
C
C***************************************************************************************
C
C                         VARIABLES AND CONSTANTS
C
C***************************************************************************************
C
C
C     ACCUM=  PRECIPITATION ACCUMULATION OF STORM SEGMENT, INCHES.
C     ACML$=  ACCUM MAXIMUMS USED TO DETERMINE ACCESS POINTS IN THE 'SHAPE'
C             FILE, WHERE $= DURSS= 2,3,4,5.
C     ALMT=  TEMPORARY WORKING STORAGE FOR ACML$.
C     DAY=  CURRENT DAY.
C     DIST$=  RELATIVE DISTRIBUTION OF ACCUM OVER STORM SEGMENT (SHAPE FILE),
C             WHERE $= DURSS= 2,3,4,........14.
C     DURAB=  ABSOLUTE DURSS FREQUENCIES BY PERIOD FOR 1 THRU 14 HOURS.
C     DURABT=  SUM OF DURSS ABSOLUTE FREQUENCIES BY PERIOD.
C     DURSS=  DURATION OF STORM SEGMENT, HOURS.
C     EXPMN=  SAMPLE MEAN OF IATSE FOR EACH OF 6 PERIODS. (FOR EXPONENTIAL FIT)
C     FDURSS=  UNIFORMLY DISTRIBUTED RANDOM NUMBER, FOR DURSS GENERATION.
C     FIATSE=  UNIFORMLY DISTRIBUTED RANDOM NUMBER, FOR IATSE GENERATION.
C     FIATSS=  UNIFORMLY DISTRIBUTED RANDOM NUMBER, FOR IATSS GENERATION.
C     FNSSSE=  UNIFORMLY DISTRIBUTED RANDOM NUMBER, FOR NSSSE GENERATION.
C     HOUR=  CURRENT HOUR OF DAY.
C     HRAIN=  FINAL HOURLY PRECIPITATION ACCUMULATIONS FOR STORM EVENT, INCHES.
C     IATAB=  ABSOLUTE IATSS FREQUENCIES BY PERIOD FOR 0 THRU 12 HOURS.
C     IATABT=  SUM OF IATSS ABSOLUTE FREQUENCIES BY PERIOD.
C     IATCO=  INTERARRIVAL TIME CUTOFF LEVELS FOR EACH OF 6 PERIODS. (IATSS
C            MAXIMUM)
C     IATSE=  INTERARRIVAL TIME TO STORM EVENT, HOURS.
C     IATSS=  INTERARRIVAL TIME TO STORM SEGMENT, HOURS.
C     LENGTH=  STORM EVENT LENGTH, HOURS.
C     LYR=  LAST YEAR TO BE GENERATED.
C     M=  PERIOD COUNTER.
C     MHRS=  NUMBER OF HOURS IN EACH OF 6 PERIODS OF THE YEAR.
C     MLNACM=  SAMPLE MEAN OF ALOG(ACCUM) BY PERIOD FOR DURSS VALUES 1 THRU 14.
C     MONTH=  CURRENT MONTH.
C     NBYR=  CURRENT YEAR; INITIAL VALUE IS FIRST YEAR TO BE GENERATED.
C     NHOURS=  ACCUMULATED TIME IN HOURS, FROM BEGINNING OF PERIOD, M.
C     NODAYS=  NUMBER OF DAYS PER MONTH OF THE YEAR.
C     NSSAB=  ABSOLUTE NSSSE FREQUENCIES BY PERIOD FOR 1 THRU 21.
C     NSSABT=  SUM OF NSSSE ABSOLUTE FREQUENCIES BY PERIOD.
C     NSSSE=  NUMBER OF STORM SEGMENTS PER STORM EVENT.
C     PKHR=  PKHR LOCATION WITH RESPECT TO BEGINNING OF STORM SEGMENT, HOURS.
C     RAIN=  FINAL HOURLY PRECIPITATION ACCUMULATIONS FOR STORM SEGMENT, INCHES.
C     RFDURS=  DURSS RELATIVE FREQUENCIES BY PERIOD.
C     RFIATS=  IATSS RELATIVE FREQUENCIES BY PERIOD.
C     RFNSS=  NSSSE RELATIVE FREQUENCIES BY PERIOD.
C     RFPKHR=  PKHR RELATIVE FREQUENCIES FOR EACH VALUE OF DURSS BY PERIOD.
C     SHAPE=  TEMPORARY WORKING STORAGE FOR DIST$.
C     STDNOR=  STANDARD NORMAL RANDOM NUMBER, FOR ACCUM GENERATION.
C     TRAIN=  STORM EVENT TOTAL RAINFALL ACCUMULATION, INCHES.
C     VLNACM=  SAMPLE VARIANCE OF ALOG(ACCUM) BY PERIOD FOR DURSS VALUES
C               1 THRU 14.
C
C
C***************************************************************************************
C
      REAL*4 EXPMN(6),RFNSS(6,21),RFIATS(6,13),RFDURS(6,14),ACCUM(21),ML
     &NACM(6,14),VLNACM(6,14),RFPKHR(6,1
     &3,14)/1092*0.0/,ACML3(6,3,3),ACML4(6,4,3),ACMI5(6,5,3),DIST3(6,3,3
     &,3),DIST4(6,4,3,4),DIST5(6,5,3,5),DIST6(6,5,6),DIST7(6,6,7),DIST8(
     &6,6,8),DIST9(5,9),DIST10(6,10),DIST11(7,11),DIST13(9,13),DIST14(10
     &,14),SHAPE(3,14),ALMT(3),RAIN(21,14),ACML2(6,2,3),DIST2(6,2,3,2)
     &,HRAIN(200)
      INTEGER*4 IATCO(6),NSSABT(6),NSSAB(6,21),IATABT(6),IATAB(6,13),DUR
     &ABT(6),DURAB(6,14),MHRS(6),NODAYS(12),DAY,HOUR,IATSS(20),DURSS(21)
     &,PKHR(21)
C***************************************************************************************
C   READ STATEMENTS
C***************************************************************************************
      READ(5,312) (NODAYS(K),K=1,12)
  312 FORMAT(12I3)
      READ(5,311) (MHRS(K),K=1,6)
  311 FORMAT(6I5)
      READ(5,300) (IATCO(K),K=1,6)
```

```
  300 FORMAT(6I3)
      READ(5,301) (EXPMN(K),K=1,6)
  301 FORMAT(6F7.2)
      DO 303 I=1,6
      READ(5,304) (NSSAB(I,K),K=1,21)
  304 FORMAT(21I3)
  303 CONTINUE
      DO 306 I=1,6
      READ(5,307) (IATAB(I,K),K=1,13)
  307 FORMAT(13I4)
  306 CONTINUE
      DO 309 I=1,6
      READ(5,310) (DURAB(I,K),K=1,14)
  310 FORMAT(14I4)
  309 CONTINUE
      DO 320 I=1,6
      READ(5,321) (MLNACH(I,K),K=1,14)
  321 FORMAT(4X,8F8.5,/,6F8.5)
  320 CONTINUE
      DO 322 I=1,6
      READ(5,323) (VLNACH(I,K),K=1,14)
  323 FORMAT(4X,5F8.5,/,9F8.5)
  322 CONTINUE
      DO 329 I=1,6
      DO 329 J=1,13
      IDUR=J+1
      READ(5,330) (RFPKHR(I,J,K),K=1,IDUR)
  330 FORMAT(15X,7F7.4,/,15X,7F7.4)
  329 CONTINUE
      DO 353 I=1,6
      DO 353 J=1,2
      DO 353 L=1,3
      READ(5,354)ACML2(I,J,L),(DIST2(I,J,L,K),K=1,2)
  354 FORMAT(16X,F6.3,12X,2F8.5)
  353 CONTINUE
      DO 331 I=1,6
      DO 331 J=1,3
      DO 331 L=1,3
      READ(5,332)ACML3(I,J,L),(DIST3(I,J,L,K),K=1,3)
  332 FORMAT(16X,F6.3,12X,3F8.5)
  331 CONTINUE
      DO 333 I=1,6
      DO 333 J=1,4
      DO 333 L=1,3
      READ(5,334)ACML4(I,J,L),(DIST4(I,J,L,K),K=1,4)
  334 FORMAT(16X,F6.3,12X,4F8.5)
  333 CONTINUE
      DO 335 I=1,6
      DO 335 J=1,5
      DO 335 L=1,3
      READ(5,336)ACML5(I,J,L),(DIST5(I,J,L,K),K=1,5)
  336 FORMAT(16X,F6.3,12X,5F8.5)
  335 CONTINUE
      DO 337 I=1,6
      DO 337 J=1,5
      READ(5,338) (DIST6(I,J,K),K=1,6)
  338 FORMAT(22X,6F8.5)
  337 CONTINUE
      DO 339 I=1,6
      DO 339 J=1,6
      READ(5,340) (DIST7(I,J,K),K=1,7)
  340 FORMAT(22X,7F8.5)
  339 CONTINUE
      DO 341 I=1,6
      DO 341 J=1,6
      READ(5,342) (DIST8(I,J,K),K=1,8)
  342 FORMAT(22X,7F8.5,/,F8.5)
  341 CONTINUE
      DO 343 J=1,5
      READ(5,344) (DIST9(J,K),K=1,9)
  344 FORMAT(4X,9F8.5)
  343 CONTINUE
      DO 345 J=1,6
      READ(5,346) (DIST10(J,K),K=1,10)
  346 FORMAT(4X,9F8.5,/,F8.5)
  345 CONTINUE
      DO 347 J=1,7
      READ(5,348) (DIST11(J,K),K=1,11)
  348 FORMAT(4X,9F8.5,/,2F8.5)
  347 CONTINUE
      DO 349 J=1,9
      READ(5,350) (DIST13(J,K),K=1,13)
  350 FORMAT(4X,9F8.5,/,4F8.5)
  349 CONTINUE
      DO 351 J=1,10
      READ(5,352) (DIST14(J,K),K=1,14)
  352 FORMAT(4X,9F8.5,/,5F8.5)
  351 CONTINUE
      DO 313 I=1,6
      ISUM=0
      DO 314 K=1,21
      ISUM=ISUM+NSSAB(I,K)
  314 CONTINUE
      NSSABT(I)=ISUM
```

```
  313 CONTINUE
      DO 315 I=1,6
      ISUM=0
      DO 316 K=1,13
      ISUM=ISUM+IATAB(I,K)
  316 CONTINUE
      IATABT(I)=ISUM
  315 CONTINUE
      DO 317 I=1,6
      ISUM=0
      DO 318 K=1,14
      ISUM=ISUM+DURAB(I,K)
  318 CONTINUE
      DURABT(I)=ISUM
  317 CONTINUE
      DO 328 I=1,6
      DO 328 J=1,21
      RNSS=NSSAB(I,J)
      RPNSS(I,J)=RNSS/NSSABT(I)
  328 CONTINUE
      DO 326 I=1,6
      DO 326 J=1,13
      RIAT=IATAB(I,J)
      RPIATS(I,J)=RIAT/IATABT(I)
  326 CONTINUE
      DO 327 I=1,6
      DO 327 J=1,14
      RDUR=DURAB(I,J)
      RPDURS(I,J)=RDUR/DURABT(I)
  327 CONTINUE
C*******************************************************************************
C   INITIALIZE VARIABLES
C*******************************************************************************
      M=1
      NHOURS=0
      NBYR=1976
      LYR=1977
      ISTART=192711
      JSTART=622435
      CALL RSTART(ISTART,JSTART)
C*******************************************************************************
C   IF M=1, TEST FOR LEAP YEAR AND INITIALIZE MHRS(1) WITH PROPER VALUE
C*******************************************************************************
      IF(M.NE.1)GO TO 100
      CALL LEAPYR(NBYR,MHRS(1))
  100 CONTINUE
C*******************************************************************************
C   GENERATE ONE VALUE OF IATSE
C*******************************************************************************
      PIATSE=UNI(0)
      IATSE=IATCO(M)+(IATCO(M)-EXPMN(M))*ALOG(1.0-PIATSE)
      IATSE=IATSE+1
      NHOURS=NHOURS+IATSE
C*******************************************************************************
C   TEST NHOURS FOR PERIOD EXCEEDENCE
C*******************************************************************************
  103 IF(NHOURS.LT.MHRS(M))GO TO 101
C*******************************************************************************
C   ADVANCE TO NEXT PERIOD AND REPEAT EXCEEDENCE TEST
C*******************************************************************************
      NHOURS=NHOURS-MHRS(M)
      M=M+1
      IF(M.GT.6)GO TO 102
      GO TO 103
  102 M=1
      NBYR=NBYR+1
      IF(NBYR.GT.LYR)GO TO 999
C*******************************************************************************
C   TEST FOR LEAP YEAR AND INITIALIZE MHRS(1) WITH PROPER VALUE
C*******************************************************************************
      CALL LEAPYR(NBYR,MHRS(1))
      GO TO 103
  101 CONTINUE
C*******************************************************************************
C   COMPUTE MONTH, DAY, AND HOUR OF STORM START
C*******************************************************************************
      IF(M.GT.1)GO TO 114
      IF(MHRS(1).NE.1440)GO TO 115
      NODAYS(2)=29
      GO TO 114
  115 NODAYS(2)=28
  114 CONTINUE
      K2=M*2
      K1=K2-1
      IF(NHOURS.GT.(NODAYS(K1)*24))GO TO 113
      MONTH=K1
      DAY=1+NHOURS/24
      HOUR=NHOURS+1-(DAY-1)*24
      GO TO 116
  113 MONTH=K2
      XHOURS=NHOURS-(NODAYS(K1)*24)
      DAY=1+XHOURS/24
      HOUR=XHOURS+1-(DAY-1)*24
  116 CONTINUE
```

```
C*******************************************************************************
C   GENERATE ONE VALUE OF NSSSE
C*******************************************************************************
      FNSSSE=UNI(0)
      SUM=0.0
      DO 118 K=1,21
      SUM=SUM+RFNSS(M,K)
      IF(FNSSSE.LE.SUM)GO TO 119
  118 CONTINUE
      NSSSE=21
      GO TO 201
  119 NSSSE=K
C*******************************************************************************
C   GENERATE NSSSE-1 VALUS OF IATSS
C*******************************************************************************
  201 IF(NSSSE.EQ.1)GO TO 124
      INS=NSSSE-1
      DO 122 N=1,INS
      FIATSS=UNI(0)
      SUM=0.0
      DO 121 L=1,13
      SUM=SUM+RFIATS(M,L)
      IF(FIATSS.LE.SUM)GO TO 123
  121 CONTINUE
      IATSS(N)=12
      GO TO 122
  123 IATSS(N)=L-1
  122 CONTINUE
C*******************************************************************************
C   STORM SEGMENT GENERATION LOOP: NSSSE CYCLES
C   (EACH CYCLE GENERATES ONE STORM SEGMENT)
C*******************************************************************************
  124 LENGTH=0
      TRAIN=0.0
      LL=0
      DO 126 N=1,NSSSE
C*******************************************************************************
C   GENERATE ONE VALUE OF DURSS
C*******************************************************************************
      FDURSS=UNI(0)
      SUM=0.0
      DO 127 L=1,14
      SUM=SUM+RFDURS(M,L)
      IF(FDURSS.LE.SUM)GO TO 128
  127 CONTINUE
      DURSS(N)=14
      GO TO 202
  128 DURSS(N)=L
C*******************************************************************************
C   GENERATE ONE VALUE OF ACCUM
C*******************************************************************************
  202 STDNOR=RNOR(0)
      ACCUM(N)=EXP(STDNOR*SQRT(VLNACM(M,DURSS(N)))+MLNACM(M,DURSS(N)))
      IF(ACCUM(N).GT.0.001)GO TO 135
      ACCUM(N)=0.001
  135 CONTINUE
C*******************************************************************************
C   GENERATE ONE VALUE OF PKHR
C*******************************************************************************
      IF(DURSS(N).EQ.1)GO TO 145
      FPKHR=UNI(0)
      SUM=0.0
      IDUR=DURSS(N)
      DO 149 L=1,IDUR
      SUM=SUM+RFPKHR(M,IDUR-1,L)
      IF(FPKHR.LE.SUM)GO TO 147
  149 CONTINUE
      PKHR(N)=IDUR
      GO TO 148
  147 PKHR(N)=L
      GO TO 148
  145 PKHR(N)=1
  148 CONTINUE
C*******************************************************************************
C   SELECT STORM SEGMENT SHAPE
C*******************************************************************************
      IF(DURSS(N)-2) 180,181,182
  181 DO 195 J=1,3
         DO 196 I=1,2
  196    SHAPE(J,I)=DIST2(M,PKHR(N),J,I)
  195 ALMT(J)=ACML2(M,PKHR(N),J)
      GO TO 183
  182 IF(DURSS(N)-4) 151,152,153
  152 DO 163 J=1,3
         DO 164 I=1,4
  164    SHAPE(J,I)=DIST4(M,PKHR(N),J,I)
  163 ALMT(J)=ACML4(M,PKHR(N),J)
      GO TO 183
  151 DO 165 J=1,3
         DO 166 I=1,3
  166    SHAPE(J,I)=DIST3(M,PKHR(N),J,I)
  165 ALMT(J)=ACML3(M,PKHR(N),J)
      GO TO 183
  153 IF(DURSS(N)-6) 154,155,156
```

