ESTIMATING RUNOFF IN SOUTHERN ONTARIO

TECHNICAL BULLETIN No. 7

A. COULSON

INLAND WATERS BRANCH
DEPARTMENT OF ENERGY, MINES AND RESOURCES
OTTAWA 1967

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CONTENTS

ILLUSTRATIONS

TABLES

SYNOPSIS

A major problem in the design of many water-use projects is the lack of streamflow data necessary to calculate the amount of water which will be available to a completed project. A number of techniques can be used for estimating the flow in streams for which records either are not available or are available for short periods only. The technique used in this study consists essentially of establishing a set of regional characteristics, based upon existing streamflow records for gauged streams in Southern Ontario, and the application of these characteristics to estimate flow at any point of interest on streams in this region where flow information is meagre or unavailable.

ESTIMATING RUNOFF IN SOUTHERN ONTARIO

INTRODUCTION

The design of any water-use project requires an estimate of the amount of water which will be available to the completed project The basis for this estimate has traditionally been a historical sequence of streamflow records on the stream on which the project is to be located. A disadvantage of a simple analysis of these data is that it will not yield any information as to the probability of design flows occurring within the life of the project. In recent years, more complex studies have been coming into use: these studies often take the form of sequential generation of long periods of non-historic synthetic streamflow data upon which the project design is based.

Such hydrologic investigations can be quite complex or, at best, tedious, and are usually not justified for minor projects. Also, they are dependent upon the existence of flow records on the stream under investigation.

The purpose of this study, therefore, is to analyze the available streamflow records in Southern Ontario in order to obtain parametric relationships which may be used to estimate the runoff and its distribution in ungauged streams or in streams with short periods of record in this region. These relationships may also be used to obtain a quick estimate of the runoff characteristics of a stream on which flow records are available, without recourse to an analysis of those records. They may also be used in a complete analysis of such a stream, by providing a comparison of the actual streamflow records with the regional characteristics based on all flow records obtained on the surrounding streams.

The relationships developed do not account for all the variance in runoff. In their application, therefore, discretion and good judgement on the part of the hydrologist are of prime importance.

As a supplementary result of this study, recommendations are presented concerning areas in which the hydrometric network should be expanded.

DATA USED IN STUDY

All streamflow records available in Southern Ontario for periods of at least five years prior to September 30, 1961, have been analysed for this study. There are 59 gauging stations in the area with records longer than five years; only eight of these have records longer than 40 years and the majority have records of less than 15 years.

At 25 of these stations the flow is not affected by regulation. At 11 stations there is minor regulation where the storage capacity is not sufficient to affect monthly or annual flows but where the weekly operating pattern could affect individual daily flows. At the remaining 23 stations the flow is affected considerably by upstream regulation the storage capacity of which is large enough to affect both daily and monthly flows. However, it is felt that the change in storage from the beginning to the end of each water year is not sufficient to seriously affect the annual flow and also that the difference between evaporation loss from the water surface of the reservoirs and the evapotranspiration from an equivalent area is negligible. There are very little data available as to the extent of irrigation in Southern Ontario; however, the amount of water diverted for irrigation during the period covered by this study is believed to be small enough to warrant the assumption that annual runoff is not affected by irrigation. This assumption may not be valid when later records are analysed, because of the increase in irrigation during recent years.

The 59 gauging stations used in the study are listed in Table 1, with the drainage areas, the amount of regulation, and a bar chart showing the periods of record. The locations of the gauging stations are shown in Figure 1. Actual streamflow data are not listed but this information may be found in the series of Water Resources Papers covering the St. Lawrence and Southern Hudson Bay drainage, published by the Inland Waters Branch.

ACCURACY OF STREAMFLOW DATA

There are many factors which can affect the accuracy of records obtained at streamflow gauging stations. The station rating curve may not be defined by discharge measurements over the whole range of stage, in which case the computed discharges at the undefined stages will be less reliable than those at other stages. The station control may not be stable and adjustments must be made to the rating curve, with consequent loss of accuracy during periods when the control is shifting. Ice or weed growth cause backwater, and the discharge records collected under these conditions are never as reliable as those collected during the open water period when there is no backwater.

