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EFFECTS OF BASIN SIZE ON STREAMFLOW IN SOUTHERN ONTARIO

EFFECT OF BASIN SIZE ON STREAMFLOW IN SOUTHERN ONTARIO

by

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A 4B6 Research Paper

Submitted to the Department of Geography

in Partial Fulfillment of the Requirements

for the Degree

Bachelor of Science

McMaster University

April 1979

BACHELOR OF SCIENCE (1979)
(Geography)

McMASTER UNIVERSITY
Hamilton, Ontario

TITLE: Effects of Basin Size on Streamflow in Southern Ontario

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SUPERVISOR: Dr. M. K. Woo

NUMBER OF PAGES: x, 101

ACKNOWLEDGEMENTS

My thanks are especially given to my supervisor, Dr. M. K. Woo. His constant interest and availability were as valuable as his help and advice throughout the project. I am grateful to the Natural Sciences and Engineering Research Council for providing funding for the use of the McMaster University computer.

Time taken to start the paper during the summer of 1978 was made financially possible by the generous grant of the Southern Ontario Economic Development Council. Although the selection of Southern Ontario as a study area was a requirement to be eligible for the grant, the choice, as shall be seen later, is an excellent one for this study.

Much thanks also goes to my husband, Stuart, for his moral support and drafting skills.

Thanks to my mother, Patricia, for her professional drafting and lettering.

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ABSTRACT

Daily discharge data from five Southern Ontario river systems were statistically analysed to seek relationships between streamflow characteristics and basin size. From each river system, at least two stations were used to determine such relationships. The physiographic characteristics of each river system were also examined and qualitatively related to the streamflow statistics. Comparisons between physiographic regions were expected to support the general nature of the results obtained for each river system.

In Southern Ontario, drainage area is correlated with mean annual peak flows. When the flows were transformed into discharge per unit area no consistent effects of basin area on the streamflow characteristics were found. However, differences in streamflow per unit area between various sub-basins can be qualitatively explained by several physical characteristics of the drainage basins.

CHAPTER 1

INTRODUCTION

1.1 Introduction

Many existing streamflow studies focus on the frequency analysis or the regionalization of streamflow characteristics. Usually, either the flood or the low flows are considered in view of their applications to design problems. Characterization of streamflow by parameters of probability distributions provides a qualitative basis on which to compare and predict streamflow. Such types of study have been carried out in Southern Ontario, including that of Sangal and Kallio (1977) who performed distribution testing on annual flood series.

Comparison of streamflow between basins or extension of results to ungauged basins requires consideration of physical factors which vary between basins. These factors include index latitude, index elevation, barrier elevation (Schermerhorn, 1967), frost depth, percentage of cultivated land and climatic variables (Seppo, 1967). Size of drainage area has been related to mean annual flood (Sangal and Kallio, 1977) but few studies relate unit area streamflow to basin size.

Regionalization of any such relationships would define the area of applicability of each relation. Division of Southern Ontario into physiographic regions (Sangal and Kallio, 1977) was performed by correlating major physical features and climatic factors (Brown et al, 1968). By relating basin size to unit area streamflow in various physiographic regions of Southern Ontario existing streamflow analyses could be applied to other basins of different sizes within the applicable region.

1.2 Objective of the Study

This study attempts to determine the effect of basin size upon the unit area streamflow statistics within various physiographic regions of Southern Ontario.

1.3 Literature Review

The two separate, topics included in this study have each been the subject of numerous papers: (a) frequency analysis of streamflow, and (b) regionalization of streamflow characteristics.

(a) Frequency analyses of flood or low flows in a given area are commonly performed to be applied to water-resource management or structural design of water works. It is from these frequency analyses, first used in 1890, that many of the techniques and hydrologically-applicable distributions have arisen. Frequency curves were first approximated by normal distributions; results were improved by use of the log-normal and subsequently, other distributions now in common use (Chow, 1966).

For Southern Ontario, Sangal and Kallio (1977) performed frequency analyses of flood flows for 130 stations, including nine of the seventeen used in the present study. Five of the most common hydrological theoretical frequency distributions were fitted to the annual floods, including the Gumbel, Pearson Type III, log-Pearson Type III, log-normal and the Three-Parameter-Log-Normal distributions.

Throughout present day literature, the variety of distributions used for frequency analysis emphasizes that there is no single best distribution for any hydrological time series. The five types noted above are, however, those used most often. Recommendations by U.S. Government Authorities suggest the use of the Log-Pearson Type III (Sangal and Kallio, 1977).

(b) Regionalization of streamflow (i) allows data to be extended from gauged sites to ungauged basins and (ii) consolidate measurements at gauged sites by averaging information over a region, thus effectively extending the length of record and approaching more closely the theoretical population of the data (Riggs, 1973). Regional flood frequencies have been analysed using the Index-Flood and the Multiple Regression methods (Riggs, 1973). The latter has also been applied to regionalization of mean monthly flows, annual minimum flows, and others. Sangal and Kallio (1977) used a modified Index-Flood method.

The effect of basin area upon runoff has been the subject of much discussion as the following two opinions show:

> "So pronounced is the effect of watershed area on flood flow, that widely scattered watersheds of equal area but of dissimilar topographical characteristics experience quite similar flood flows" (Meyer from Wisler et al, 1957, p. 41)

> "Based on analysis of many major floods, especially those in the north-central, northeastern, middle Atlantic, and some in the North Pacific States and California, it appears that the amount of direct run-off that has occurred during single flood-rises of record has a fairly definite range for certain regions and that, except possibly for small drainage basins, the total direct run-off has been about the same for the various sizes of drainage areas in a particular region." (Hoyt et al, 1939 from Wisler et al, 1957, p. 41)

In spite of the dilemma, Riggs (1973) found basin area to be included in all of 10 published regional flood-frequency regressions. Other significant variables were: main-channel slope, percentage of basin covered by lakes and swamps and mean annual precipitation. Relations of flows to drainage area may not be useable if there are other stronger influences in the basin (Riggs, 1968).

The work of Sangal and Kallio (1977) in regionalizing flood flows in Southern Ontario was discussed and incorporated where useful into the present study. Portions of their work of particular interest are:

(1) division of Southern Ontario into regions based on physiography, named by them "Flood Frequency Regions"

(2) distribution tests performed upon annual floods at stations throughout Southern Ontario

(3) establishment of regional relationships between size of drainage basin and mean annual floods.

The flood frequency regions are discussed with the appropriate spatial divisions used in this study in Chapter 2. Sangal and Kallio's distribution testing is described briefly, and their findings provide evidence cited later during discussions of this analysis. Their regional studies, however linked basin size to mean annual flood flows, which relationship is assumed to exist but not considered in this study. While Sangal and Kallio's establishment of a mathematical relation between drainage area and mean annual flood flows could be of some value, the unit area statistics of streamflow are of greater interest in this study.

CHAPTER 2

STUDY AREA AND METHOD

2.1 Study Area

To analyze the effect of basin size on streamflow, a set of basins of various sizes was first selected in a common drainage basin. The chosen basins were emptied by streams of one Hortonian order less than the outlet stream from the common basin; the physical difference between drainage basins was thus minimized, allowing the basin size to be the prime variable. Several similar sets of basins were then selected from the other parts of the study area for a comparison of results.

Southern Ontario is a suitable area because it can be subdivided into several regions based on climatic and land use criteria. Within Southern Ontario, there is a dense network of streamflow stations, some of which provide long records. Results of the present type of analysis may have useful applications to hydrologically-related resource management and design projects. Such applications are particularly pertinent in Southern Ontario, whose dense population is supported by industrial and farming activities.

Figure 2.1 shows the extent of the study area in Southern Ontario. The primary region or study area is divided into secondary regions, consisting of one or two river systems, each of which are named by code letters. Tertiary division is based upon basin size and each sub-system is drained by a stream monitored by a station. Stations are numbered within the secondary regions and are each identified by a

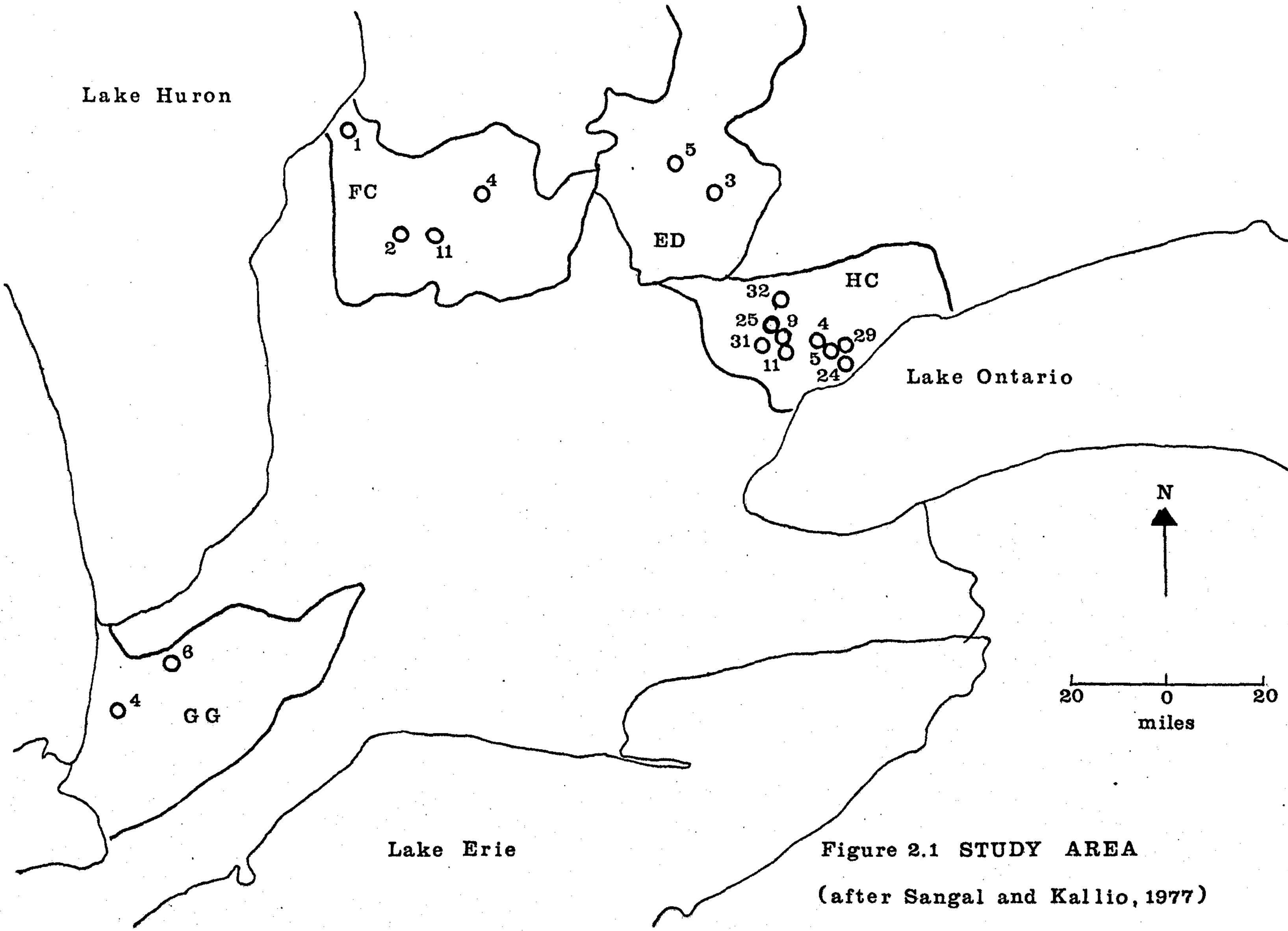


Figure 2.1 STUDY AREA

(after Sangal and Kallio, 1977)

letter code and a number.

Hierarchial arrangement of the basins selected is shown in Figure 2.2. Note that secondary region HC contains two drainage systems whereas in each other secondary region only one river system was studied.

Criteria by which stations were chosen are:

(1) at least 10 years of record length. A list from Sangal & Kallio (1977) was consulted.

(2) natural flow conditions occur upstream of the station

(3) more than one station satisfying criteria (1) and (2) are located on the same river system in the secondary region

(4) stations were chosen from as many secondary regions as possible, provided that criteria (1), (2) and (3) were satisfied.

By the preceeding criteria, only those stations listed in Figure 2.2 were eligible; the number of tertiary units was thus limited. Locations of selected stations are shown in Figures 2.3 to 2.7 inclusively. Table 2.1 lists the stations, their areas, and the year of data available.

FIGURE 2.2

HIERARCHIAL STRUCTURE OF THE STUDY AREA

PRIMARY REGION	Southern Ontario (draining into Lake Ontario, Lake Erie and Georgian Bay)				
SECONDARY REGIONS	FC	ED	GG	HC	
RIVER SYSTEMS	Saugeen River	Nottawasaga River	Bear Creek	(a) Humber River	(b) Don River
TERTIARY UNITS = STATIONS	FC001	ED003	GG004	HC009	HC004
	FC002	ED005	GG006	HC011	HC005
	FC004			HC025	HC024
	FC011			HC031	HC029
				HC032	

TABLE 2.1

STREAMFLOW RECORDS AVAILABLE FOR

CHOSEN STATIONS

STATION	AREA (Km^2)	NUMBER OF YEARS OF DATA AVAILABLE	YEARS
FC001	4070	62	1915-76
FC002	2203	62	1915-76
FC004	249	24	1916-39
FC011	163	23	1954-76
FD003	1181	27	1950-76
FD005	295	13	1964-76
GG004	596	12	1965-76
GG006	267	10	1967-76
HC009	197	23	1954-76
HC011	495	5	1957-61
HC025	303	14	1963-76
HC031	95	5	1966-70
HC032	95	9	1966-74
HC004	119	15	1949-53, 55-64
HC005	88	17	1954-58, 61-66, 69, 72-76
HC024	287	14	1963-76
HC029	129	12	1965-76

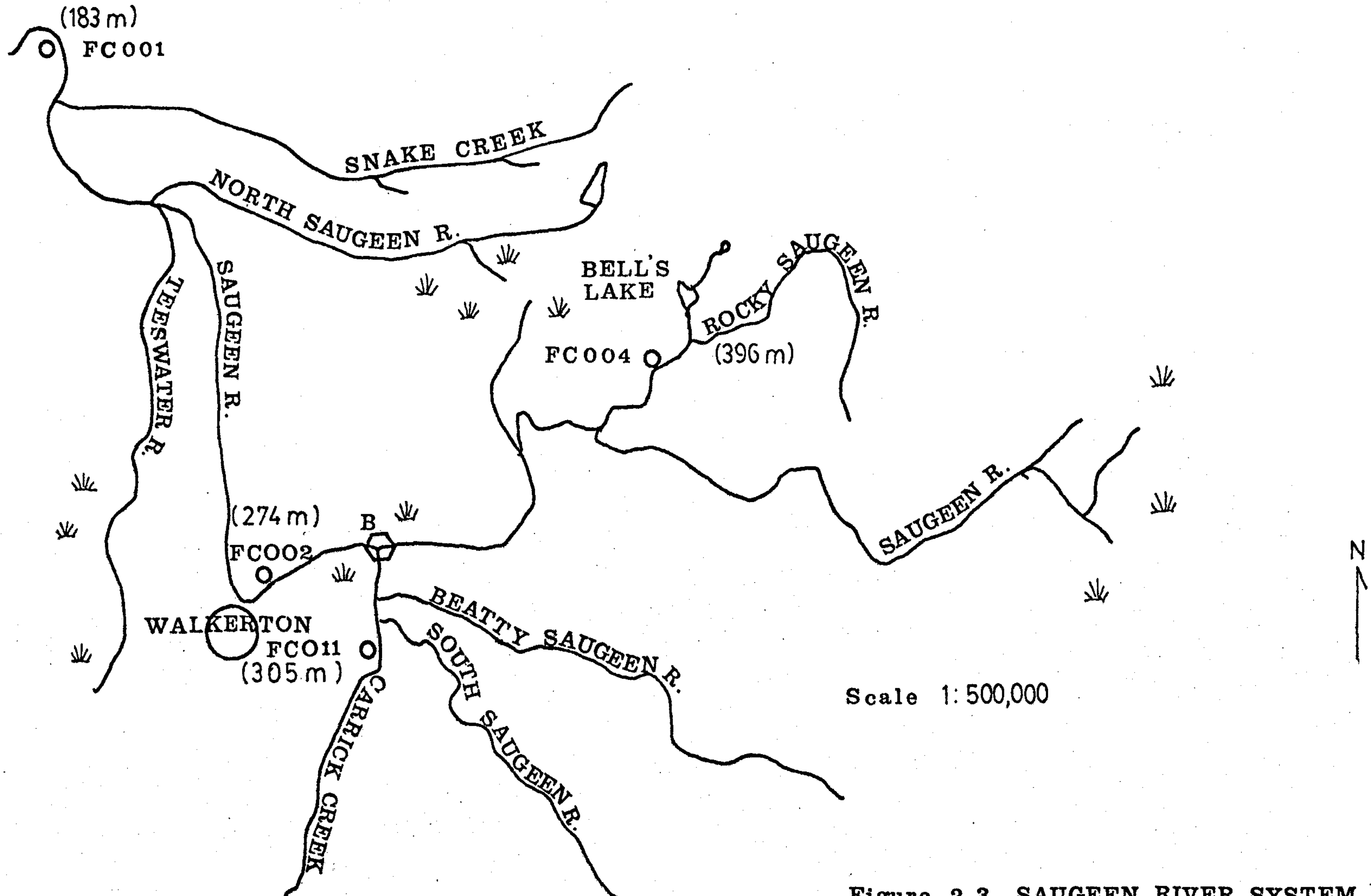


Figure 2.3 SAUGEEN RIVER SYSTEM

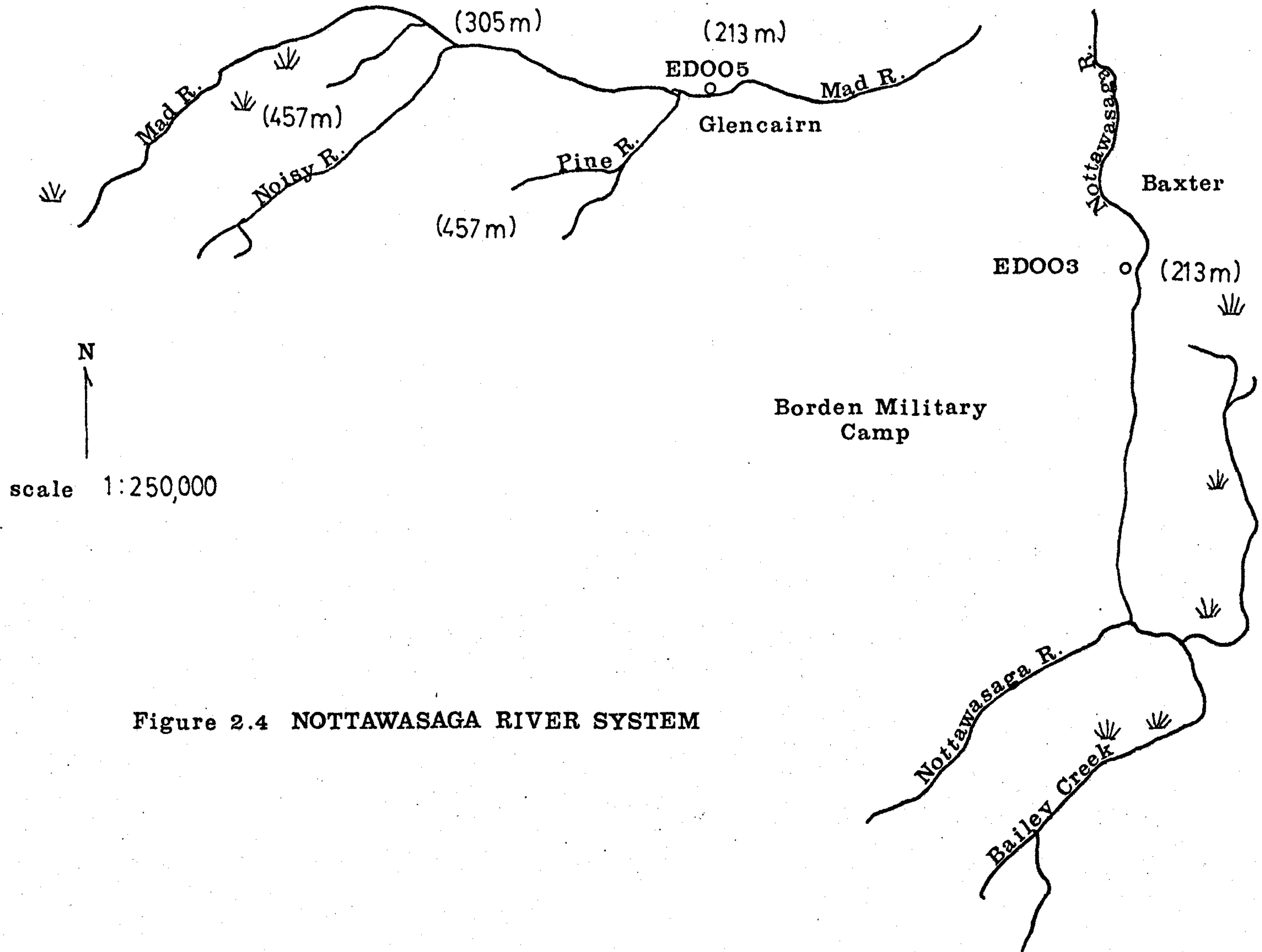


Figure 2.4 NOTTAWASAGA RIVER SYSTEM

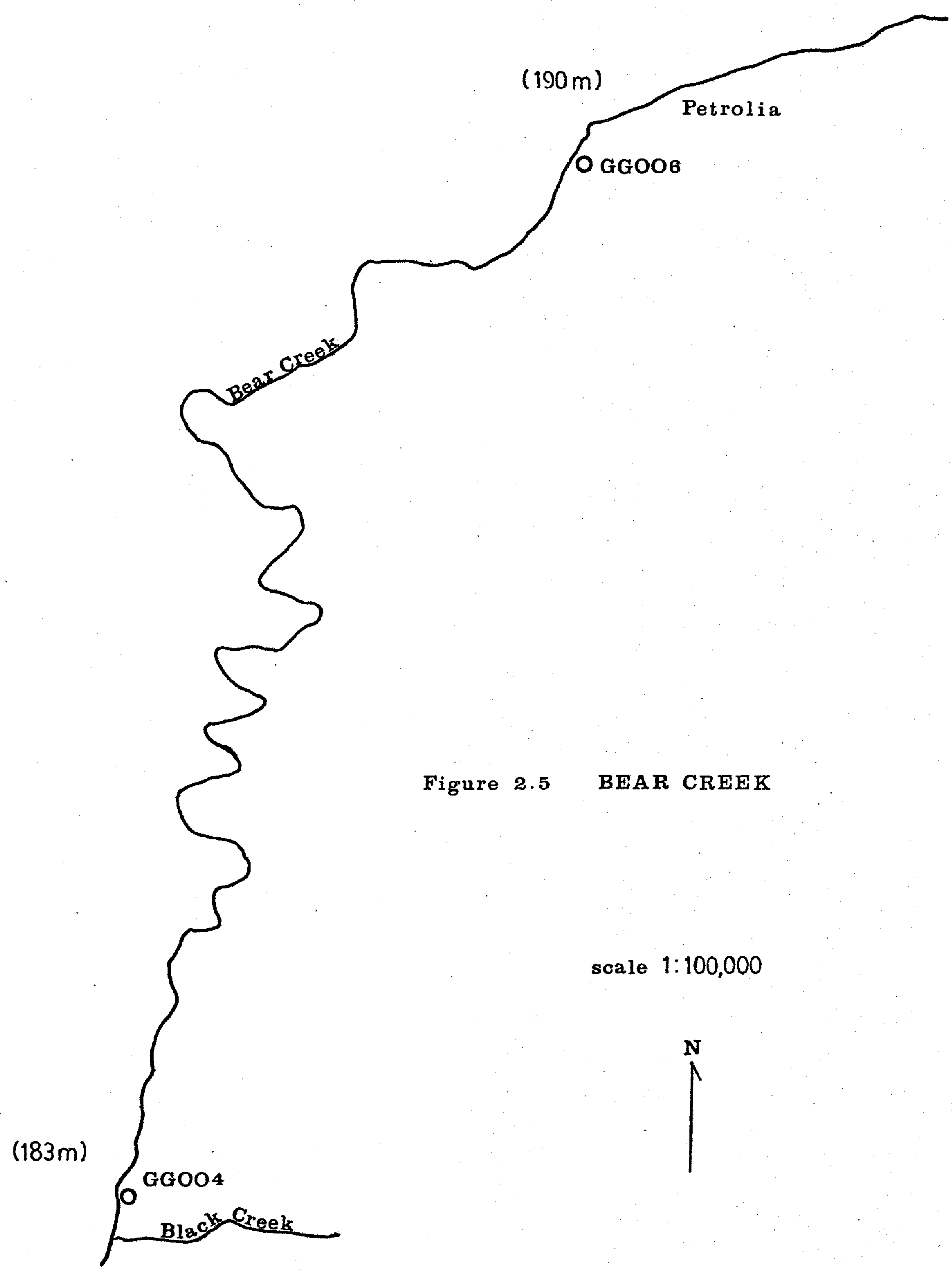
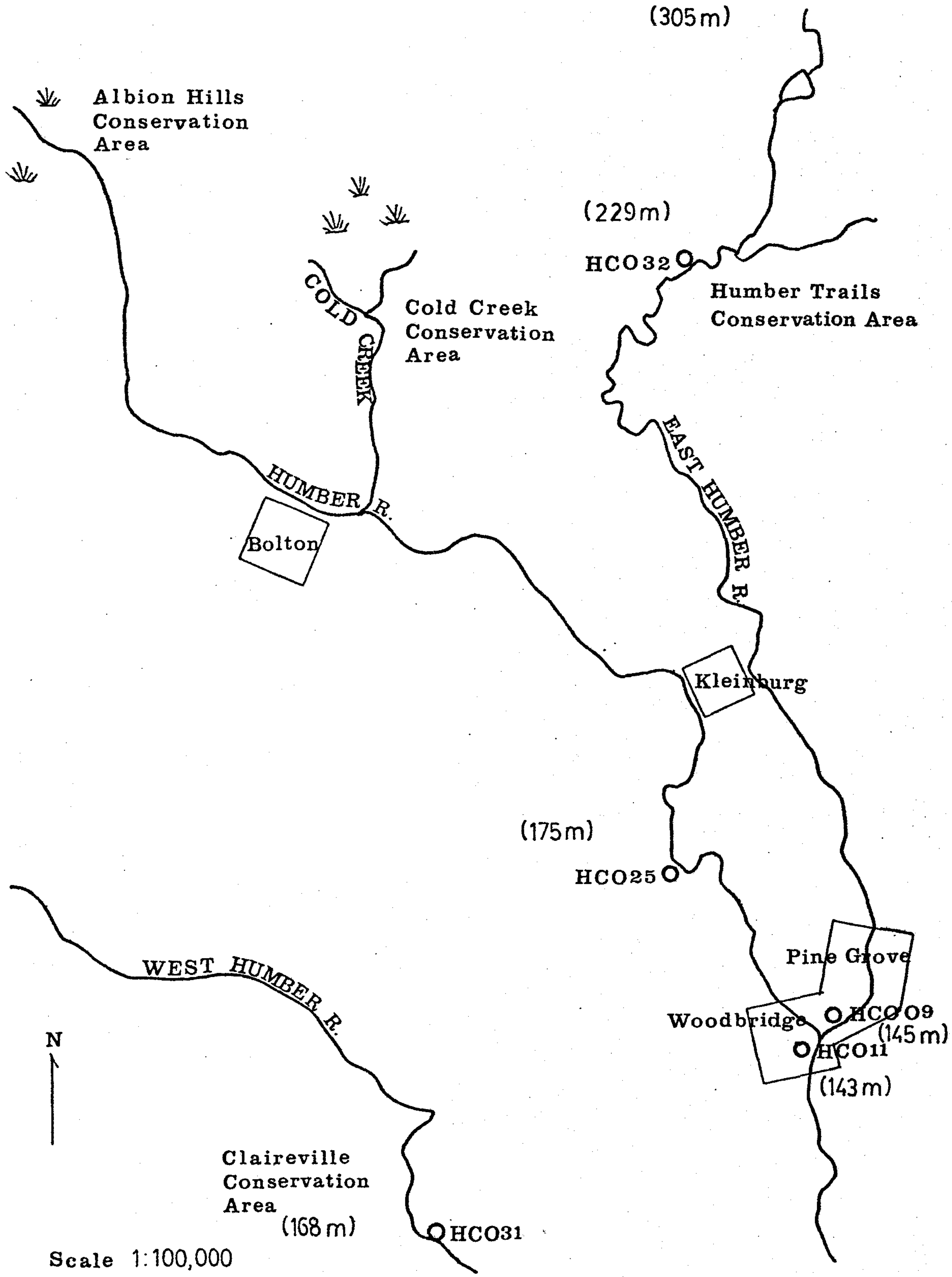


Figure 2.5 BEAR CREEK

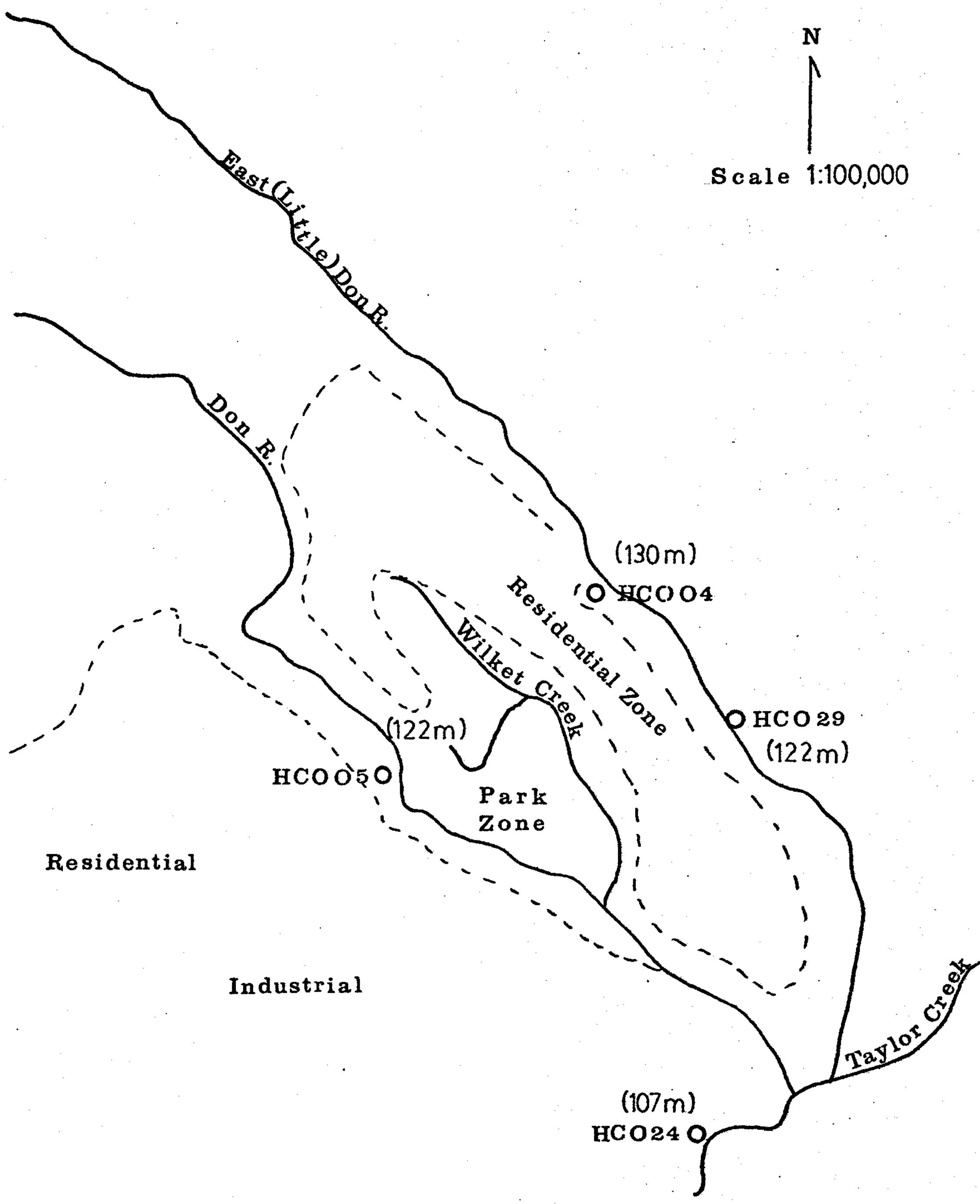
scale 1:100,000

Figure 2.6 HUMBER RIVER SYSTEM



Scale 1:100,000

Figure 2.7 DON RIVER SYSTEM



2.2 Physiography and Climate

The climate of Southern Ontario is influenced by such topographic features as the Great Lakes, the Niagara Escarpment, and the Dundalk Uplands. Figure 2.8 shows the climatic regions (Brown et al, 1968) of the area, together with the major topographical features. Note the general correspondence of spatial boundaries for the two types of regions. On a primarily physiographic and soil nature basis, with some attention to climatic conditions and land use, Sangal and Kallio (1977) divided Southern Ontario into nine flood-frequency regions (Figure 2.9). Of these, Regions 3 to 8 are included in the area of the present study. Descriptions of these Flood Frequency regions and relations to this study's Secondary Regions are given and referred to during later analyses.