```
  154 DO 167 J=1,3
      DO 168 I=1,5
  168 SHAPE(J,I)=DIST5(M,PKHR(N),J,I)
  167 ALMT(J)=ACML5(M,PKHR(N),J)
      GO TO 183
  155 DO 169 I=1,6
  169 SHAPE(1,I)=DIST6(M,PKHR(N),I)
      GO TO 194
  156 IF(DURSS(N)-8) 157,158,159
  157 DO 171 I=1,7
  171 SHAPE(1,I)=DIST7(M,PKHR(N),I)
      GO TO 194
  158 DO 170 I=1,8
  170 SHAPE(1,I)=DIST8(M,PKHR(N)-1,I)
      GO TO 194
  159 IF(DURSS(N)-10) 160,161,162
  160 DO 173 I=1,9
  173 SHAPE(1,I)=DIST9(PKHR(N)-2,I)
      GO TO 194
  161 DO 172 I=1,10
  172 SHAPE(1,I)=DIST10(PKHR(N)-2,I)
      GO TO 194
  162 IF(DURSS(N)-13) 174,175,176
  174 DO 178 I=1,11
  178 SHAPE(1,I)=DIST11(PKHR(N)-2,I)
      GO TO 194
  175 DO 177 I=1,13
  177 SHAPE(1,I)=DIST13(PKHR(N)-2,I)
      GO TO 194
  176 DO 179 I=1,14
  179 SHAPE(1,I)=DIST14(PKHR(N)-2,I)
      GO TO 194
  180 RAIN(N,1)=ACCUM(N)
      GO TO 191
  183 DO 184 J=1,3
      IF(ACCUM(N).LE.ALMT(J))GO TO 185
  184 CONTINUE
  185 IDUR=DURSS(N)
      DO 186 I=1,IDUR
  186 RAIN(N,I)=SHAPE(J,I)*ACCUM(N)
      GO TO 191
  194 IDUR=DURSS(N)
      DO 187 I=1,IDUR
  187 RAIN(N,I)=SHAPE(1,I)*ACCUM(N)
  191 IDUR=DURSS(N)
      DO 193 I=1,IDUR
      IF(RAIN(N,I).GE.0.001)GO TO 193
      RAIN(N,I)=0.001
  193 CONTINUE
C*******************************************************************************
C   ADD TO STORM LENGTH AND STORM RAINFALL ACCUMULATION
C*******************************************************************************
      IF(N.EQ.1)GO TO 105
      LENGTH=LENGTH+DURSS(N)+IATSS(N-1)
      TRAIN=TRAIN+ACCUM(N)
      GO TO 104
  105 LENGTH=LENGTH+DURSS(1)
      TRAIN=TRAIN+ACCUM(1)
  104 DO 204 I=1,IDUR
      LL=LL+1
      HRAIN(LL)=RAIN(N,I)
  204 CONTINUE
      IF(N.EQ.NSSSE)GO TO 126
      IF(IATSS(N).EQ.0)GO TO 126
      ITS=IATSS(N)
      DO 203 I=1,ITS
      LL=LL+1
      HRAIN(LL)=0.0
  203 CONTINUE
  126 CONTINUE
C*******************************************************************************
C   END OF STORM EVENT GENERATION LOOP
C*******************************************************************************
C
C*******************************************************************************
C   WRITE STATEMENTS
C*******************************************************************************
      WRITE(6,416)HOUR,DAY,MONTH,NBYR,IATSE,LENGTH,TRAIN
  416 FORMAT(/16X,'DATE OF STORM EVENT=',1X,I2,'/',I2,'/',I2,'/',I4,3X,'
     &IATSE=',I4,3X,'LENGTH=',I3,3X,'TRAIN=',F6.3)
      WRITE(6,417)(HRAIN(K),K=1,LENGTH)
  417 FORMAT(16X,'STORM EVENT HOURLY RAINFALL ACCUMULATIONS=',5F6.3,/,16
     &X,12F6.3,/,16X,12F6.3,/,16X,12F6.3,/,16X,12F6.3,/,16X,12F6.3,/,16X
     &,12F6.3,/,16X,12F6.3,/,16X,12F6.3,/,16X,12F6.3,/,16X,12F6.3)
C*******************************************************************************
C   ADD STORM LENGTH TO NHOURS COUNTER AND UPDATE MHRS AND NBYR
C*******************************************************************************
      NHOURS=NHOURS+LENGTH
      IF(NHOURS.GE.MHRS(M))GO TO 106
      GO TO 100
  106 NHOURS=NHOURS-MHRS(M)
      M=M+1
      IF(M.GT.6)GO TO 107
      GO TO 100
```

```
107 M=1
    NBYR=NBYR+1
    IF(NBYR.GT.LYR) GO TO 999
    CALL LEAPYR(NBYR,MHRS(1))
    GO TO 100
999 CONTINUE
    STOP
    END




      SUBROUTINE LEAPYR(NBYR,MHRS)
      XBYR=NBYR
      XLEAP=XBYR/4.0
      TLEAP=AINT(XLEAP)
      IF(TLEAP.NE.XLEAF)GO TO 200
      MHRS=1440
      GO TO 201
  200 MHRS=1416
  201 CONTINUE
      RETURN
      END
```

DATA

```
 31 28 31 30 31 30 31 31 30 31 30 31
 1416 1464 1464 1488 1464 1464
 12 12  6  6  9 12
 144.61  99.32  69.78  91.74 114.27 138.73
 71 72 61 29 25 15 12  8  2  4  5  3  0  0  0  0  0  0  0  0  0
 87 81 79 56 40 26 15 10 10  9  2  6  1  1  2  0  2  0  0  0  1
253150 83 44 28 22 14  7  2  2  0  0  1  0  1  0  0  0  0  0  0
248124 59 31 11 13  1  2  1  1  0  0  0  0  0  0  0  0  0  0  0
152 68 43 27 22 16 11 12  4  4  2  1  1  0  3  1  0  1  0  0  2
 69 66 49 38 30 17 16 11  5  6  2  5  2  0  1  0  0  0  0  0  0
 410 162  57  34  19   9   8   6   4   3   3   3   2
 641 264  97  63  48  21  23  17   7   5   8   9   6
 404 220  98  46  33  32  30   0   0   0   0   0   0
 255 122  48  24  12   8  12   0   0   0   0   0   0
 403 178  63  39  23  25  16  14   7  10   0   0   0
 493 187  63  42  26  13   8  11   7   5   4   1   3
 161 241 240 180  97  49  28  13   6   4   1   0   0   0
 281 404 361 250 167  86  52  25   6   3   1   0   1   0
 277 395 322 232 135  66  22  17   3   1   0   0   0   0
 148 273 258 149  87  30  15   7   2   2   1   0   0   0
 201 283 279 201  90  53  22  10   4   2   2   0   0   1
 187 309 260 197 106  65  36  14   4   3   1   0   0   0
1   -5.58749-4.20259-3.45760-2.95842-2.41308-2.28000-2.08000-1.80000
-1.61500-1.44000-1.28000-1.14500-1.02000-0.89000
2   -5.45398-3.74805-2.92189-2.43427-2.09251-1.74500-1.49000-1.27000
-1.07500-0.90000-0.74000-0.60000-0.47500-0.35000
3   -5.05107-3.34045-2.34901-1.88140-1.41327-1.08000-0.80000-0.56000
-0.34000-0.16000+0.02000+0.17500+0.32000+0.45500
4   -4.74407-3.01913-2.20657-1.51294-1.04825-0.73000-0.42500-0.15000
+0.08000+0.28500+0.47500+0.65000+0.81000+0.96000
5   -5.11467-3.38167-2.59447-1.83576-1.63345-1.21000-0.93000-0.69000
-0.47500-0.29000-0.12500+0.03000+0.17500+0.31000
6   -5.46267-3.90286-3.09410-2.67908-2.50404-2.05000-1.82000-1.62500
-1.45500-1.30000-1.17000-1.04000-0.93000-0.82500
1     1.04534 1.03508 1.11852 0.89882 0.88413
0.83500 0.69500 0.57700 0.47600 0.39300 0.32200 0.26300 0.21400 0.17500
2     1.05617 1.38066 1.19290 1.11063 1.01208
0.83500 0.69500 0.57700 0.47600 0.39300 0.32200 0.26300 0.21400 0.17500
3     2.11778 1.97749 1.64247 1.31571 0.94917
0.83500 0.69500 0.57700 0.47600 0.39300 0.32200 0.26300 0.21400 0.17500
4     2.36789 2.46168 1.56440 1.27112 1.06078
0.83500 0.69500 0.57700 0.47600 0.39300 0.32200 0.26300 0.21400 0.17500
5     1.52530 1.92166 1.46105 1.00583 0.97946
0.83500 0.69500 0.57700 0.47600 0.39300 0.32200 0.26300 0.21400 0.17500
6     1.18981 1.31823 1.09449 1.10360 0.90931
0.83500 0.69500 0.57700 0.47600 0.39300 0.32200 0.26300 0.21400 0.17500
   DURSS= 2         0.8423 0.1577
   DURSS= 3         0.4542 0.4583 0.0875
   DURSS= 4         0.1944 0.4333 0.3223 0.0500
   DURSS= 5         0.1340 0.2784 0.3711 0.2165 0.0
   DURSS= 6         0.0408 0.2245 0.3469 0.2857 0.1021 0.0
   DURSS= 7         0.0357 0.1072 0.3571 0.2143 0.2143 0.0714 0.0

   DURSS= 8         0.0    0.0930 0.3140 0.2330 0.1740 0.1630 0.0230
                    0.0
   DURSS= 9         0.0    0.0    0.2797 0.2399 0.2000 0.1601 0.1204
                    0.0    0.0
   DURSS=10         0.0    0.0    0.2331 0.2065 0.1799 0.1534 0.1268
                    0.1003 0.0    0.0
   DURSS=11         0.0    0.0    0.1998 0.1808 0.1618 0.1428 0.1239
                    0.1049 0.0860 0.0    0.0
   DURSS=12         0.0    0.0    0.1748 0.1606 0.1463 0.1321 0.1179
                    0.1036 0.0894 0.0753 0.0    0.0
   DURSS=13         0.0    0.0    0.1554 0.1443 0.1333 0.1222 0.1111
                    0.1000 0.0890 0.0779 0.0669 0.0    0.0
   DURSS=14         0.0    0.0    0.1399 0.1310 0.1221 0.1133 0.1044
                    0.0956 0.0867 0.0778 0.0690 0.0602 0.0    0.0
   DURSS= 2         0.8540 0.1460
   DURSS= 3         0.4432 0.5069 0.0499
   DURSS= 4         0.2400 0.4280 0.3120 0.0200
   DURSS= 5         0.1377 0.3293 0.3713 0.1617 0.0
   DURSS= 6         0.1047 0.2209 0.2442 0.3372 0.0930 0.0
   DURSS= 7         0.0192 0.2115 0.2500 0.2308 0.1923 0.0962 0.0

   DURSS= 8         0.0    0.0930 0.3140 0.2330 0.1740 0.1630 0.0230
                    0.0
   DURSS= 9         0.0    0.0    0.2797 0.2399 0.2000 0.1601 0.1204
                    0.0    0.0
   DURSS=10         0.0    0.0    0.2331 0.2065 0.1799 0.1534 0.1268
                    0.1003 0.0    0.0
   DURSS=11         0.0    0.0    0.1998 0.1808 0.1618 0.1428 0.1239
                    0.1049 0.0860 0.0    0.0
   DURSS=12         0.0    0.0    0.1748 0.1606 0.1463 0.1321 0.1179
                    0.1036 0.0894 0.0753 0.0    0.0
   DURSS=13         0.0    0.0    0.1554 0.1443 0.1333 0.1222 0.1111
                    0.1000 0.0890 0.0779 0.0669 0.0    0.0
   DURSS=14         0.0    0.0    0.1399 0.1310 0.1221 0.1133 0.1044
                    0.0956 0.0867 0.0778 0.0690 0.0602 0.0    0.0
   DURSS= 2         0.7747 0.2253
   DURSS= 3         0.4130 0.5311 0.0559
   DURSS= 4         0.1983 0.4526 0.3276 0.0215
   DURSS= 5         0.1185 0.4222 0.2741 0.1778 0.0074
```

```
DURSS= 6         0.1061 0.3030 0.2879 0.1970 0.1060 0.0
DURSS= 7         0.0    0.2273 0.3182 0.2273 0.1364 0.0908 0.0

DURSS= 8         0.0    0.0930 0.3140 0.2330 0.1740 0.1630 0.0230
                 0.0
DURSS= 9         0.0    0.0    0.2797 0.2399 0.2000 0.1601 0.1204
                 0.0    0.0
DURSS=10         0.0    0.0    0.2331 0.2065 0.1799 0.1534 0.1268
                 0.1003 0.0    0.0
DURSS=11         0.0    0.0    0.1998 0.1808 0.1618 0.1428 0.1239
                 0.1049 0.0860 0.0    0.0
DURSS=12         0.0    0.0    0.1748 0.1606 0.1463 0.1321 0.1179
                 0.1036 0.0894 0.0753 0.0    0.0
DURSS=13         0.0    0.0    0.1554 0.1443 0.1333 0.1222 0.1111
                 0.1000 0.0890 0.0779 0.0669 0.0    0.0
DURSS=14         0.0    0.0    0.1399 0.1310 0.1221 0.1133 0.1044
                 0.0956 0.0867 0.0778 0.0690 0.0602 0.0    0.0
DURSS= 2         0.7399 0.2601
DURSS= 3         0.4457 0.5233 0.0310
DURSS= 4         0.2282 0.4631 0.2819 0.0268
DURSS= 5         0.0805 0.4483 0.3218 0.1494 0.0
DURSS= 6         0.1333 0.2333 0.3000 0.2333 0.1001 0.0
DURSS= 7         0.0667 0.0    0.4000 0.4000 0.0    0.1333 0.0
DURSS= 8         0.0    0.0930 0.3140 0.2330 0.1740 0.1630 0.0230
                 0.0
DURSS= 9         0.0    0.0    0.2797 0.2399 0.2000 0.1601 0.1204
                 0.0    0.0
DURSS=10         0.0    0.0    0.2331 0.2065 0.1799 0.1534 0.1268
                 0.1003 0.0    0.0
DURSS=11         0.0    0.0    0.1998 0.1808 0.1618 0.1428 0.1239
                 0.1049 0.0860 0.0    0.0
DURSS=12         0.0    0.0    0.1748 0.1606 0.1463 0.1321 0.1179
                 0.1036 0.0894 0.0753 0.0    0.0
DURSS=13         0.0    0.0    0.1554 0.1443 0.1333 0.1222 0.1111
                 0.1000 0.0890 0.0779 0.0669 0.0    0.0
DURSS=14         0.0    0.0    0.1399 0.1310 0.1221 0.1133 0.1044
                 0.0956 0.0867 0.0778 0.0690 0.0602 0.0    0.0
DURSS= 2         0.8269 0.1731
DURSS= 3         0.4086 0.5305 0.0609
DURSS= 4         0.2488 0.4179 0.3333 0.0
DURSS= 5         0.0667 0.3222 0.4111 0.2000 0.0
DURSS= 6         0.0943 0.1698 0.3774 0.2642 0.0943 0.0
DURSS= 7         0.0455 0.2727 0.1818 0.3182 0.1364 0.0454 0.0
DURSS= 8         0.0    0.0930 0.3140 0.2330 0.1740 0.1630 0.0230
                 0.0
DURSS= 9         0.0    0.0    0.2797 0.2399 0.2000 0.1601 0.1204
                 0.0    0.0
DURSS=10         0.0    0.0    0.2331 0.2065 0.1799 0.1534 0.1268
                 0.1003 0.0    0.0
DURSS=11         0.0    0.0    0.1998 0.1808 0.1618 0.1428 0.1239
                 0.1049 0.0860 0.0    0.0
DURSS=12         0.0    0.0    0.1748 0.1606 0.1463 0.1321 0.1179
                 0.1036 0.0894 0.0753 0.0    0.0
DURSS=13         0.0    0.0    0.1554 0.1443 0.1333 0.1222 0.1111
                 0.1000 0.0890 0.0779 0.0669 0.0    0.0
DURSS=14         0.0    0.0    0.1399 0.1310 0.1221 0.1133 0.1044
                 0.0956 0.0867 0.0778 0.0690 0.0602 0.0    0.0
DURSS= 2         0.8867 0.1133
DURSS= 3         0.3962 0.5423 0.0615
DURSS= 4         0.2690 0.3858 0.3350 0.0102
DURSS= 5         0.1132 0.2453 0.3868 0.2547 0.0
DURSS= 6         0.0615 0.2462 0.4000 0.2154 0.0769 0.0
DURSS= 7         0.0556 0.1944 0.1667 0.3611 0.1667 0.0555 0.0
DURSS= 8         0.0000 0.0930 0.3140 0.2330 0.1740 0.1630 0.0230
                 0.0
DURSS= 9         0.0    0.0    0.2797 0.2399 0.2000 0.1601 0.1204
                 0.0    0.0
DURSS=10         0.0    0.0    0.2331 0.2065 0.1799 0.1534 0.1268
                 0.1003 0.0    0.0
DURSS=11         0.0    0.0    0.1998 0.1808 0.1618 0.1428 0.1239
                 0.1049 0.0860 0.0    0.0
DURSS=12         0.0    0.0    0.1748 0.1606 0.1463 0.1321 0.1179
                 0.1036 0.0894 0.0753 0.0    0.0
DURSS=13         0.0    0.0    0.1554 0.1443 0.1333 0.1222 0.1111
                 0.1000 0.0890 0.0779 0.0669 0.0    0.0
DURSS=14         0.0    0.0    0.1399 0.1310 0.1221 0.1133 0.1044
                 0.0956 0.0867 0.0778 0.0690 0.0602 0.0    0.0
2  1   1  1       0.055     0.015     0.67536 0.32462
2  1   1  2       0.111     0.067     0.66565 0.33435
2  1   1  3       0.166     0.130     0.68863 0.31137
2  1   2  1       0.065     0.015     0.32362 0.67637
2  1   2  2       0.130     0.095     0.30753 0.69247
2  1   2  3       0.195     0.195     0.27692 0.72308
2  2   1  1       0.238     0.037     0.69953 0.30046
2  2   1  2       0.476     0.294     0.78637 0.21363
2  2   1  3       0.714     0.686     0.80952 0.19048
2  2   2  1       0.204     0.049     0.24566 0.75434
2  2   2  2       0.409     0.253     0.44151 0.55849
2  2   2  3       0.613     0.613     0.30343 0.69657
2  3   1  1       0.310     0.058     0.72129 0.27870
2  3   1  2       0.620     0.438     0.76693 0.23307
2  3   1  3       0.930     0.774     0.72030 0.27970
2  3   2  1       0.229     0.048     0.28518 0.71482
2  3   2  2       0.458     0.295     0.19037 0.80963
```