Regional analyses, such as the one used in this study, may help to eliminate some of the inaccuracies which are found in individual streamflow records. It is usually preferable to rely on a regional analysis rather than accept the results of a short-term single-station analysis but decisions of this nature must be left to the hydrologist.

MEAN FLOW

The mean flow of the principal streams in Southern Ontario is shown in Figure 2, on which the width of the line representing a stream indicates the mean flow of that stream in cubic feet per second. This map is based on the mean flow recorded at all 59 gauging stations in the area over their respective periods of record. The mean flows were not adjusted to a common period since this is not justified by the scale used to represent discharge.

The map is useful for obtaining a quick appreciation of the mean flow of the streams but it is not suitable for estimating flows for design purposes.

MEAN RUNOFF

In devising a method for estimating the mean flow or mean runoff sufficiently accurately for design purposes, it is desirable to adjust all the recorded flows to a common base period of time in order to minimize variations due to sampling error.

This base period should be selected so that there is as complete a flow record as is feasible at every gauging station. Inspection of the bar chart in Table 1 shows that the base period should end in 1961 and should not begin before 1945. Accordingly, the means for the periods 1945-61, 1946-61, etc. at the eight stations with more than 40 years of record were compared with the long-term means at the respective stations.

It was found that the means for the period 1952-61 compared favourably with the long-term means, differences for the eight-station group having a mean of 0 per cent and a standard deviation of less than 5 per cent (see Table 2). Therefore, the 10-year period 1952-61 was selected as the required base period.

The first step in the study of mean runoff for the period 1952-61 was to estimate the flow for the missing years at those stations where the records did not cover the full 10 years. This was done by simple correlation with the flows at nearby stations.

The mean runoff in inches was then computed from the recorded flows for each of the