2.2.2. Precipitation

Prevailing westerly winds cause increased precipitation in the lee of Lake Huron. Precipitation is also affected by elevated land, forcing moist air to rise, releasing moisture on the windward slopes and causing a rain shadow effect on the leeward. Hence, the combined effects produce highest annual precipitation east of Lake Huron and Georgian Bay, on the middle slopes of the Dundalk Uplands (elevations 366-427 m). Toronto and Hamilton, however, are upwind of Lake Ontario and are therefore in the driest zone in the study area.

Winds blowing across Lake Huron also account for a large percentage of snowfall in the Dundalk, Huron, and Muskoka climatic regions. In these areas, 30 percent of the total precipitation is snow (279 cm annually). Snowfall in the Leamington-Kent-Essex Climatic Region is

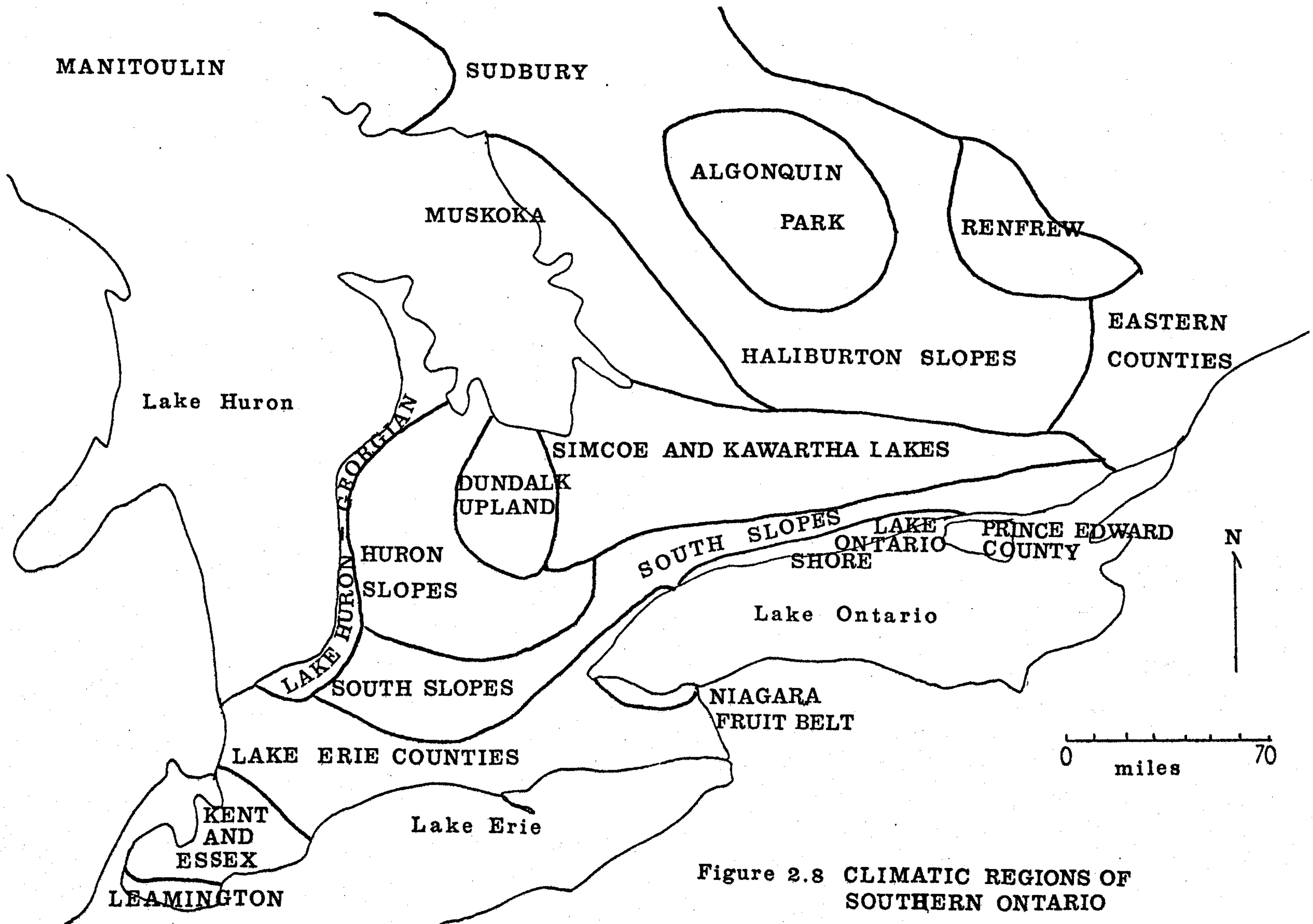


Figure 2.8 CLIMATIC REGIONS OF SOUTHERN ONTARIO
(after Brown et al, 1968)

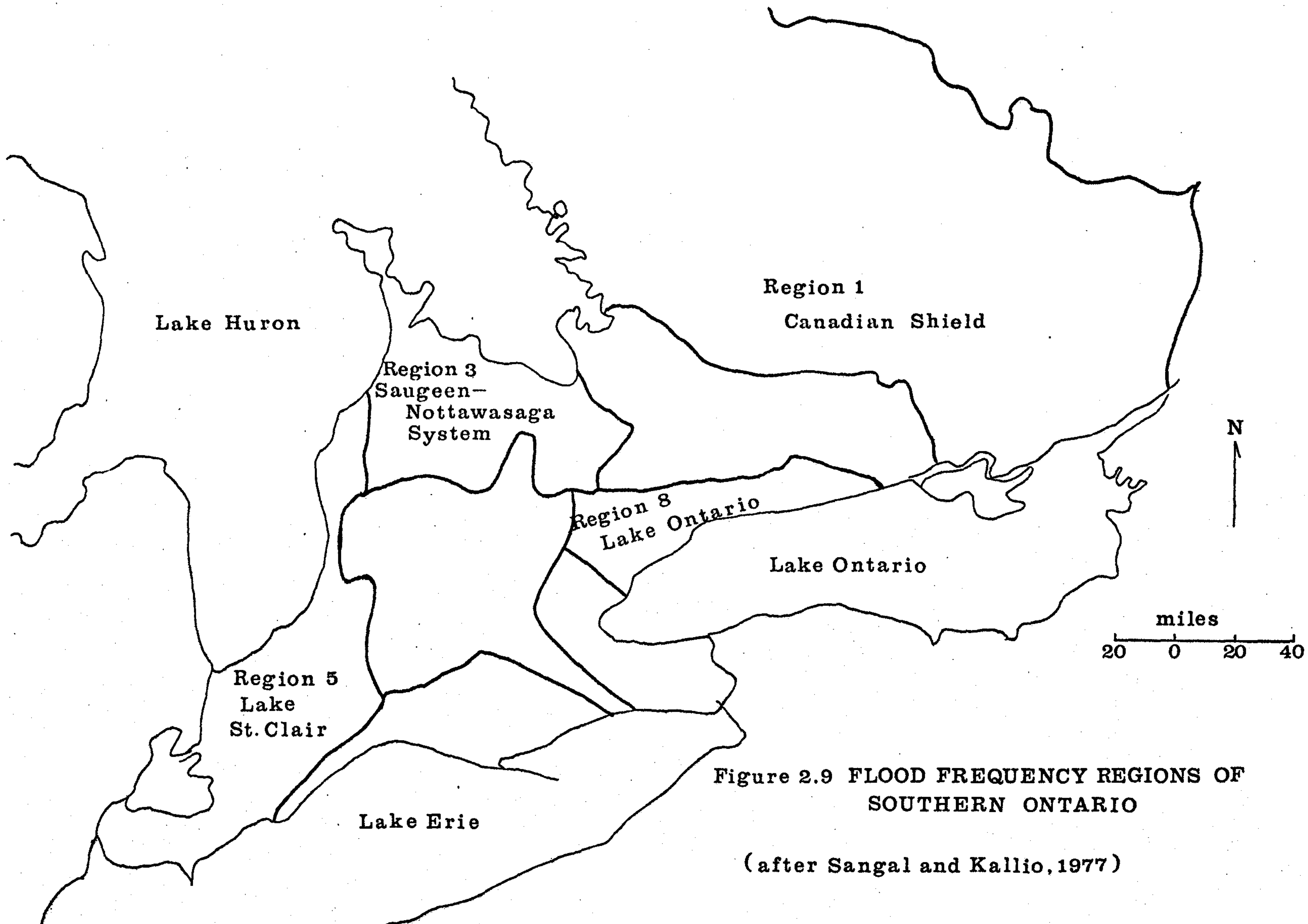


Figure 2.9 FLOOD FREQUENCY REGIONS OF SOUTHERN ONTARIO

(after Sangal and Kallio, 1977)

only 88 cm, 15 percent of the total precipitation. The Toronto-Hamilton area receives less than 122 cm of annual snowfall (Brown et al, 1968).

Seasonal variation of precipitation over Southern Ontario is small (Brown et al, 1968).

2.2.3 Snowmelt

Melting of snowcover causes the greatest percentage of yearly discharge to occur in the spring. Snowmelt characteristics thus exert a major influence on the characteristics of streamflow.

Persistence of snowcover varies between climatic regions. In the southern parts of the study area, including Kent and Essex counties and the Niagara Peninsula, winter snow does not persist. In other parts of Southern Ontario, complete snow cover usually exists in January and February. Near Lakes Ontario and Erie, snow cover can endure until March 30th; further north this date is extended to mid-April.

2.2.4 Evaporation

In Southern Ontario, regional variation of evapotranspiration is small (Brown et al, 1968). Due to this lack of spatial variations, examination of the seasonal variations was not considered necessary for the purposes of this study.

2.2.5 Secondary Region Topography

Figures 2.3 to 2.7 show the topographical characteristics of the secondary regions as well as the locations of the stations.

(i) Saugeen River System:

FC Secondary Region: Flood Frequency Region 3

First impressions of the Saugeen River System basin physiography are of a complicated drainage net with many tributaries, swamps, and a few small lakes. Few cities are situated close to the river channels, the largest being Walkerton.

The Saugeen system drains the Huron slopes climatic region of Brown et al (1968) west of the Dundalk Uplands. Mean annual precipitation is high.

Throughout the basin, soils are rough and stoney; permeability is high and a strong summer base flow is maintained. Woods and swamps occupy 30 to 35 percent of the farmlands. Headwater streams drain an area where local relief is provided by kames and drumlins, and have average gradients ranging from 1.9 to 6.6 m/km. The gradient of the main stream averages to 3.4 m/km.

(ii) Nottawasaga River System: ED Secondary Region: Flood Frequency Region 3

The Nottawasaga System is also contained in Flood Frequency Region 3, but drains the east slopes of the Dundalk Uplands. Coarse-textured soils also predominate in this area, enabling high permeability. The Mad River drains high elevations and has an average gradient of 4.8 m/km, but above Glencairn gradients may reach 18.9 m/km. Tributary Pine River above Glencairn descends with an average gradient of 6.1 m/km. Upstream of Baxter, the Nottawasaga branches into several tributaries, draining flatter, swampier area. Averaged over its total length, the Nottawasaga's gradient is 2.5 m/km.

(iii) Bear Creek: GG Secondary Region: Flood Frequency Region 5

Bear Creek drains the mild Kent and Essex climatic region. This area is a till plain of clay loams, highly impervious and thus aiding high runoff. Sand and gravel or till ridges may interrupt the flat or gently undulating terrain. Slopes of the headwaters reach only 1.9 m/km gradients while the average gradient over the length of Bear Creek is as low as .66 m/km. Farmland constitutes a large percentage of the land use.

(iv) Humber River and Don River Systems: HC Secondary Region: Flood Frequency Region 8

This area lies in the South Slopes Climatic Region. Sources for the streams are the Niagara Escarpment Cuesta moraine deposits, the interlobate Oak Ridges Moraine, and the till plain south of the Moraine. Most streams are relatively short above the Lake Iroquois Shoreline (where all stations in this study are located) with large gradients of 4.7 to 6.6 m/km along the longer streams and up to 18.9 m/km along smaller streams and headwaters. Steep valleys and channel slopes cause the very real hazard of floods, increased by effects of urbanization.

The Humber River arises from both the escarpment and the Oak Ridges moraine, whereas the Don River drains entirely from the till plain. The moraine provides a more regular flow and maintains a stronger base flow than the plain source.

Land use differences are great between the Humber and Don River areas gauged by the stations used here. Although narrow strips of parkland exist in the valleys of each, the Don River drains residential and industrial zones of Toronto. The Humber, however, flows outside Toronto, where cities are small; Woodbridge, Kleinburg and Bolton are the only towns adjacent to the channel. Many conservation areas and parks and some swampy areas are located around or on the Humber River.

2.3 Data

2.3.1 Physical Manipulation

Daily discharge data stored on magnetic tape were obtained from the Water Survey of Canada. Decoding of these tapes was necessary before the data could be processed by the CDC 6400 at McMaster University. For full descriptions of data forms, methods of transcription and storage mode; see Appendix A.

An interactive mode supplied the ease and speed necessary to write, store and edit programs. Punched cards were used for runs. Statistical methods used in the programs are described in the following chapter.

2.3.2 Data Conversion and Transformation

Since daily discharges were in units of cfs, all tape data input was immediately converted to m^3s^{-1} units.

To remove obvious effects of basin size, discharges for chosen stations were divided by their basin area. The comparatively larger absolute values of streamflow from a large basin are thus not reflected in the statistics used to characterize streamflow.

2.3.3 Analysis Procedure

Data processing sequence progressed upward through the regions of Figure 2.2.

(1) A tertiary set of stations was chosen and streamflow data from each station was input to the computer programs used for statistical analysis.

(2) Statistical comparisons were made between the stations in the

tertiary set, and the statistics examined for trends due to the effect of basin size.

(3) Physical homogeneity of the secondary region was examined.

Where departures from suspected trends examined for in (2), or where apparent random behaviour of streamflow occurred, attempts were made to base explanations on the physical inhomogeneity. An attempt was made to attach physical interpretation to all statistical results.

(4) Steps (1) to (3) were repeated for each tertiary set of stations.

(5) Results obtained from each secondary region were compared. Where inter-regional differences arise in the trends obtained during step (2), physical diversities between regions were searched for, to explain the results. Again, physical meaning was attached to statistically based conclusions.

2.4 Use of Flood-Frequency Study

As has been stated, the duplication of work done by Sangal and Kallio (1977) was considered unnecessary. Results of their flood frequency analyses for those Southern Ontario basins included in this study were examined.

Their regionalization of mean annual floods vs. drainage area relations, was referred to, and comparisons made with the results of the study.

CHAPTER 3

STATISTICAL METHODS

3.1 The Basin as a Hydrological System

Hydrologically, drainage basins can be considered as natural systems. In the present study, such a system can be represented as a black box whose only hydrological input, precipitation, is operated on by a set of processes to yield outputs including evaporative water losses and streamflow (Figure 3.1). The physical boundaries of the system are defined by drainage divides. Although there may be groundwater flow between basins, this is not a common phenomenon, and in this area, it is assumed that no hydrologic exchange takes place between basins.

Once chosen as a system unit, three aspects of a basin may be considered:

(i) inputs/outputs

(ii) Hydrologic Processes

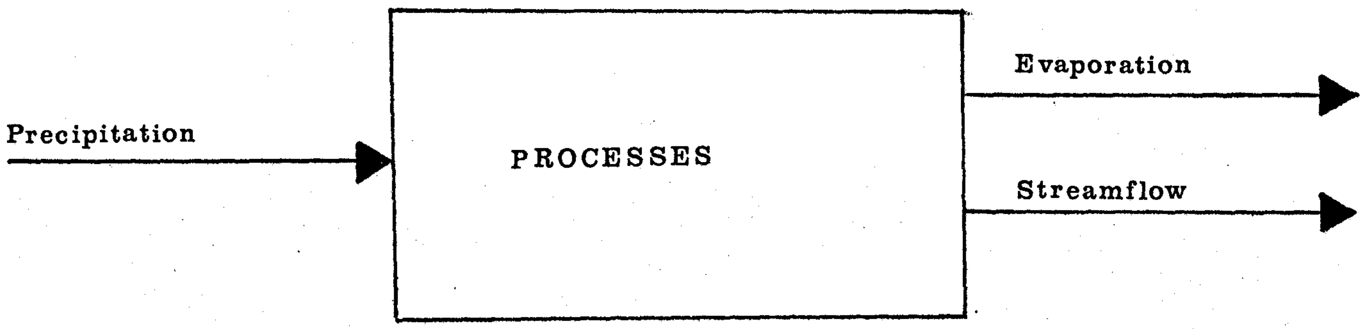
(iii) Physical Environmental Factors

The present study does not examine the hydrologic processes or the physical environment directly. The major concern is to consider the effect of physical factors upon streamflow generating processes via the output.

This presentation was limited to a description of the effect of one major environmental factor, basin size on streamflow. Secondary contributions were looked at from such physical factors as: snowmelt, slope, elevation, urbanization, agricultural land use and

FIGURE 3.1

THE BASIN AS A HYDROLOGICAL SYSTEM



drainage conditions such as swamps and lakes.

Criteria upon which the effects of basin size on streamflow could be based ideally require characterization of both factors and output. Hydrological techniques were used to numerically represent streamflow data in a condensed form as statistics. Physical factors however, were discussed qualitatively.

3.2 Description of Hydrological Processes

As are all natural hydrologic processes, streamflow is a combined result of deterministic and stochastic elements. The random element makes prediction by deterministic principles uncertain, but allows a process to be analysed, and its values represented by probability statistics. Streamflow may then be considered as a random variate X with probability distribution F(x). Events are considered to attain values described by a probability density function f(x), with which is associated the probability distribution

$$F(x) = \int_{-\infty}^{x} f(t)dt \qquad (3 - 1)$$

Some examples of statistical methods commonly used for investigating series of hydrological events are:

(1) Analysis of frequency distributions: the probability distribution of the data is sought for.

(2) Autocorrelation coefficients are examined.

(3) Spectral densities: take into account the periodicities in the data.

(4) Mean range or Queuing Theory: applied to storage problems, where the range R is the maximum surplus Sn^+ minus the maximum deficit Sn^- with respect to the mean.

(5) Mean runs: examines a series of events of the same kind followed by one or more events of another kind.

The first method was chosen in this study.

3.3 Distribution Analysis

3.3.1 Methods of Analysis

Due to limited sizes of hydrologic samples, the empirical (frequency, sample) distribution is obtained and is assumed to estimate the true (population, probability) distribution of the data.

Three methods of analysis of frequency distributions are in use:

(1) qualitative: frequency distribution is described verbally as to its graphical shape.

(2) empirical: properties of the frequency distributions are described by numbers.

(3) probability distributions are fitted to the empirical data.

Method (3) results in the most complete and condensed representation of a frequency distribution and is best used for their comparison. (Yevjevich, 1972). Three steps in this process, by statistical derivation, are:

(1) selection of the probability function to be fitted.

(2) estimation of its parameters.

(3) testing goodness of fit to the empirical distribution.

3.3.2 Probability Distributions

Hydrologists use several well-known theoretical functions to describe the form of sample distributions. Table 3.1 shows equations for the density or probability functions for five common distributions. Selection of a destribution depends on previous experience of the application of the distributions to types of processes.

3.3.3 Estimation of Parameters

Distributions may be defined by their parameters, which are listed in Table 3.1. Four methods used for estimation of the parameters of a selected distribution are; from least to most efficient:

(1) graphical

(2) least-squares

(3) method of moments

(4) maximum likelihood

In this study, as in other studies (in which it is used extensively), the method of moments was used due to the relatively simple computations of estimates. It should be noted that because hydrological variables are skewed, there is some loss of efficiency when parameters are estimated by this method; in many cases, such estimates are looked upon as first approximations.

3.3.3.1 Moments

For parameter estimation, sample moments are used directly in place of the population moments.

The kth moment of a distribution, m_k, is

$$m_k = (\Sigma(x - \overline{x})^k)/n \qquad (3 - 2)$$

TABLE 3.1

SOME COMMON THEORETICAL DISTRIBUTIONS

DISTRIBUTION	PROBABILITY DENSITY OR DISTRIBUTION FUNCTION	PARAMETERS
NORMAL	$f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-(x-\mu)^2/2\sigma^2}$ $-\infty < x < \infty$	μ, σ $C_s = 0$
LOG-NORMAL (2-parameter)	substitute $y = \ln x$ for x in Normal	$\mu = \exp(\mu_y + \sigma_y^2/2)$ $\sigma = \mu(e^{\sigma_y^2} - 1)^{1/2}$ $C_v = \exp(\sigma_y^2 - 1)^{1/2}$ $C_s = 3C_v + C_v^3$
LOG-NORMAL (3-parameter)	substitute $y = \ln(x-a)$ for x in Normal	$\mu = A + \exp(\mu_y + \sigma_y^2/2)$ $\left.\begin{array}{l}\sigma = \\ C_s = \end{array}\right\}$ see 2-parameter
TYPE I EXTREMEL or GUMBEL	$p(x) = \frac{1}{c}\exp[-(a+x)/c - \exp[-(a+x)/c]]$ $-\infty < x < \infty$	$a = \gamma c - \mu$ $\gamma = 0.57721$ $c = \frac{\sqrt{6}}{\pi}\sigma$ μ, σ $C_s = 1.139$
PEARSON TYPE III	$p(x) = p_0(1 + \frac{x}{a})^c e^{-cx/2}$, $p_0 = \frac{N}{a}\frac{c^{c+1}}{e^c\Gamma(c+1)}$	$c = \frac{\mu}{\beta_1} - 1$ $a = \frac{c\mu_3}{2\mu_2}$ mean = mode $- \mu_3/2\mu_2$ standard deviation = $\sqrt{\mu_2}$

about the mean. Usually only the first four moments are considered. Moment-derived statistics of well-known importance are:

mean $\bar{x} = \sum x/n$ (3 - 3)

standard deviation $\sigma = \sqrt{m_2} = \sqrt{(\sum(x - \bar{x})^2)/n}$ (3 - 4)

Combinations of moments expressed as coefficients are:

coefficient of skewness $= C_s = m_3/(\sqrt{m_2})^3$ (3 - 5)

coefficient of peakedness $= C_p = m_4/m_2^2$ (3 - 6)

The relationships of moments to parameters of some probability distributions are shown in Table 3.1.

3.3.4 Goodness of Fit Testing

Two measuring parameters which are used to fit the probabiltiy function to the empirical distribution are:

(i) Chi-square

(ii) Kolmogorov-Smirnov

The Kolmogorov-Smirnov test was used. Its implementation is easier than Chi-square, there is no requirement that an absolute class frequency must exceed 5 and the sorting of data in class intervals is not required.

Sample data is ranked in ascending or descending order X_1', X_2', ...X_m',...X_n' with determined plotting positions $P(X_m') = m/n + 1$. The parameters of a distribution function F(x) are estimated from the sample data.

The criterion statistic is

$$\Delta = \max \left| F(X_m) - P(X_m') \right| \qquad (3 - 8)$$

A critical value Δ_0 is obtained from a Kolmogorov-Smirnov table for sample size n and α, which is the magnitude of a type I error (rejecting a true null hypothesis), $P\left\{\max F(X_m) - P(X_m')\right| \geqslant \Delta_0\} = \alpha$ (3 - 9)

A confidence interval is thus defined about each $P(X_m')$. For use as a measure of goodness of fit, there is a bias of $\Delta - \Delta_+$, where Δ_+ is the true value of Δ if the population, rather than the sample estimates of parameters were used. Δ_o should be slightly smaller than Δ_0 from the table.

3.4 Sample Frequencies

Two sorts of frequency sets were computed and used in the analysis

(i) each month for all N years together of daily flows q_i

(ii) N values of maximum ($YQmax_i$), mean ($YQbar_i$), minimum ($YQmin_i$) yearly flows.

(i) Daily Flows in Monthly Distributions

Daily flows were divided into classes by the procedure described in Appendix B. Frequencies for each station were calculated by

$$fr(qc_i)_{\text{month } k} = \sum_{j=1}^{N} \left(\sum_{k=1}^{md_k} (qc_i)_k \right)_j \qquad (3 - 12)$$

where qc_i is a daily discharge in class i, md_k is the number of days in month k. Relative frequencies for each monthly distribution are approximated by

$$p(qc_i)_{\text{month } k} = \frac{fr(qc_i)_{\text{month } k}}{N \times md_k}$$

(ii) Yearly Statistics

For each station, yearly means, maxima and minima were ranked in descending order and the return periods (R) calculated by:

$$R\left[YQ \begin{Bmatrix} \max \\ \text{bar} \\ \min \end{Bmatrix} i \right] = \frac{N+1}{\text{rank}\left[YQ \begin{Bmatrix} \max \\ \text{bar} \\ \min \end{Bmatrix} i \right]} \qquad (3 - 14)$$

From R, probabilities are:

$$P\left[YQ \begin{Bmatrix} \max \\ \text{bar} \\ \min \end{Bmatrix} i \right] = \frac{1}{Ri} \qquad (3 - 15)$$

3.4.1 Graphs of Frequency Sets

The monthly frequency data was plotted; one set of twelve months per station, on decimal graph paper. Information concerning the seasonal variations of flow was extracted from the graphs. Those seasons during which flow was uniform for all data were declared of little interest, since the dissimilarities of streamflow are the focus of the study. From seasons of variations it was decided upon which subsets of flow characteristics to concentrate.