```
2  3  2  3    0.687    0.633    0.18376 0.81624
2  4  1  1    0.550    0.080    0.73105 0.26894
2  4  1  2    1.099    0.761    0.88263 0.11737
2  4  1  3    1.649    1.455    0.90397 0.09603
2  4  2  1    0.286    0.055    0.27381 0.72618
2  4  2  2    0.572    0.377    0.25767 0.74233
2  4  2  3    0.858    0.770    0.17511 0.82489
2  5  1  1    0.503    0.067    0.72068 0.27930
2  5  1  2    1.005    0.685    0.88197 0.11803
2  5  1  3    1.508    1.508    0.65650 0.34350
2  5  2  1    0.344    0.047    0.28665 0.71334
2  5  2  2    0.689    0.359    0.32489 0.67511
2  5  2  3    1.033    0.993    0.23684 0.76316
2  6  1  1    0.182    0.028    0.67608 0.32391
2  6  1  2    0.365    0.244    0.75C70 0.24930
2  6  1  3    0.547    0.532    0.71515 0.28485
2  6  2  1    0.161    0.022    0.32881 0.67119
2  6  2  2    0.321    0.168    0.32738 0.67262
2  6  2  3    0.482    0.482    0.24481 0.75519
3  1  1  1    0.169    0.040    0.52286 0.30737 0.16977
3  1  1  2    0.338    0.268    0.53178 0.35507 0.11315
3  1  1  3    0.507    0.438    0.71821 0.19701 0.08477
3  1  2  1    0.177    0.043    0.24056 0.52782 0.23161
3  1  2  2    0.353    0.261    0.23137 0.50307 0.26555
3  1  2  3    0.530    0.456    0.42077 0.52261 0.05661
3  1  3  1    0.049    0.021    0.19429 0.27489 0.53082
3  1  3  2    0.098    0.091    0.15394 0.36131 0.48474
3  1  3  3    0.147    0.147    0.19048 0.37415 0.43537
3  2  1  1    0.336    0.063    0.55458 0.30599 0.13942
3  2  1  2    0.672    0.427    0.76671 0.19762 0.03568
3  2  1  3    1.008    1.008    0.52778 0.46429 0.00794
3  2  2  1    0.232    0.071    0.20948 0.58758 0.20293
3  2  2  2    0.464    0.314    0.18170 0.58725 0.23106
3  2  2  3    0.696    0.566    0.20055 0.65542 0.14403
3  2  3  1    0.144    0.034    0.17846 0.32259 0.49895
3  2  3  2    0.289    0.231    0.12363 0.33973 0.53664
3  2  3  3    0.433    0.433    0.00693 0.39261 0.60046
3  3  1  1    0.322    0.091    0.64548 0.24451 0.11000
3  3  1  2    0.644    0.468    0.69792 0.22773 0.07434
3  3  1  3    0.966    0.784    0.76135 0.19131 0.04734
3  3  2  1    0.660    0.144    0.18639 0.64355 0.17005
3  3  2  2    1.319    0.900    0.19823 0.65787 0.14390
3  3  2  3    1.979    1.666    C.15109 0.82317 0.02573
3  3  3  1    0.380    0.069    0.12522 0.30265 0.57212
3  3  3  2    0.760    0.391    0.11509 0.12276 0.76215
3  3  3  3    1.140    1.056    0.08341 0.16343 0.75316
3  4  1  1    0.329    0.099    0.64182 0.26130 0.09687
3  4  1  2    0.659    0.484    0.67205 0.28367 0.04428
3  4  1  3    0.988    0.788    0.76942 0.17642 0.05416
3  4  2  1    0.589    0.147    0.19374 0.64787 0.15837
3  4  2  2    1.177    0.849    0.13762 0.78431 0.07807
3  4  2  3    1.766    1.532    0.25460 0.61504 0.13036
3  4  3  1    0.216    0.058    0.08292 0.30576 0.61131
3  4  3  2    0.431    0.244    0.01230 0.11066 0.87705
3  4  3  3    0.647    0.647    0.02782 0.06646 0.90572
3  5  1  1    0.296    0.076    0.62095 0.26535 0.11370
3  5  1  2    0.591    0.439    0.63940 0.29487 0.06574
3  5  1  3    0.887    0.753    0.78254 0.19406 0.02340
3  5  2  1    0.374    0.107    0.20108 0.61631 0.18259
3  5  2  2    0.748    0.501    0.19324 0.66896 0.13780
3  5  2  3    1.122    0.952    0.29655 0.53384 0.16961
3  5  3  1    0.090    0.034    0.15744 0.30826 0.53430
3  5  3  2    0.181    0.106    0.03957 0.19849 0.76194
3  5  3  3    0.271    0.233    0.05860 0.36762 0.57376
3  6  1  1    0.198    0.057    0.55565 0.29181 0.15253
3  6  1  2    0.397    0.292    0.58030 0.32376 0.09594
3  6  1  3    0.595    0.534    0.84135 0.13504 0.02361
3  6  2  1    0.208    0.056    0.24238 0.53756 0.22005
3  6  2  2    0.417    0.299    0.19320 0.53231 0.27449
3  6  2  3    0.625    0.591    0.24507 0.59547 0.15946
3  6  3  1    0.137    0.033    C.15332 0.29891 0.54777
3  6  3  2    0.274    0.231    0.12363 0.33973 0.53664
3  6  3  3    0.411    0.411    0.00730 0.24331 0.74939
4  1  1  1    0.212    0.053    0.42922 0.27826 0.18684 0.10568
4  1  1  2    0.425    0.275    0.49091 0.34182 0.13091 0.03636
4  1  1  3    0.637    0.637    0.50392 0.19152 0.19152 0.11303
4  1  2  1    0.464    0.087    0.19367 0.45578 0.24240 0.10814
4  1  2  2    0.928    0.422    0.11663 0.50805 0.24879 0.12652
4  1  2  3    1.392    1.392    0.01006 0.91092 0.05819 0.02083
4  1  3  1    0.112    0.046    0.10367 0.22614 0.46513 0.20506
4  1  3  2    0.224    0.159    0.13625 0.23204 0.40472 0.22699
4  1  3  3    0.336    0.296    0.10344 0.21872 0.42682 0.25102
4  1  4  1    0.016    0.008    0.12143 0.17143 0.24285 0.46428
4  1  4  2    0.032    0.020    0.10049 0.14216 0.31372 0.44363
4  1  4  3    0.048    0.041    0.10442 0.16925 0.31590 0.41043
4  2  1  1    0.285    0.094    0.50029 0.27194 0.14523 0.08254
4  2  1  2    0.571    0.411    0.54663 0.30645 0.10852 0.03841
4  2  1  3    0.856    0.856    0.61916 0.26519 0.08528 0.03037
4  2  2  1    0.278    0.104    0.17424 0.48577 0.24764 0.09234
4  2  2  2    0.555    0.381    0.21902 0.47887 0.24542 0.05669
4  2  2  3    0.833    0.699    0.06533 0.62699 0.27571 0.03196
4  2  3  1    0.206    0.076    0.10995 0.24548 0.47759 0.16697
4  2  3  2    0.411    0.292    0.07348 0.22084 0.57242 0.13325
4  2  3  3    0.617    0.503    0.07603 0.23451 0.57913 0.11034
```

```
4  2  4  1    0.037    0.010    0.20000 0.20000 0.20000 0.40000
4  2  4  2    0.074    0.057    0.03644 0.19309 0.31042 0.46003
4  2  4  3    0.111    0.101    0.15350 0.20800 0.30601 0.33249
4  3  1  1    0.413    0.130    0.54939 0.26662 0.12140 0.06258
4  3  1  2    0.826    0.511    0.63295 0.27887 0.07630 0.01188
4  3  1  3    1.239    1.098    0.52984 0.33275 0.11236 0.02505
4  3  2  1    0.889    0.242    0.16024 0.56493 0.21434 0.06048
4  3  2  2    1.777    1.121    0.13944 0.74790 0.10660 0.00606
4  3  2  3    2.666    2.666    0.09415 0.51313 0.28245 0.11028
4  3  3  1    0.403    0.137    0.07583 0.24659 0.55584 0.12173
4  3  3  2    0.807    0.559    0.04669 0.18214 0.62322 0.14795
4  3  3  3    1.210    1.021    0.04739 0.29903 0.49861 0.15497
4  3  4  1    0.278    0.027    0.14719 0.16234 0.28355 0.40693
4  3  4  2    0.557    0.384    0.04427 0.13542 0.35937 0.46094
4  3  4  3    0.835    0.835    0.00359 0.08024 0.25269 0.66347
4  4  1  1    0.461    0.188    0.60193 0.27205 0.08802 0.03800
4  4  1  2    0.923    0.604    0.61435 0.29947 0.06396 0.02222
4  4  1  3    1.384    1.374    0.63542 0.28365 0.07370 0.00723
4  4  2  1    1.042    0.299    0.18446 0.57220 0.19720 0.04615
4  4  2  2    2.085    1.333    0.14175 0.68711 0.14698 0.02416
4  4  2  3    3.127    3.032    0.10028 0.67466 0.22136 0.00369
4  4  3  1    0.735    0.251    0.06821 0.21214 0.56583 0.15382
4  4  3  2    1.469    0.935    0.00357 0.05805 0.87233 0.06603
4  4  3  3    2.204    2.204    0.23730 0.28584 0.45009 0.02677
4  4  4  1    0.375    0.090    0.01847 0.04600 0.10378 0.83174
4  4  4  2    0.750    0.548    0.09489 0.09854 0.37044 0.43613
4  4  4  3    1.125    1.125    0.06844 0.14578 0.29600 0.48978
4  5  1  1    0.618    0.223    0.54598 0.27690 0.12335 0.05377
4  5  1  2    1.237    0.878    0.64839 0.26767 0.05916 0.02477
4  5  1  3    1.855    1.855    0.63342 0.28949 0.07655 0.00054
4  5  2  1    0.637    0.200    0.19227 0.50100 0.22444 0.08227
4  5  2  2    1.274    0.767    0.14555 0.59737 0.21639 0.04069
4  5  2  3    1.911    1.600    0.21191 0.67711 0.10914 0.00182
4  5  3  1    0.472    0.150    0.09090 0.22005 0.50290 0.18613
4  5  3  2    0.943    0.551    0.09158 0.18240 0.48019 0.24583
4  5  3  3    1.415    1.278    0.07250 0.20989 0.59178 0.12582
4  5  4  1
4  5  4  2
4  5  4  3
4  6  1  1    0.269    0.075    0.46435 0.28256 0.16755 0.08553
4  6  1  2    0.539    0.451    0.62139 0.27246 0.08810 0.01804
4  6  1  3    0.808    0.808    0.37129 0.30941 0.25124 0.06807
4  6  2  1    0.311    0.087    0.20184 0.45491 0.22162 0.12163
4  6  2  2    0.623    0.422    0.11663 0.50805 0.24879 0.12652
4  6  2  3    0.934    0.792    0.19800 0.58592 0.18494 0.03114
4  6  3  1    0.610    0.104    0.11586 0.22230 0.46550 0.19633
4  6  3  2    1.221    0.995    0.14427 0.23519 0.37887 0.24166
4  6  3  3    1.831    1.831    0.03004 0.38667 0.58165 0.00164
4  6  4  1    0.012    0.008    0.12143 0.17143 0.24285 0.46428
4  6  4  2    0.023    0.015    0.06667 0.06667 0.20000 0.66667
4  6  4  3    0.035    0.035    0.05714 0.17143 0.37143 0.40000
5  1  1  1    0.145    0.072    0.38068 0.28467 0.15478 0.10434 0.07553
5  1  1  2    0.291    0.254    0.48819 0.23228 0.20079 0.05512 0.02362
5  1  1  3    0.436    0.376    0.33109 0.29256 0.22381 0.08871 0.06382
5  1  2  1    0.139    0.067    0.17311 0.37169 0.23370 0.15893 0.06256
5  1  2  2    0.277    0.173    0.12834 0.39948 0.27924 0.13102 0.06191
5  1  2  3    0.416    0.386    0.13890 0.45582 0.19128 0.12869 0.08530
5  1  3  1    0.168    0.071    0.08629 0.22072 0.42392 0.17932 0.08975
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5  1  4  3    0.626    0.626    0.00479 0.07668 0.20607 0.40895 0.30351
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5  1  5  2
5  1  5  3
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5  2  4  1    0.160    0.071    0.07133 0.15086 0.23069 0.38501 0.16210
5  2  4  2    0.320    0.222    0.02302 0.09046 0.18967 0.44146 0.25538
5  2  4  3    0.480    0.397    0.03595 0.16664 0.27641 0.41784 0.10316
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5  2  5  2
5  2  5  3
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5  3  4  1    0.442    0.150    0.06266 0.10889 0.22300 0.43582 0.16963
5  3  4  2    0.885    0.688    0.06183 0.14408 0.34435 0.37073 0.07901
5  3  4  3    1.327    1.180    0.01711 0.05381 0.25773 0.63948 0.03186
5  3  5  1    0.365    0.150    0.06266 0.10889 0.16963 0.22300 0.43582
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5   4   1  1      0.338      0.145      0.46049 0.33699 0.14212 0.04426 0.01614
5   4   1  2      0.675      0.403      0.52019 0.28936 0.15161 0.03386 0.00497
5   4   1  3      1.013      1.013      0.52912 0.41066 0.05232 0.00592 0.00197
5   4   2  1      0.463      0.249      0.14667 0.50714 0.23943 0.08255 0.02421
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5   4   3  1      0.903      0.263      0.08413 0.22499 0.46490 0.17287 0.05311
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5   4   3  3      2.710      2.710      0.00406 0.24834 0.56125 0.18450 0.00185
5   4   4  1      0.877      0.321      0.03434 0.09283 0.24951 0.49583 0.12750
5   4   4  2      1.754      0.900      0.01111 0.07778 0.09333 0.42222 0.39556
5   4   4  3      2.631      2.621      0.06050 0.08900 0.25990 0.44140 0.14918
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5   4   5  3
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5   5   1  2      0.479      0.308      0.25325 0.25325 0.23701 0.19481 0.06169
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5   5   2  1      0.680      0.219      0.15653 0.46570 0.23143 0.09482 0.05152
5   5   2  2      1.360      0.912      0.19494 0.48815 0.24521 0.06418 0.00752
5   5   2  3      2.040      1.620      0.12088 0.56846 0.22142 0.05816 0.03107
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5   5   3  2      0.636      0.394      0.03002 0.17949 0.50393 0.21514 0.07143
5   5   3  3      0.954      0.828      0.01283 0.17723 0.42573 0.26854 0.11567
5   5   4  1      0.333      0.150      0.05020 0.13116 0.23410 0.39054 0.19400
5   5   4  2      0.667      0.375      0.03665 0.06477 0.22211 0.51955 0.15693
5   5   4  3      1.000      1.000      0.02000 0.16500 0.24200 0.31400 0.25900
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5   5   5  2
5   5   5  3
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5   6   1  3      0.235      0.234      0.42312 0.24134 0.18807 0.12180 0.02566
5   6   2  1      0.338      0.117      0.15175 0.37015 0.26618 0.12864 0.08326
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6   1   4     0.207      0.05422 0.14085 0.21516 0.35589 0.17212 0.06176
6   1   5     0.113      0.02228 0.08208 0.16872 0.21234 0.32229 0.19229
6   2   1     0.314      0.34550 0.27185 0.21414 0.10491 0.04503 0.01857
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6   3   1     0.427      0.49195 0.31293 0.13341 0.03262 0.01822 0.01087
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6   3   4     0.585      0.03296 0.07822 0.20530 0.39622 0.23256 0.05474
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6   5   4     0.367      0.04723 0.11166 0.20205 0.38143 0.17870 0.07894
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 0.00626 0.00469
 6    0.00626 0.03443 0.03756 0.06103 0.13772 0.28951 0.20970 0.11737 0.07512
 0.02661 0.00469
 7    0.00469 0.00626 0.03443 0.03756 0.06103 0.13772 0.28951 0.20970 0.11737
 0.07512 0.02661
 8    0.00469 0.00626 0.02661 0.03443 0.03756 0.06103 0.13772 0.28951 0.20970
 0.11737 0.07512
 9    0.00469 0.00626 0.02661 0.03443 0.03756 0.06103 0.07512 0.13772 0.28951
 0.20970 0.11737
 3    0.03641 0.10922 0.20227 0.15453 0.14401 0.12460 0.07767 0.05583 0.04045
 0.02023 0.01780 0.01133 0.00565
 4    0.02023 0.03641 0.10922 0.20227 0.15453 0.14401 0.12460 0.07767 0.05583
 0.04045 0.01780 0.01133 0.00565
 5    0.01780 0.02023 0.03641 0.10922 0.20227 0.15453 0.14401 0.12460 0.07767
 0.05583 0.04045 0.01133 0.00565
 6    0.01133 0.01780 0.02023 0.03641 0.10922 0.20227 0.15453 0.14401 0.12460
 0.07767 0.05583 0.04045 0.00565
 7    0.00565 0.01133 0.01780 0.02023 0.03641 0.10922 0.20227 0.15453 0.14401
 0.12460 0.07767 0.05583 0.04045
 8    0.00565 0.01133 0.01780 0.02023 0.03641 0.04045 0.10922 0.20227 0.15453
 0.14401 0.12460 0.07767 0.05583
 9    0.00565 0.01133 0.01780 0.02023 0.03641 0.04045 0.05583 0.10922 0.20227
 0.15453 0.14401 0.12460 0.07767
10    0.00565 0.01133 0.01780 0.02023 0.03641 0.04045 0.05583 0.07767 0.10922
 0.20227 0.15453 0.14401 0.12460
11    0.00565 0.01133 0.01780 0.02023 0.03641 0.04045 0.05583 0.07767 0.10922
 0.12460 0.20227 0.15453 0.14401
 3    0.03398 0.10922 0.20227 0.15453 0.14401 0.12460 0.07767 0.05583 0.04045
 0.02023 0.01780 0.01133 0.00565 0.00243
 4    0.02023 0.03398 0.10922 0.20227 0.15453 0.14401 0.12460 0.07767 0.05583
 0.04045 0.01780 0.01133 0.00565 0.00243
 5    0.01780 0.02023 0.03398 0.10922 0.20227 0.15453 0.14401 0.12460 0.07767
 0.05583 0.04045 0.01133 0.00565 0.00243
 6    0.00243 0.01780 0.02023 0.03398 0.10922 0.20227 0.15453 0.14401 0.12460
 0.07767 0.05583 0.04045 0.01133 0.00565
 7    0.00243 0.00565 0.01780 0.02023 0.03398 0.10922 0.20227 0.15453 0.14401
 0.12460 0.07767 0.05583 0.04045 0.01133
 8    0.00243 0.00565 0.01133 0.01780 0.02023 0.03398 0.10922 0.20227 0.15453
 0.14401 0.12460 0.07767 0.05583 0.04045
 9    0.00243 0.00565 0.01133 0.01780 0.02023 0.03398 0.04045 0.10922 0.20227
 0.15453 0.14401 0.12460 0.07767 0.05583
10    0.00243 0.00565 0.01133 0.01780 0.02023 0.03398 0.04045 0.05583 0.10922
 0.20227 0.15453 0.14401 0.12460 0.07767
11    0.00243 0.00565 0.01133 0.01780 0.02023 0.03398 0.04045 0.05583 0.07767
 0.10922 0.20227 0.15453 0.14401 0.12460
12    0.00243 0.00565 0.01133 0.01780 0.02023 0.03398 0.04045 0.05583 0.07767
 0.10922 0.12460 0.20227 0.15453 0.14401
/*
//
```

Table E.2. Sample Computer Program Output

```
DATE OF STORM EVENT= 23/ 2/ 7/1976   IATSE=  70   LENGTH= 10   TRAIN= 1.988
STORM EVENT HOURLY RAINFALL ACCUMULATIONS= 0.007 0.023 0.006 0.622 0.277
 0.072 0.007 0.134 0.764 0.076

DATE OF STORM EVENT= 17/ 3/ 7/1976   IATSE=   8   LENGTH=  2   TRAIN= 0.031
STORM EVENT HOURLY RAINFALL ACCUMULATIONS= 0.023 0.008

DATE OF STORM EVENT= 10/ 4/ 7/1976   IATSE=  15   LENGTH=  4   TRAIN= 0.037
STORM EVENT HOURLY RAINFALL ACCUMULATIONS= 0.003 0.008 0.021 0.006

DATE OF STORM EVENT= 24/ 5/ 7/1976   IATSE=  34   LENGTH=  8   TRAIN= 1.006
STORM EVENT HOURLY RAINFALL ACCUMULATIONS= 0.176 0.545 0.188 0.044 0.0
 0.035 0.014 0.005

DATE OF STORM EVENT=  1/ 8/ 7/1976   IATSE=  41   LENGTH=  8   TRAIN= 1.097
STORM EVENT HOURLY RAINFALL ACCUMULATIONS= 0.014 0.048 0.012 0.161 0.548
 0.218 0.069 0.027

DATE OF STORM EVENT= 16/21/ 7/1976   IATSE= 319   LENGTH=  4   TRAIN= 0.192
STORM EVENT HOURLY RAINFALL ACCUMULATIONS= 0.035 0.110 0.038 0.009

DATE OF STORM EVENT= 21/22/ 7/1976   IATSE=  25   LENGTH=  8   TRAIN= 0.109
STORM EVENT HOURLY RAINFALL ACCUMULATIONS= 0.074 0.027 0.0   0.0   0.0
 0.0   0.0   0.008