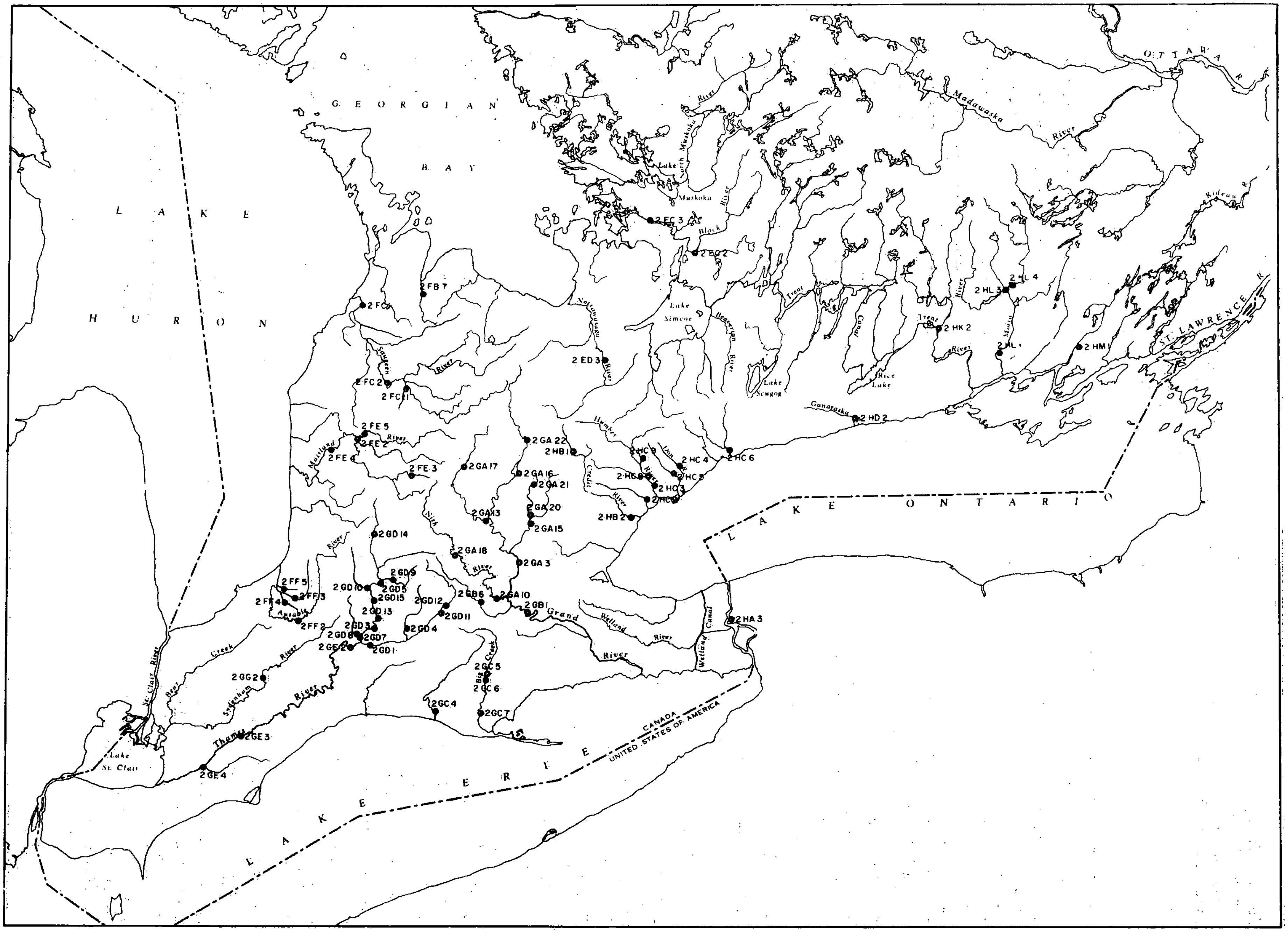


Figure 1. Location of gauging stations.

TABLE 1

SOUTHERN ONTARIO GAUGING STATIONS WITH A MINIMUM OF FIVE YEARS OF RECORD TO 1961

Station	Index Number	Regulation	Drainage Area Sq. Mi.
Severn River at Swift Rapids	2EC-3	Major	2,260
Black River near Washago	2EC-2	Major	585
Nottawasaga River near Baxter	2ED-3	Nil	456
Sydenham River near Owen Sound	2FB-7	Major	70
Saugeen River near Walkerton	2FC-2	Nil	850
Saugeen River near Port Elgin	2FC-1	Nil	1,570
Carrick Creek near Carlsruhe	2FC-11	Minor	63
Maitland River above Wingham	2FE-5	Nil	205
Maitland River below Wingham	2FE-2	Minor	628
Maitland River near Donnybrook	2FE-4	Nil	680
Middle Maitland River near Listowel	2FE-3	Nil	30
Ausable River near Springbank	2FF-2	Nil	334
Parkhill Creek at Parkhill	2FF-3	Nil	48
Sydenham River at Alvinston	2GG-2	Nil	283
Thames River at Woodstock	2GD-12	Minor	98
Thames River near Ealing	2GD-1	Minor	519
Thames River at Byron	2GE-2	Major	1,200
Thames River at Thamesville	2GE-3	Major	1,660
Cedar Creek at Woodstock	2GD-11	Nil	36
Middle Thames River at Thamesford	2GD-4	Major	118
North Thames River near Mitchell	2GD-14	Major	123
North Thames River at St. Mary's	2GD-5	Major	416
North Thames River near Thorndale	2GD-15	Major	518
North Thames River below Fanshawe Dam	2GD-3	Major	560
North Thames River at London	2GD-7	Major	657
Trout Creek near St. Mary's	2GD-9	Nil	54
Fish Creek near Prospect Hill	2GD-10	Nil	58
Medway River near London	2GD-8	Nil	70
Big Otter Creek near Vienna	2GC-4	Nil	269
Big Creek near Delhi	2GC-6	Major	140
Big Creek near Walsingham	2GC-7	Minor	228
North Creek at Delhi	2GC-5	Major	21
Grand River at Waldemar	2GA-22	Major	253
Grand River below Shand Dam	2GA-16	Major	309
Grand River at Galt	2GA-3	Major	1,360
Grand River at Brantford	2GB-1	Major	2,010
Conestogo River at Drayton	2GA-17	Nil	125