Sets of yearly means, maxima and minima probabilities were graphed for groups of proximal stations as a first attempt to see if the samples fitted any known theoretical distribution. Parameters were then estimated by the method of moments.

3.4.2 Graphs of Yearly Statistics

Annual means maxima and minima were calculated and plotted against time for N years of each sample station. Correspondence (or lack of) the fluctuations between stations in a set was observed. Longterm trends in the statistics were examined for and, if suspected, were tested for by computing statistics for time periods expected to be representative of the trend. Persistent differences in absolute magnitude were noted as possible indices of basin size to be compared with indices within other sets of stations.

Each of the statistics for N years together were plotted together on 4 graphs. Graphical groupings were examined for definite boundaries between sets of stations which could imply regional characteristics.

3.4.3. Distribution Analysis

For small samples, determination of the frequency distribution is often impossible. However, fitting of probability distribution was attempted for the yearly means, and low flows. The method of moments was used to estimate parameters and the Kolmogorov-Smirnov test was used to establish goodness of fit.

Distributions were compared for basins of different sizes in the same river system, and, following the general mode set out in Chapter 2, any conclusions drawn were compared to those from other river systems.

If the frequency distributions to be compared fit the same probability function, the parameters are directly compared. If the probability distributions differ, the relationship between distribution parameters should first be determined.

In the case of flood flow distribution analyses, the study of Sangal and Kallio (1977) is referred to. Their methods are slightly different with respect to parameter determination than used here, but their results are more detailed over a more narrow topic than could be attempted here. Sangal and Kallio fitted each station to five theoretical distributions: Gumbel, Pearson, Log-Pearson, Log-Normal and Log-Normal 3 parameters. Estimation of parameters were made by the Method of Maximum Likelihood.

3.5 Regionalization of Annual Floods

The method used by Sangal and Kallio was similar to the index-flood technique used by the U.S. Geological survey. Riggs (1973) describes the method.

The study area is divided into regions to which a single relation of mean annual flood will apply. Originally, this was performed graphically, but Sangal and Kallio used judgement of physiographic and climatic characteristics to decide the divisions. A regional curve is obtained by averaging individual frequency curves.

Mean annual flood was the arithmetic mean of the annual flood sequence. For further details of the method, see Sangal and Kallio (1977).

3.6 Environmental Factors

Physical factors selected for referral with respect to their effect on streamflow characteristics were:

(1) channel gradients

(2) swamps, small lakes

(3) presence of urban areas

(4) timing and magnitude of snow melt

(5) soil permeability

(6) relative receipt of precipitation

Channel gradients were obtained from Sangal and Kallio (1977), averaged over total streamlengths and applicable to head waters. Factor (5) was also described by Sangal and Kallio.

Factors (2) and (3) were qualitatively obtained from topographical maps.

Factors (4) and (6) were obtained from the climatological study of Southern Ontario by Brown et al (1968).

CHAPTER 4

EFFECT OF BASIN SIZE ON STREAMFLOW

Methods of allocating statistics to characteristics of streamflow, and description of physical aspects of a drainage basin were discussed in the last chapter. Using the analysis procedure listed in Chapter 2 as a basis for organization, the results of analyses of teritary station sets are separated into sections.

Single station flood frequency results of Sangal and Kallio may be summarized as follows. It was concluded that the best fitting distribution for the annual flood frequency series was the 3-parameter log-normal distribution. Although middle-range values were in agreement using each distribution, the skew of the fitted 3-parameter log-normal was found to be close to zero. Since the theoretical skew is zero, this was defined as a valid criterion for use of the distribution Kite (1976) also concluded that the 3-parameter log-normal was most applicable to data of the St. Mary's River at Stillwater, Nova Scotia. His conclusions were backed by three goodness of fit tests. Therefore, the parameters for the 3-parameter log-normal only are considered necessary in the analysis of flood flows in Southern Ontario.

After each tertiary set results has been presented, comparisons are made as per step (5) in the processing sequence listed in Chapter 2.

4.1 Saugeen River System - FC Tertiary Set

4.1.1 Annual Means Per Unit Area

Annual mean flows per unit area vs. time (Figure 4.1) showed no

TABLE 4.1-(a)

OVERALL MEANS AND STANDARD DEVIATIONS PER UNIT AREA

(a) BY RIVER SYSTEM

STATION	AREA (km^2)	MEAN/AREA ($m^3s^{-1}\ km^{-2}$)	STANDARD DEVIATION/AREA ($m^3s^{-1}\ km^{-2}$)
FC001	4070	1.37×10^{-2}	3.08×10^{-3}
FC002	2203	1.36×10^{-2}	3.18×10^{-3}
FC004	249	1.14×10^{-2}	2.96×10^{-3}
FC011	163	1.25×10^{-2}	3.30×10^{-3}
HC011	495	6.40×10^{-3}	1.87×10^{-3}
HC025	303	7.60×10^{-3}	1.45×10^{-3}
HC009	197	5.50×10^{-3}	1.92×10^{-3}
HC031	153	5.40×10^{-3}	1.73×10^{-3}
HC032	95	5.10×10^{-3}	1.15×10^{-3}
GG004	596	9.42×10^{-3}	2.60×10^{-3}
GG006	267	9.50×10^{-3}	2.83×10^{-3}
ED003	1181	7.79×10^{-3}	2.08×10^{-3}
ED005	295	1.28×10^{-2}	2.78×10^{-3}
HC024	287	1.24×10^{-2}	1.89×10^{-3}
HC029	129	9.88×10^{-3}	1.80×10^{-3}
HC004	119	8.02×10^{-3}	2.58×10^{-3}
HC005	88	8.56×10^{-3}	2.13×10^{-3}

TABLE 4.1-(b)

OVERALL MEANS AND STANDARD DEVIATIONS PER UNIT AREA

(b) BY DECREASING BASIN SIZE

STATION	AREA (km^2)	MEAN/AREA (m^3s^{-1} km^{-2})	STANDARD DEVIATION/AREA (m^3s^{-1} km^{-2})
FC001	4070	1.37×10^{-2}	3.08×10^{-3}
FC002	2203	1.36×10^{-2}	3.18×10^{-3}
ED003	1181	7.79×10^{-3}	2.08×10^{-3}
GG004	596	9.42×10^{-3}	2.60×10^{-3}
HC011	495	6.40×10^{-3}	1.87×10^{-3}
HC025	303	7.60×10^{-3}	1.45×10^{-3}
ED005	295	1.28×10^{-2}	2.79×10^{-3}
HC021	287	1.24×10^{-2}	1.89×10^{-3}
GG006	267	9.50×10^{-3}	2.83×10^{-3}
FC004	249	1.14×10^{-2}	2.96×10^{-3}
HC009	197	5.50×10^{-3}	1.92×10^{-3}
FC011	163	1.25×10^{-2}	3.30×10^{-3}
HC031	153	5.40×10^{-3}	1.73×10^{-3}
HC029	129	9.88×10^{-3}	1.80×10^{-3}
HC004	119	8.02×10^{-3}	2.58×10^{-3}
HC032	95	5.10×10^{-3}	1.15×10^{-3}
HC005	88	8.56×10^{-3}	2.13×10^{-3}

Figure 4.1 ANNUAL MEANS/AREA– FC

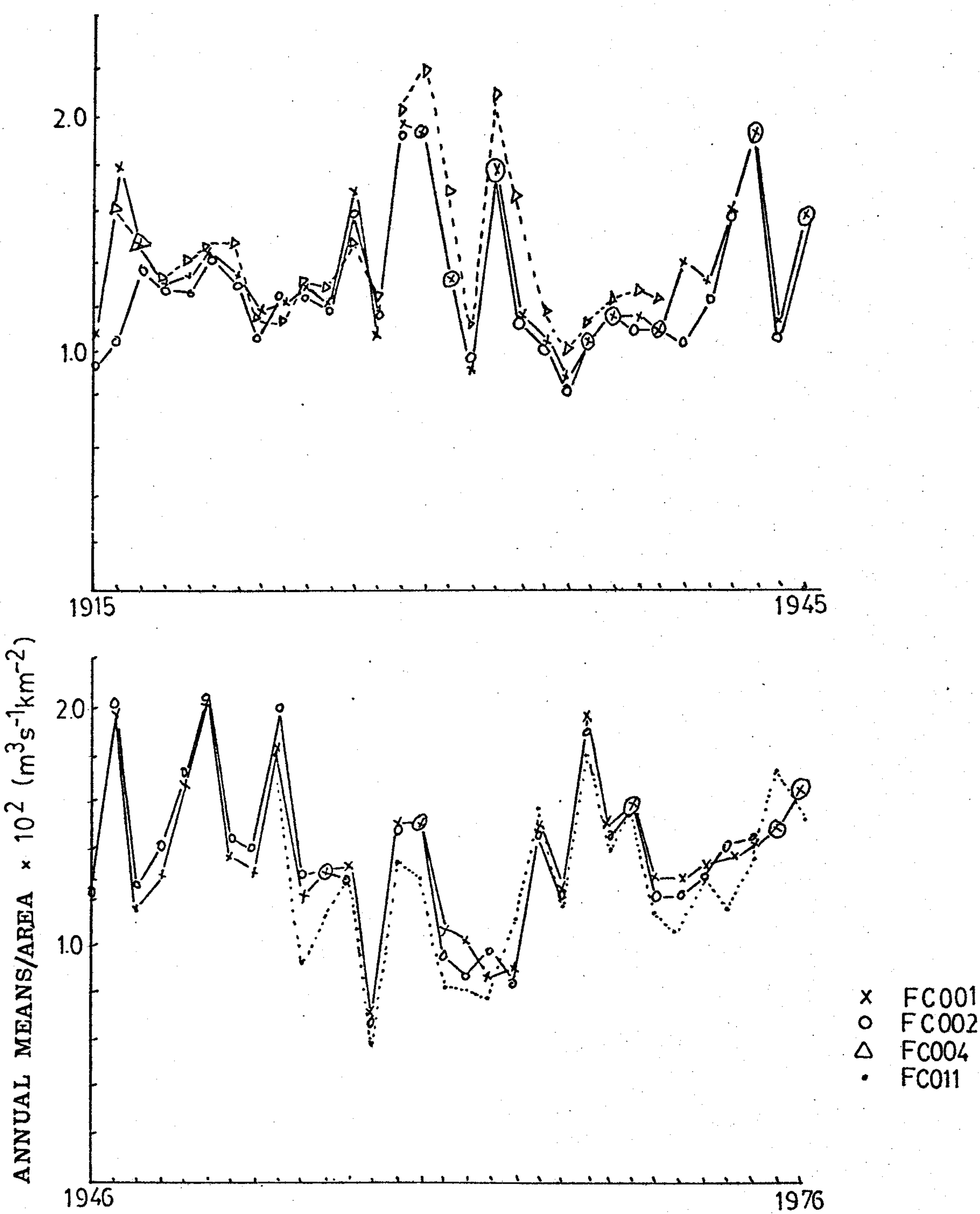


Figure 4.2 RANKED ANNUAL DISCHARGE STATISTICS– FC

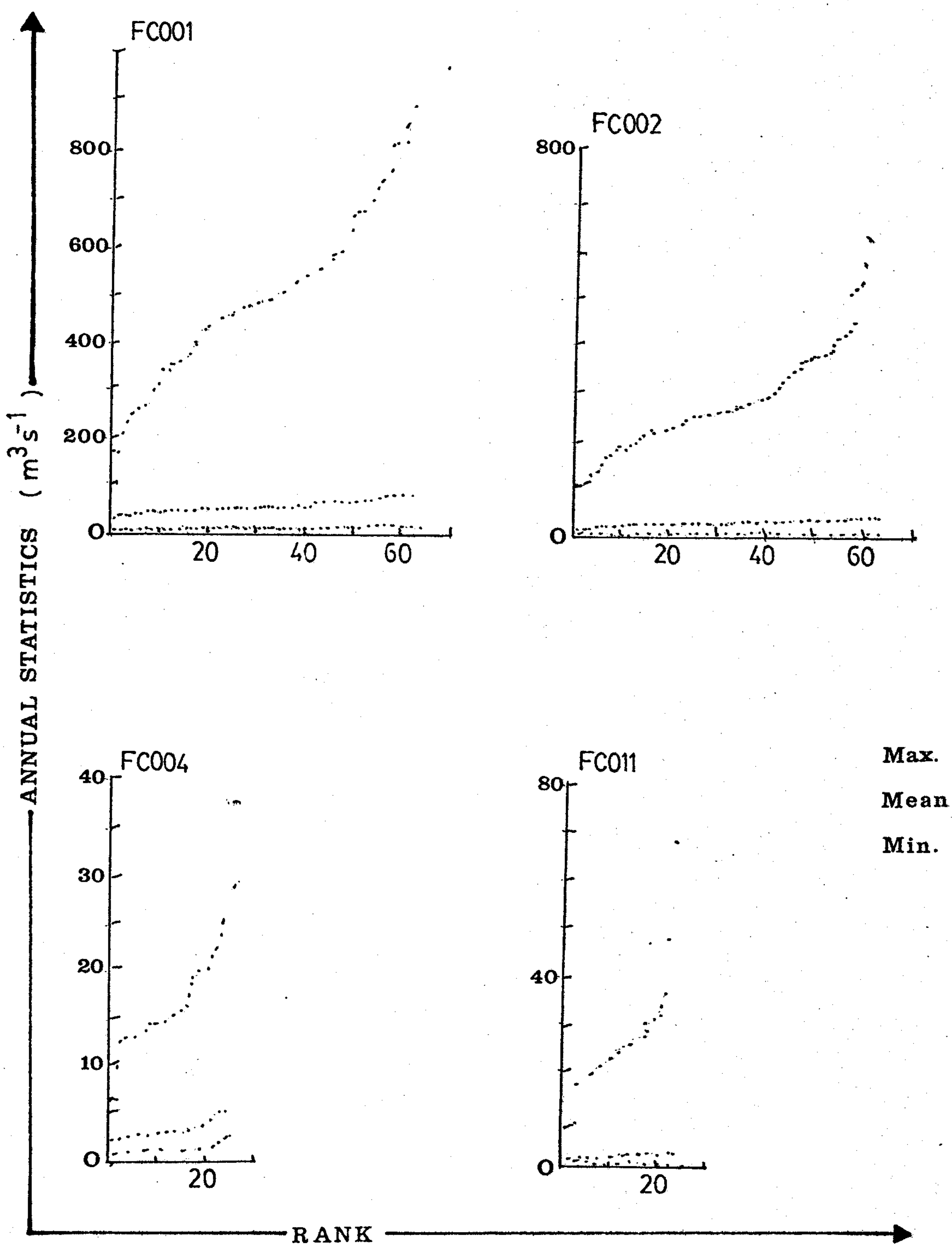
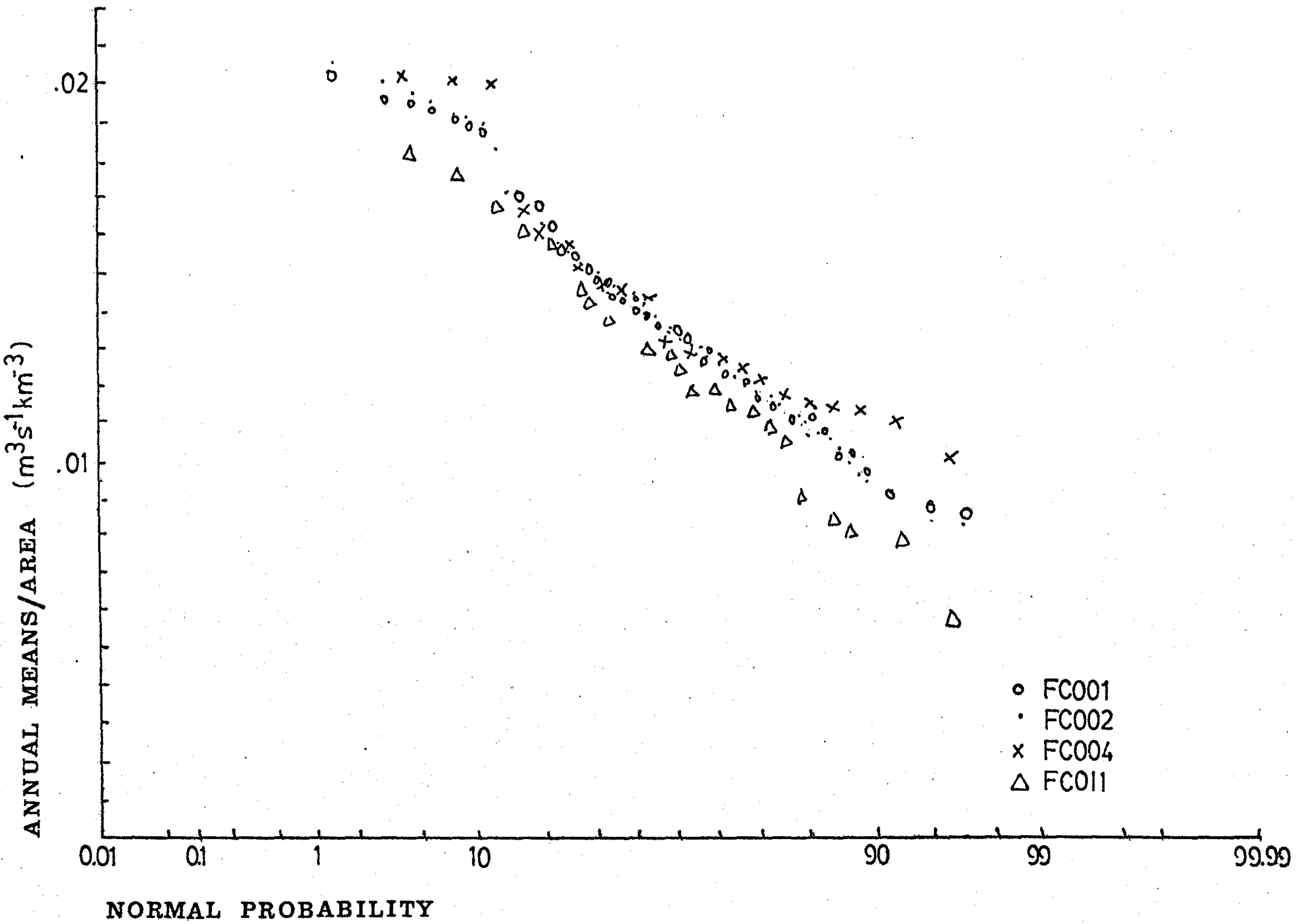


Figure 4.3 DISTRIBUTION OF ANNUAL MEANS/AREA – FC



noticeable long term trends. There was close correspondence in timing and magnitude of yearly fluctuations of all four stations. FC001 and FC002 are virtually indistinguishable; FC004 tends to rise above their plots but not consistently while FC011 lies consistently below. Consultation of Table 4.1 shows lesser means in both smaller basins. The sizes of FC001 (4070 km^2) and FC002 (2203 km^2) does not appear to have differentiated their annual mean flows per unit area. Although the records of FC004 (1916-1939) and FC011 (1954-1976) do not overlap in time, their graphical positions relative to FC001 and FC002 (1915-1976 each) do not indicate values of mean discharge per unit area are related to basin area.

4.1.2 Distribution of Annual Means Per Unit Area

Stations FC001 and FC002 were the only chosen stations which possessed long term (greater than 30 years) streamflow records. Thus, any frequency analysis would be most accurate when performed using the 62 years of data from each of these stations. Graphs of ascending means shown in Figure 4.2 are S-shaped, suggesting normally distributed populations. Equivalent graphs of FC004 and FC011 show nothing due to insufficient data.

Subsequent plotting of annual means/unit area on normal-probability paper (Figure 4.3) again suggested a normal distribution and emphasized the similarity of the FC001 and FC002 distributions. FC004 seems to follow similarly, but shows more pronounced bulges at the extremities than do the graphs of FC001 and FC002 and slopes less steeply. An approximate straight line through FC001 and FC002 slopes less steeply than a straight line through the points of FC011 which does not show the extremity bulges. These observations coincide with the standard deviations listed in Table 4.1.

It was strongly suspected that the theoretical distribution which fits the annual means per unit area for any station was the Normal. It was obvious however, from the graphs and from Table 4.1 that no trend existed which correlated the magnitude of the mean/area statistics or the form of the empirical distribution with the basin area. On this basis, the intended distribution fitting described in Chapter 3 was suspended. Since the correlation is nonexistent, quantitative assessment of the relation via comparison of distribution parameters is irrelevant. Relationships observed between streamflow at the four stations and drainage area were easily explained by the effects of the physical characteristics of the basin. Deviations in the form of "bumps" or "bulges" are often considered as possible indicators of dual flow causes in a basin (Foster 1948 from Riggs 1968). Dual causes could be variations in bedrock type, or sources from two areas such as mountains and swamps, or simply the effects of storage on precipitation.

Consultation of Figure 2.3 reveals that Carrick Creek, via the South Saugeen, and Rock Saugeen, are tributaries to the Saugeen. Consider the Saugeen River System divided at point B on Figure 2.3 into two branches. A larger area is drained by the Rock Saugeen-Saugeen Branch than by the South Saugeen Branch. Therefore, providing that Carrick Creek and Rocky Saugeen are representative of the characteristics of streamflow on their branch, the characteristics of the Saugeen downstream of the branch will more closely resemble those of the branch which contributes a greater portion of the total flow. This could explain why the observed distributions of the streams at FC001 and FC002 are most similar to that observed at FC004. The bulges noted at FC004 are subdued by the effects of the other branch of the system, represented by FC011.

4.1.3 Monthly Frequency Distributions

Figures 4.4 to 4.7 show monthly frequency distributions for each of the four stations. Flow distributions in months July to December was almost identical for all stations. Low flow distribution, then, is not affected by basin size. The remainder of the year is considered of more interest. January, February and June at FC004 are months of flow shifted decidedly toward Class 2 (.0125 - .025 $m^3s^{-1}km^{-2}$) frequencies. Both FC004 and FC011 show slightly increased February Class 2 frequencies.

No consistent trends with basin size could be deduced. Early season rising and late season falling at FC004 may be the result of the lakes and swampy areas drained by the Rocky Saugeen. Stored water adds to melt flow in the spring and maintains a larger base flow longer than the remainder of the basin. Effects at FC004 are dampened downstream by the south branch of the Saugeen.

4.1.4 Annual Minima Per Unit Area

From Figure 4.8, three important points should be noted.

(1) Low flows/unit area of FC001 and Fc002 are very similar in timing and magnitude of fluctuation.

(2) Plot at FC004 lies consistently above the FC001 and FC002 plots. (maximum difference = 7.0×10^{-3} $m^3s^{-1}km^{-2}$)

(3) FC011 plot lies consistently below those of FC001 and FC002 (maximum difference = $2.0 \times 10^{-3} m^3s^{-1}km^{-2}$)