DATE OF STORM EVENT= 18/ 1/ 8/1976   IATSE= 229   LENGTH=  3   TRAIN= 0.179
STORM EVENT HOURLY RAINFALL ACCUMULATIONS= 0.115 0.047 0.017

DATE OF STORM EVENT=  3/ 4/ 8/1976   IATSE=  54   LENGTH=  6   TRAIN= 0.209
STORM EVENT HOURLY RAINFALL ACCUMULATIONS= 0.014 0.005 0.123 0.045 0.0
 0.020

DATE OF STORM EVENT=  9/ 5/ 8/1976   IATSE=  24   LENGTH=  1   TRAIN= 0.011
STORM EVENT HOURLY RAINFALL ACCUMULATIONS= 0.011

DATE OF STORM EVENT=  5/11/ 8/1976   IATSE= 139   LENGTH=  3   TRAIN= 0.041
STORM EVENT HOURLY RAINFALL ACCUMULATIONS= 0.007 0.009 0.025

DATE OF STORM EVENT=  9/16/ 8/1976   IATSE= 121   LENGTH=  3   TRAIN= 0.066
STORM EVENT HOURLY RAINFALL ACCUMULATIONS= 0.013 0.042 0.010

DATE OF STORM EVENT= 12/18/ 8/1976   IATSE=  48   LENGTH=  5   TRAIN= 0.203
STORM EVENT HOURLY RAINFALL ACCUMULATIONS= 0.007 0.019 0.051 0.101 0.026


DATE OF STORM EVENT= 13/24/ 8/1976   IATSE= 140   LENGTH=  7   TRAIN= 0.286
STORM EVENT HOURLY RAINFALL ACCUMULATIONS= 0.023 0.077 0.019 0.008 0.031
 0.103 0.025

DATE OF STORM EVENT=  4/27/ 8/1976   IATSE=  56   LENGTH=  3   TRAIN= 0.261
STORM EVENT HOURLY RAINFALL ACCUMULATIONS= 0.051 0.169 0.041

DATE OF STORM EVENT= 22/28/ 8/1976   IATSE=  39   LENGTH=  5   TRAIN= 0.162
STORM EVENT HOURLY RAINFALL ACCUMULATIONS= 0.006 0.015 0.040 0.080 0.021