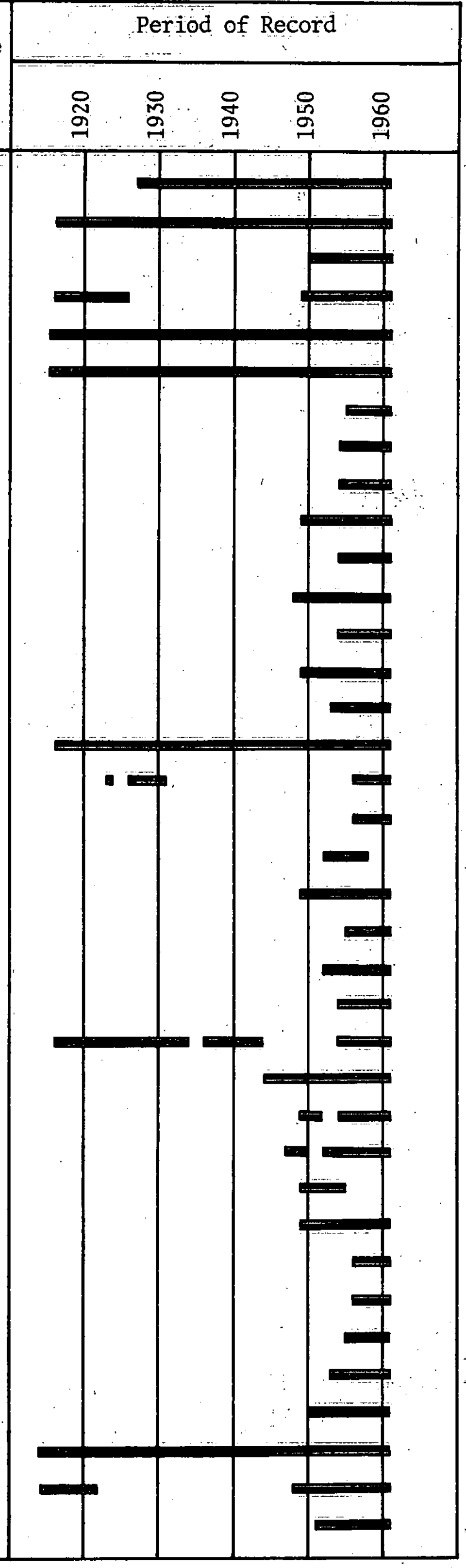
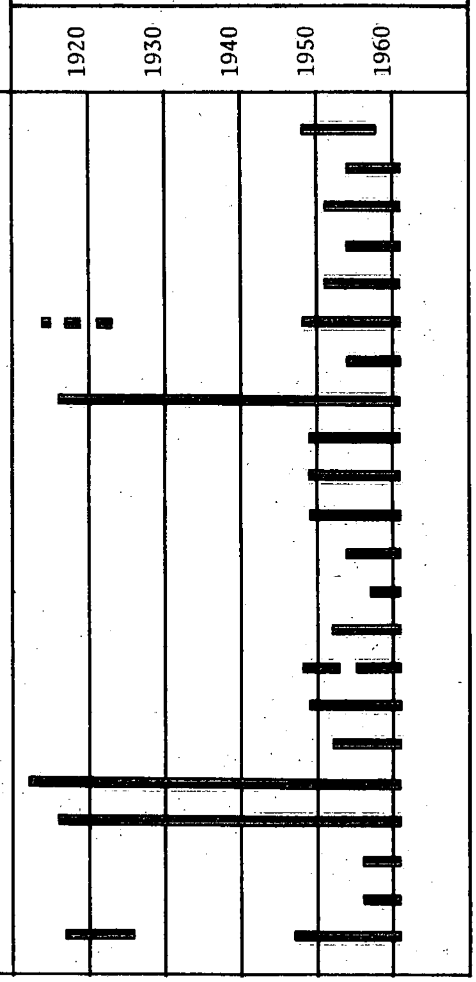


TABLE 1 (Continued)