The trend is not correlated with basin size; distribution testing

Figure 4.4 MONTHLY FLOW DISTRIBUTION – FCOO1

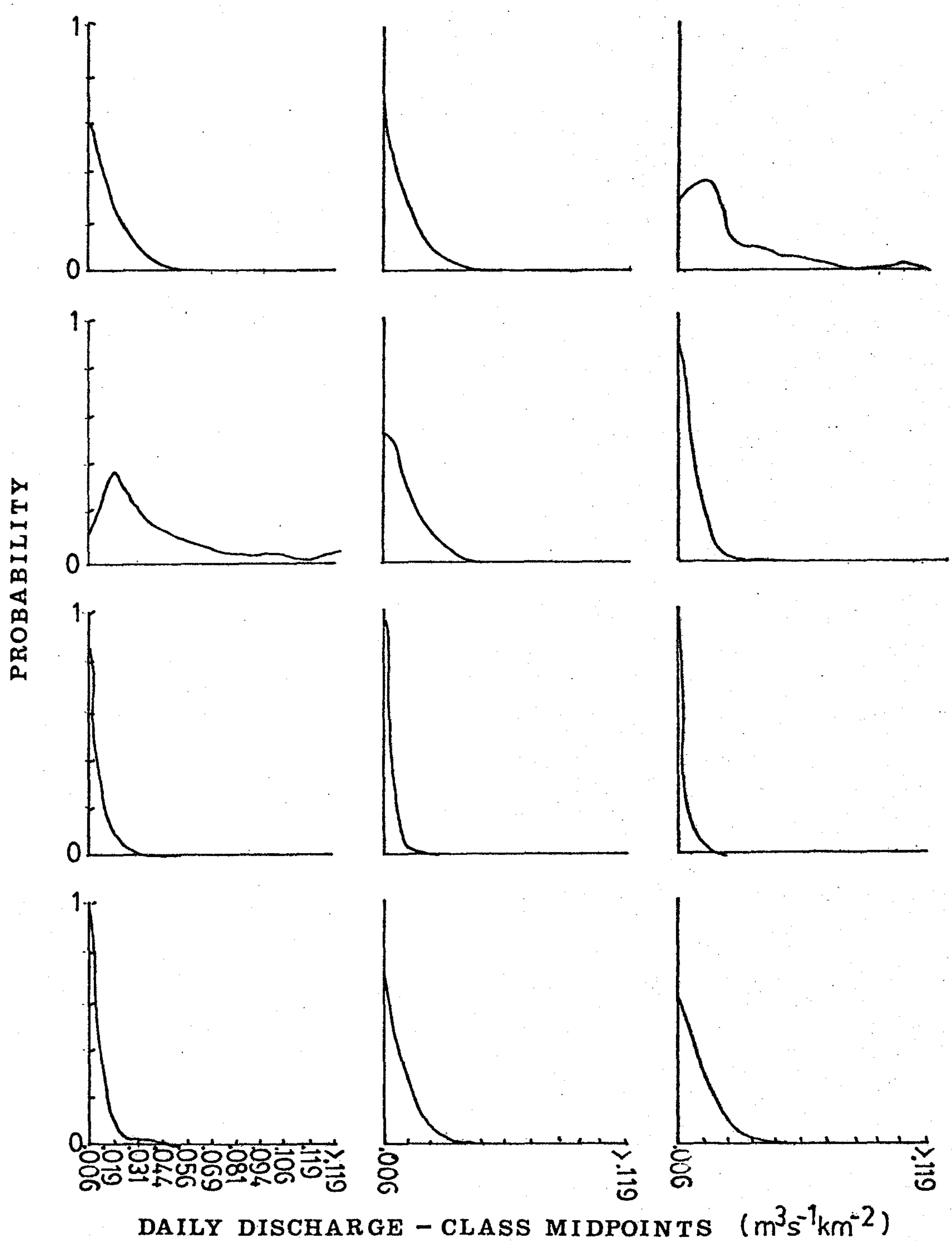


Figure 4.5 MONTHLY FLOW DISTRIBUTION - FCOO2

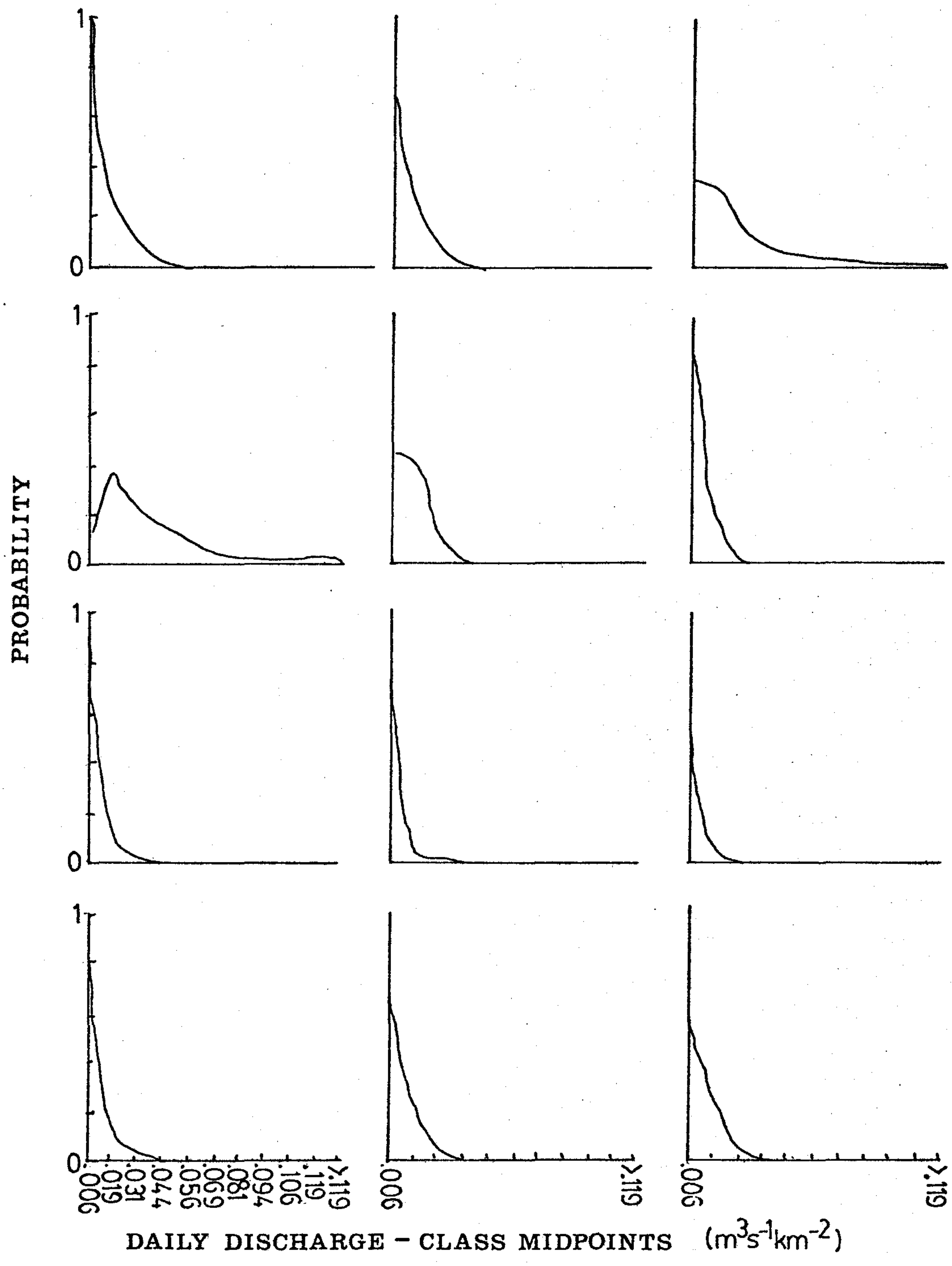


Figure 4.6 MONTHLY FLOW DISTRIBUTION - FCOO4

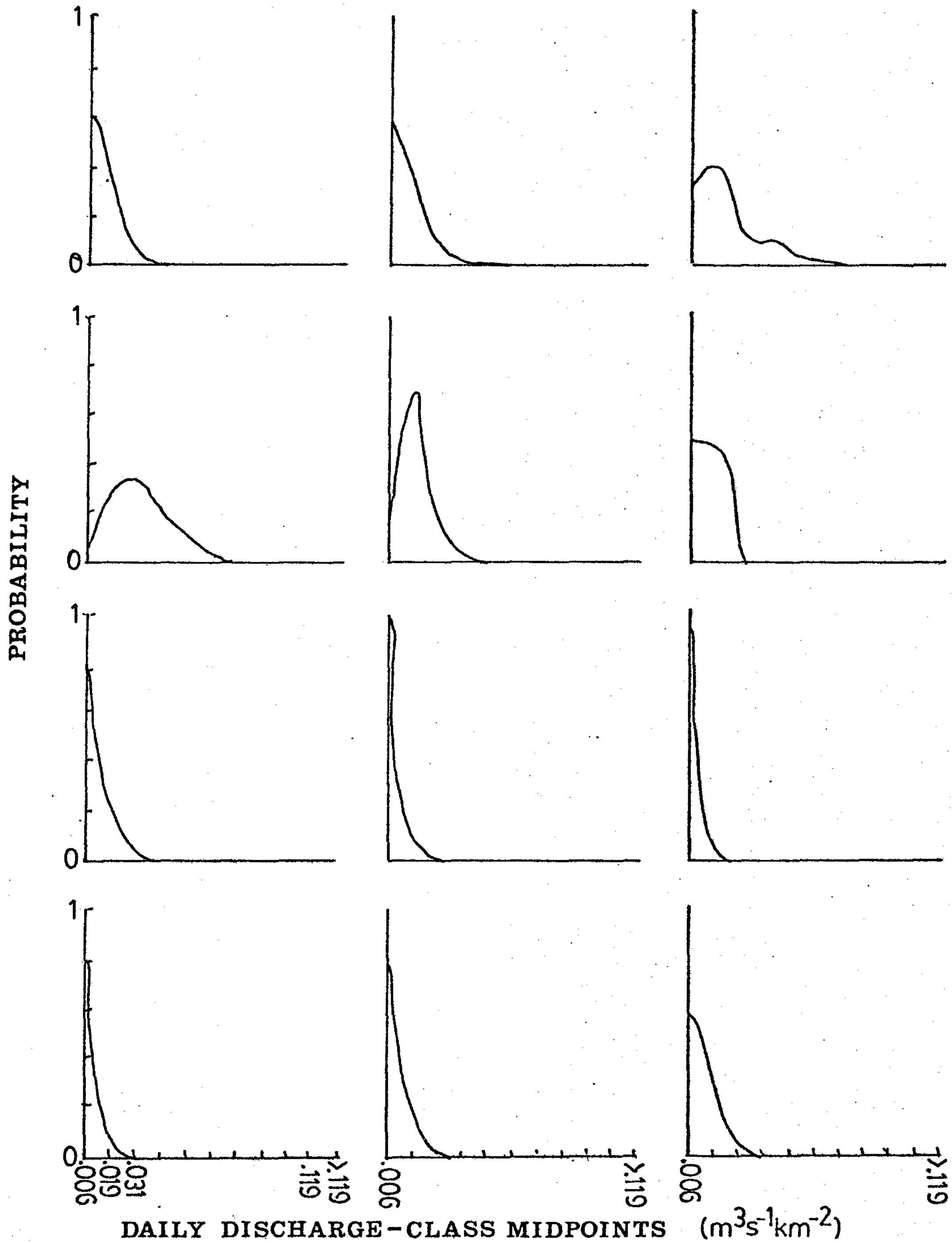


Figure 4.7 MONTHLY FLOW DISTRIBUTION – FCO11

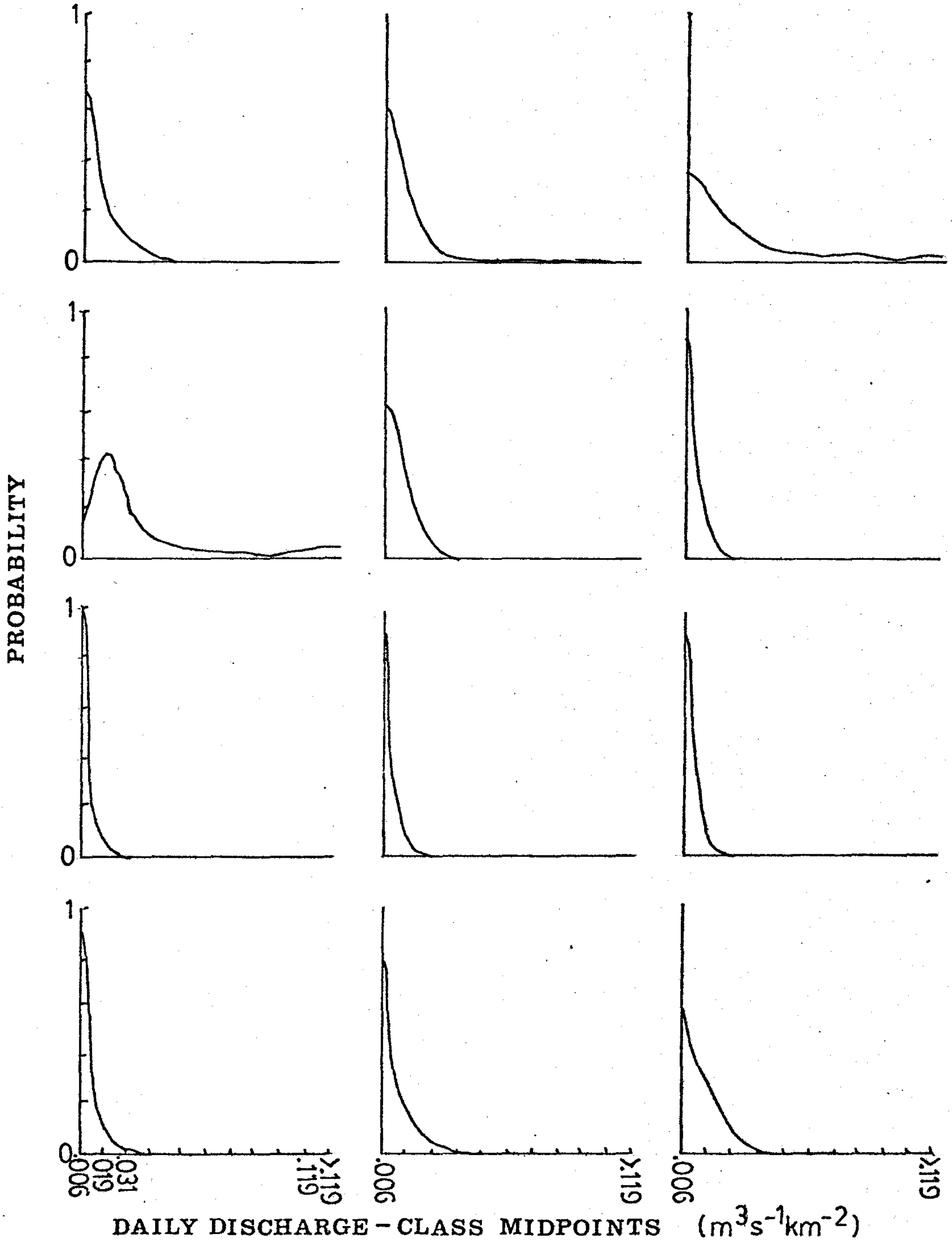
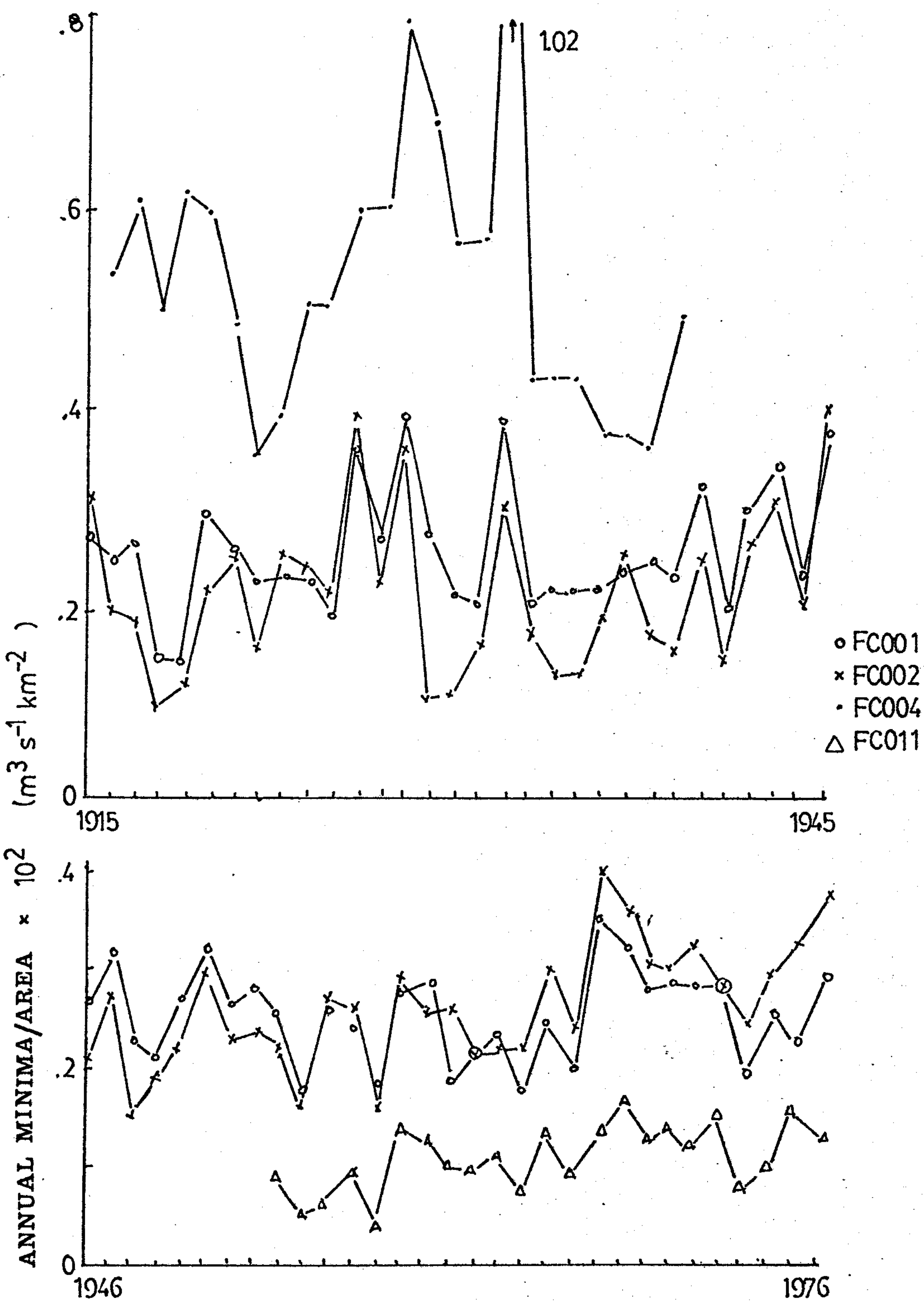


Figure 4.8 ANNUAL MINIMA/AREA-FC



was not performed for the same reasons as given with respect to the annual means. Again, the physical characteristic must be consulted to explain the results.

Probability graphs in Figure 4.9 substantiate this conclusion. Trends of streamflow minima/unit area are not primarily associated with basin size. The close correspondence of the large-area FC001 and FC002 distributions, contrasting the widely differing slopes and magnitudes of the two smaller streams, emphasizes dominance of physical factors. Slope of a straight-line approximation of the plots indicates the variance of the streamflow. In increasing order of variation:

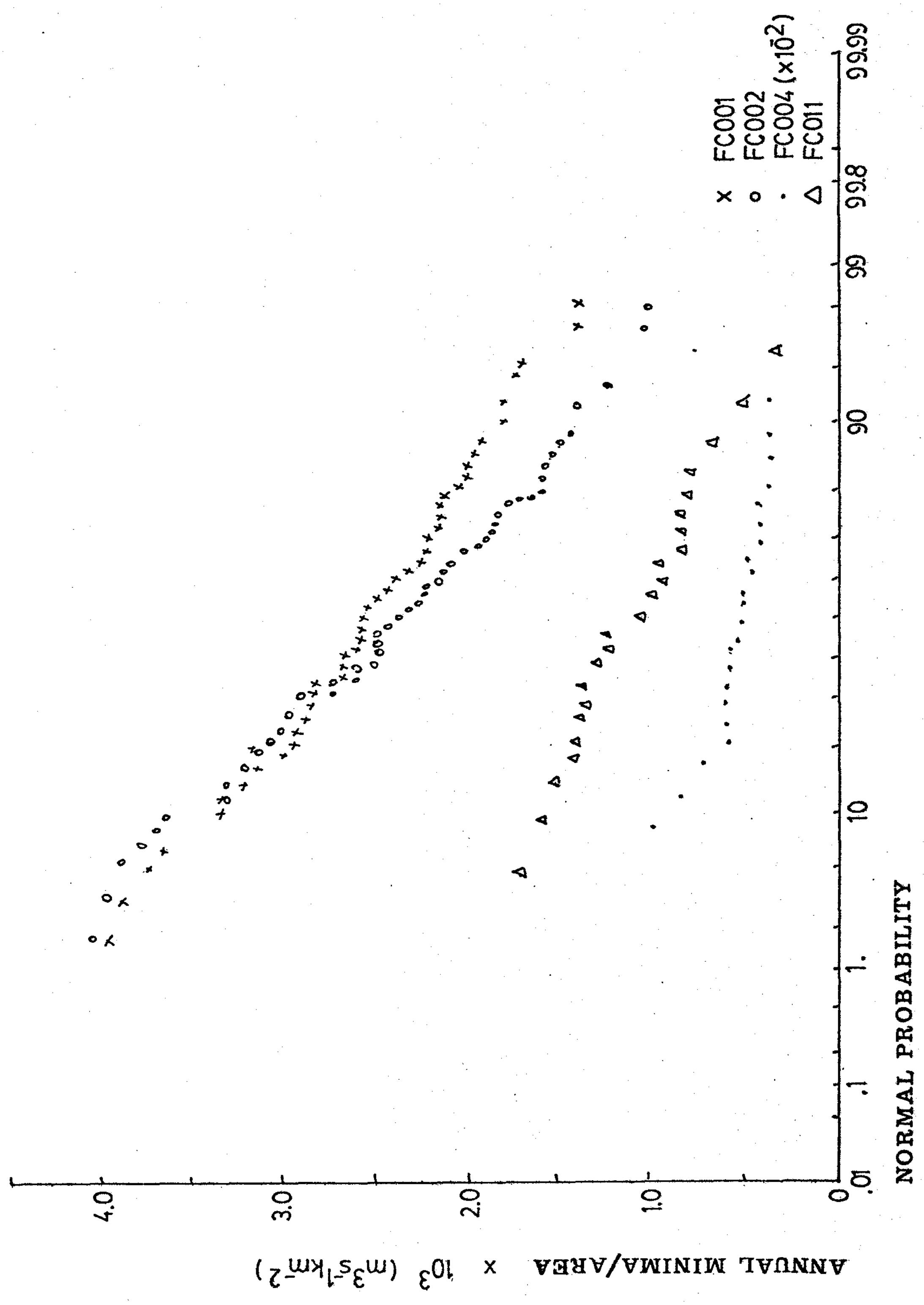
Station	Area
FC004	249
FC011	163
FC001	4070
FC002	2203

The smaller variations (see Table 4.1) of flow and maintenance of higher low flows at FC004 could be a result of storage in swampy, low land and small lakes in the drainage area of the Rock Saugeen. The large variation in FC002 is caused by the combined effects of its two contributing branches: the Saugeen-Rocky Saugeen, and the South Saugeen. Further downstream at FC001, this effect has possibly been dampened by channel storage along the stream.

4.1.5 Annual Maxima Per Unit Area

Figure 4.10 plots fluctuations of annual maxima per unit area against time. As was the case in the mean and minima fluctuations, correspondence of FC001 and FC002 was fairly consistent. No trend with

Figure 4.9 DISTRIBUTION OF ANNUAL MINIMA/AREA – FC



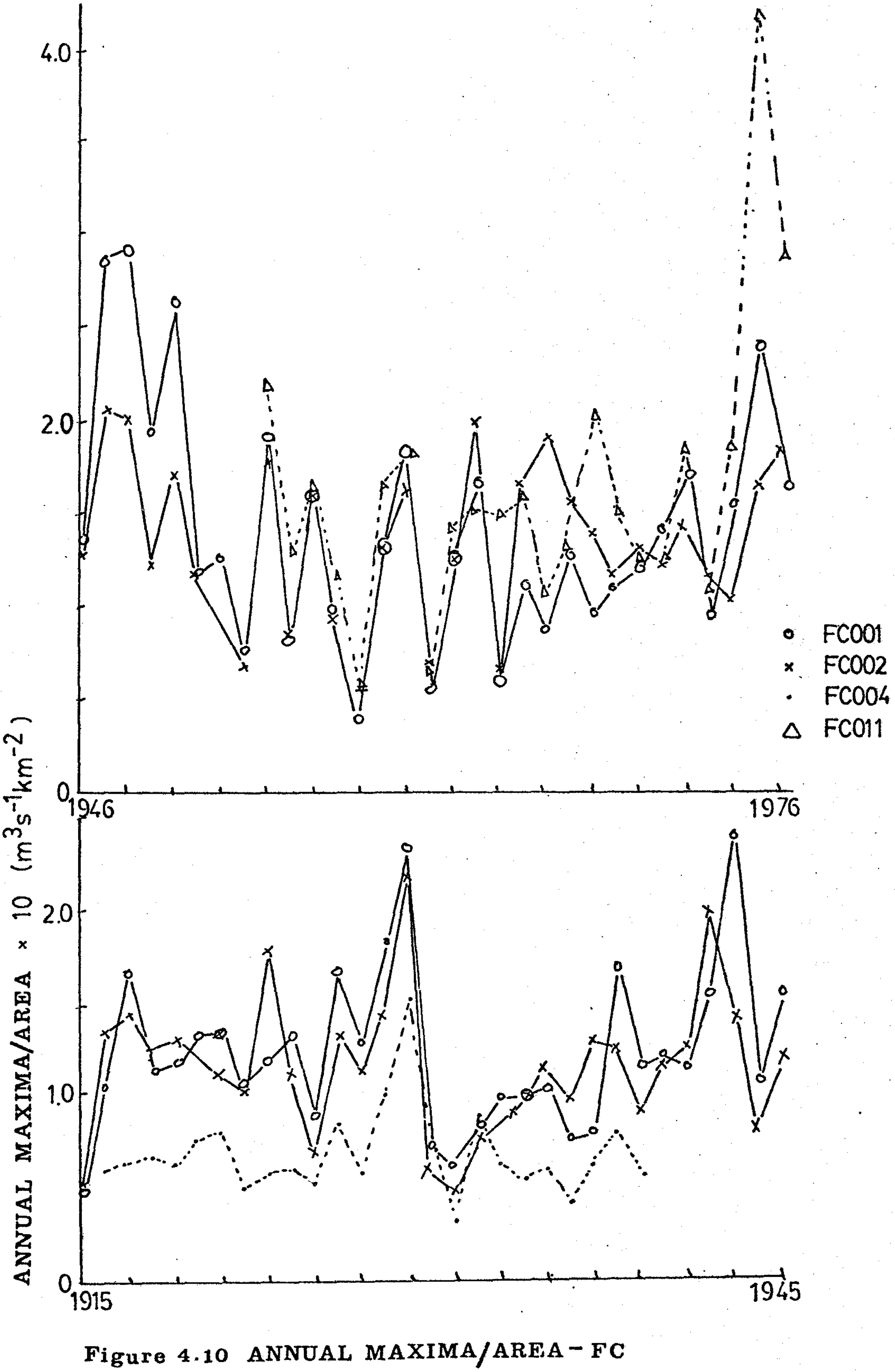


Figure 4.10 ANNUAL MAXIMA/AREA – FC

basin area could be seen. The plot of FC011 cannot be concluded to lie above or below FC001 and FC002, but FC004 lies consistently below. The storage capacity of that branch could dampen effects of large rainfall events, thus reducing the magnitude of maximum flows.

4.1.6 Summary

Major physical features of this system (Figure 2.3) were primary causes of streamflow characteristic variations between basin sizes. Small lakes and swamps affected the Saugeen-Rocky Saugeen branch; higher base-flows were maintained over a longer period, rainfall events were stored, effectively reducing maximum flows, variations in flow were dampened, and mean annual flows/unit area showed extremity bulges. Downstream, the effects listed above were progressively dampened by channel storage and streamflow from the South Saugeen, not subject to the lake-swamp storage. No relations between characteristics of streamflow and basin size were deduced.

4.1.7 Revisions to Subsequent Study

Based on the analyses of records from the Saugeen basin, the following decisions were made regarding the analyses of streamflow data from the other selected basins.

(a) All other stations used in the study have less than 30 years of record; therefore no further graphs of the type shown in Figure 4.2 (ranked annual statistics) were justified.

(b) Suspension of distribution fitting of the annual means and minima per unit area was justified for other regions by similar conditions arising from the analyses.

4.2 Nottawasaga System - ED Tertiary Set

4.2.1 Annual Means Per Unit Area

Figure 4.11 shows the time plot of annual means per unit area. Fluctuations are coordinated in timing but seem to be slightly more amplified in the ED005 series. Means of means from Table 4.1 is higher for the small (ED005) basin. Standard deviations of annual means from Table 4.1 substantiate conclusions regarding the increased fluctuations in the ED005 series.

4.2.2 Distribution of Annual Means Per Unit Area

Plotted on normal-probability paper, the two sets of data seem to conform to straight lines, but with deviations in the form of bumps (Figure 4.12) more pronounced for the ED005 (small basin) series. The greater variance of the ED005 means is exemplified both by the greater slopes and the "bumps" of the ED005 plot.

Reference to Chapter 2 recalls the physical characteristics of this area. ED005 data represents drainage from high elevations with steep gradients (as high as 6.1 mkm^{-1}). Drainage into the stream above ED003 is from swamps and flat land, which would act as storage. Rainfall or water added to the basin by snowmelt would not be drained as quickly to ED003 as on the Mad River to ED005. A stream such as the Mad River is more responsive to water inputs than the Nottawasaga Steep gradients promote quick runoff and therfore high floodpeaks. Thus year to year variations in basin inputs as precipitation or snowmelt would be magnified as variations in streamflow.

4.2.3 Monthly Frequency Distributions

Figure 4.11 ANNUAL MEANS/AREA- ED

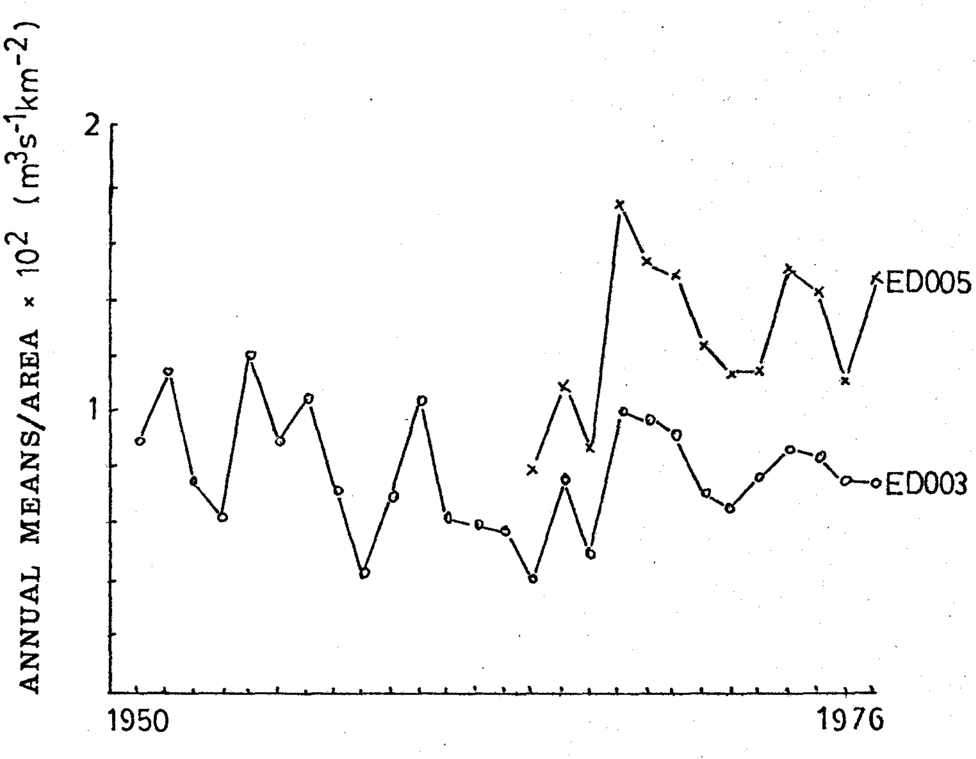
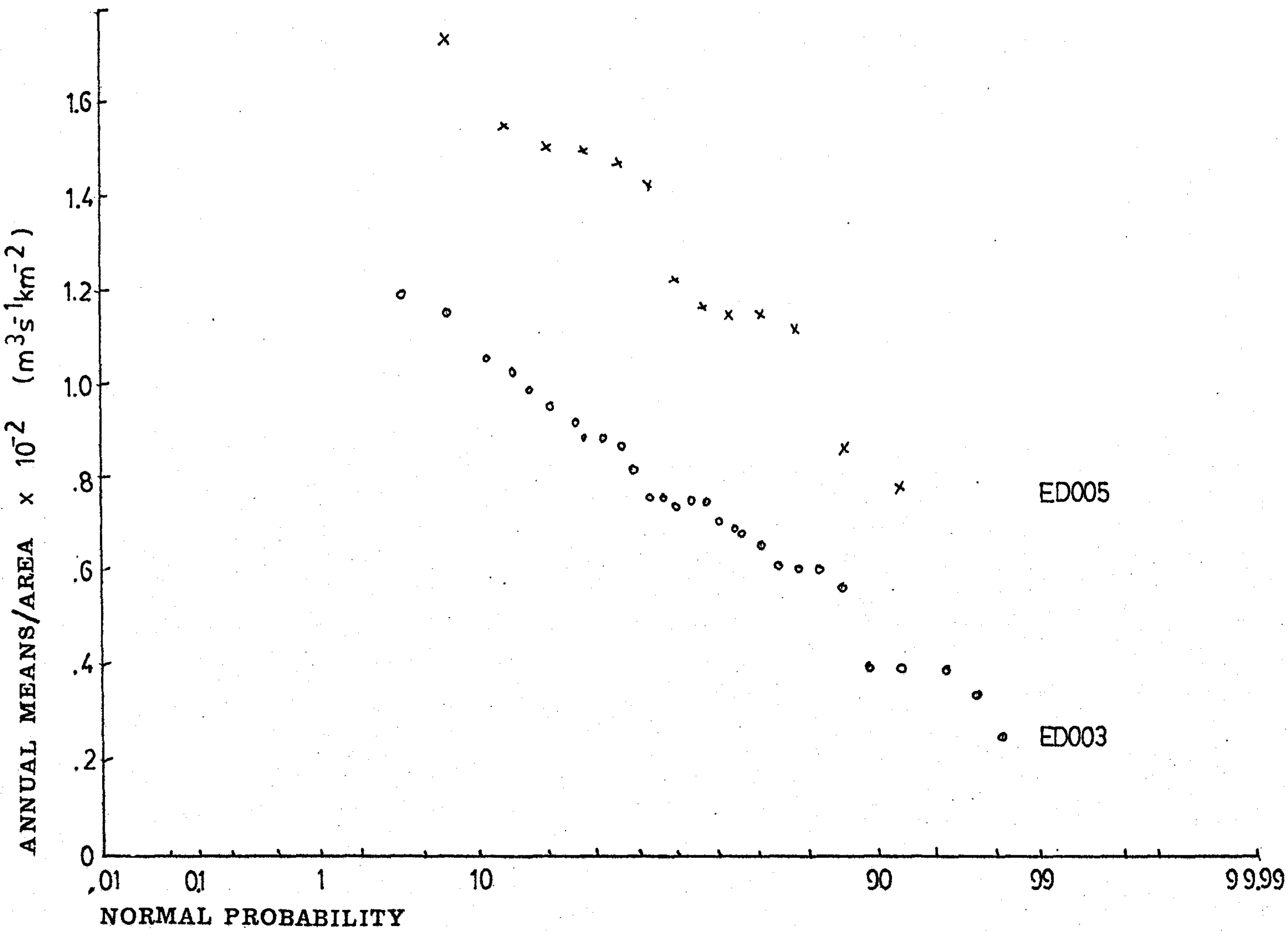


Figure 4.12 DISTRIBUTION OF ANNUAL MEANS/AREA – ED



Figures 4.13 and 4.14 show monthly frequency distributions of the areas drained above ED003 and ED005 respectively. Months July to November are very similar in form, but the ED005 tail is larger. December to June are radically different. Class 1 frequencies (0.00 - $.07m^3s^{-1}km^{-2}$) are always lower than Class 2 ($.07$ - $.014m^3s^{-1}km^{-2}$) at ED005, and are so in April at ED003. The month of June shows a transition at ED005, as the form of the distribution shifts from peaked to exponential. The peaked forms are caused by the lack of very low flows. Starting in December in the Dundalk Uplands, where precipitation is particularly high in winter, meltwater will not infiltrate the frozen ground but contribute quickly to direct runoff. Such is not the case upstream of ED003, where the swamps and lowlying land tend to hold the water as surface puddles. More infiltration probably occurs in spring in the ED003 drainage area due to the slow runoff and storage effects.