DATE OF STORM EVENT= 17/ 4/ 9/1976   IATSE= 158   LENGTH= 35   TRAIN= 1.471
STORM EVENT HOURLY RAINFALL ACCUMULATIONS= 0.032 0.098 0.029 0.016 0.049
 0.015 0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.025 0.077 0.023 0.0
 0.008 0.026 0.013 0.008 0.004 0.001 0.039 0.102 0.046 0.017 0.028 0.012
 0.005 0.337 0.224 0.134 0.068 0.035
```

MODEL TEST RESULTS

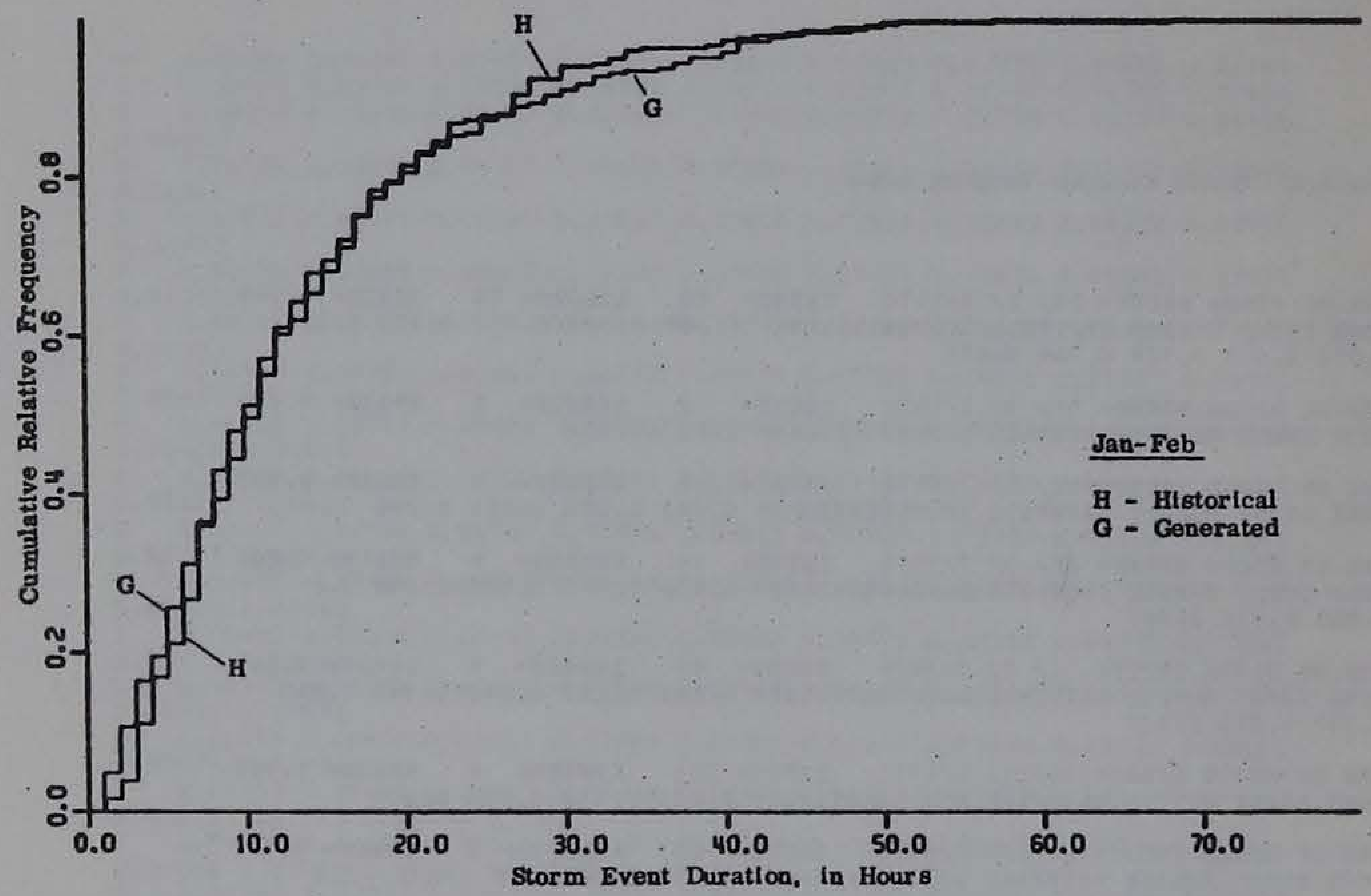

Figure F.1. Historical and Generated Storm Event Duration Distributions, Period 1

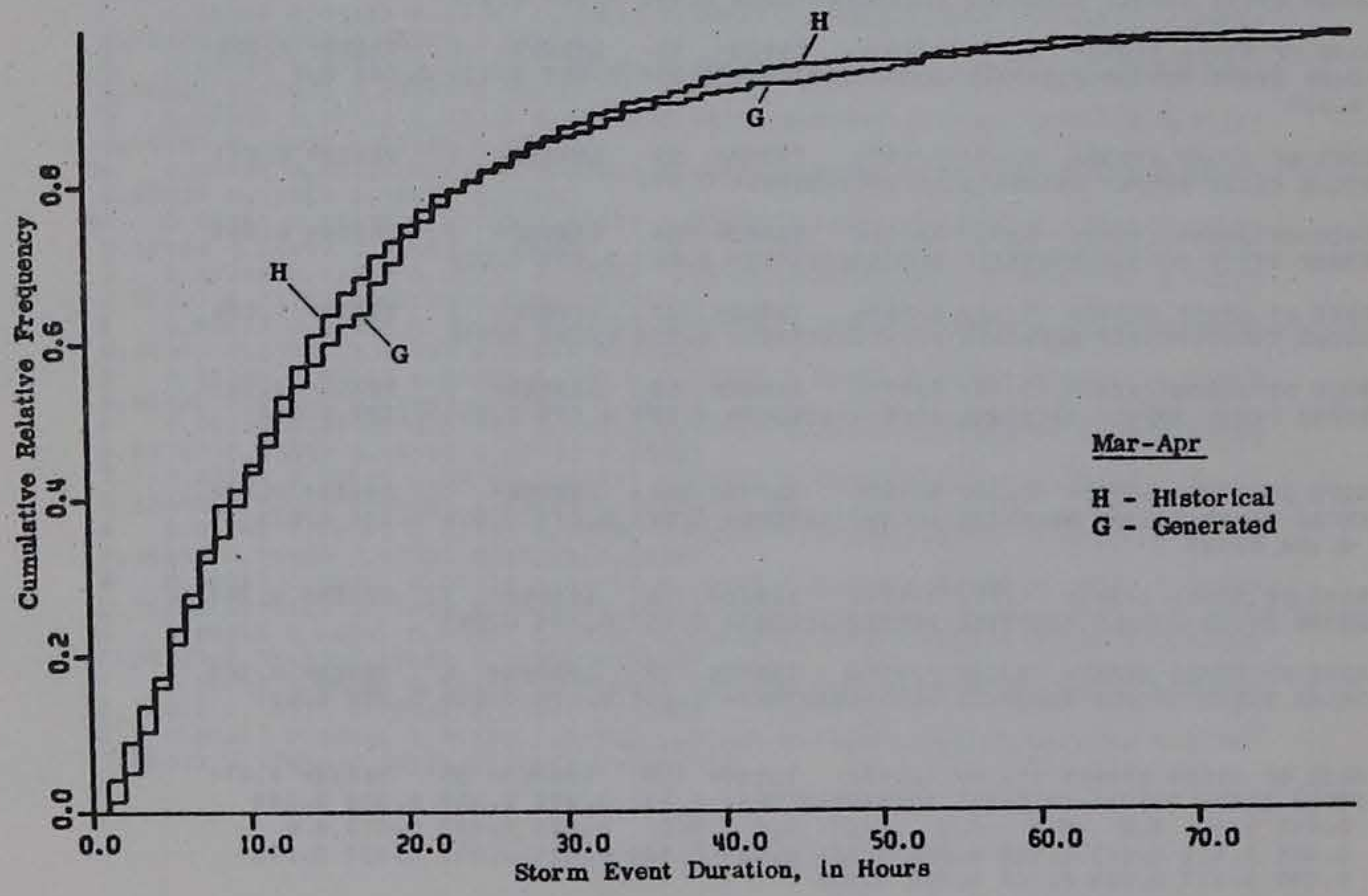

Figure F.2. Historical and Generated Storm Event Duration Distributions, Period 2

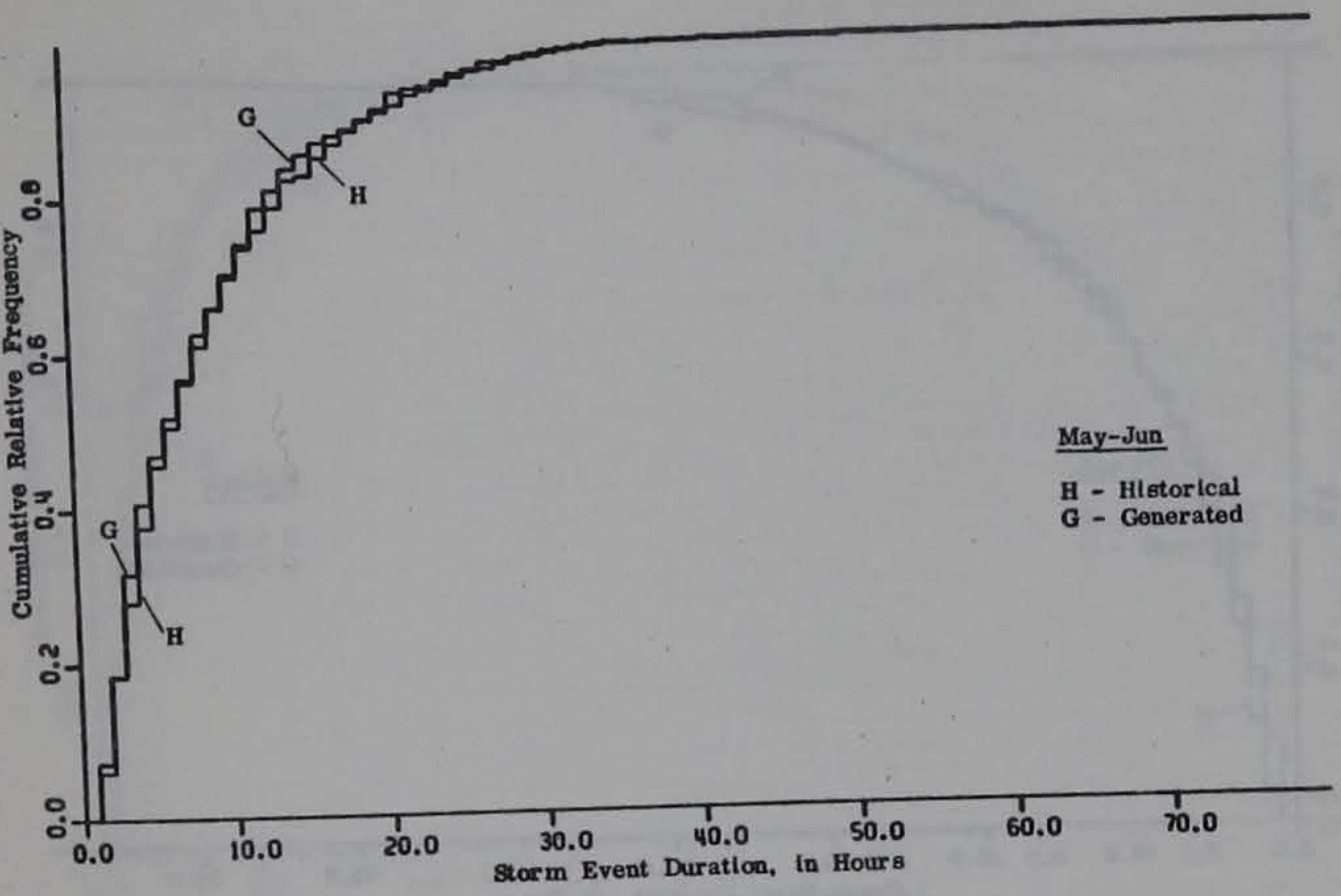

Figure F.3. Historical and Generated Storm Event Duration Distributions, Period 3

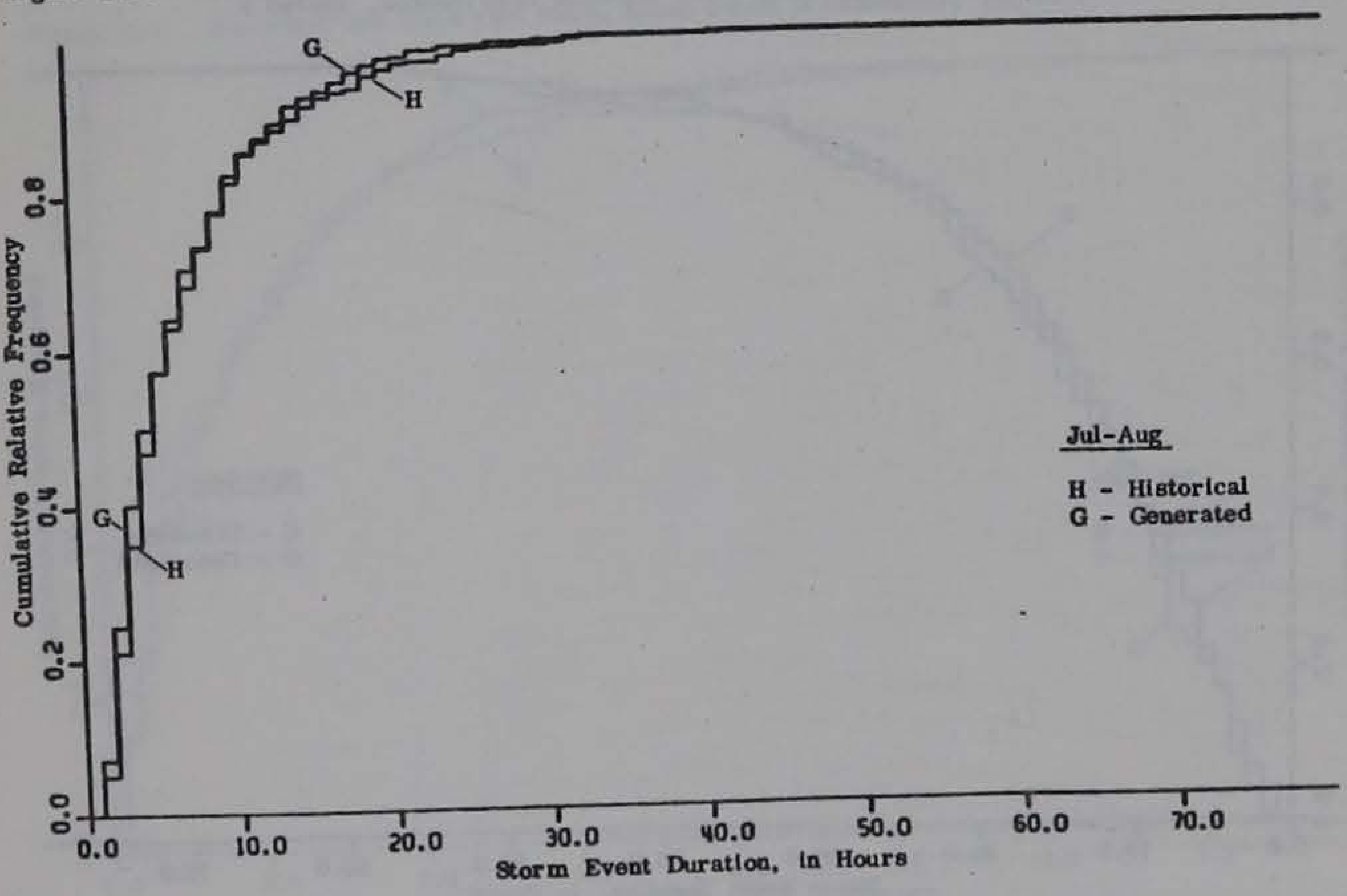

Figure F.4. Historical and Generated Storm Event Duration Distributions, Period 4