Station	Index Number	Regulation	Drainage Area Sq. Mi.	Period of Record
Conestogo River near Conestogo	2GA-13	Major	317	
Speed River above Guelph	2GA-20	Minor	104	
Speed River below Guelph	2GA-15	Minor	229	
Luttrells Creek near Oustic	2GA-21	Nil	21	
Nith River at New Hamburg	2GA-18	Minor	209	
Nith River near Canning	2GA-10	Minor	398	
Horner Creek near Princeton	2GB-6	Nil	58	
Credit River near Cataract	2HB-1	Nil	82	
Credit River near Erindale	2HB-2	Minor	320	
Etobicoke Creek near Summerville	2HC-2	Nil	64	
Humber River at Weston	2HC-3	Nil	309	
East Humber River near Pine Grove	2HC-9	Nil	75	
West Humber River near Thistletown	2HC-8	Nil	79	
Don River at York Mills	2HC-5	Nil	34	
Little Don River at Lansing	2HC-4	Nil	46	
Duffin Creek at Pickering	2HC-6	Nil	110	
Ganaraska River near Dale	2HD-2	Minor	94	
Trent River at Heely Falls	2HK-2	Major	3,510	
Moira River near Foxboro	2HL-1	Major	1,040	
Black River near Actinolite	2HC-3	Major	155	
Skootamatta River at Actinolite	2HL-4	Major	275	
Napanee River near Napanee	2HM-1	Major	300	



59 gauged drainage areas and for 16 drainage areas lying between gauging stations. These values of runoff were plotted on a map at the centres of the appropriate drainage areas.

Preliminary lines of equal runoff were then drawn through the plotted values. By planimetering the areas enclosed by these lines and the drainage boundaries, the runoff was computed for each drainage area. These values were compared with the values of runoff computed from streamflow records and the lines progressively adjusted to bring the two sets of data into approximate coincidence, the differences being in the order of one per cent at the end of the process.

At this point, despite the close agreement in the runoff values from the two sources, there were some areas where the pattern of runoff lines was obviously unrealistic. A further adjustment to the pattern was then made by comparing the runoff map with the isohyetal map of mean annual precipitation (Figure 3) prepared by the Meteorological Branch, Department of Transport. This adjustment was done by overlaying a transparency of one map on the other and plotting values of water loss (precipitation minus runoff). The water loss values showed a definite pattern, with the unconformities most evident in the areas where the runoff lines had previously been noted as unrealistic. For this reason, and also because the isohyetal map was based on a larger and more extensive network than the runoff map, the runoff map was further adjusted to make it compatible with the isohyetal map.