4.2.4 Annual Minima Per Unit Area

Figure 4.15 shows the lack of correlation with respect to magnitude and timing between the ED003 and ED005 series of low flows/area. The contrasting basin conditions afore-mentioned, is probably the cause. Lack of sufficient length of record does not aid the analysis. Upon examining Figure 4.16, it can be seen that the probability distributions of annual minima/area reflect the extreme responsiveness of the Mad River in its widely scattered formation and the more conforming nature of the ED003 stream.

4.2.5 Annual Maxima Per Unit Area

The time series in Figure 4.17 does not show much due to the short time span. Differences in magnitudes are as high as 1.5×10^{-1}

Figure 4.13 MONTHLY FLOW DISTRIBUTION – ED003

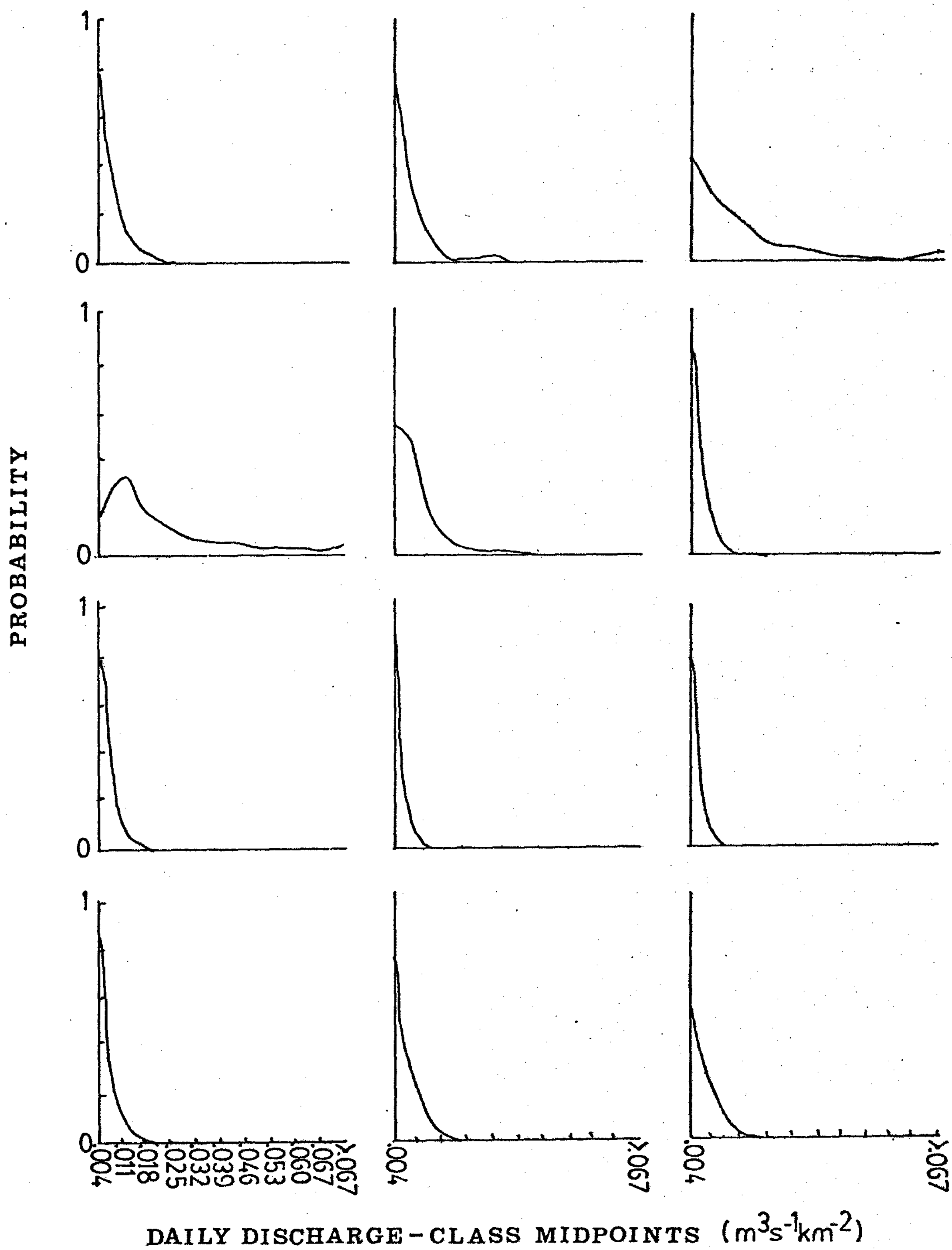


Figure 4.14 MONTHLY FLOW DISTRIBUTION– ED005

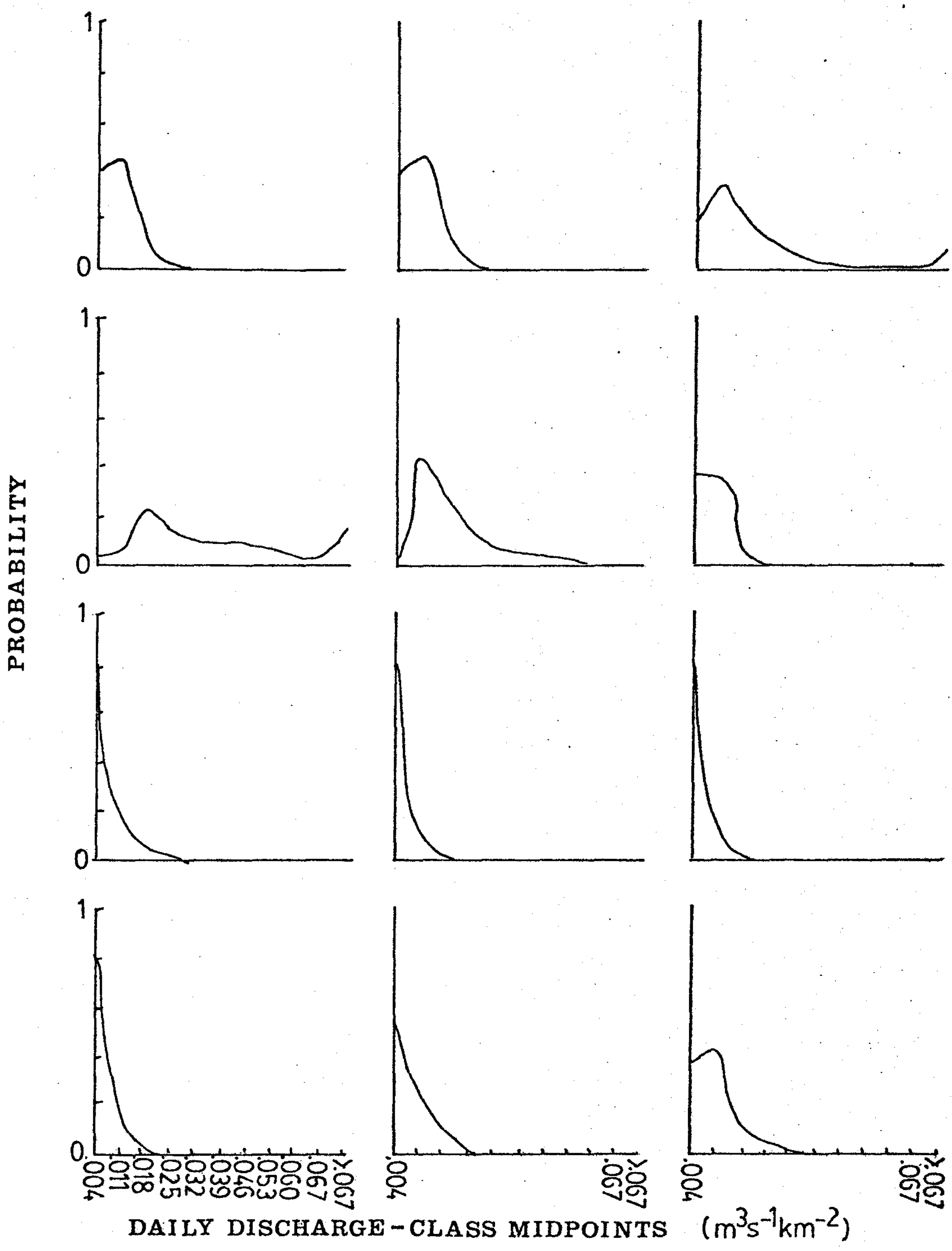


Figure 4.15 ANNUAL MINIMA/AREA – ED

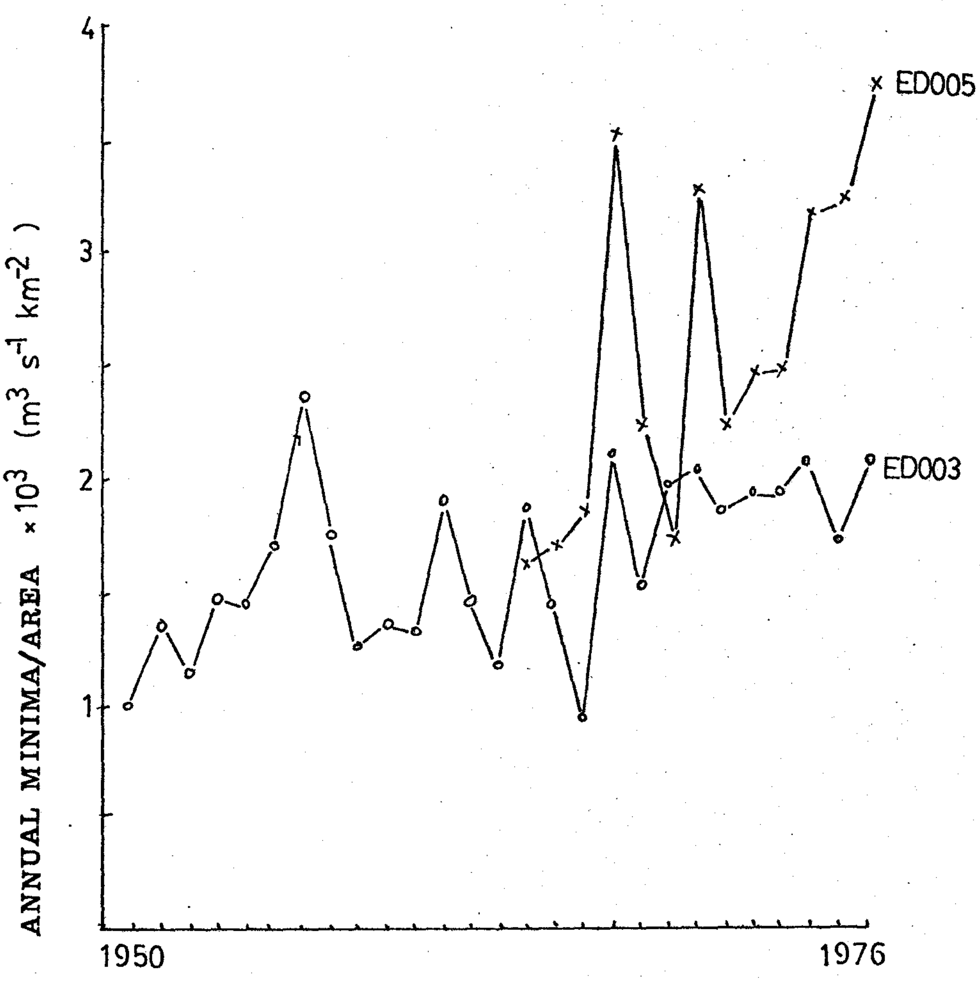


Figure 4.16 DISTRIBUTION OF ANNUAL MINIMA/AREA – ED

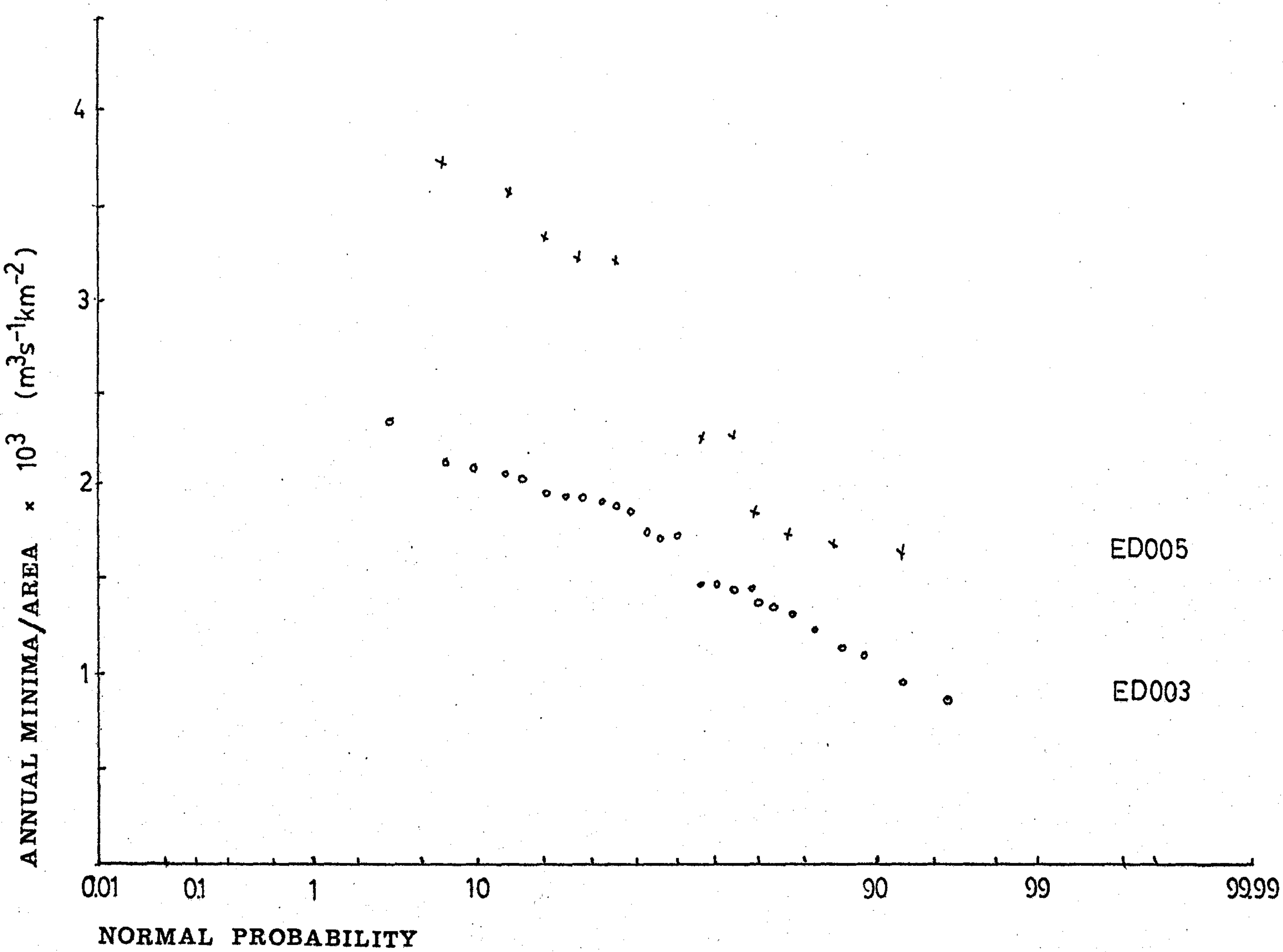
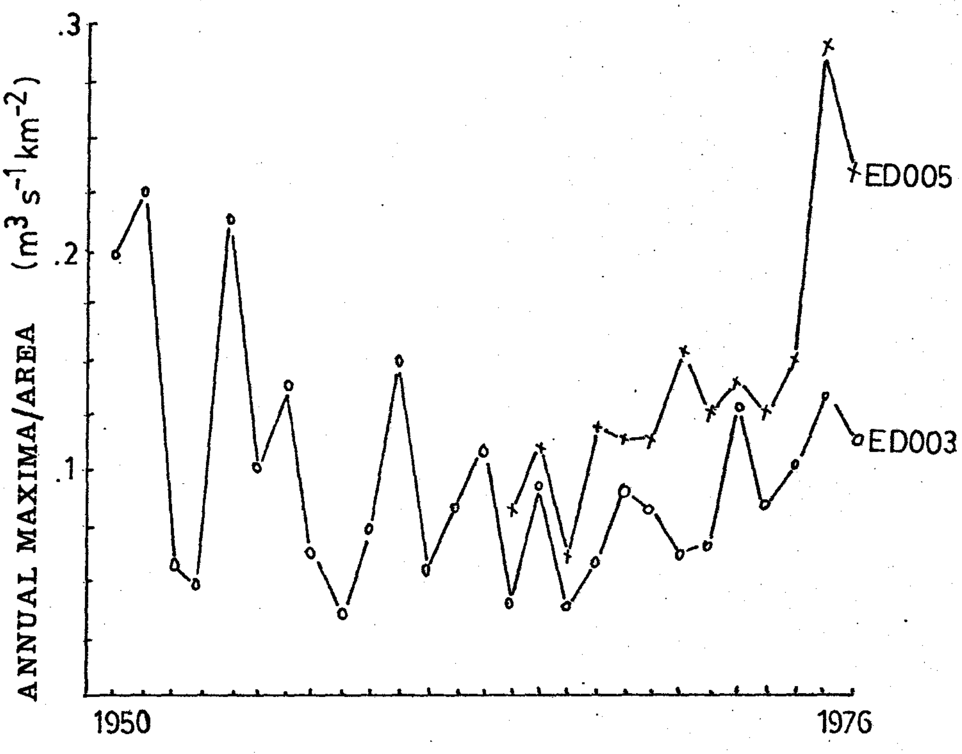


Figure 4.17 ANNUAL MAXIMA/AREA– ED



$m^3s^{-1}km^{-2}$. Once again, the variability due to the nature of the ED005 areas is brought out. No positive conclusions can be made relating basin size to flood flows/area.

4.2.6 Summary

Although the magnitudes of annual means, minima and maxima per unit area, and standard deviation (see Table 4.1) were in all cases greater for the smaller basin, the facts may all be explained by physical characteristics of the areas. Steep gradients lead to extreme responsiveness of the Mad River, while swamps and lowlands dampen events on the Nottawasaga above ED003.

4.3 Bear Creek - GG Tertiary Set

4.3.1 Annual Means Per Unit Area

Figure 4.18 shows the almost perfect timing and magnitude correspondence of fluctuations of annual means/area. From Table 4.1, the differences in overall means and standard deviations is slight and could be due to the short record lengths.

Figure 4.19 shows the similar distributions of means; a single straight line may approximate both. The uniform nature of the land, and the location of both stations on a stretch of Bear Creek unaffected by other tributaries has rendered annual means/area virtually identical in spite of the difference in basin area.

4.3.2 Monthly Frequency Distributions

Figures 4.20 and 4.21 show the remarkably similar forms of the monthly distributions. Small variations are most likely the result of

Figure 4.18 ANNUAL MEANS/AREA – G G

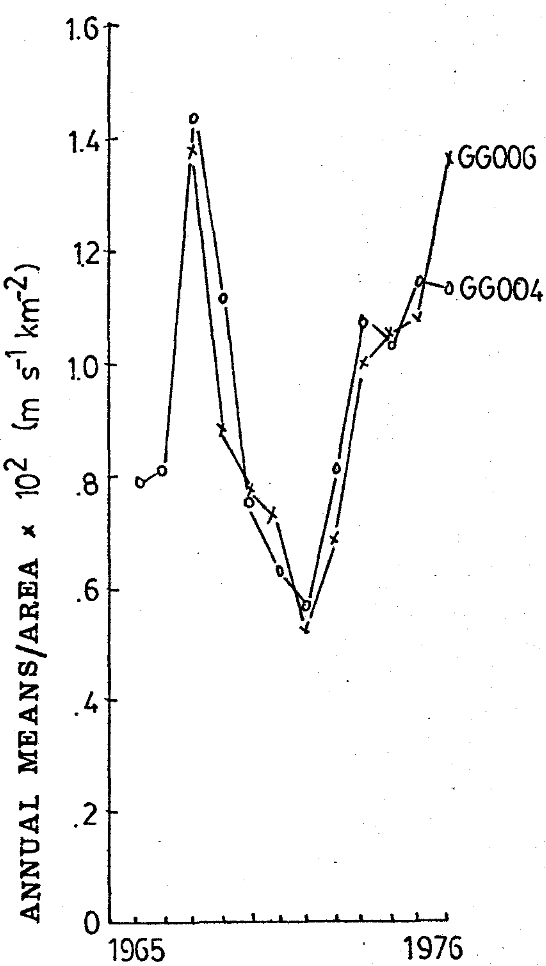


Figure 4.19 DISTRIBUTION OF ANNUAL MEANS/AREA – GG

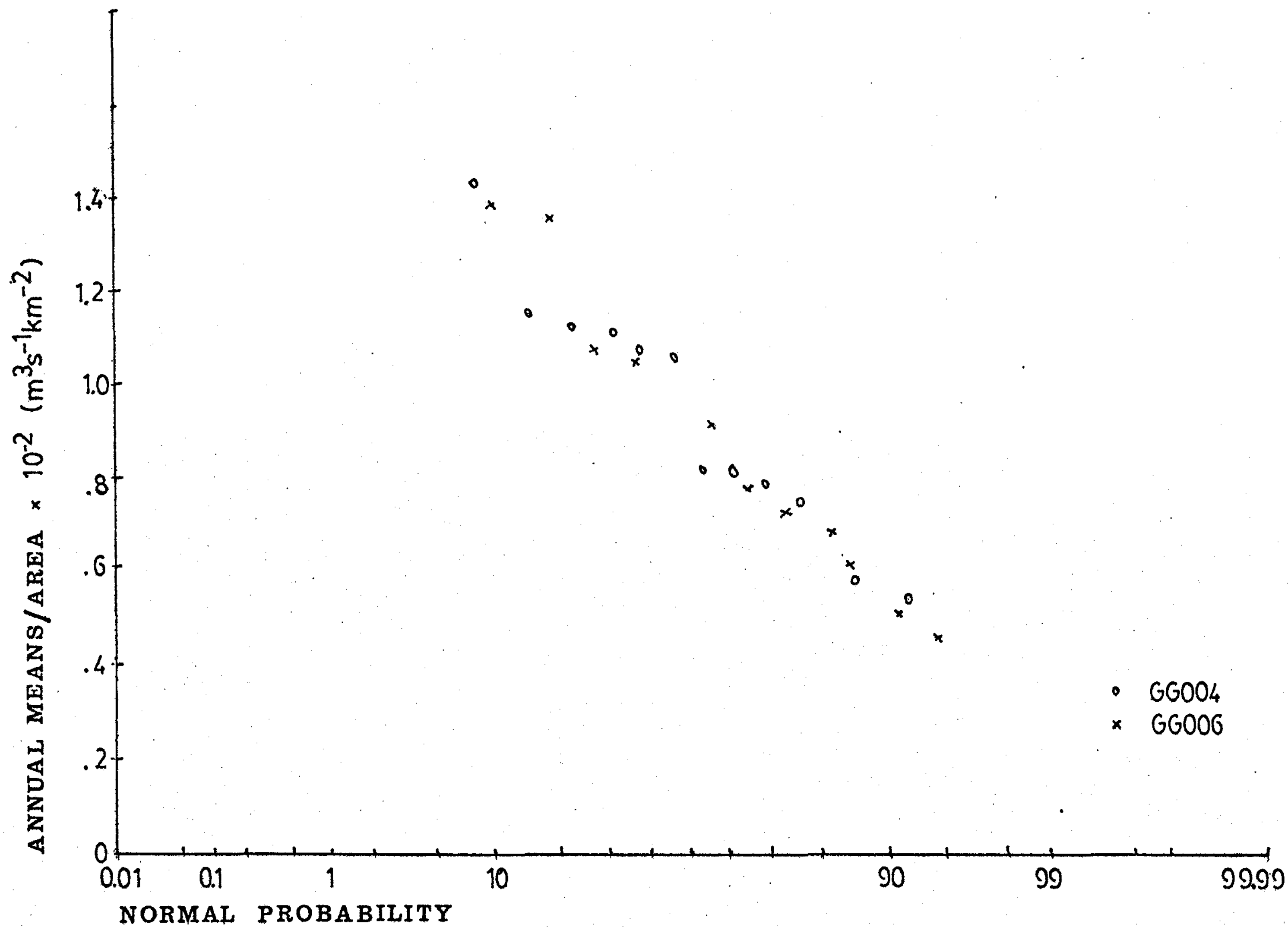


Figure 4.20 MONTHLY FLOW DISTRIBUTION-GGOO4

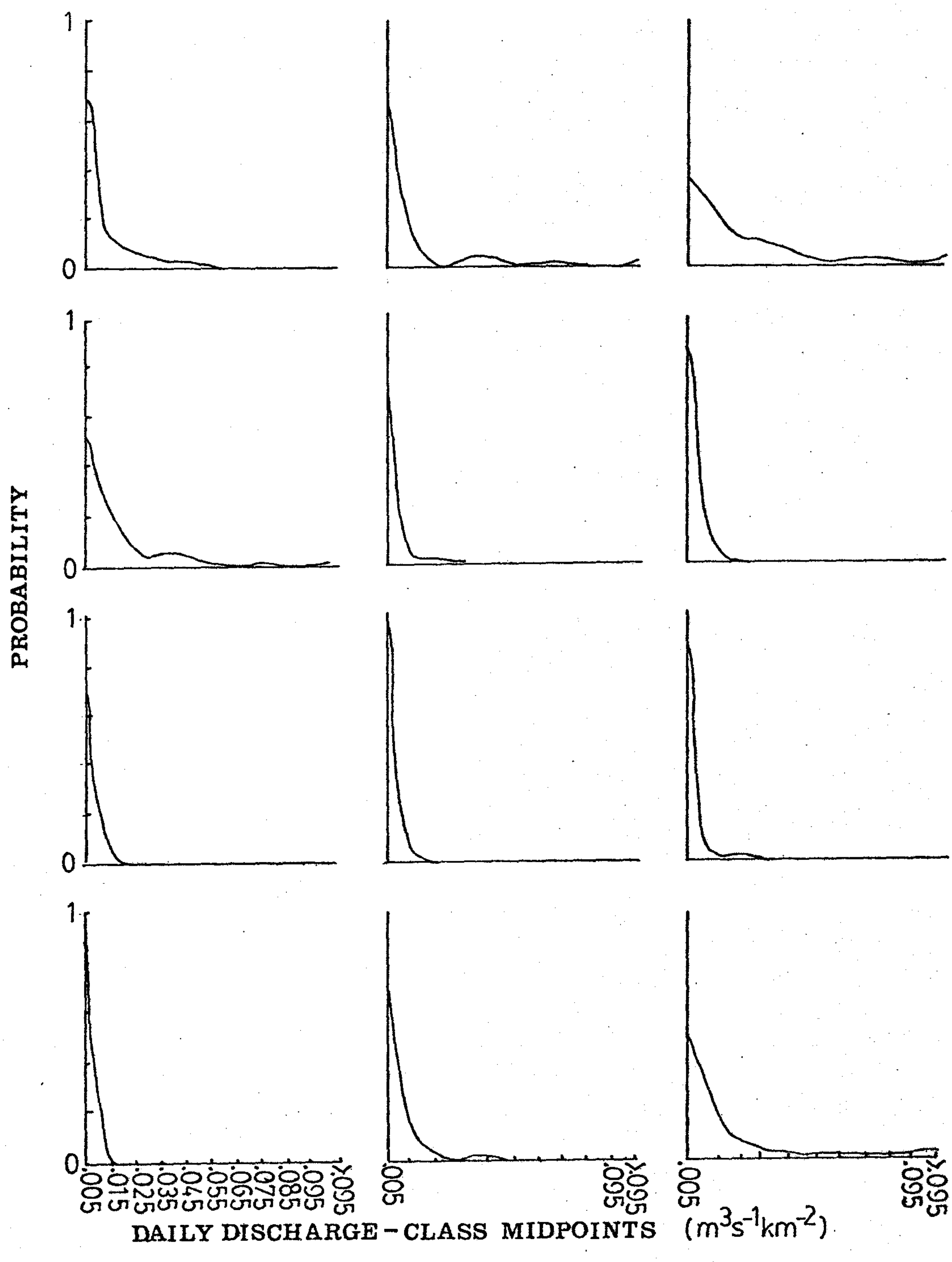
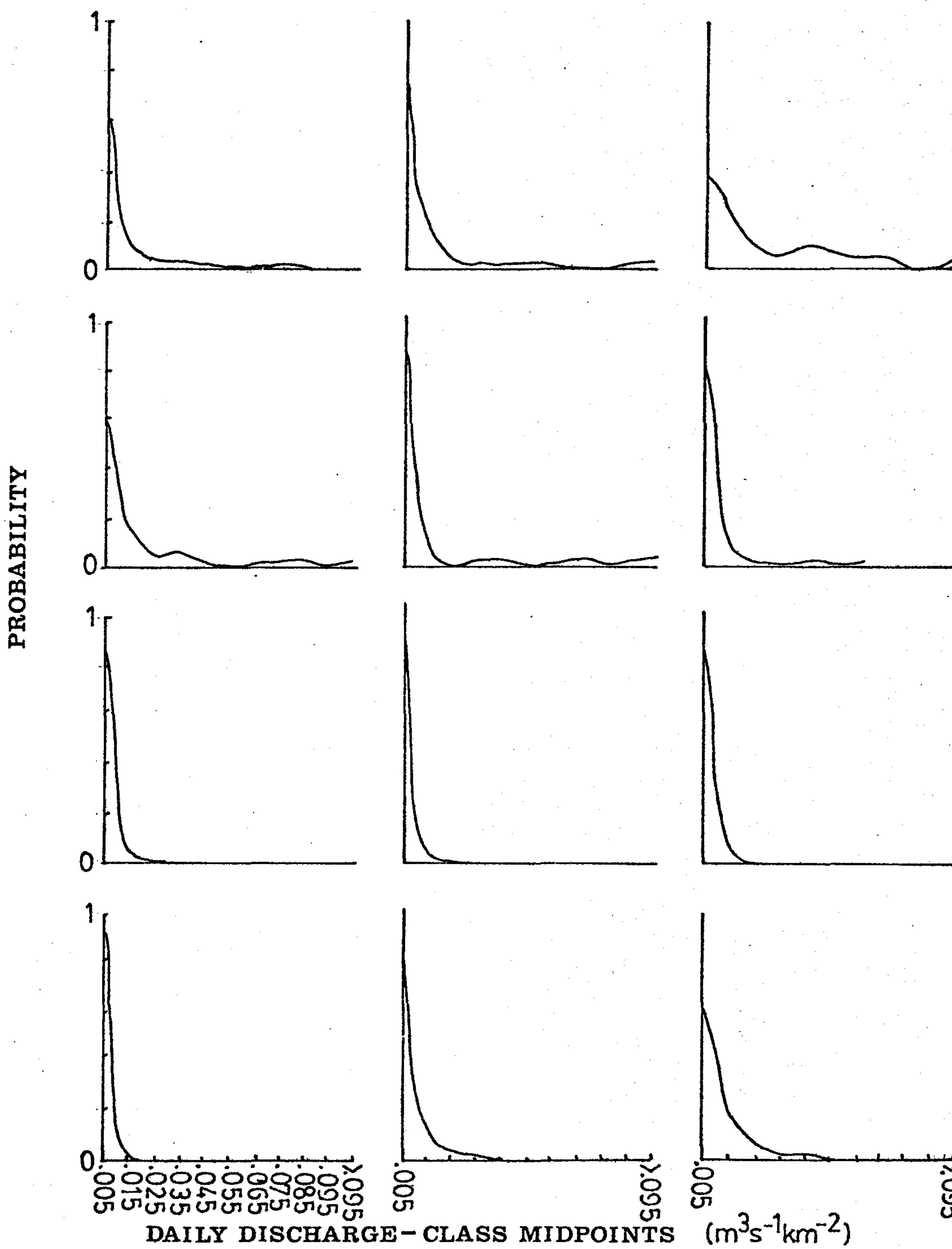


Figure 4.21 MONTHLY FLOW DISTRIBUTION-GG006



small samples.