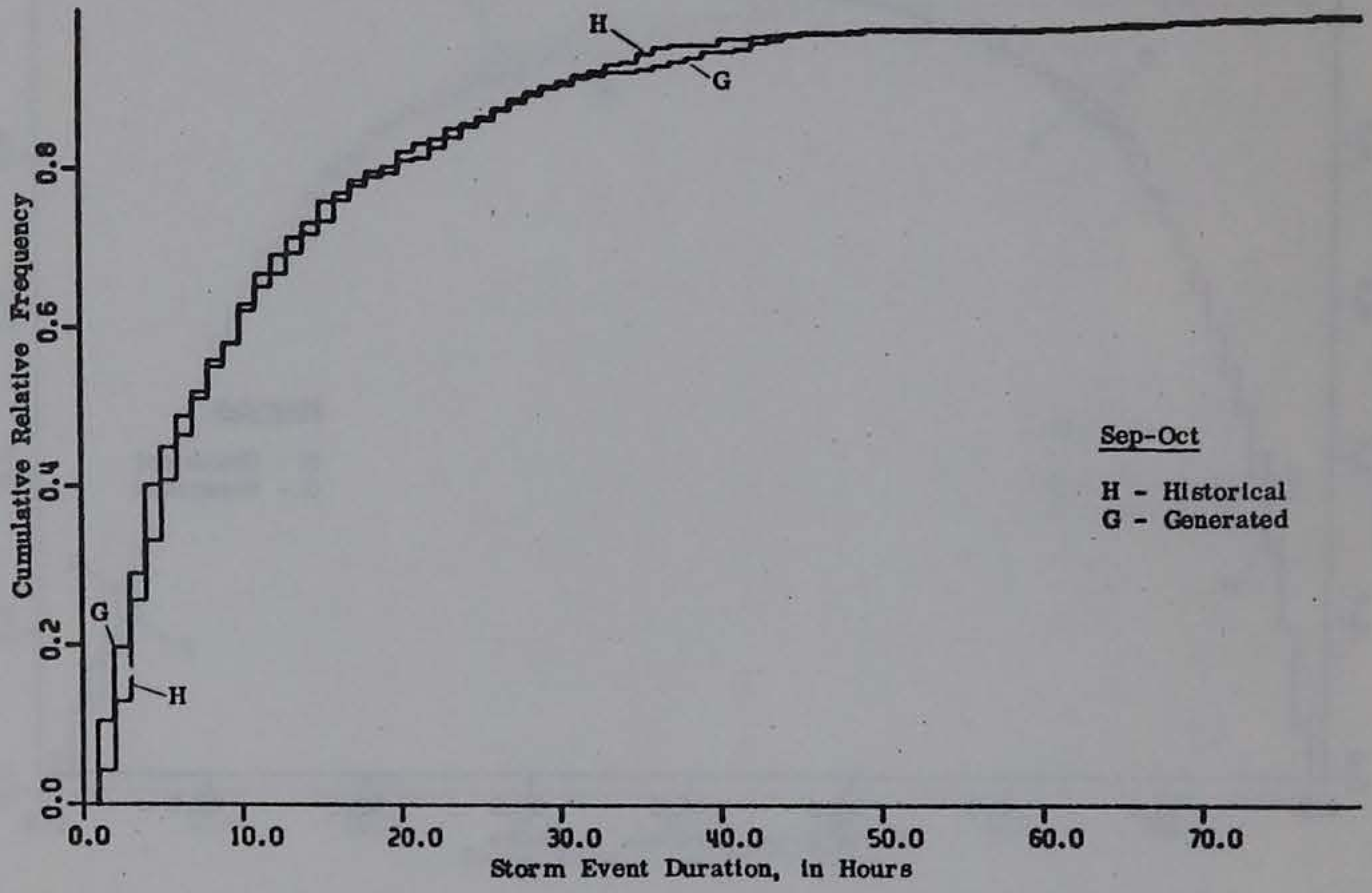

Figure F.5. Historical and Generated Storm Event Duration Distributions, Period 5

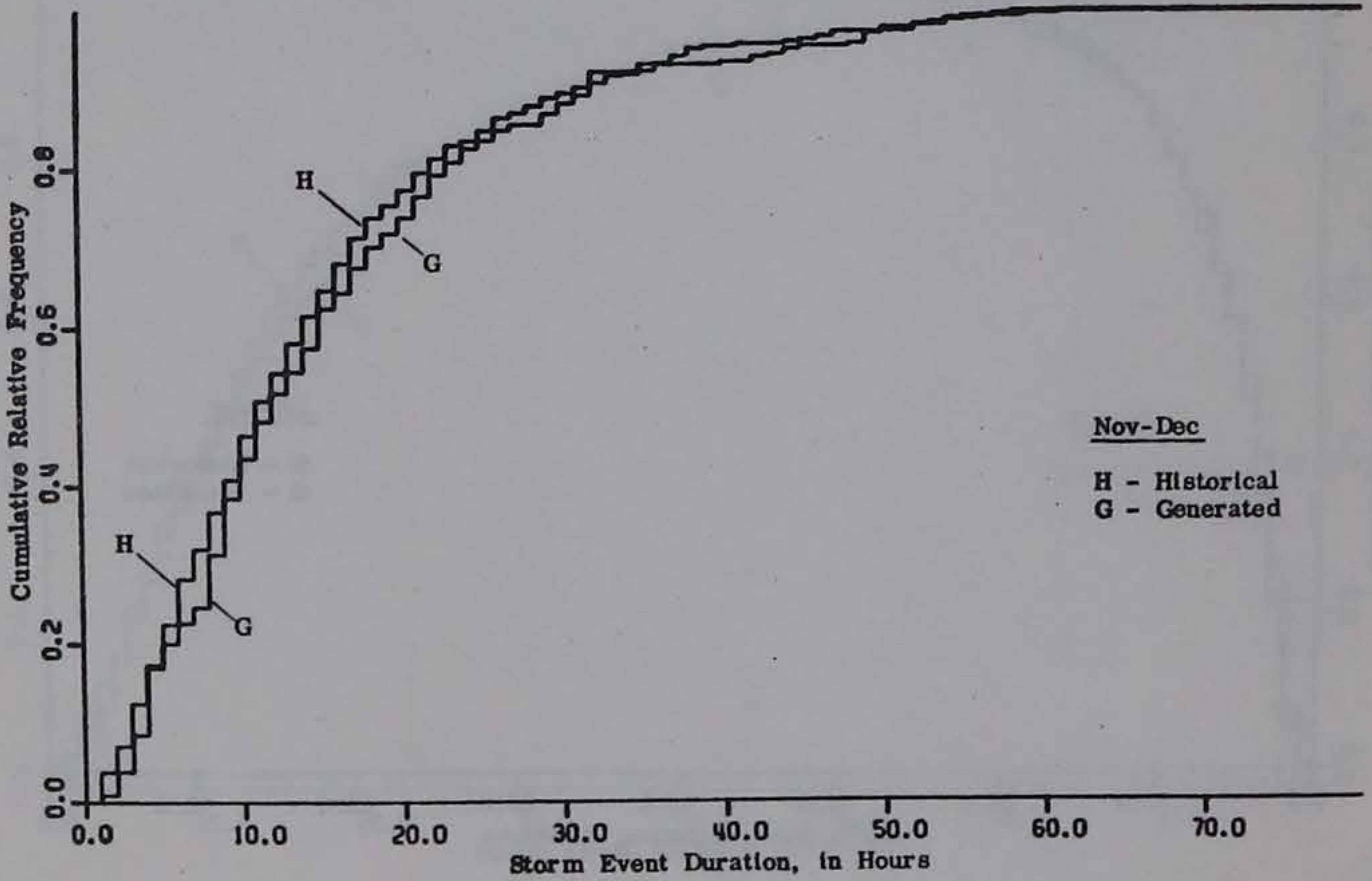

Figure F.6. Historical and Generated Storm Event Duration Distributions, Period 6

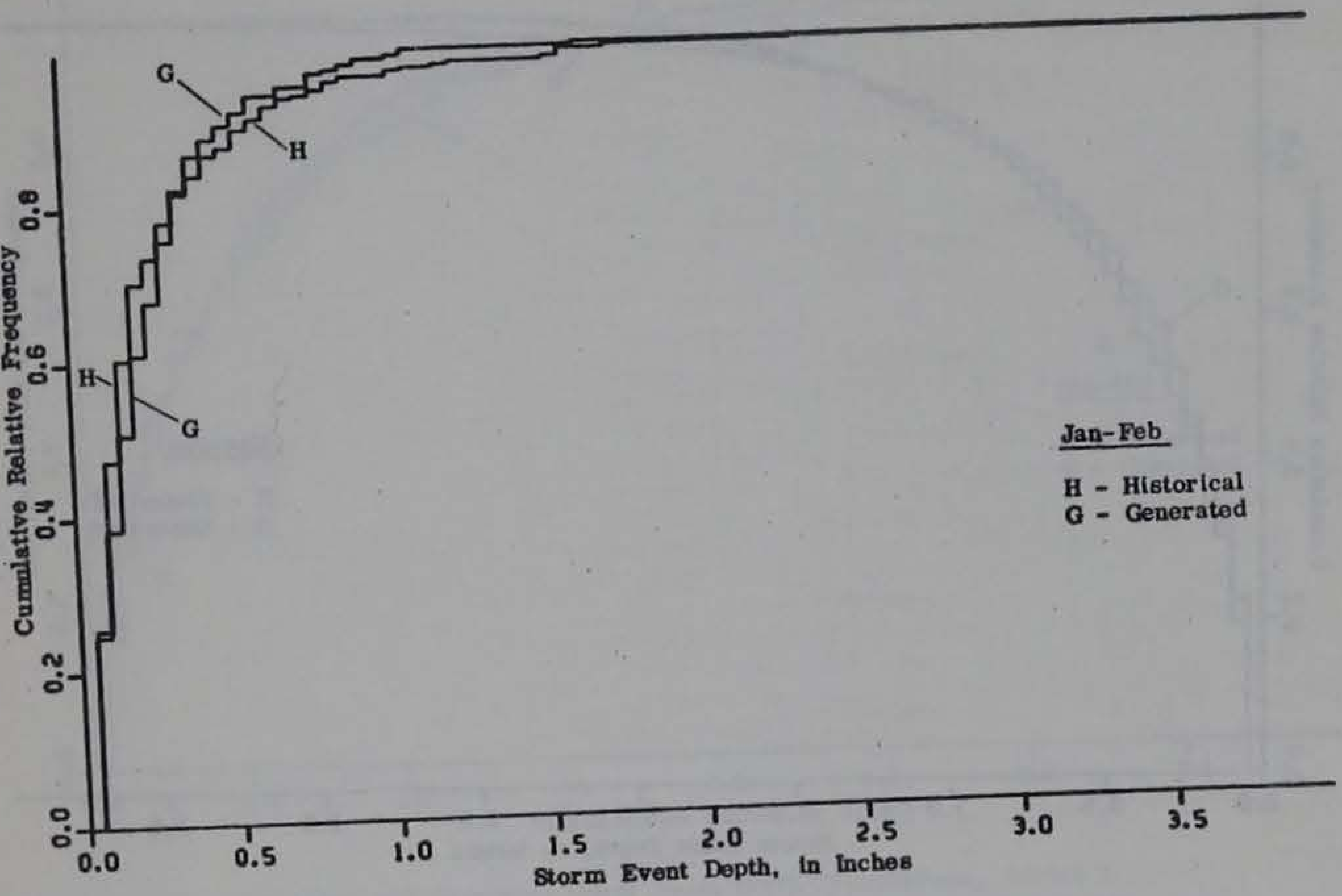

Figure F.7. Historical and Generated Storm Event Depth Distributions, Period 1

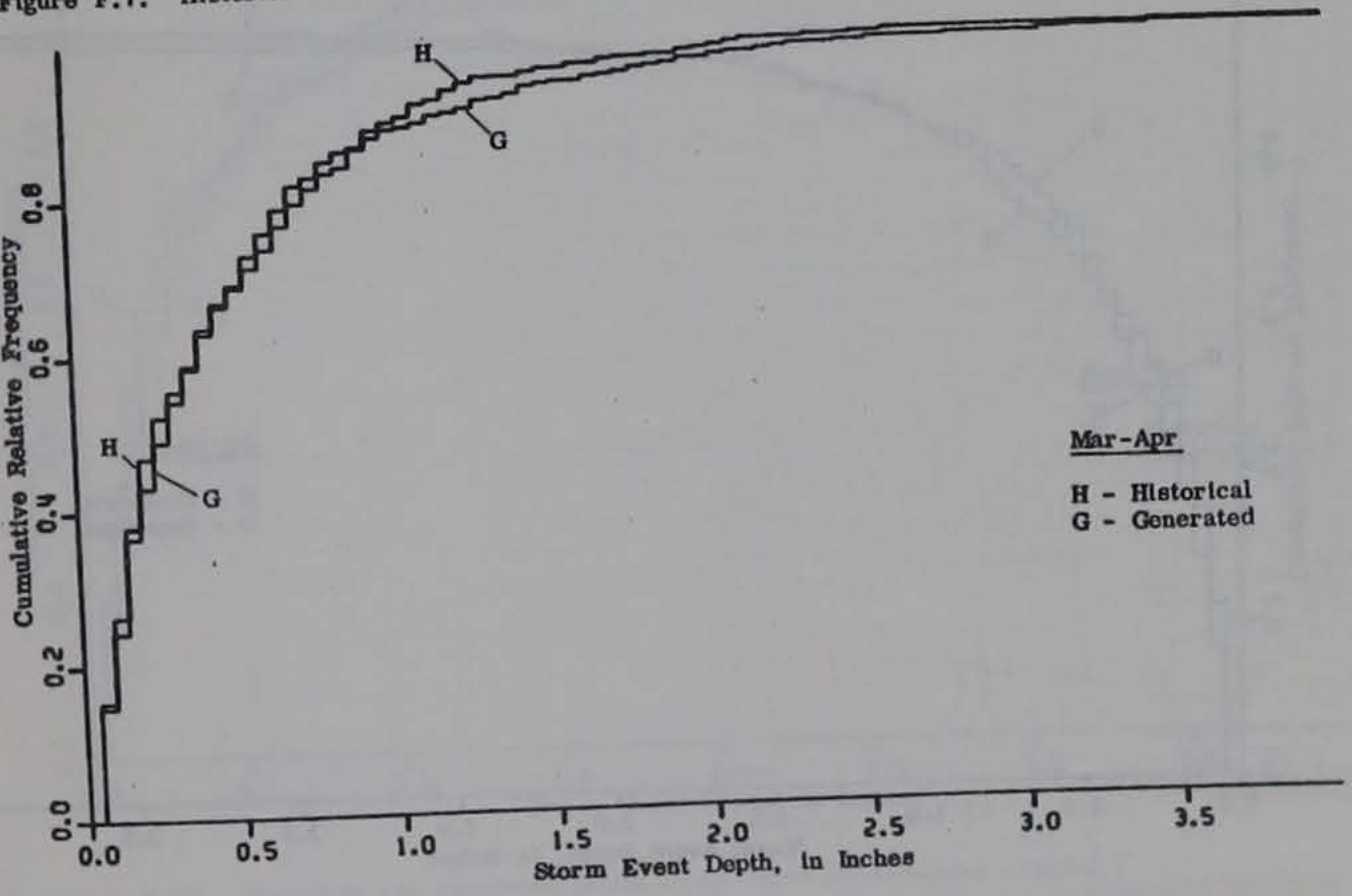

Figure F.8. Historical and Generated Storm Event Depth Distributions, Period 2

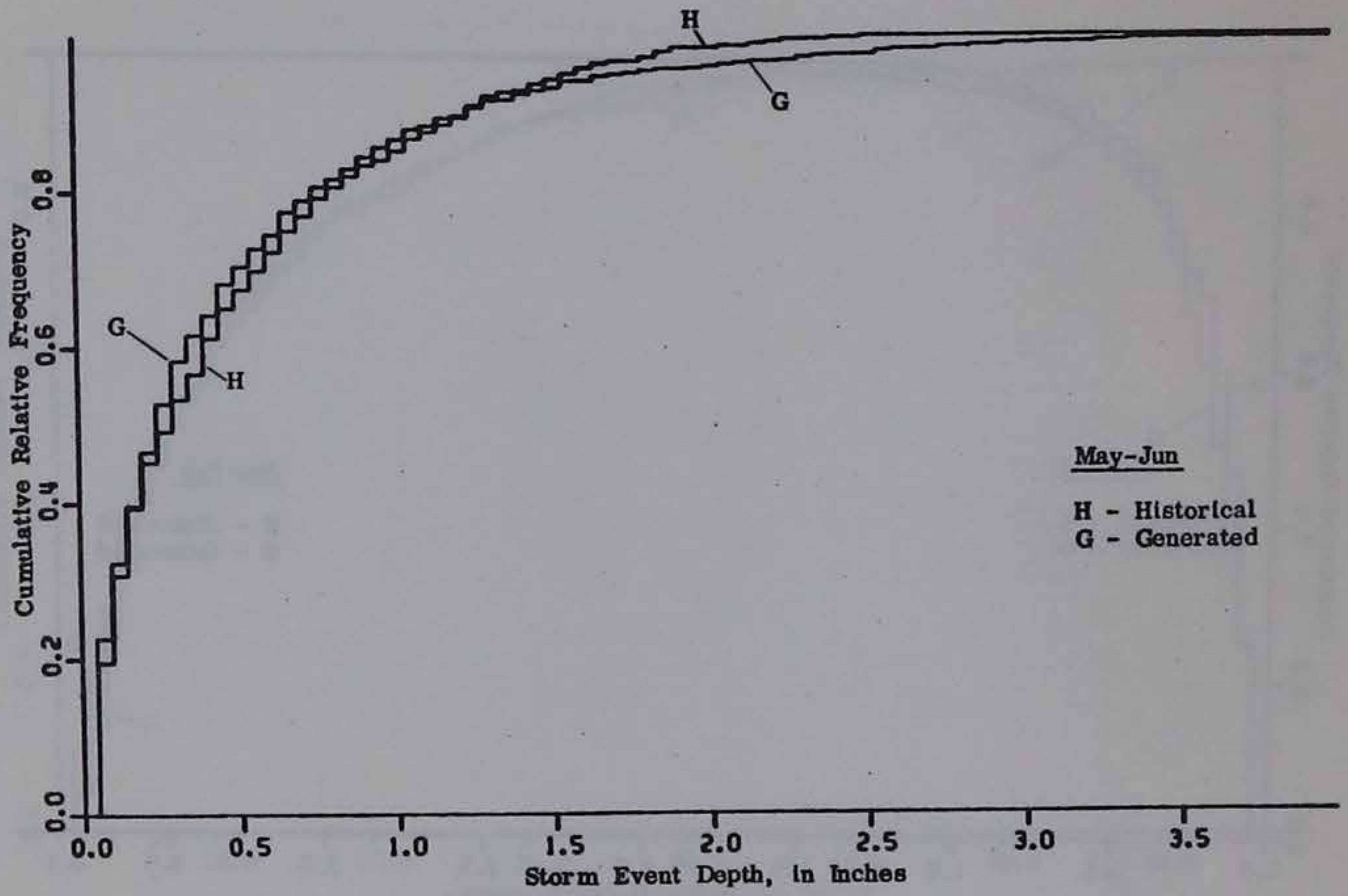

Figure F.9. Historical and Generated Storm Event Depth Distributions, Period 3

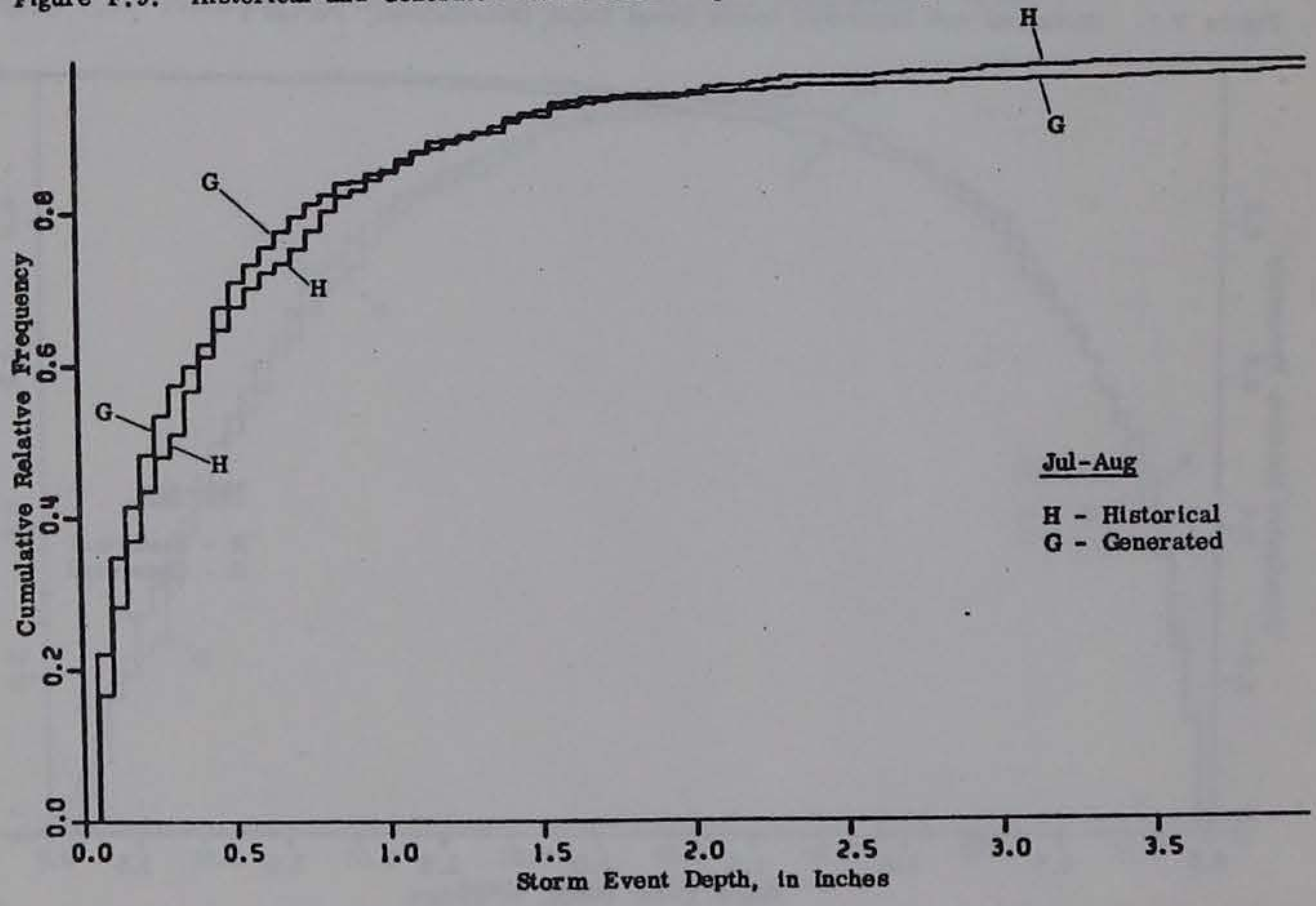

Figure F.10. Historical and Generated Storm Event Depth Distributions, Period 4

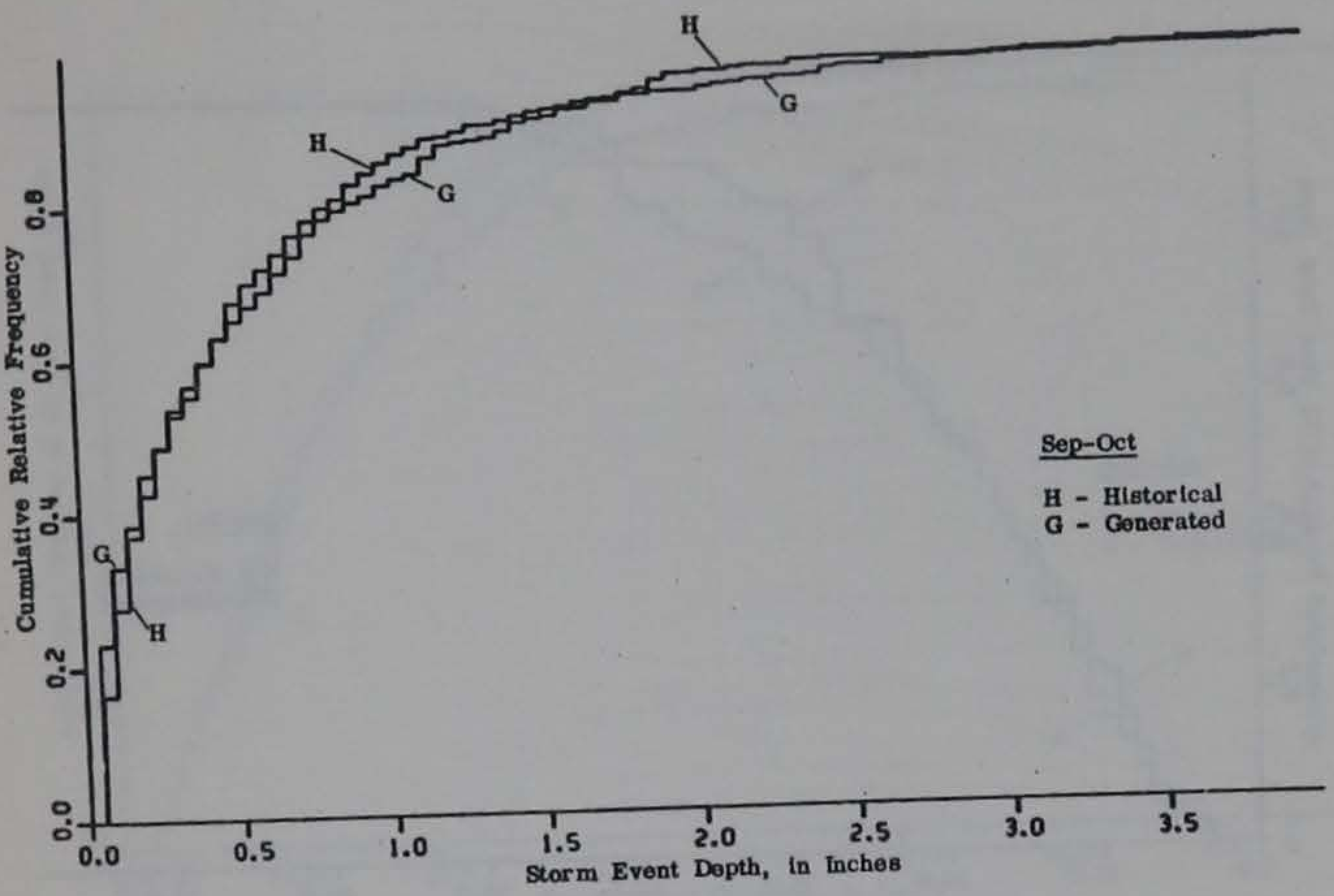

Figure F.11. Historical and Generated Storm Event Depth Distributions, Period 5