The final map showing the adjusted lines

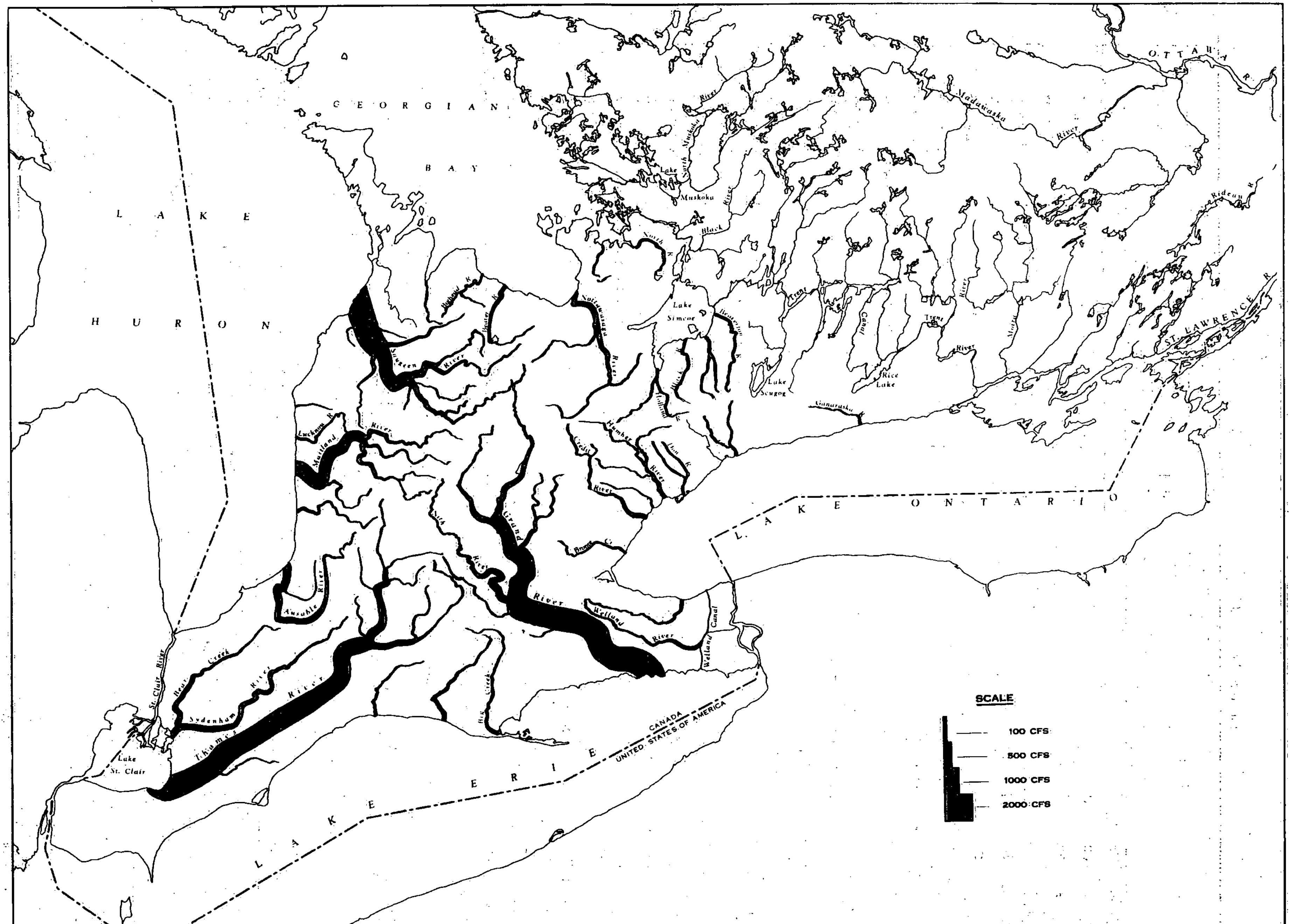


Figure 2. Mean flow of principal streams.