4.3.3 Annual Minima Per Unit Area

Low flows in Figure 4.22 are not identical in timing. Maximum magnitudinal difference is 1.04 x $10^{-4} m^3 s^{-1} km^{-2}$, a small variation. Years of zero minimum flow offset the distribution plot in Figure 4.23. Due to the short data record, no conclusive remarks may be made.

4.3.4 Annual Maxima Per Unit Area

Figure 4.24 shows similar timing of floods. Magnitudes differ by as much as 2 x $10^{-1} m^3 s^{-1} km^{-2}$. Since the basin areas are homogeneous the greater maxima/area for GG006 (267 km^2) over GG004 (596 km^2) could be related to basin size. However, the trend is not consistent for each year. Such a conclusion would need to be examined over a long record.

4.3.5 Summary

No noticeable differences in means/area were noted. Timing differences in fluctuations of annual maxima and minima cannot be explained within the scope of this study. The homogeneity of the area, however,might suggest possible relationships with basin area, if longer records were available.

4.4 Humber River System - HC-(a) Tertiary Set

4.4.1 Annual Means Per Unit Area

The series plotted in Figure 4.25 shows consistent magnitudinal differences between stations. There was, however, no trend due to basin size in either magnitude or deviations as seen from Table 4.1. However,

Figure 4.22 ANNUAL MINIMA/AREA – GG

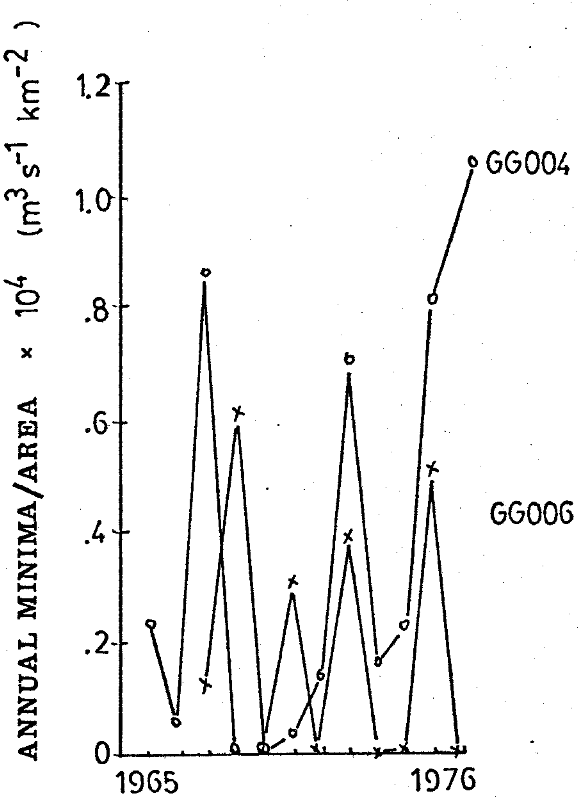


Figure 4.23 DISTRIBUTION OF ANNUAL MINIMA/AREA - G G

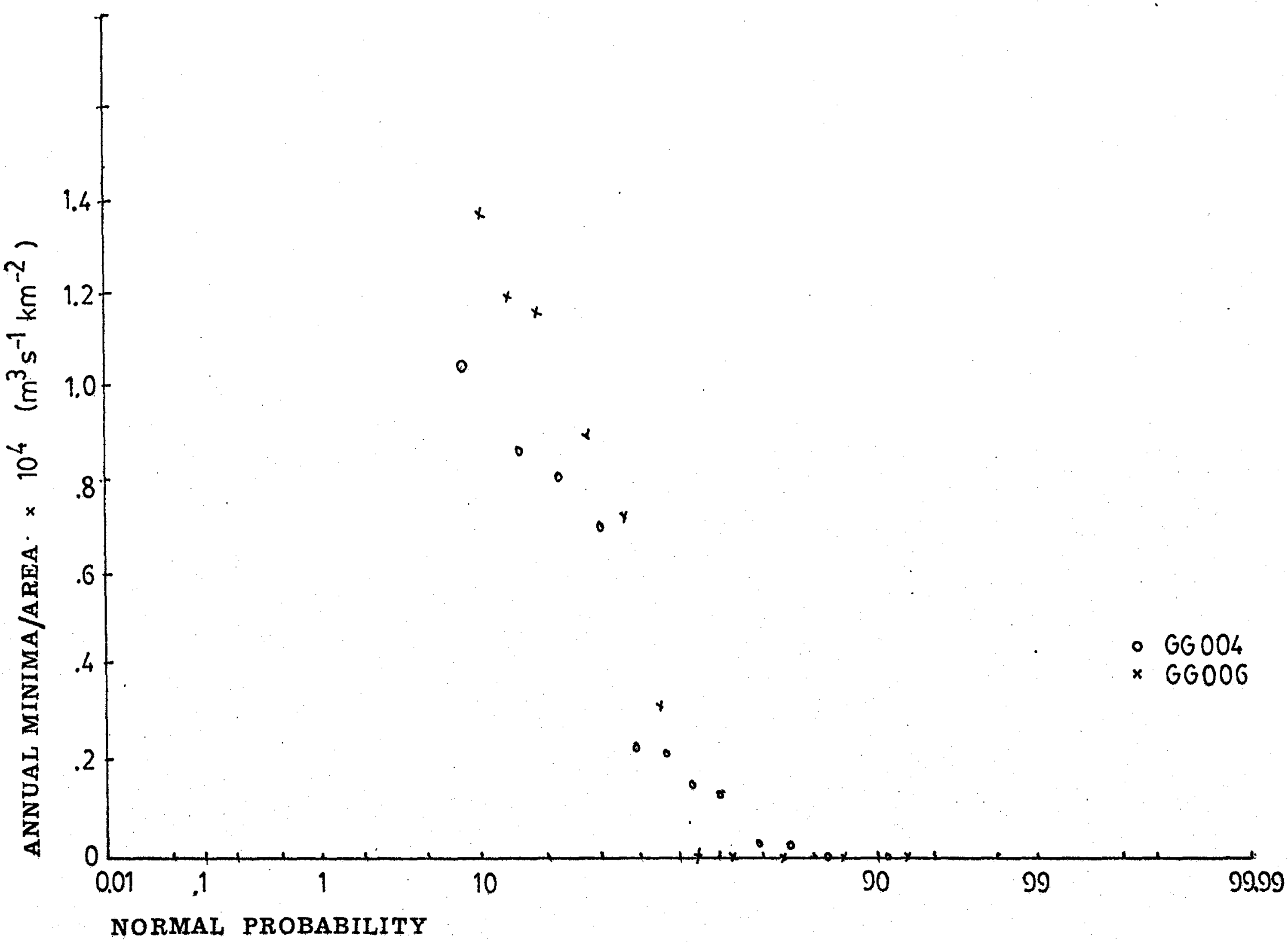
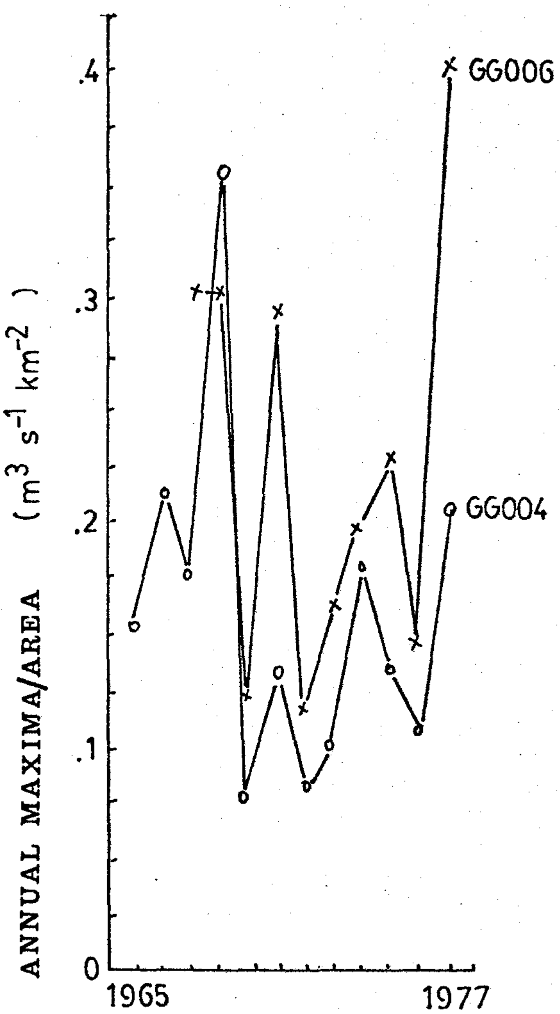


Figure 4.24 ANNUAL MAXIMA/AREA – G G



HC025 is seen to have a mean above all other stations; HC011 mean lies between HC025 and the other three stations whose means are similar. Consultation of Figure 2.6 reveals that HC025 is on a branch of the creek which is the major contributor to streamflow at HC011. Therefore, the characteristics of the Humber River rather than the East Humber (gauged by HC031 and HC009) will show at HC011.

Probability plots in Figure 4.26 again show HC025 distinct from the other plots with HC011 in between, the effect of HC025 characteristics dampened by the East Humber. Storage of water in Conservation Areas and swamps could account for the higher mean flows on the Humber River.

4.4.2 Monthly Frequency Distributions

Figures 4.27 to 4.31 show that months June to February are virtually identical for all stations. HC011 has higher Class 2 (.020 - .040$m^3s^{-1}km^{-2}$) and lower tail frequencies for March. HC031 and HC032 conform to low-flow form earlier (in May) than other stations. Years of record are not many, which could lead to some of the variations seen.

The open area, Conservation Areas, and swamplands drained by HC025 maintain a stronger baseflow by acting as storage media. Connection with basin size is not seen.

4.4.3 Annual Minima Per Unit Area

Trends are again for HC011 and HC025 to lie above other plots in Figure 4.32. Magnitude differences were, at maximum, 2.3 x $10^{-3}s^{-1}km^{-3}$. Once again, the effects of the contributions of the East Humber at HC011 modified the characteristics of the Humber River gauged by HC025.

Figure 4.25 ANNUAL MEANS/AREA – HC –(a)

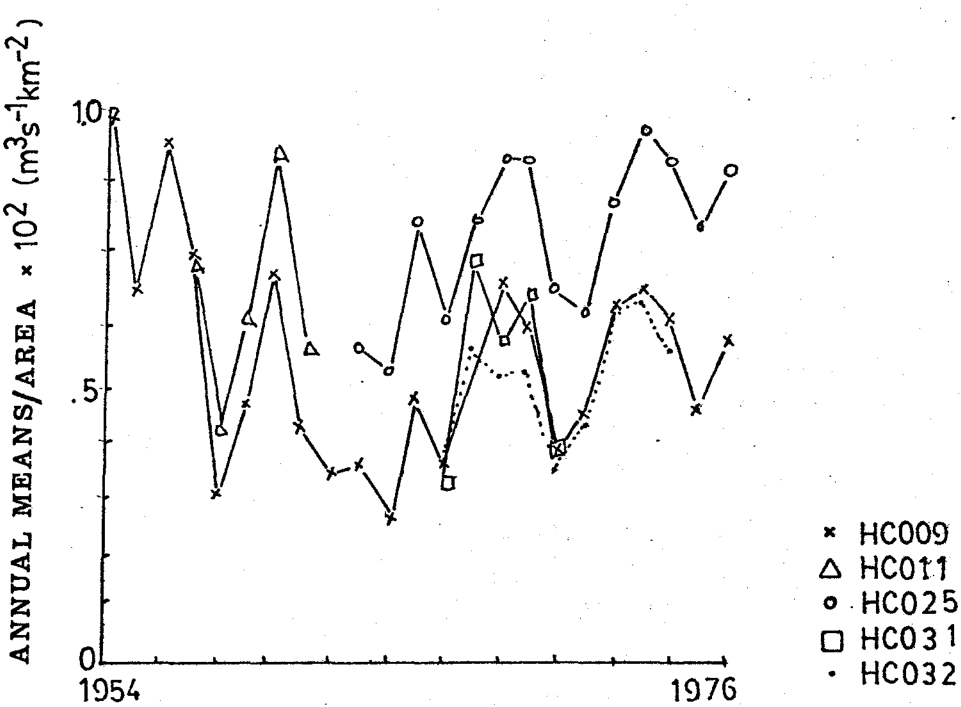


Figure 4.26 DISTRIBUTION OF ANNUAL MEANS/AREA – HC –(a)