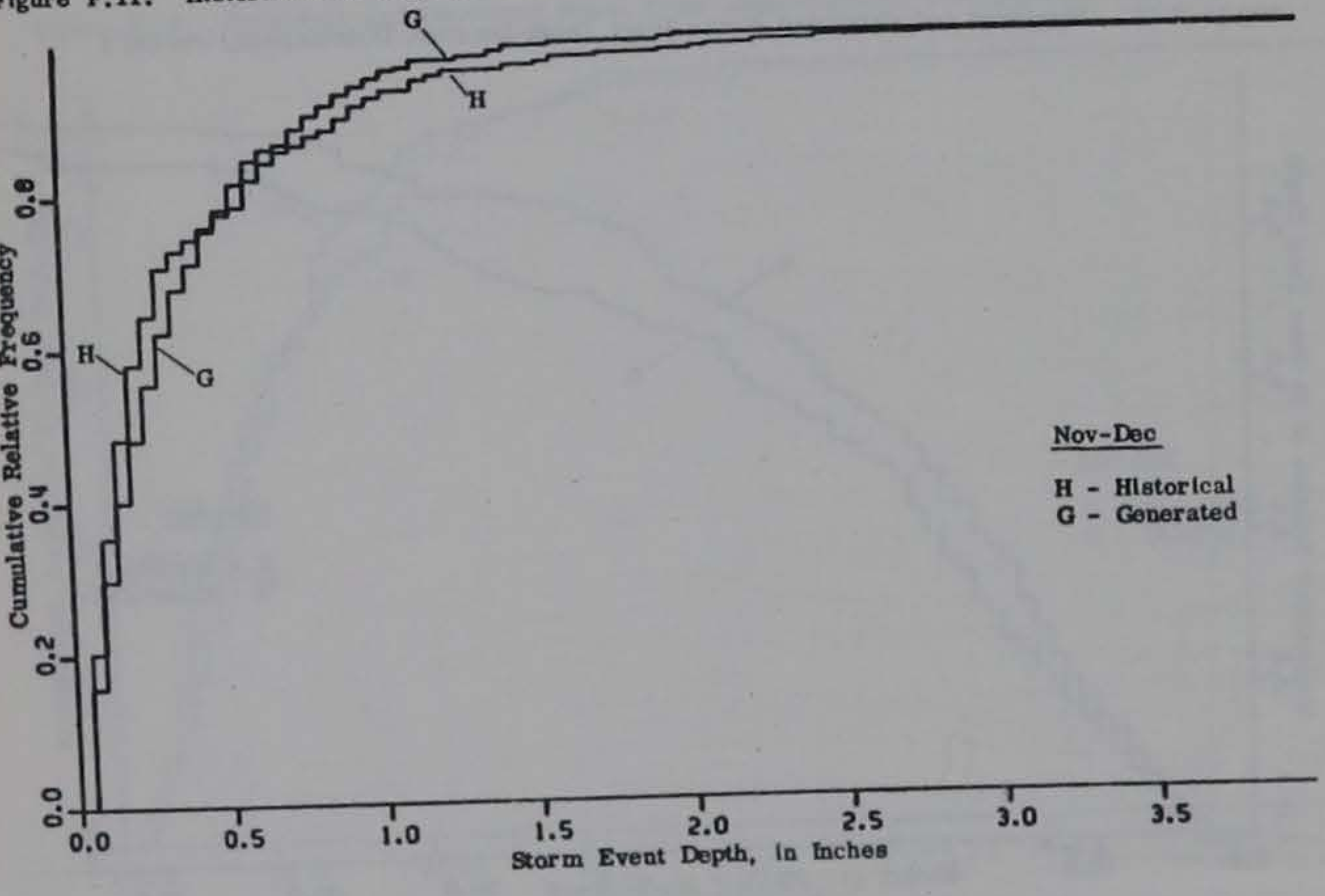

Figure F.12. Historical and Generated Storm Event Depth Distributions, Period 6

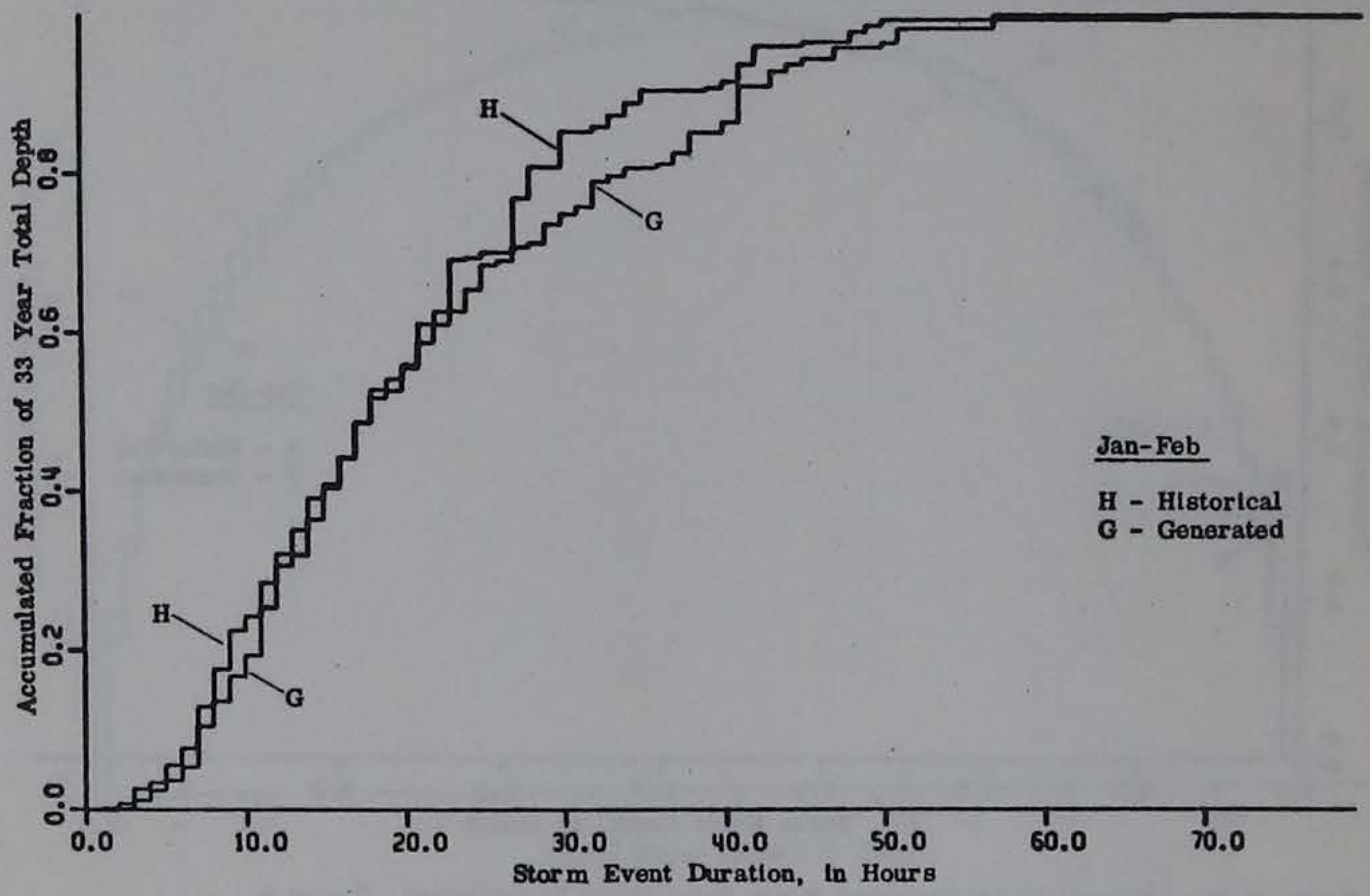

Figure F.13. Historical and Generated Storm Event Depth-Duration Distributions, Period 1

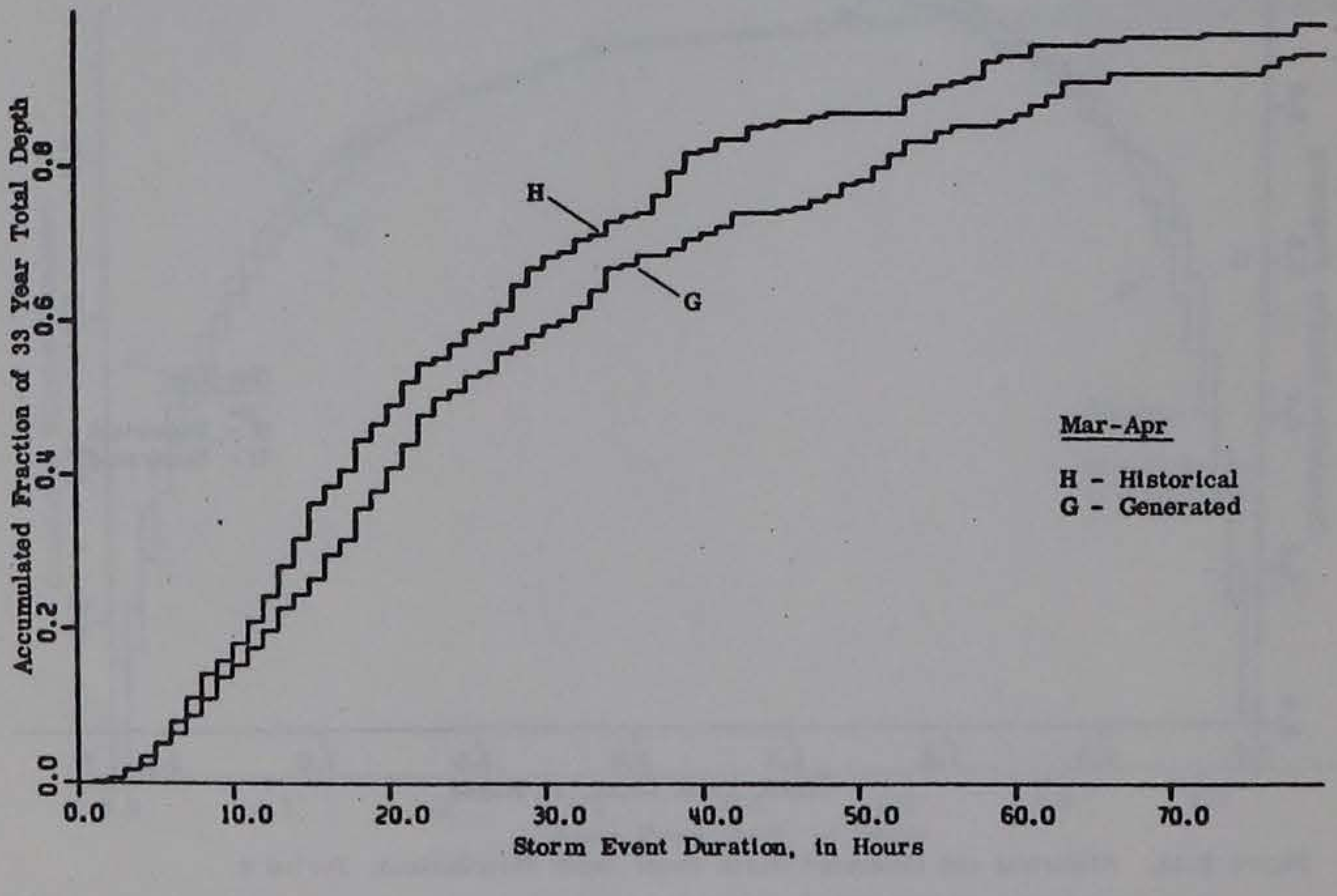

Figure F.14. Historical and Generated Storm Event Depth-Duration Distributions, Period 2

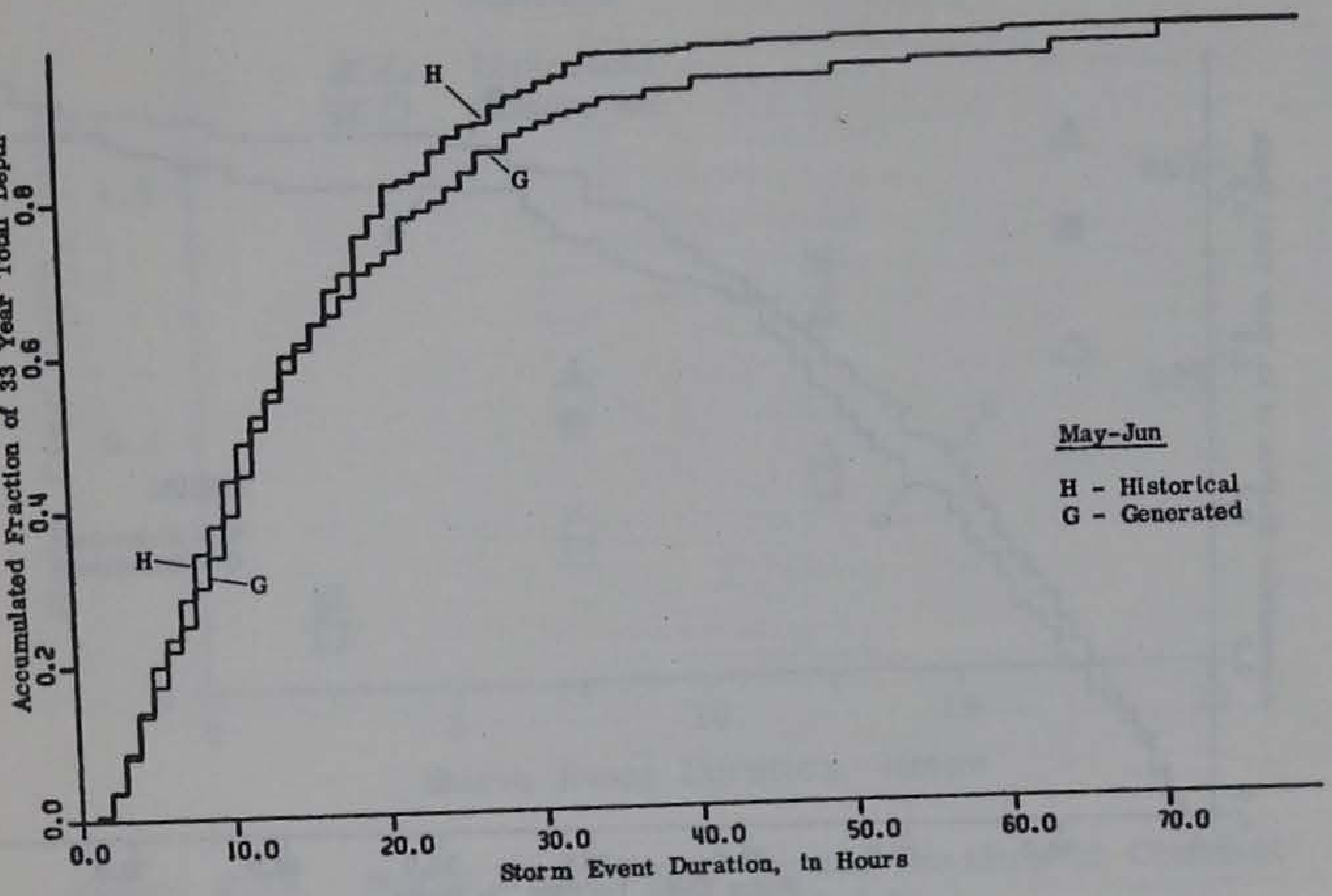

Figure F.15. Historical and Generated Storm Event Depth-Duration Distributions, Period 3

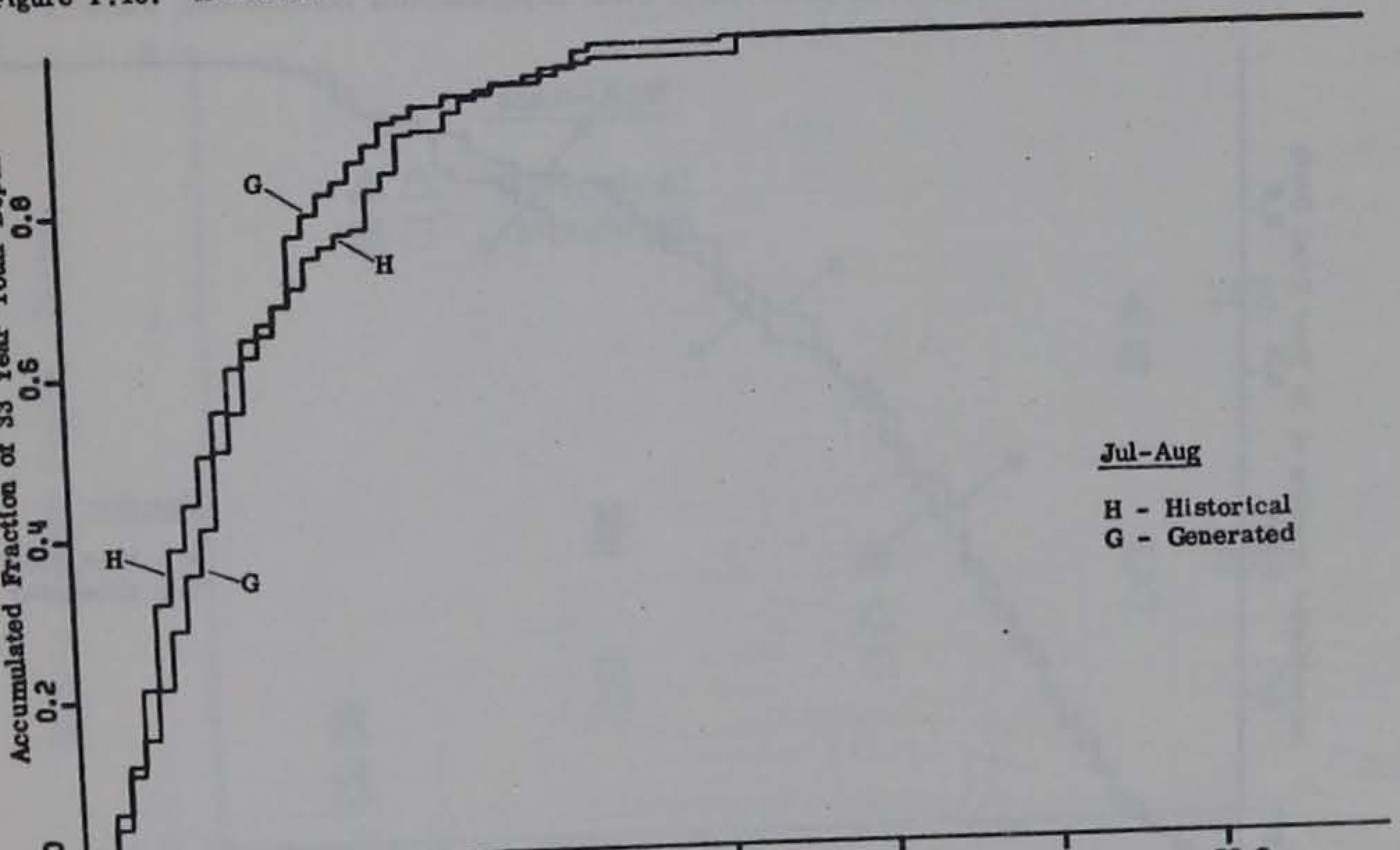

Figure F.16. Historical and Generated Storm Event Depth-Duration Distributions, Period 4

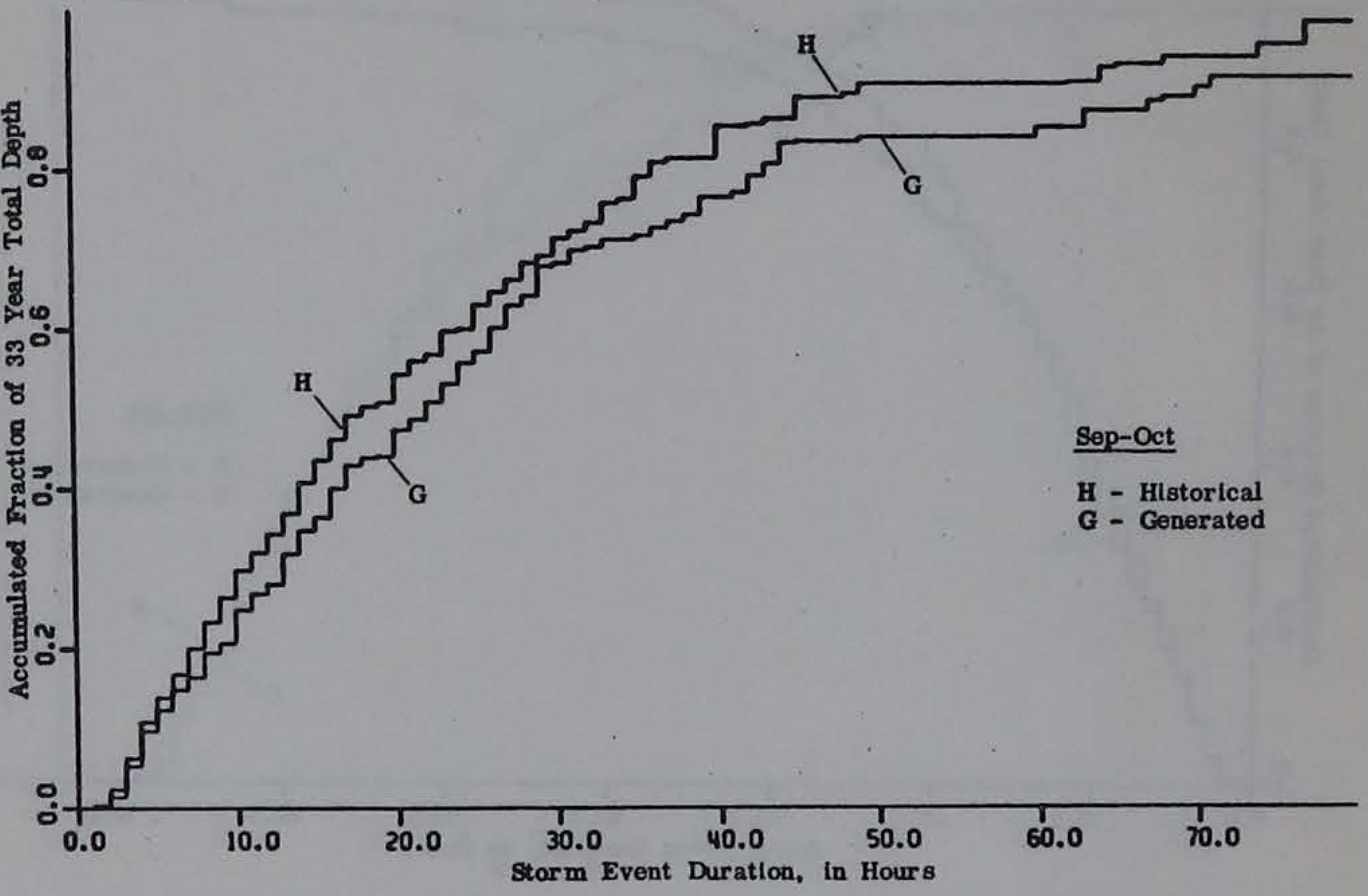

Figure F.17. Historical and Generated Storm Event Depth-Duration Distributions, Period 5

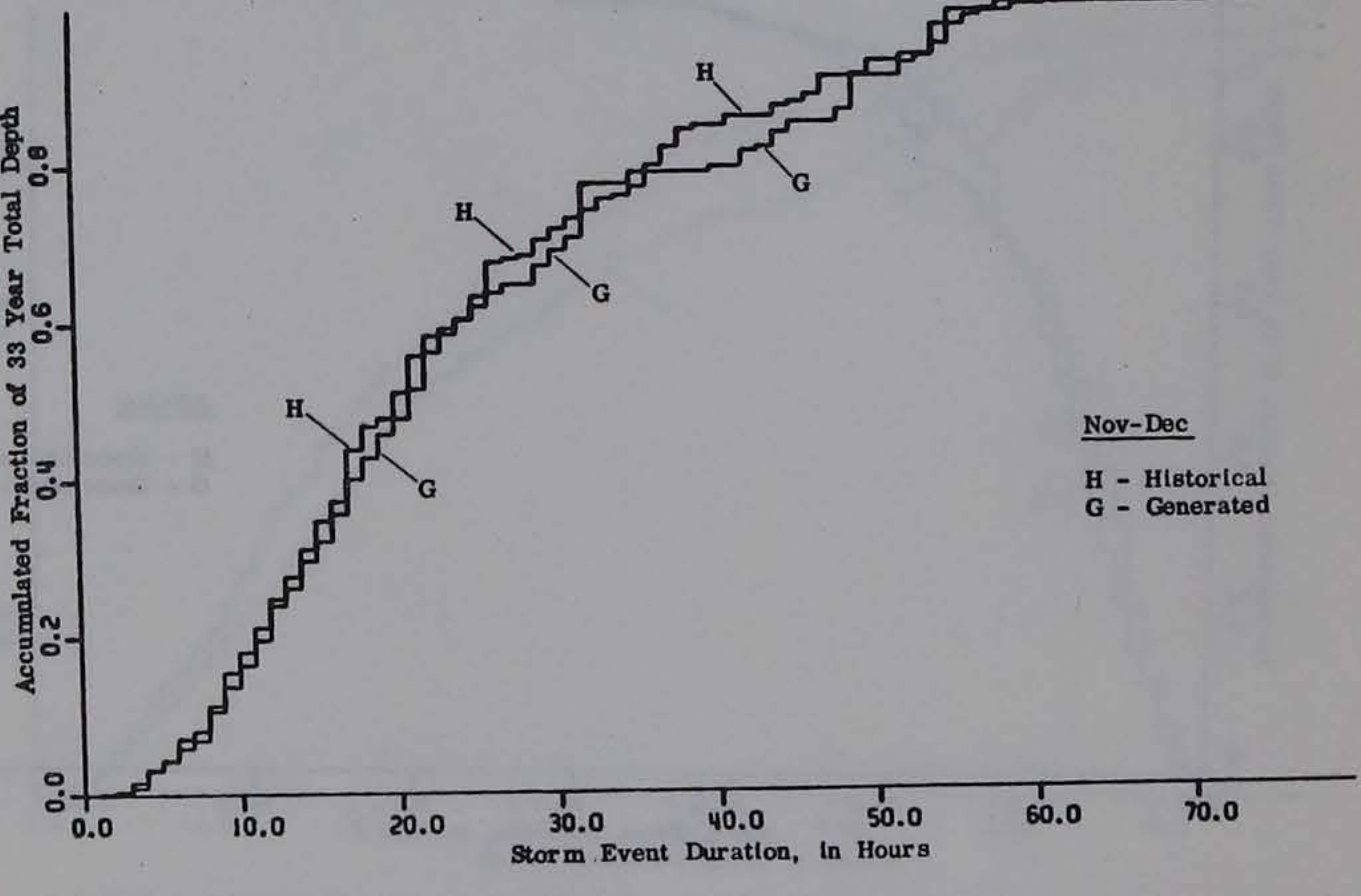