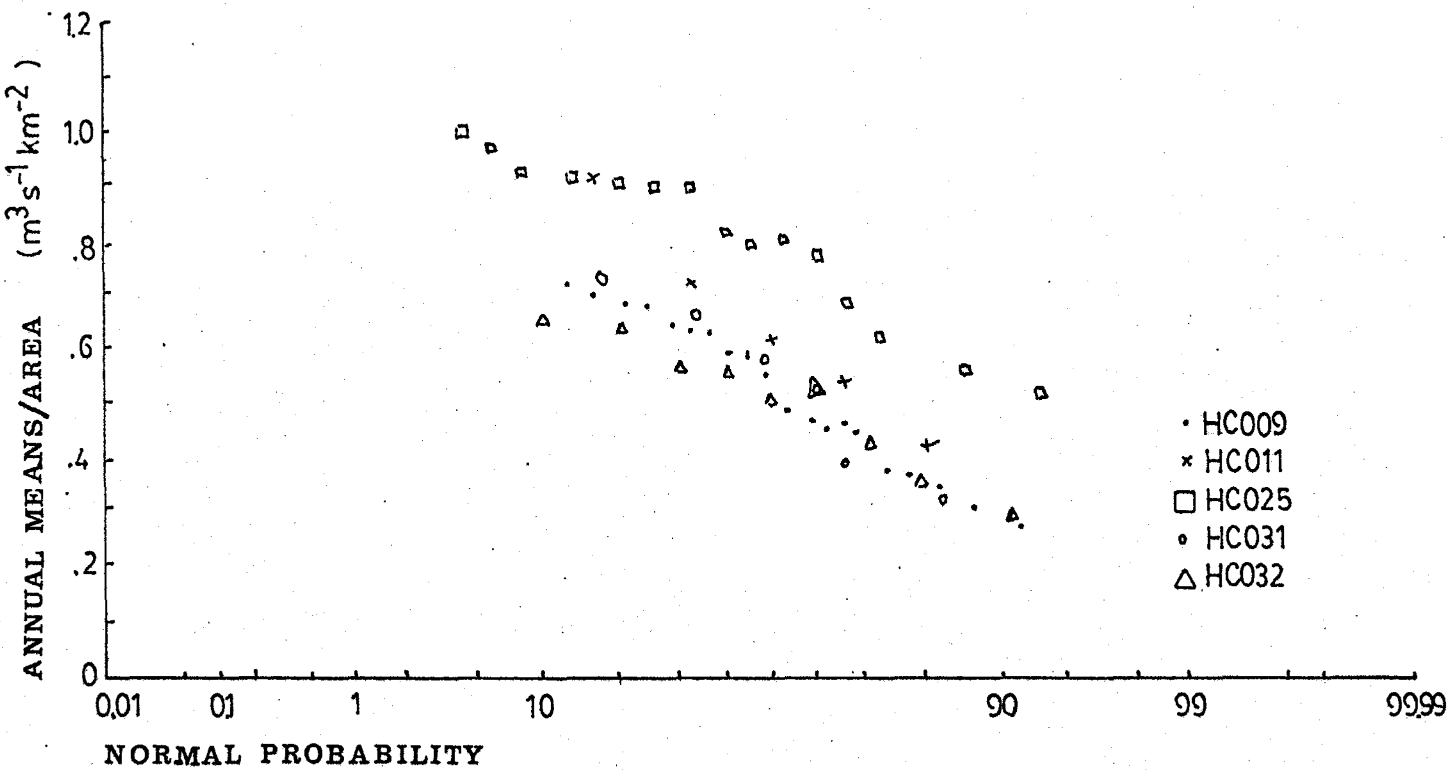


Figure 4.27 MONTHLY FLOW DISTRIBUTION - HC009

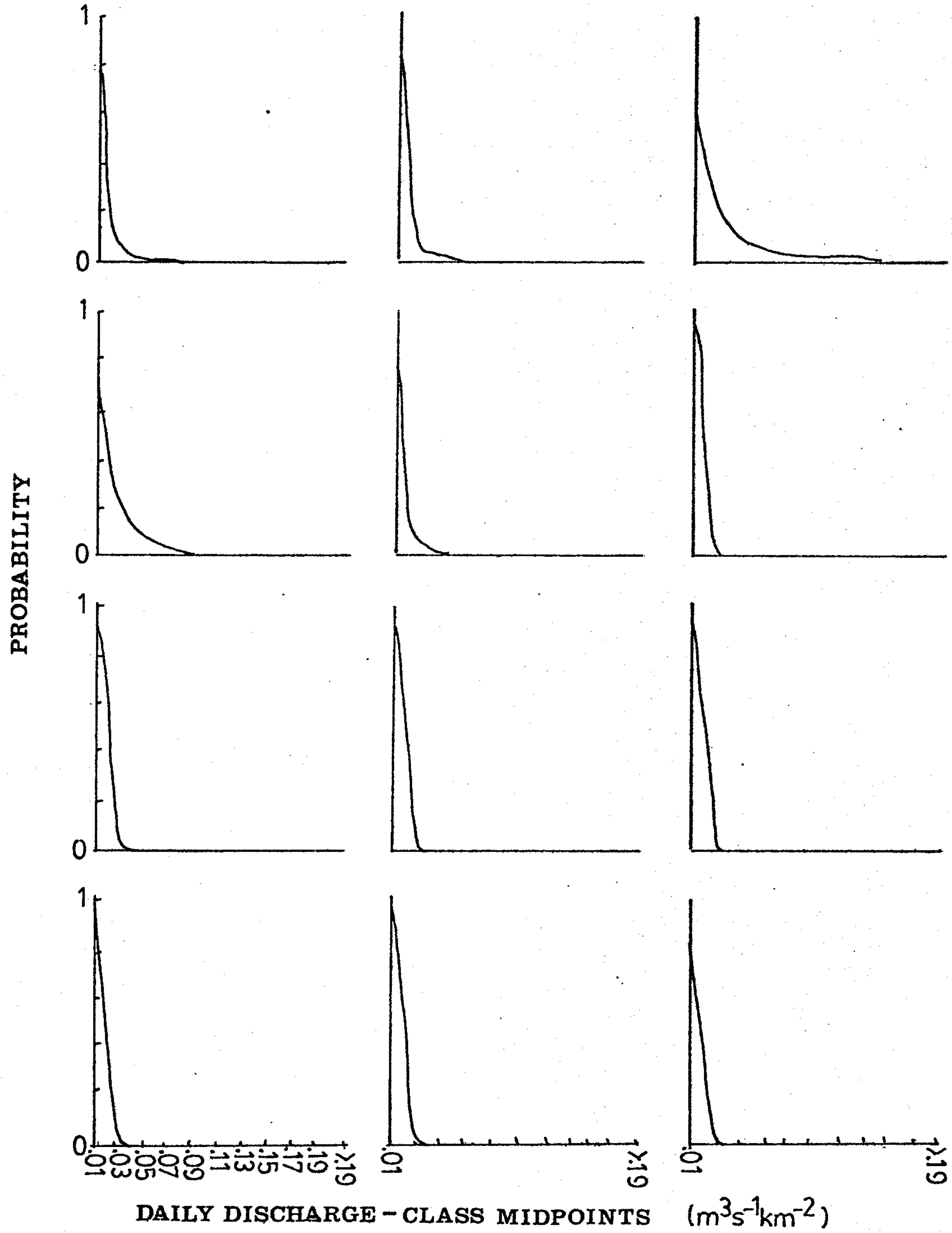


Figure 4.28 MONTHLY FLOW DISTRIBUTJON - HCO11

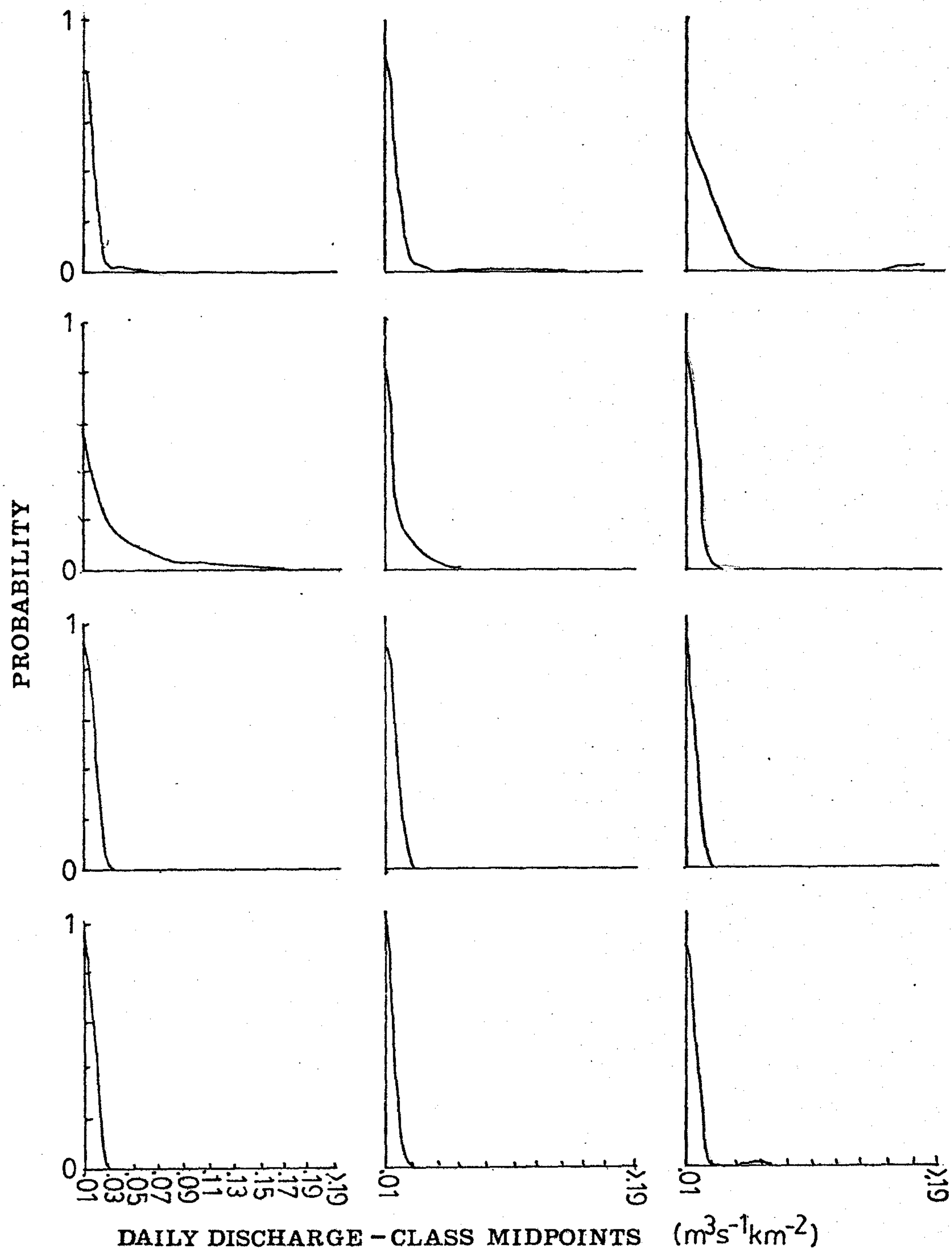


Figure 4.29 MONTHLY FLOW DISTRIBUTION - HC025

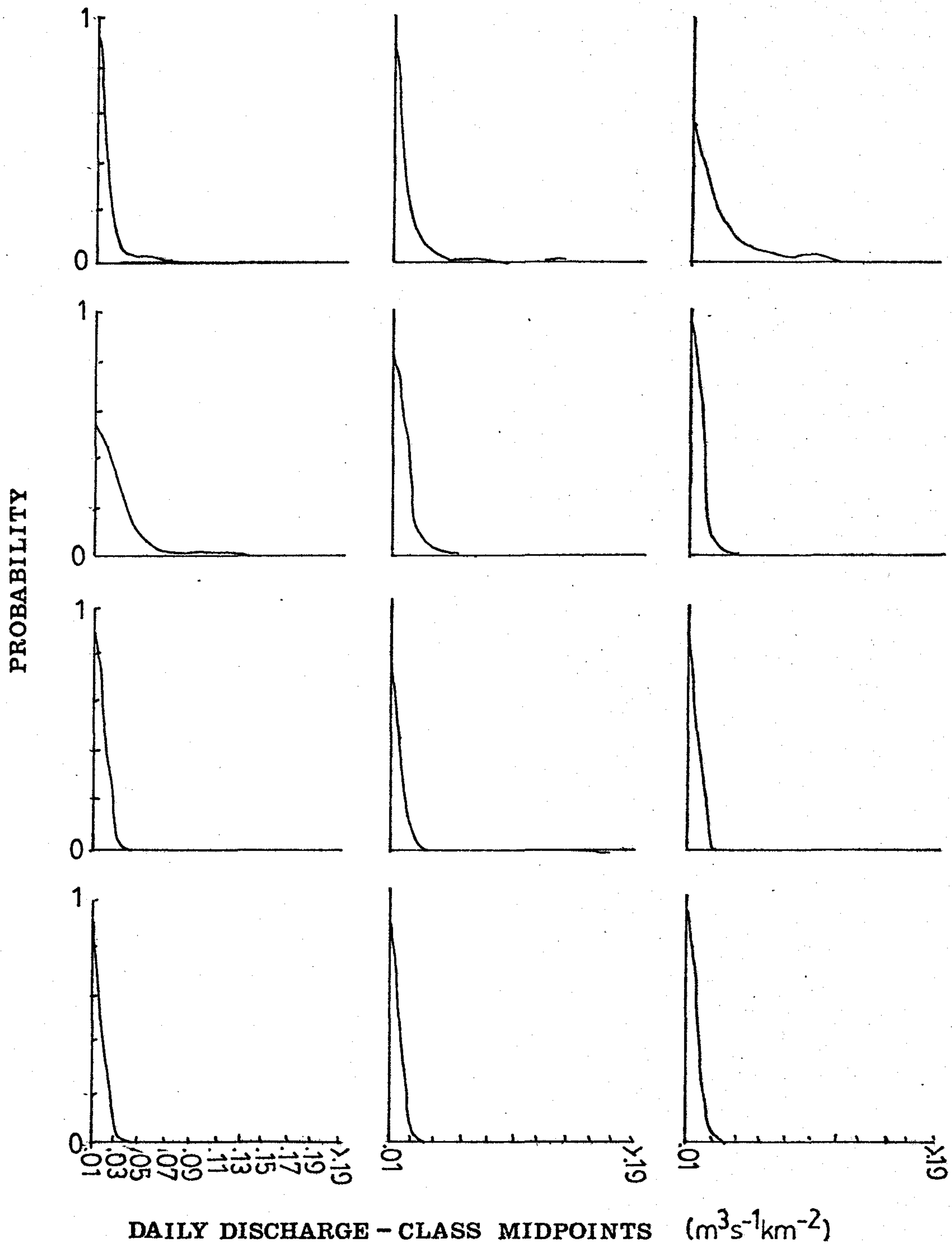


Figure 4.30 MONTHLY FLOW DISTRIBUTION – HCO31

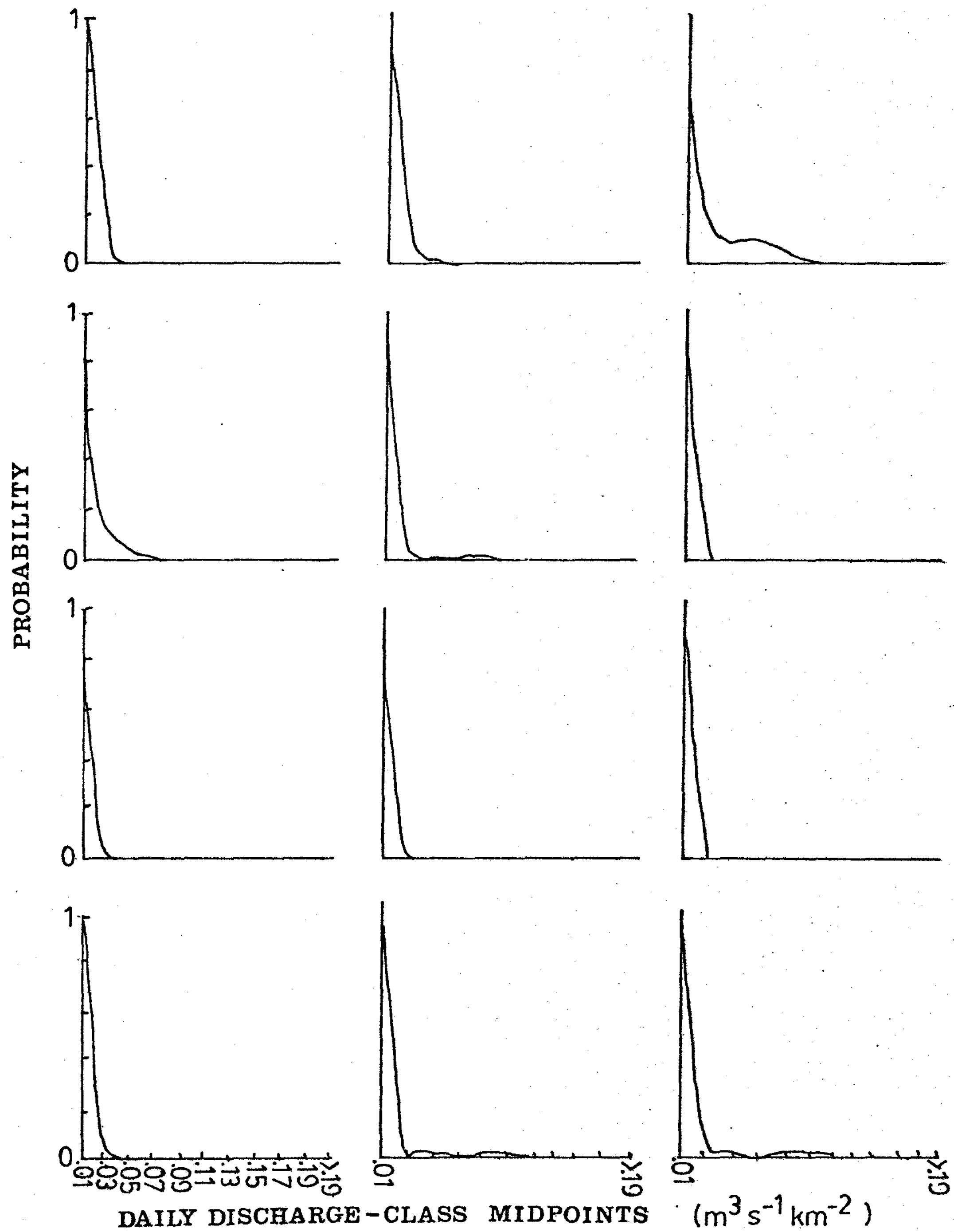


Figure 4.31 MONTHLY FLOW DISTRIBUTION – HCO32

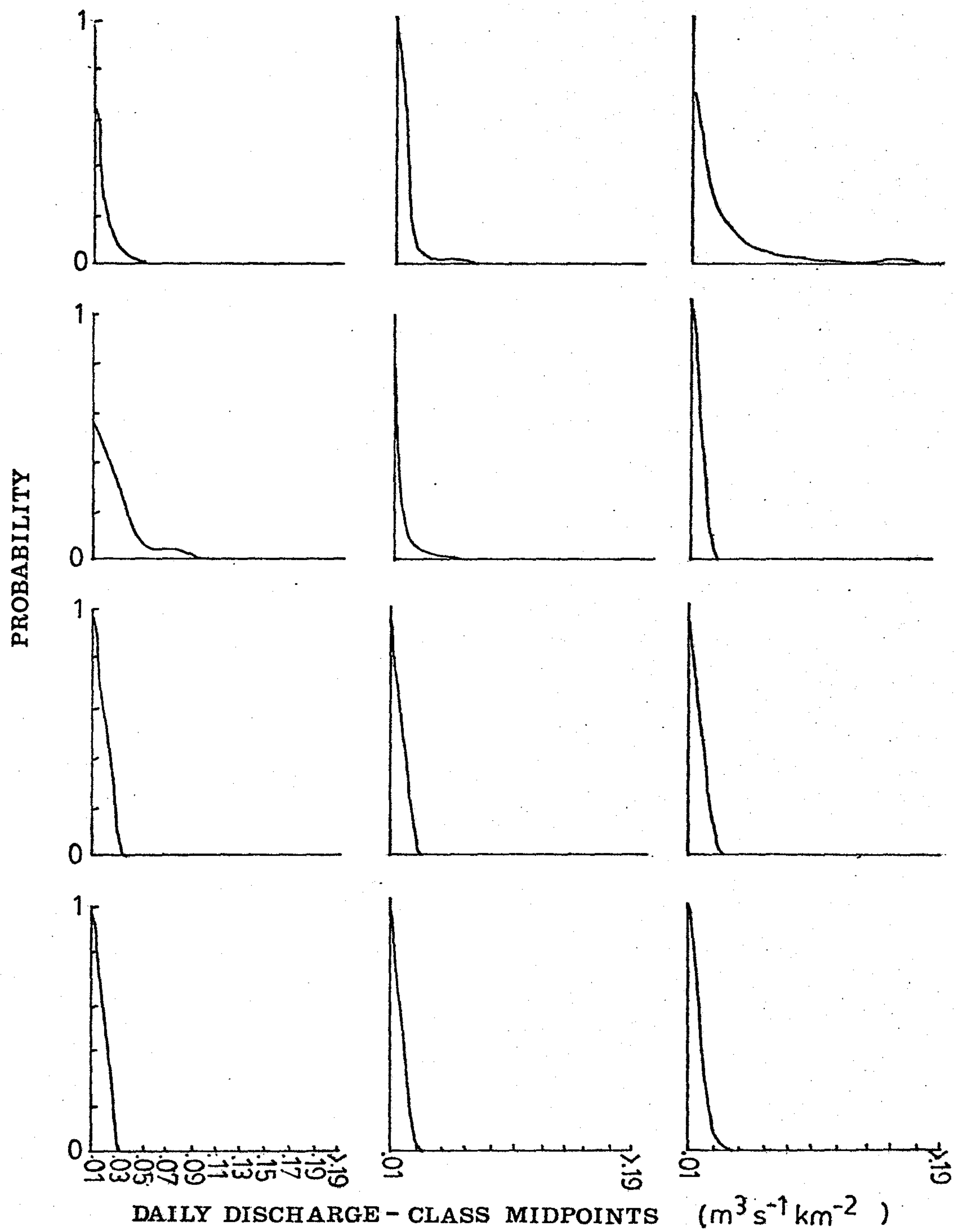


Figure 4.32 ANNUAL MINIMA/AREA – HC –(a)

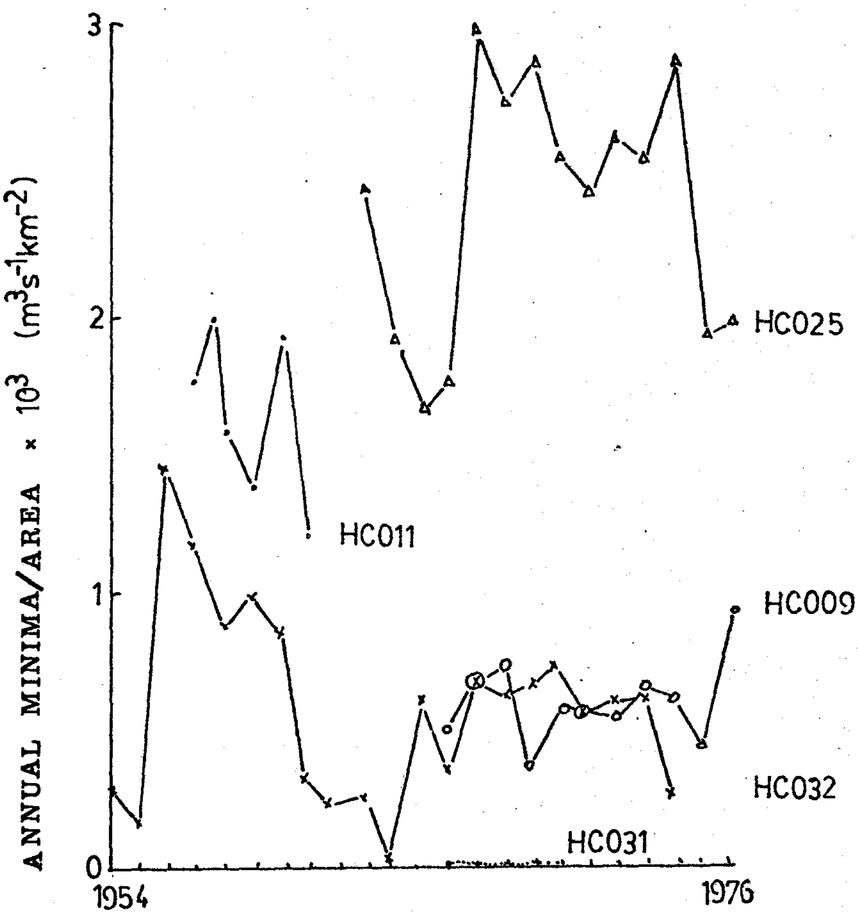


Figure 4.33 DISTRIBUTION OF ANNUAL MINIMA/AREA– HC–(a)

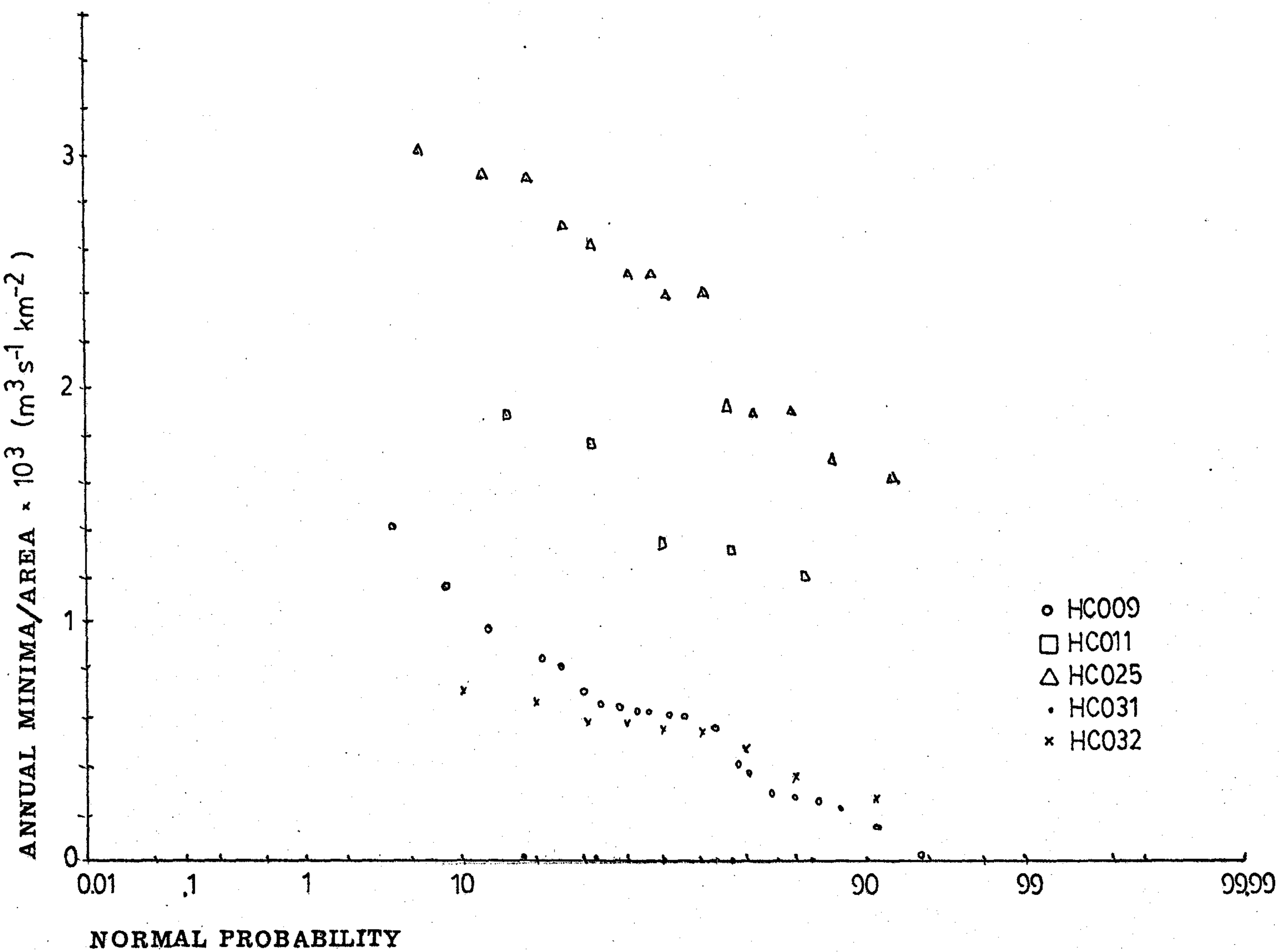
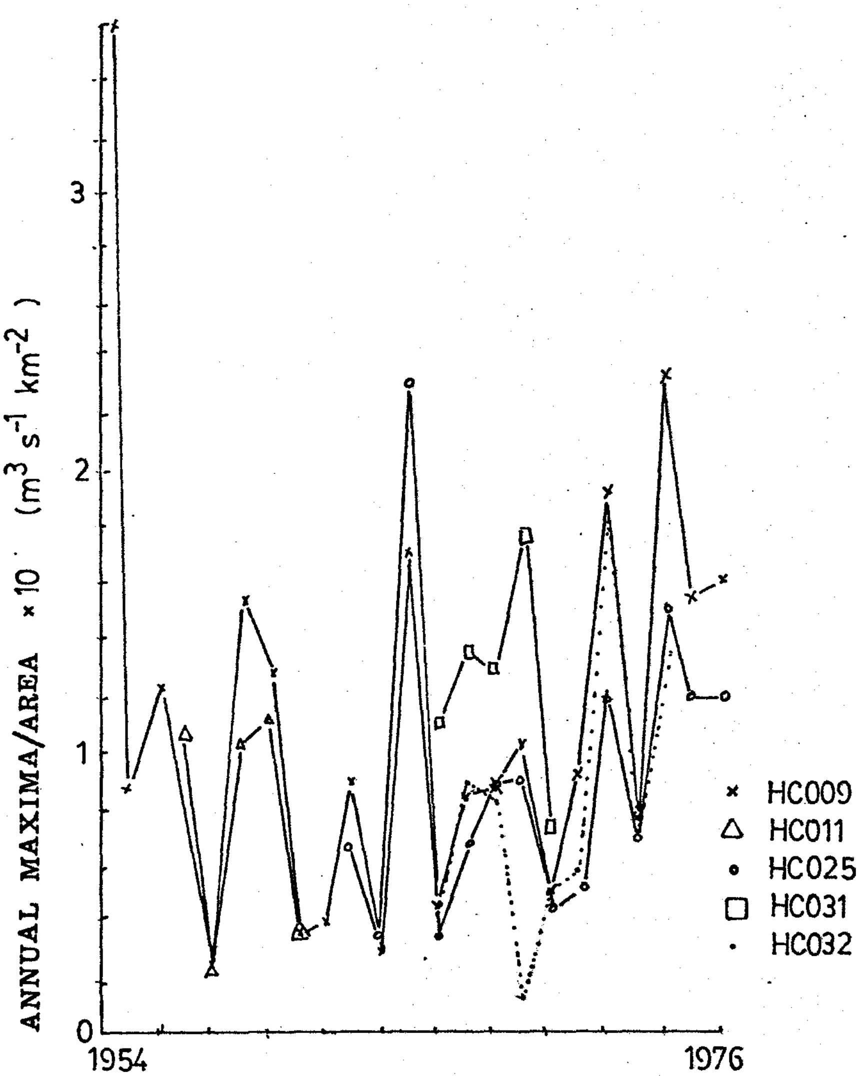


Figure 4.34 ANNUAL MAXIMA/AREA– HC(a)



The probability plot in Figure 4.33 supports this analysis of the situation.

The storing actions of the area drained by the Humber above HC025 maintained greater low flows than the East Humber drainage basin.

4.4.4 Annual Maxima Per Unit Area

Figure 4.34 shows the annual flood series to be similar for all stations, but shows HC031 above other plots by a maximum of $8 \times 10^{-2} m^3 s^{-1} km^{-2}$. The significance of this difference is uncertain due to short records. The maximum floods at HC025 do not differ from the other series.

4.4.5 Summary

No trends relating streamflow of the Humber River to basin area were found. Conservation Areas and swamplands drained by HC025 maintained a stronger base flow/area than the other areas. Maximum floods/area are not differentiated in magnitude; the minimum flows/area affect the means, raising magnitudes of meanflows/area on the Humber River.

4.5 Don River System - HC-(b) Tertiary Set

4.5.1 Annual Means Per Unit Area

Data, as can be seen from Figure 4.3.5 are very fragmented for this system. However, timing of fluctuations is similar. The only definite conclusion which can be made regarding the magnitude is that HC024 is greater (maximum difference = $2.5 \times 10^{-4} m^3 s^{-1} km^{-2}$).

Figure 4.36 backs the above conclusion with the empirical distribution. Table 4.1 shows the greater mean/area of HC024. Table 4.1 also shows the mean/area of HC029 to lie between those of HC024 and HC005,

Figure 4.35 ANNUAL MEANS/AREA- HC(b)

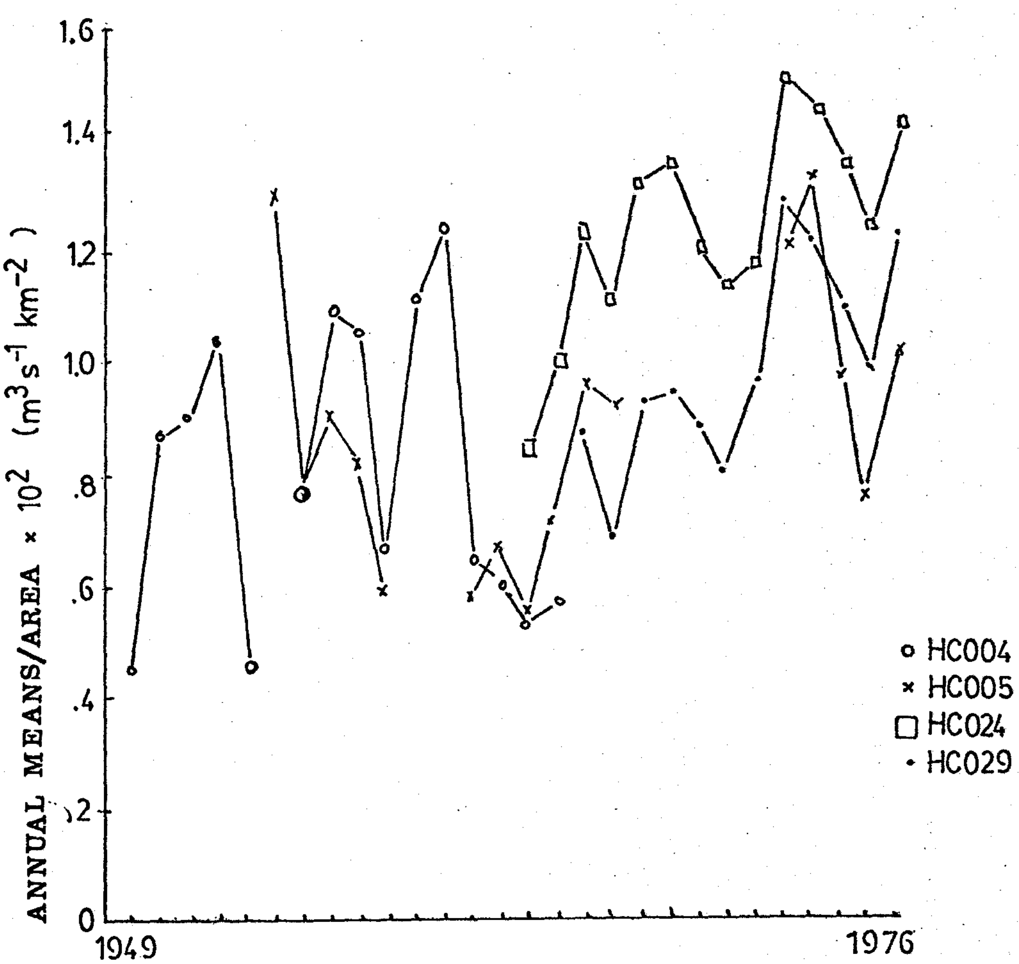
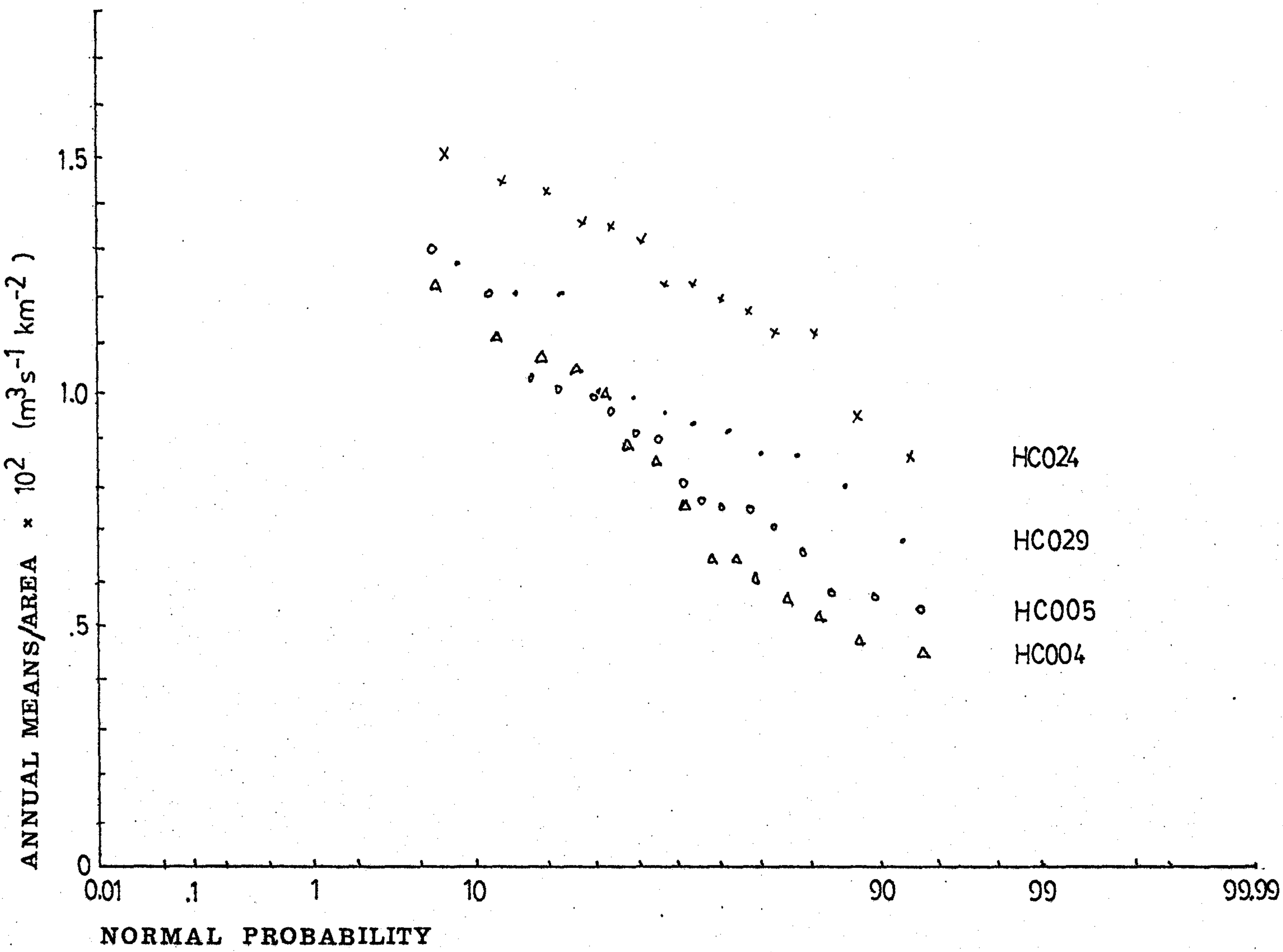


Figure 4.36 DISTRIBUTION OF ANNUAL MEANS/AREA – HC–(a)



and HC004 to be below HC005.

HC029 and HC024 both drain highly urbanized residential areas. However, streams are surrounded by park strips; Wilket Creek is situated in the heart of a large gardened and forested ravine-park and contributes to streamflow gauged by HC024. HC004 and HC005 gauge different tributaries, both on the outskirts of the suburbs of Toronto. As flow continues downstream, if the observed statistics result from effects of parkland and/or urbanization, both tributaries will become increasingly affected and HC024 will show magnified effects of each, including those of Wilket Creek.

4.5.2 Monthly Frequency Distributions

Figures 4.37 to 4.40 show that the monthly frequency distributions of daily flow per unit area are almost identical for all stations, even with limited data from these stations.

4.5.3 Annual Minima Per Unit Area

Low flow time plots show, again, the distinct increased magnitude of flow at HC024 and, to a lesser degree an increase at HC029. Maximum differences are $3.6 \times 10^{-3} m^3 s^{-1} km^{-2}$ and $2.2 \times 10^3 s^{-1} km^{-2}$, respectively.

The frequency distribution plotted on Figure 4.42 corroborates these observations. Increased parkland acts as storage and maintains larger base flows.

4.5.4 Annual Maxima Per Unit Area

Figure 4.43 shows no distinguishing features between streams. Short term records allow no conclusions.

Figure 4.37 MONTHLY FLOW DISTRIBUTION- HC004

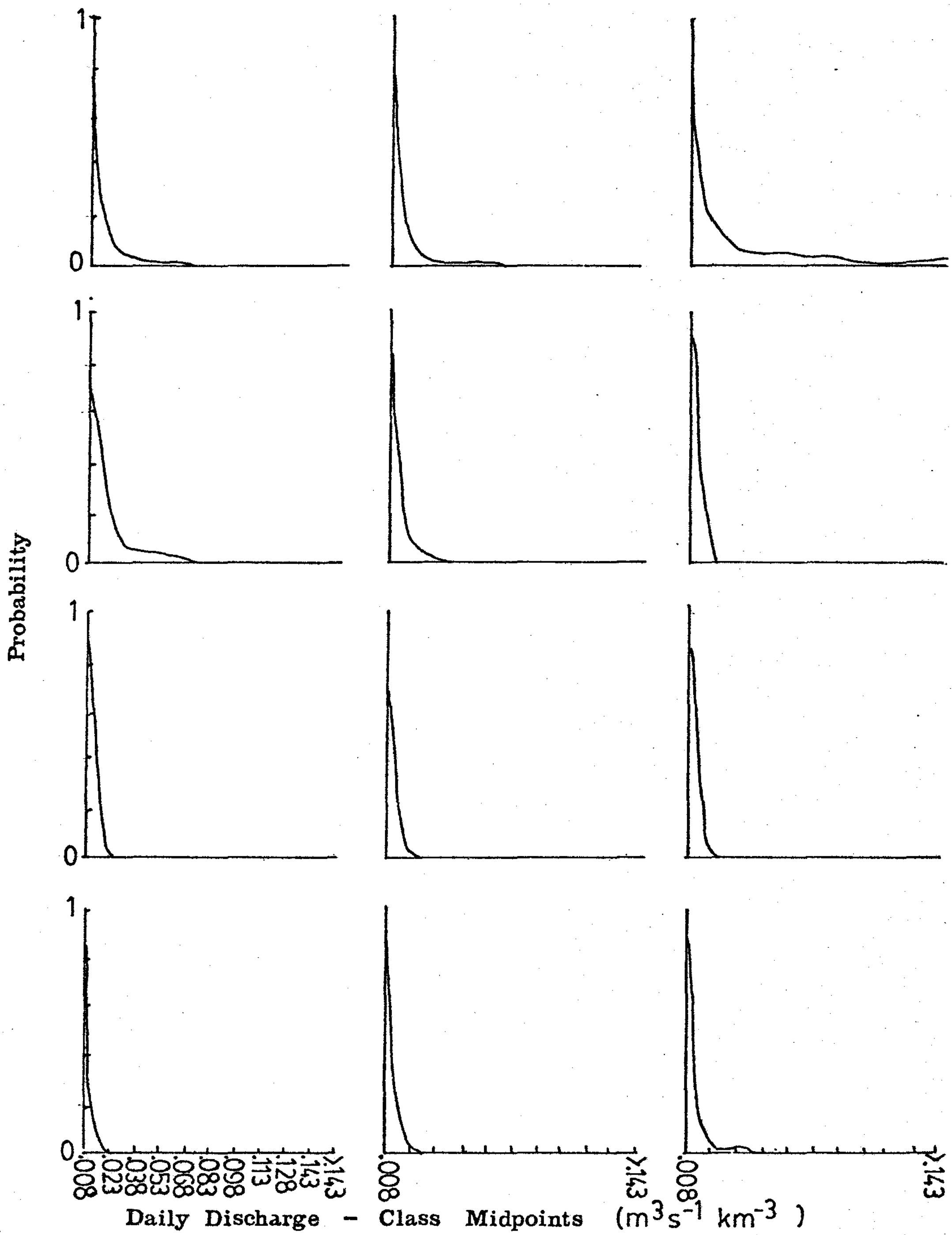


Figure 4.38 MONTHLY FLOW DISTRIBUTION - HCOO5

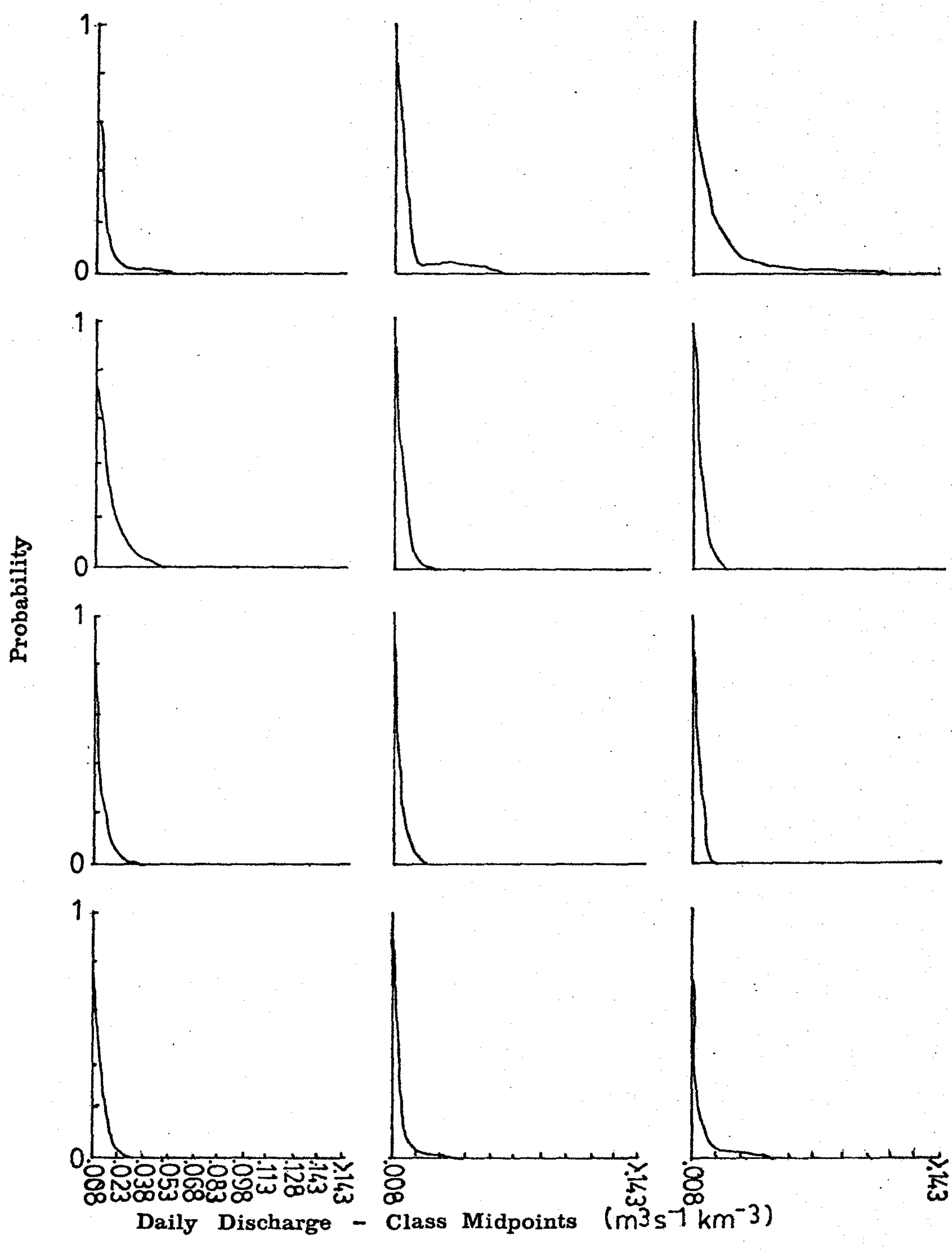
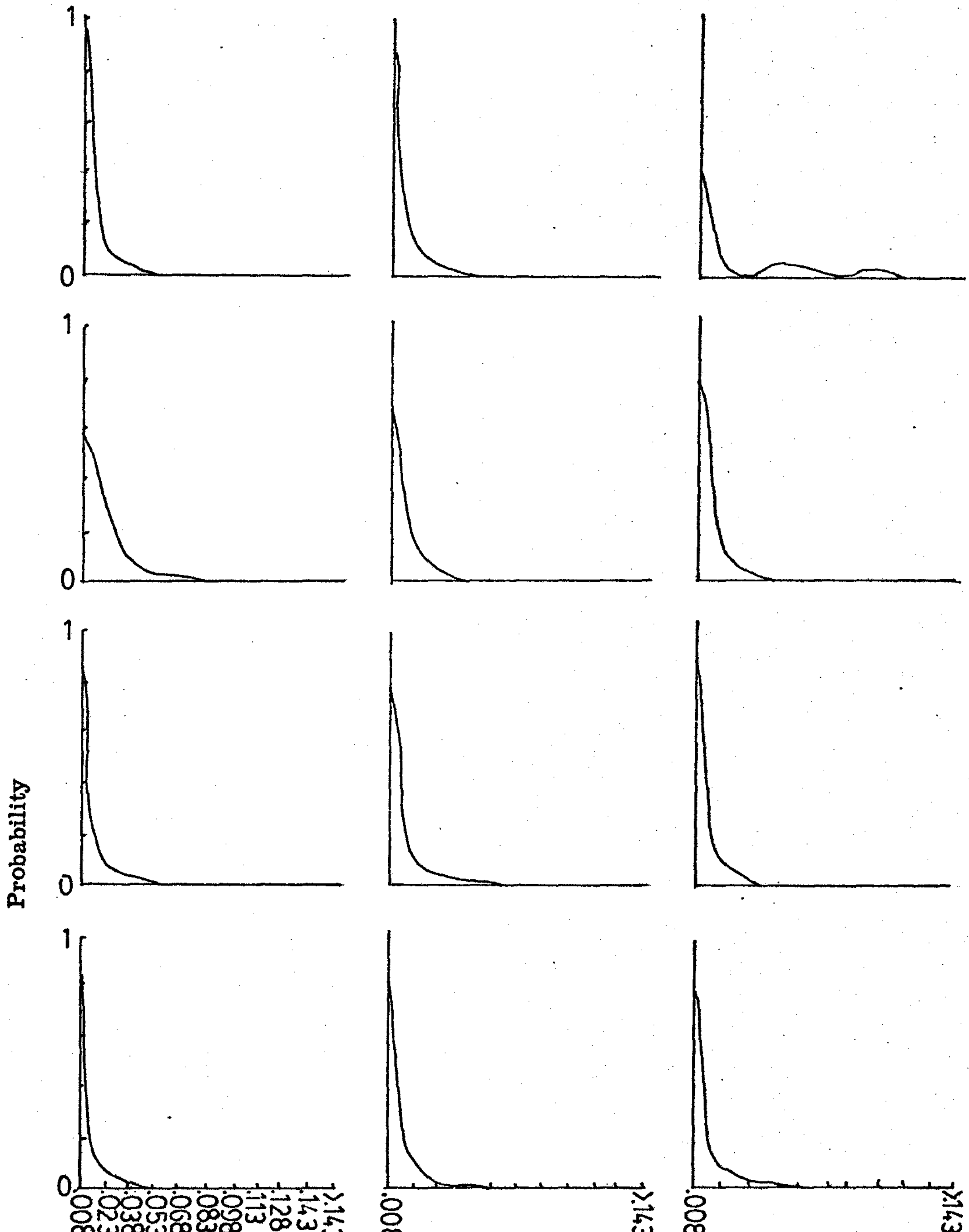
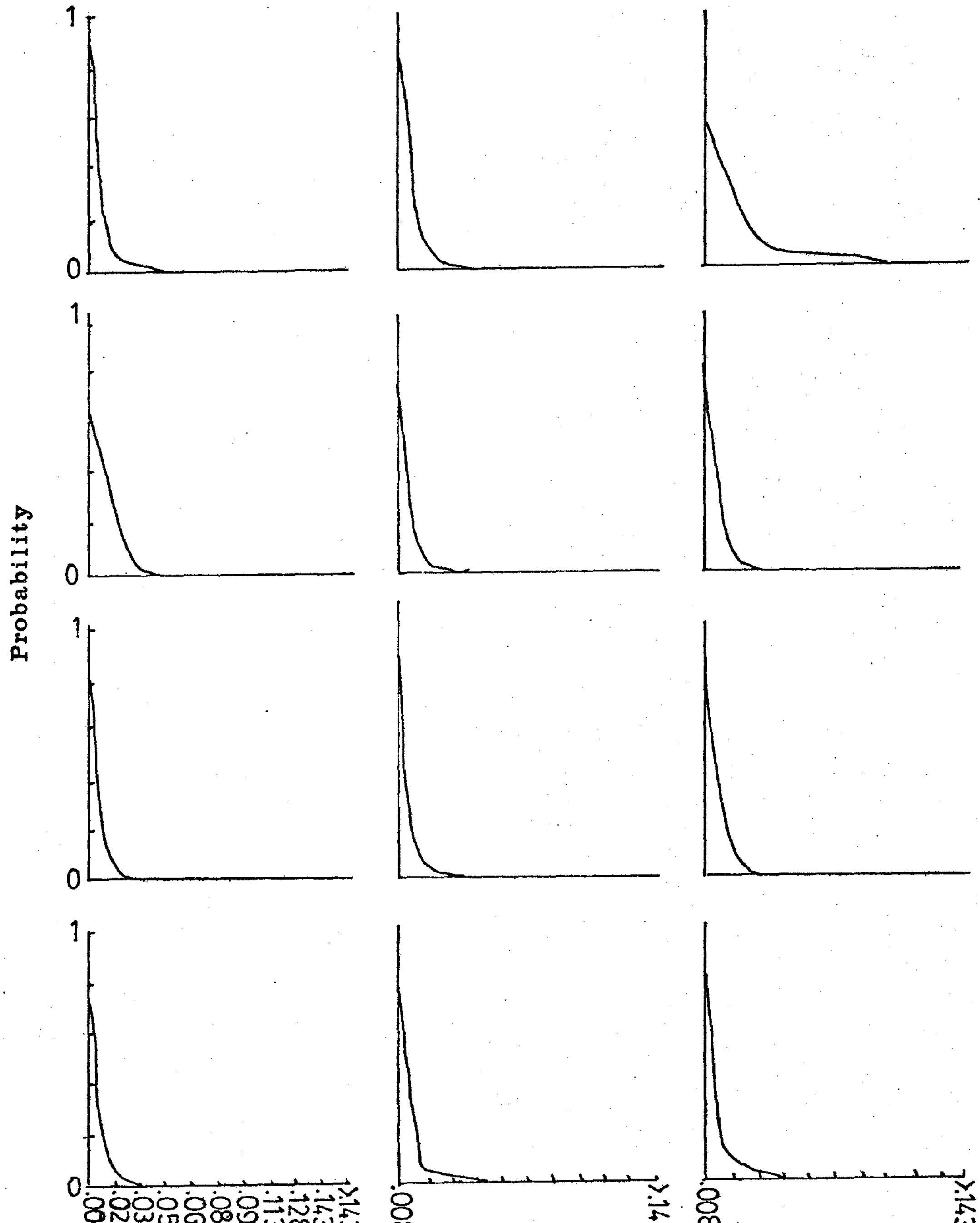


Figure 4.39 MONTHLY FLOW DISTRIBUTION-HCO24



Daily Discharge - Class Midpoints $(m^3 s^{-1} km^{-3})$

Figure 4.40 MONTHLY FLOW DISTRIBUTION - HCO29



Daily Discharge - Class Midpoints ($m^3s^{-1}km^{-3}$)

Figure 4.41 ANNUAL MINIMA/AREA – HC – (b)

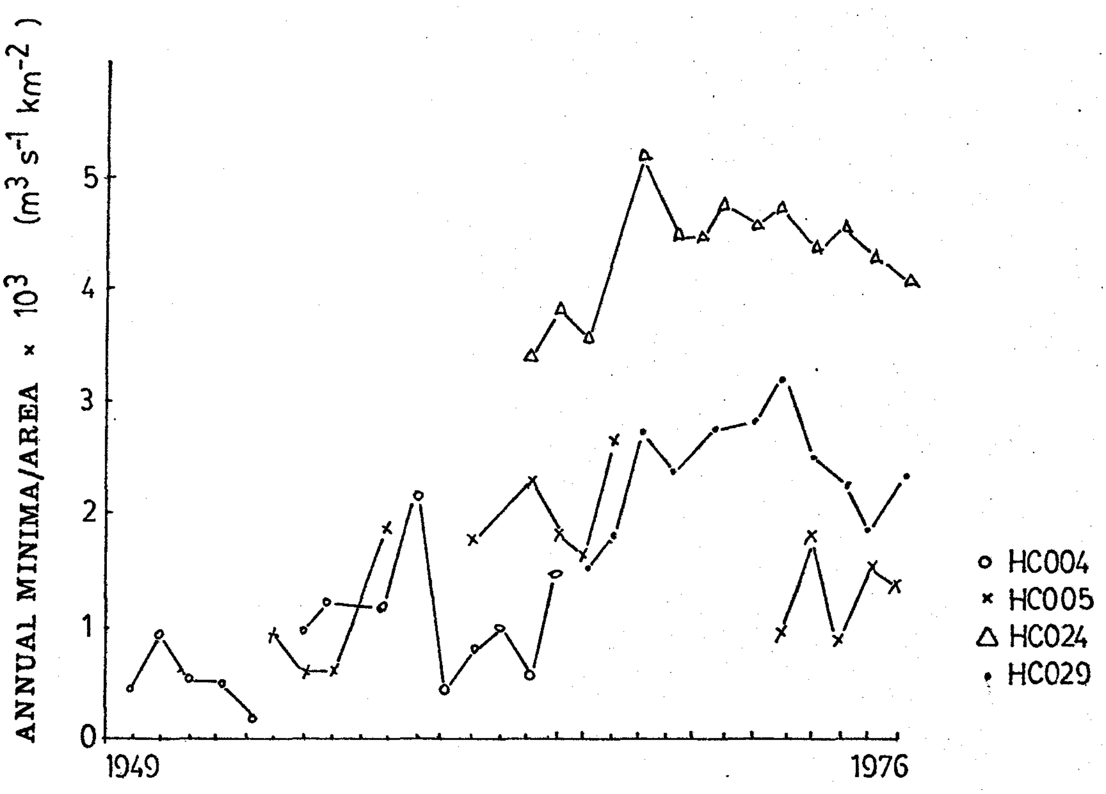


Figure 4·42 DISTRIBUTION OF ANNUAL MINIMA/AREA – HC –(b)

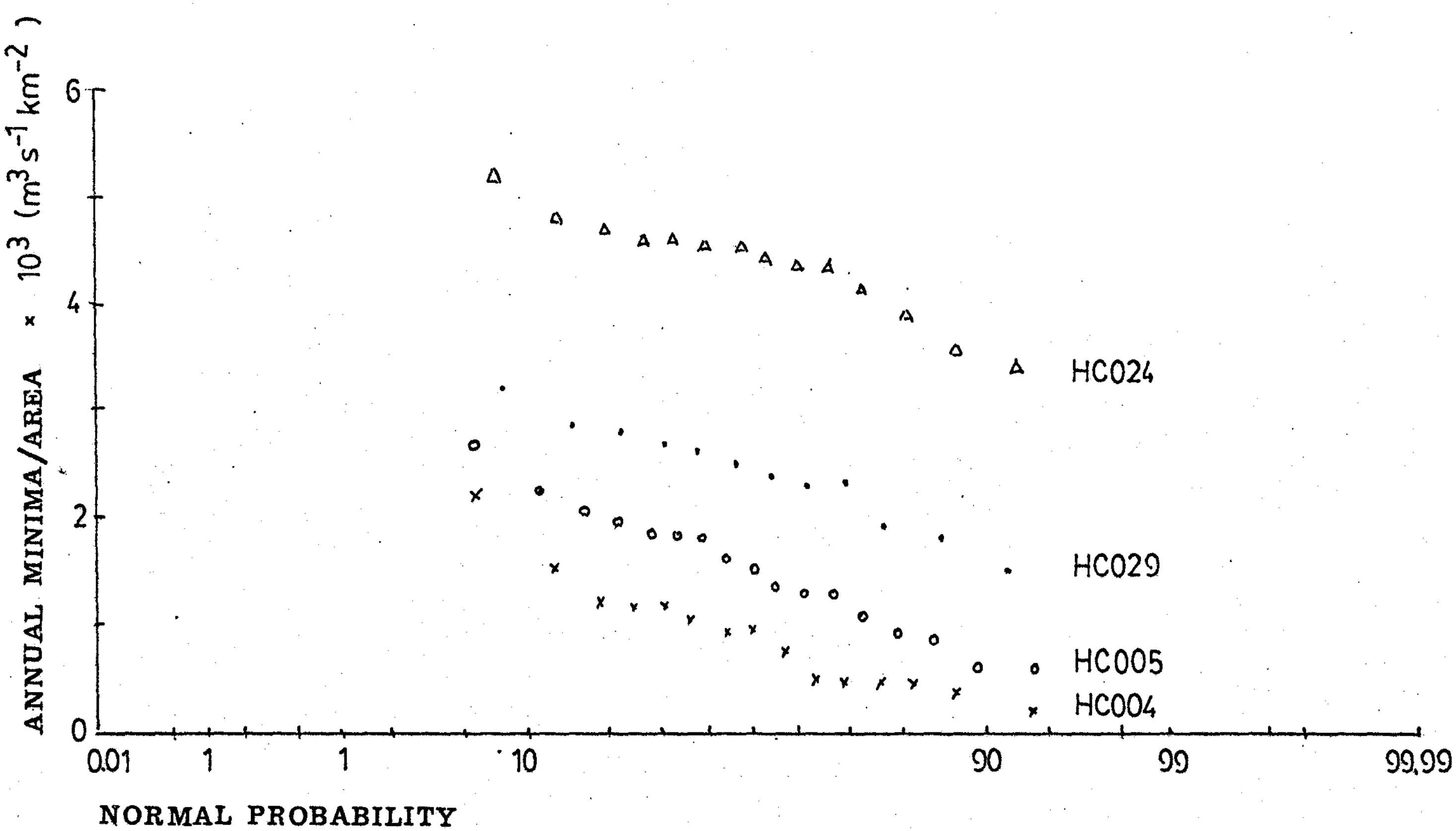
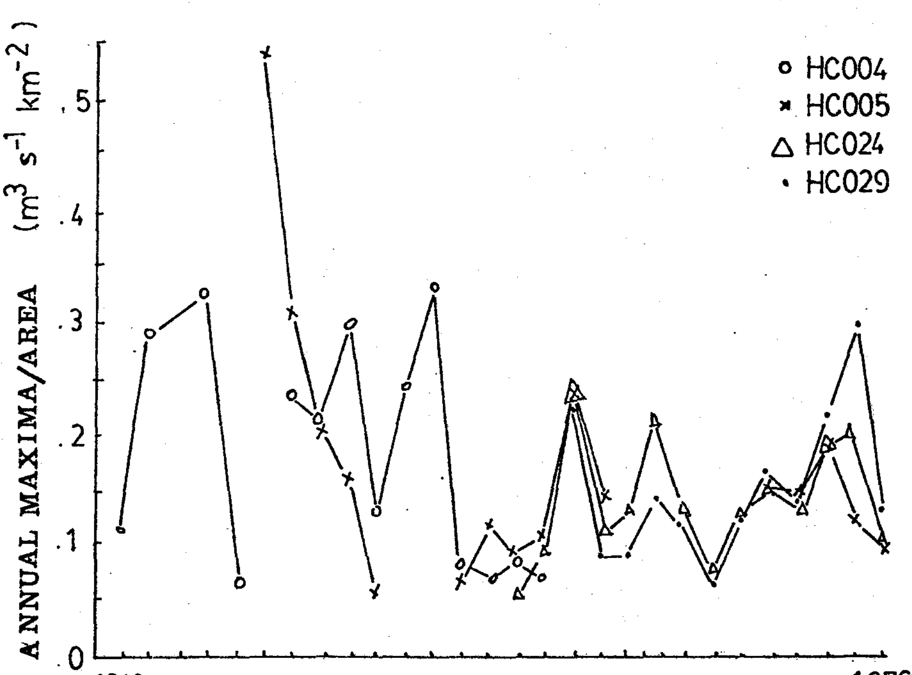


Figure 4.43 ANNUAL MAXIMA/AREA– HC –(b)



4.5.5 Summary

The Don River System characteristics are not found to be affected by basin size. The effect of urbanization on the drainage area are thought to increase overland flow to stream areas while parklands store water thus maintaining high minimum flows. Maximum flows will not be heightened by urbanization, but dampened by storage media along the channel.

4.6 Comparisons Between River Systems

4.6.1 Annual Means Per Unit Area

No trends of means/area with basin size were conclusively found in any basin. From Table 4.1, no overall trends are even possible. Physical characteristics of the basin were primary determinants of streamflow in all cases. Bear Creek provided the most homogeneous drainage area. In this basin, the smaller basin was found to have a higher mean annual flow and standard deviation of annual flow. However, as can be seen from Table 4.1, the differences are slight and the short time span of records prevents these observations from being conclusive.

4.6.2 Probability of Annual Means Per Unit Area

Distribution of means were probably normal, as shown by Figure 4.2, ranked means of Saugeen streams, and each probability graph, on which the annual means conform to straight lines. Variations on these plots were of four types.

(a) deviations from a straight line in the form of "bumps"

(b) separation of lines representing magnitude differences between stations

(c) slope differences

(d) non-conformity to one line due to scattered points

All of these were related to characteristics of the basin rather than to basin area.

Variations in means/area depended upon the basin storage, which reduces variations and steep gradients, which increase variations. Differences in magnitude were due to the effects of the above factors on maximum and minimum annual flows. Urbanization is a possible cause for increased means of the Don River.

4.6.3 Monthly Frequency Distributions

Climatic factors such as precipitation and snowmelt, and the physical aspects such as gradients and basin storage were the causes of variations of monthly frequency distributions between basins in each system.

4.6.4 Annual Minima Per Unit Area

No trends were correlated with basin area. Variations in low flow magnitudes were mainly due to the presence of storage media in the basin such as swamps, lakes and parkland.

4.6.5 Annual Maxima Per Unit Area

Flood magnitudes per unit area were again, more affected by physical characteristics than basin size. Storage in the basin reduced flood magnitudes.

CHAPTER 5

DISCUSSION

The selected streamflow data for Southern Ontario did not indicate any simple relationships between basin area and streamflow characteristics per unit area. Physical characteristics of the basin were the primary determinants of unit area flow statistics in all cases. On the basis of this study, it appears that further distribution analyses of annual means, maxima and minima would not be fruitful.

Qualitatively, however, variations in unit area means, maxima and minima can be related to several basin environmental factors. These flow statistics would be more relevantly studied by such statistical methods as multiple regression with physical factors. Studies along this line will further contribute to the statistical analysis of streamflow for the purpose of regionalization.

APPENDIX A

1. Water Survey of Canada Tape

Daily discharges in cfs were received on 9-track magnetic tape in BCD. Header labels were omitted, but the last data record is followed by end-of-data and end-of-file marks. Information was recorded continuously on the tape without logical record divisions, but the information itself was recorded in 80 character records. Fields were defined as follows:

Col. 1	type of data	= 1
Col. 2-8	station number	eg. 08FC004
Col. 9-11	year	eg. 979 for 1979
Col. 12-13	month	eg. b7 for July
Col. 14	time interval of data in record:	
		1 for days 1-10 of month in Col. 12-13
		2 for days 11-20 of month in Col. 12-13
		3 for days 21-31 of month in Col. 12-13
Col. 15-80	eleven 6-digit data fields	

Three such records complete a month of data:

Formatted as above:

Card 1:	Col. 75-78	unused
	Col. 79-80	number of days in month
Card 2:	Col. 75-80	unused
Card 3:	-11111 entered in any of the eleven data fields which do not apply to the particular month.	

Data Format: - right-justified, decimal if necessary

- read as F6.0
- -99999 entered where data missing

With the tape is a printout describing each station and listing all years of station operation as to whether data was complete, partial, or missing.

To obtain the Water Survey data, a user must send his own tape onto which the information is to be written.

2. Tape Conversion

For use on the CDC 6400, it was necessary to label the information with headers, logical record divisions, and file marks to divide the data into stations and years. To safeguard the data, the original tape was not written over; another tape received the labelled information.

3. New Tape Format

The new tape was set up in logical records exactly as the descriptions in part -1. EOF - marks were placed after each year of data, whether the information for that year was complete or partial. Printed out during transcription was an index, listing file numbers and the stations they contained. From this listing, the required stations and years were accessed and copied to a third, smaller tape which became the source for the study. By using the third tape, all original Southern Ontario data was kept intact, and access to the required data was faster and cheaper. It was found to be even more economical to copy immediately required data on a disk file, then erase the file after use.

4. Processing Notes

(1) To read more than one year at a time, the EOF marks were erased between years of a station. Thus, on the third tape, each file constituted all the years of data of one station.

(2) To avoid reading years of incomplete data, the printout which arrived with the Water Survey tape was consulted. Because each year on Tape 2 was a file, these partially gauged years were skipped during transcription to the tape accessed during analysis.

APPENDIX B

CLASS INTERVAL DETERMINATION

Let $B = (Q\max - Q\min)/40$

where; B has b significant digits

Q indicates streamflow statistic over N years .

$B = a \times 10^{c}$

Multiply:

$$B = B \times 10^{b-1} \quad =, \quad BB = aa \times 10^{c-(b-1)}$$

Then, $aa \times 10^{c-(b-1)} \leq CI < (aa+5) \times 10^{c-(b-1)}$

and the class interval CI is such that:

$$\left[CI - (aa \times 10^{c-(b-1)}) \right] + \left[(aa + 5) \times 10^{c-(b-1)} - CI \right] = 5$$

The range of q_i was divided by 40 because the program handled up to 40 classes. The number of classes was later reduced, the high class becoming openended.

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