Figure F.18. Historical and Generated Storm Event Depth-Duration Distributions, Period 6

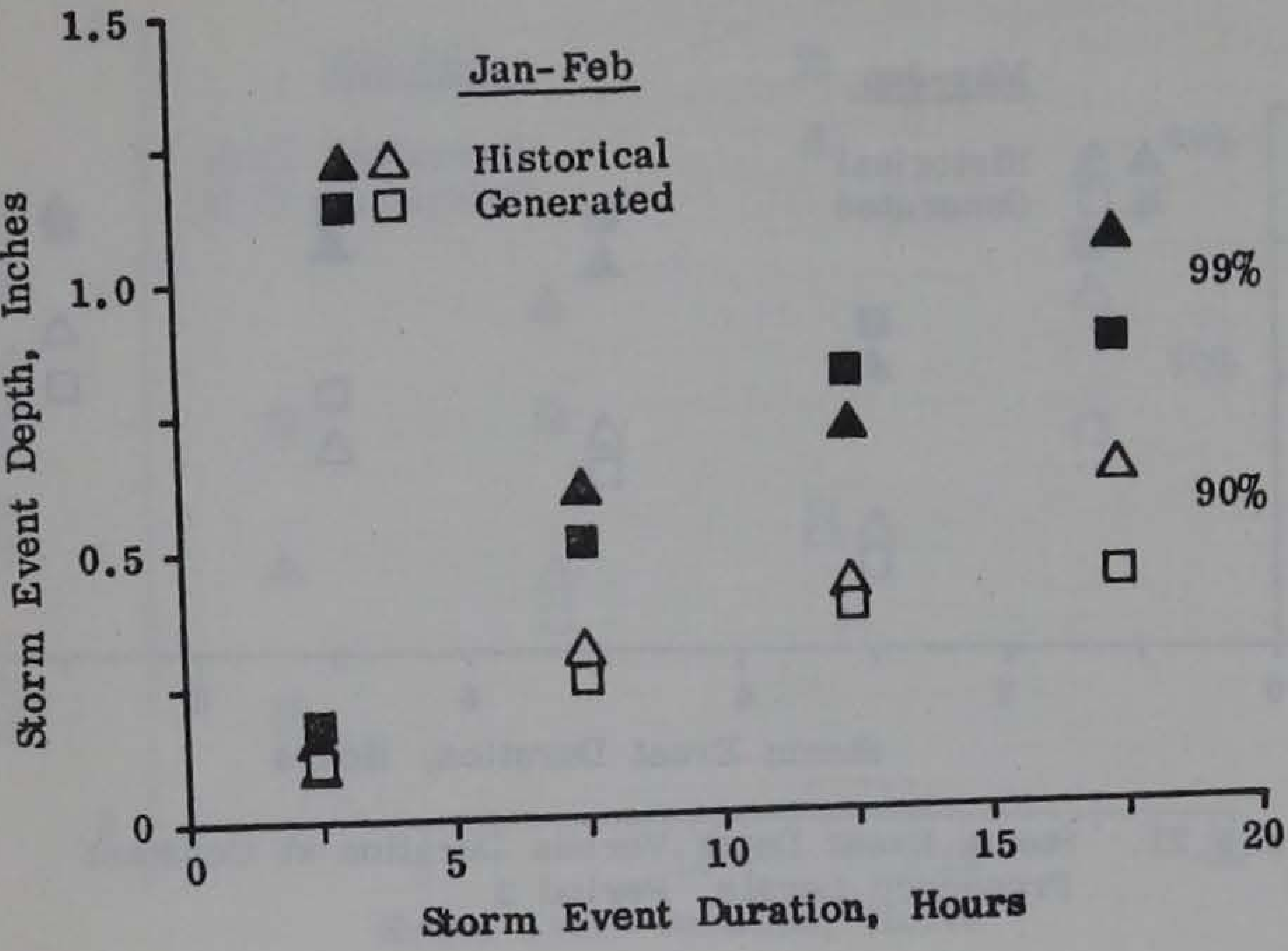

Figure F.19. Storm Event Depth Versus Duration at Constant Frequency Levels, Period 1

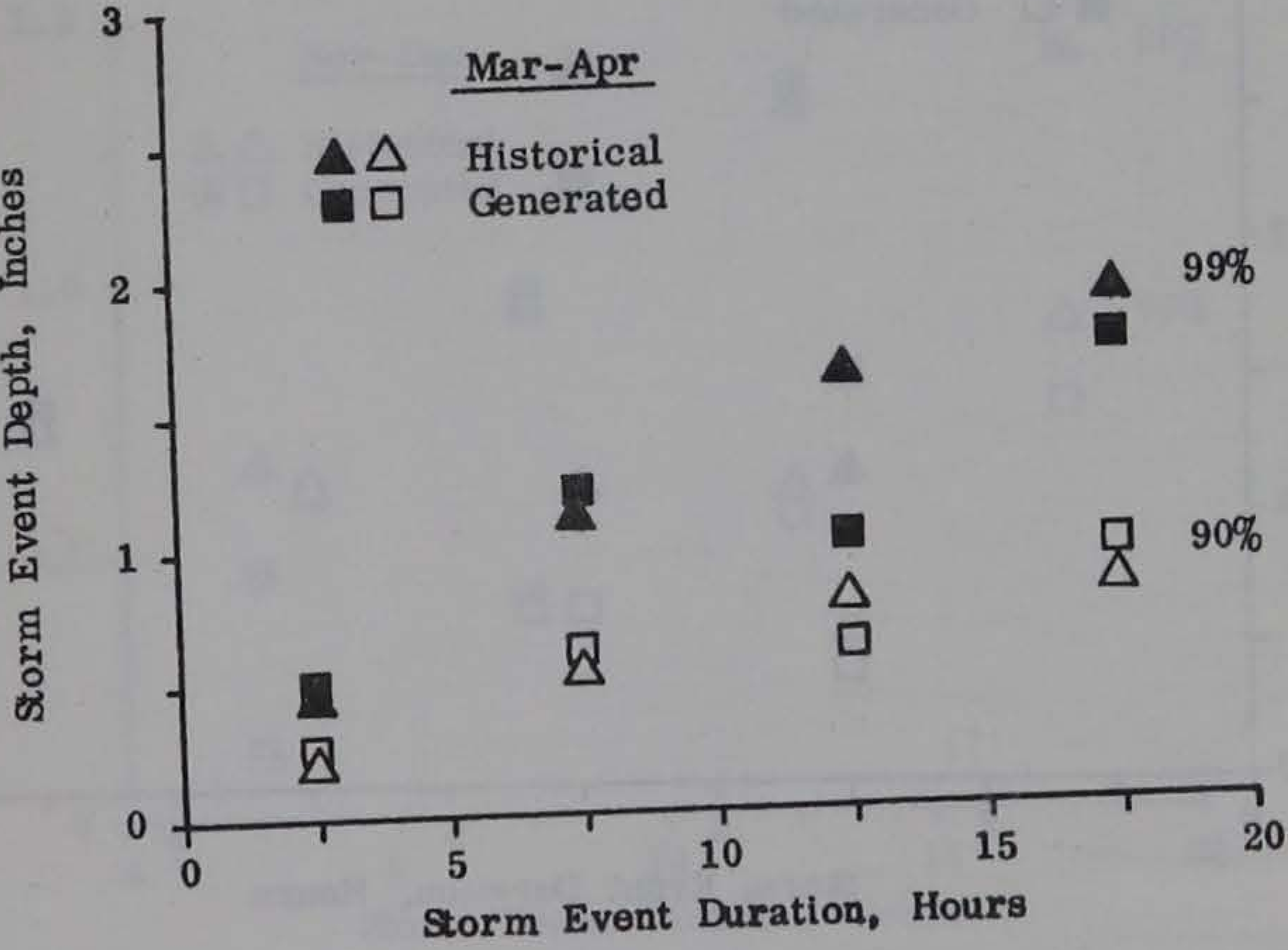

Figure F.20. Storm Event Depth Versus Duration at Constant Frequency Levels, Period 2

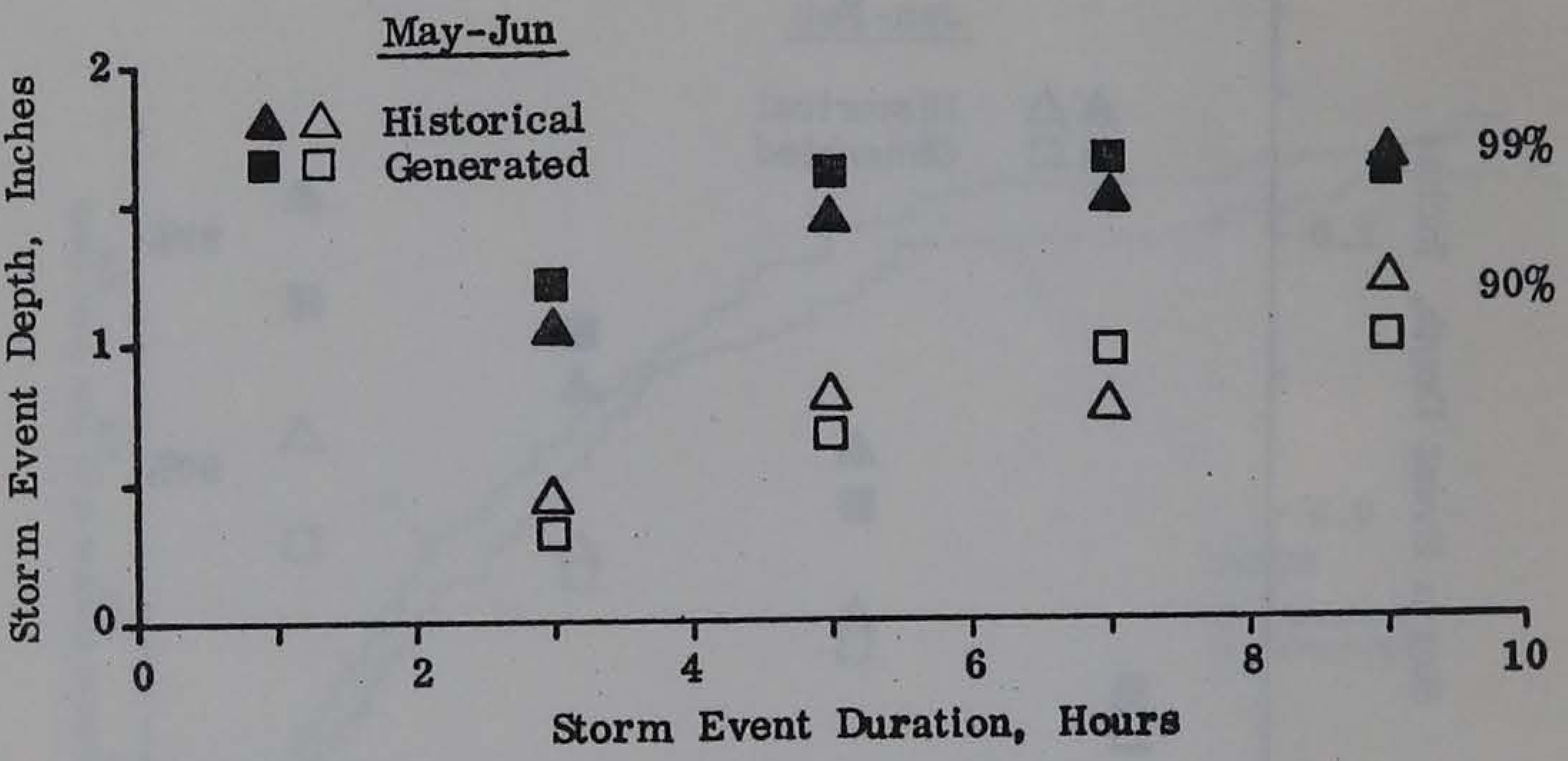

Figure F.21. Storm Event Depth Versus Duration at Constant Frequency Levels, Period 3

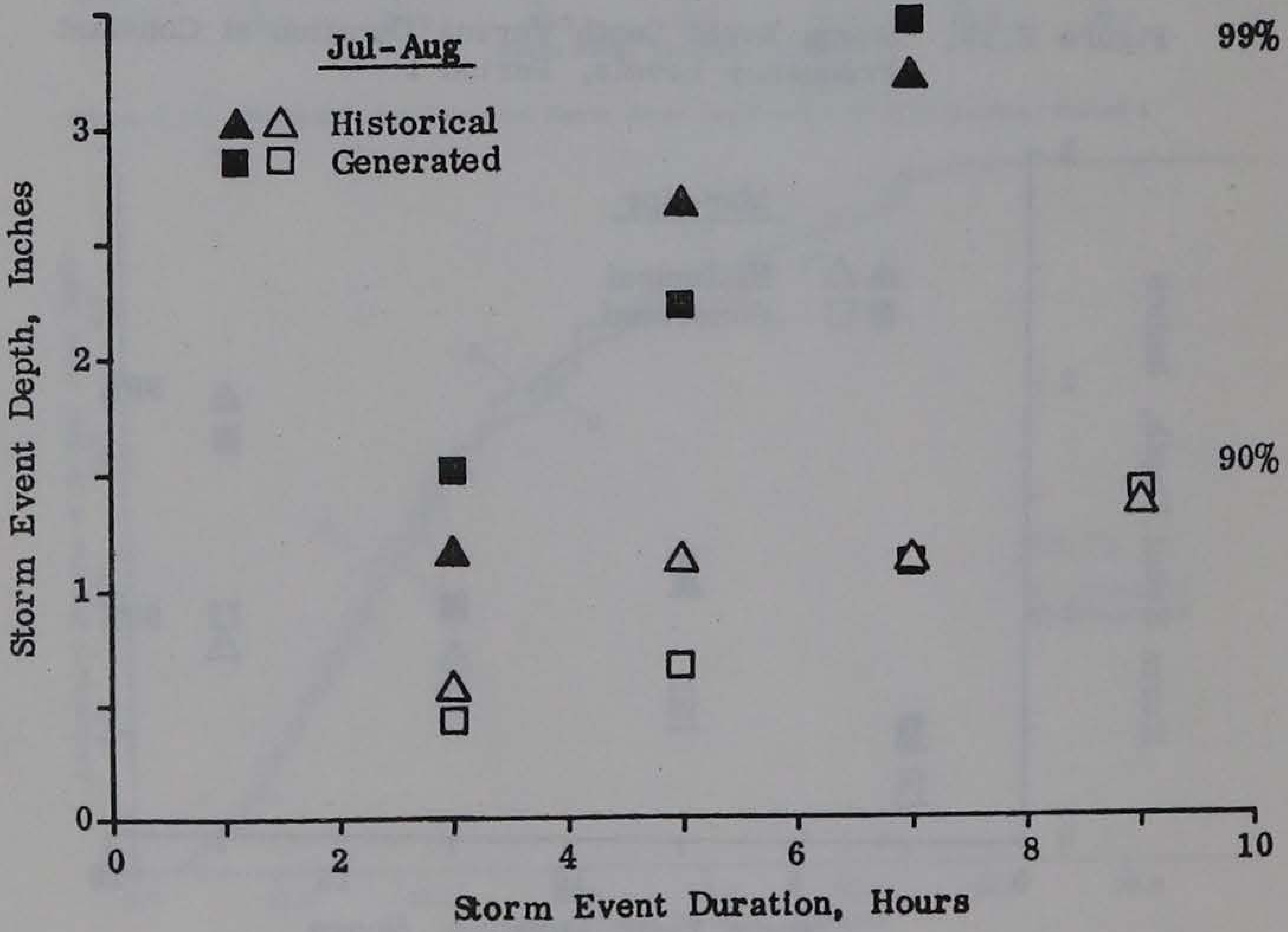

Figure F.22. Storm Event Depth Versus Duration at Constant Frequency Levels, Period 4

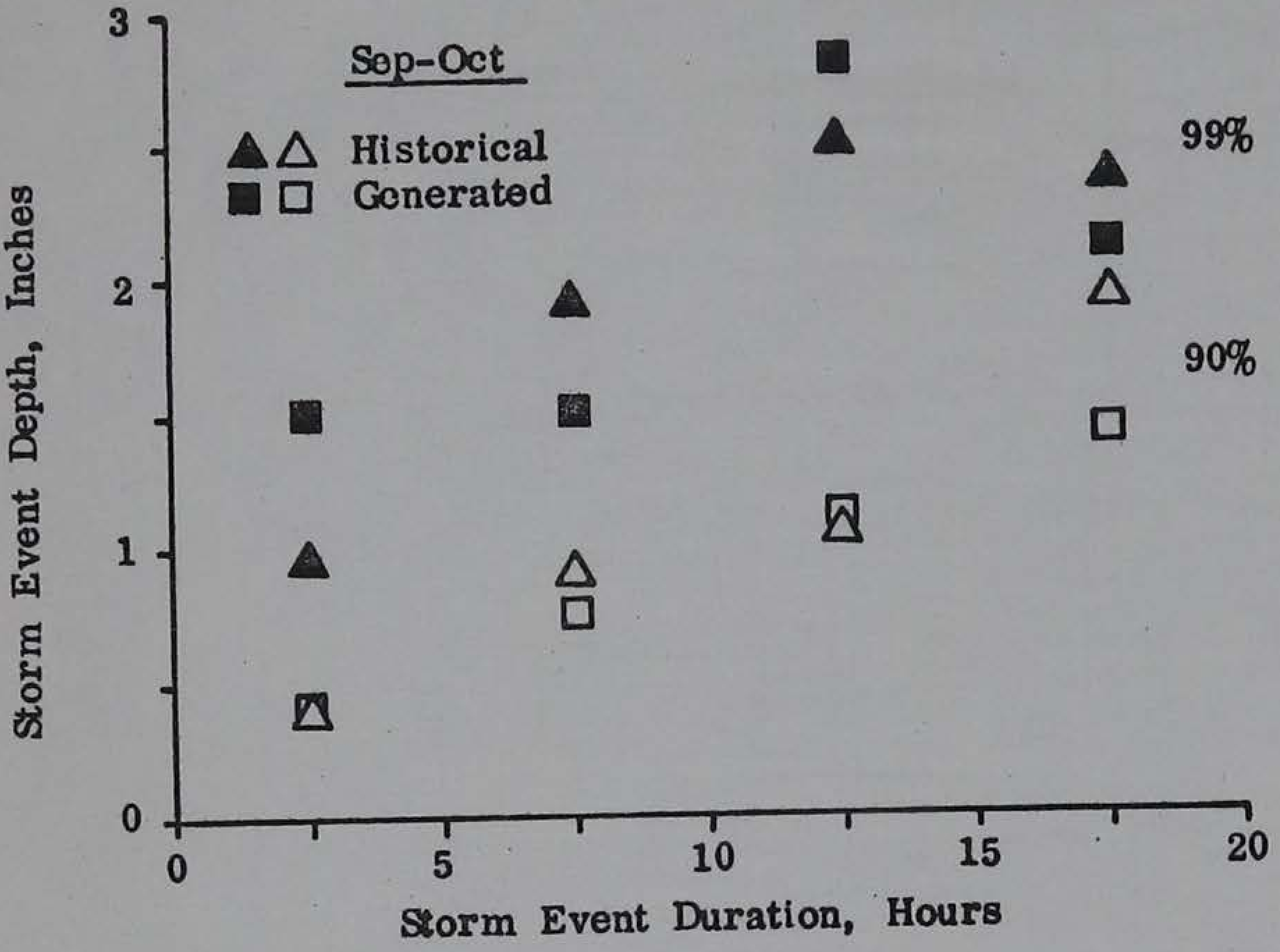

Figure F.23. Storm Event Depth Versus Duration at Constant Frequency Levels, Period 5

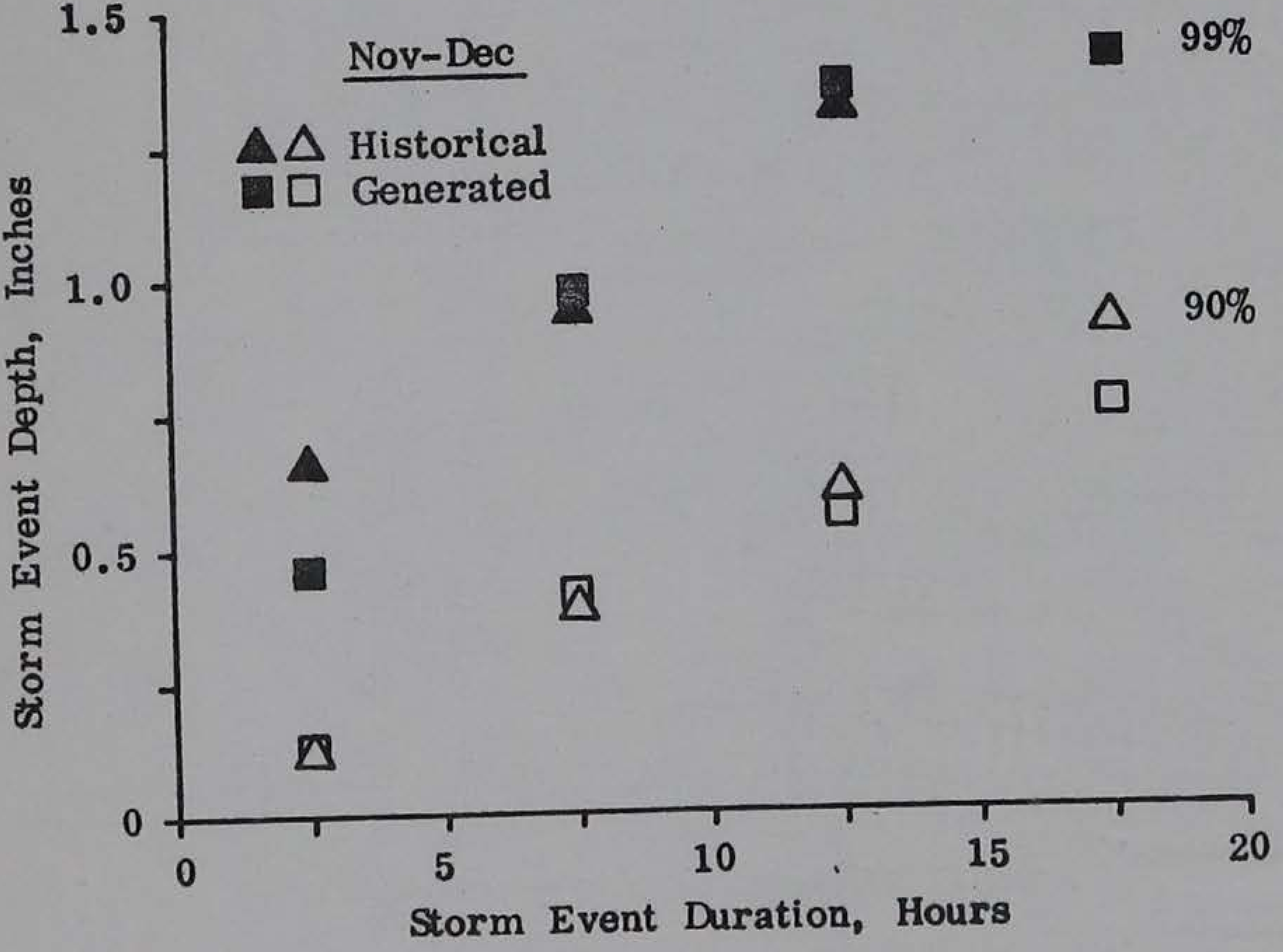

Figure F.24. Storm Event Depth Versus Duration at Constant Frequency Levels, Period 6