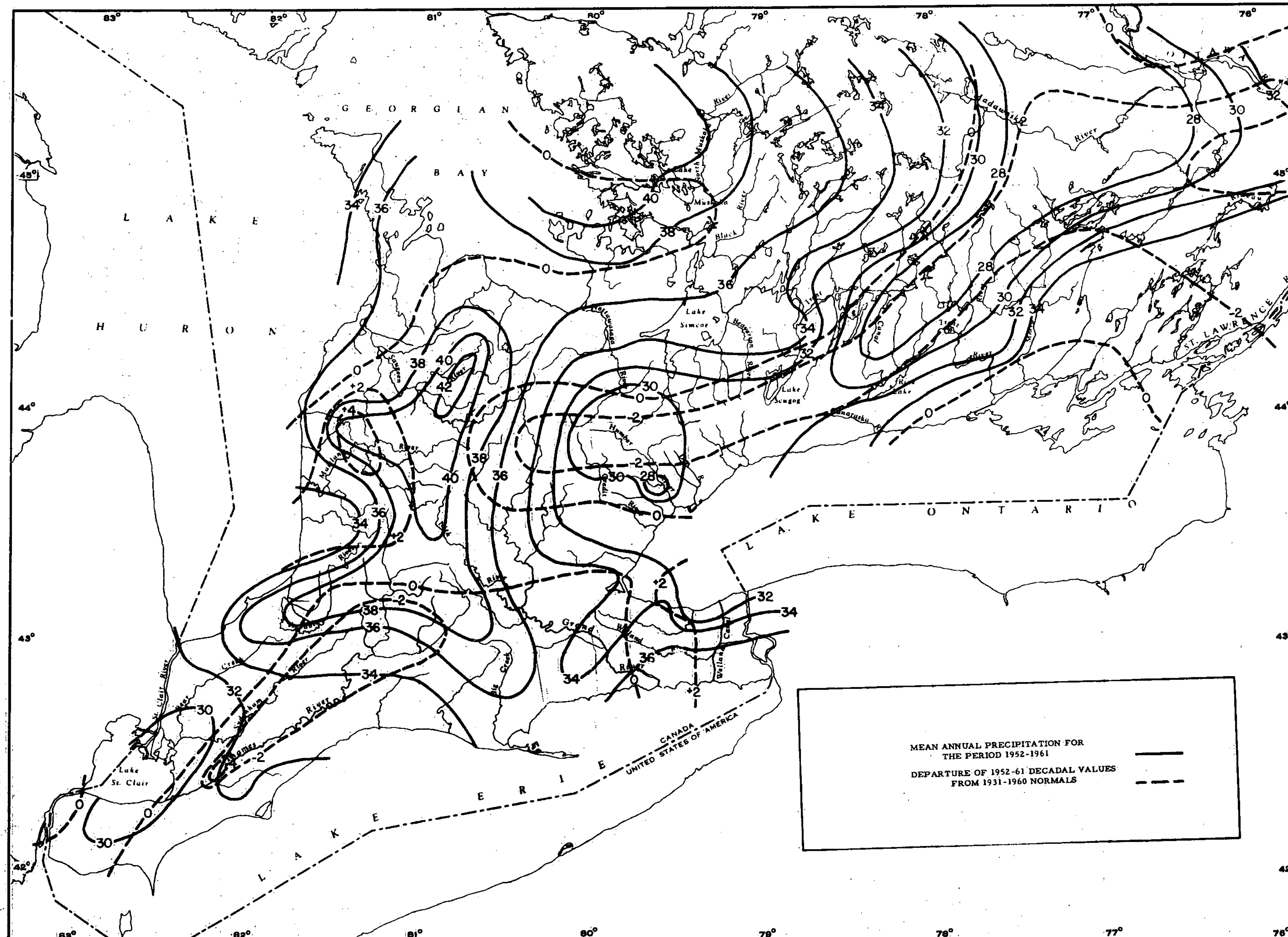


Figure 3. Mean annual precipitation in inches for the period 1952 to 1961, with departures from 1931-60 normals.

TABLE 2

COMPARISON OF MEAN FLOW FOR 1952-61 WITH LONG-TERM MEAN FLOW

Station	Long Term		1952-61	1952-61 as a Percentage of Long Term
	No. of Years	Mean Flow cfs	Mean Flow cfs	
Black River near Washago	46	772	754	98 %
Credit River near Cataract	46	61	65	106
Grand River at Galt	48	1,190	1,270	107
Moira River near Foxboro	46	1,070	989	92
Saugeen River near Port Elgin	47	1,970	1,940	98
Saugeen River near Walkerton	47	1,050	1,070	102
Thames River at Ealing	46	484	478	99
Trent River at Heely Falls	50	3,100	3,040	98
Mean of ratios.				100 %
Standard deviation of ratios.				4.9 %

of equal mean annual runoff is shown on Figure 4. The solid lines are supported by actual streamflow records while the broken lines are based on the isohyetal map and an extension of the water loss pattern.

As an indication of the reliability of the lines of equal runoff, the mean flows computed from these lines are compared in Table 3 with the recorded flows for 1952-61 for those stations with little or no regulation. Also listed are the deviations of the computed values from the recorded values expressed both in cubic feet per second and in per cent. These deviations are plotted on normal probability paper in Figure 5. It may be seen that they are normally distributed with a mean of 0 per cent and a standard deviation of ± 15 per cent. Thus, the lines of equal runoff given in Figure 4 may be used to estimate the mean runoff for the period 1952-61 from any drainage area in the region with an accuracy that may be sufficient for many purposes.

From the data in Table 2 it was established that the mean annual flow, based on the period 1952-61, can be assumed to be equivalent to that for a longer period of 46 to 50 years, within a standard error of about 5 per cent. Thus estimates of mean annual runoff for a 46 to 50-year period may be obtained from Figure 4 with a standard error of about 16 per cent (root of sum of squares of 15 per cent and 5 per cent). Going further, it must be considered that the streamflow records upon which Figure 4 was based are themselves samples of a much larger population. The mean of a 46 to 50-year record of annual flows in Southern Ontario may be shown to have a sampling error of about 5 per cent, providing we may assume that the record is a random sample. Combining this error with those mentioned previously, we arrive at a value of about 17 per cent as the standard error in the estimates of annual means derived from Figure 4. It must be emphasized that this is a relatively superficial analysis of the errors involved but it does provide an indication of the accuracy to be expected in the use of Figure 4 for a specific problem.

The isohyetal map in Figure 3 shows the departure of the 1952-61 decadal values of mean annual precipitation from the 1931-60 normals. The user might wish to consider these values in conjunction with the lines of equal runoff in Figure 4. They provide some indication as to where and in which direction the long-term mean annual runoff is most likely to differ from the values obtained from Figure 4.

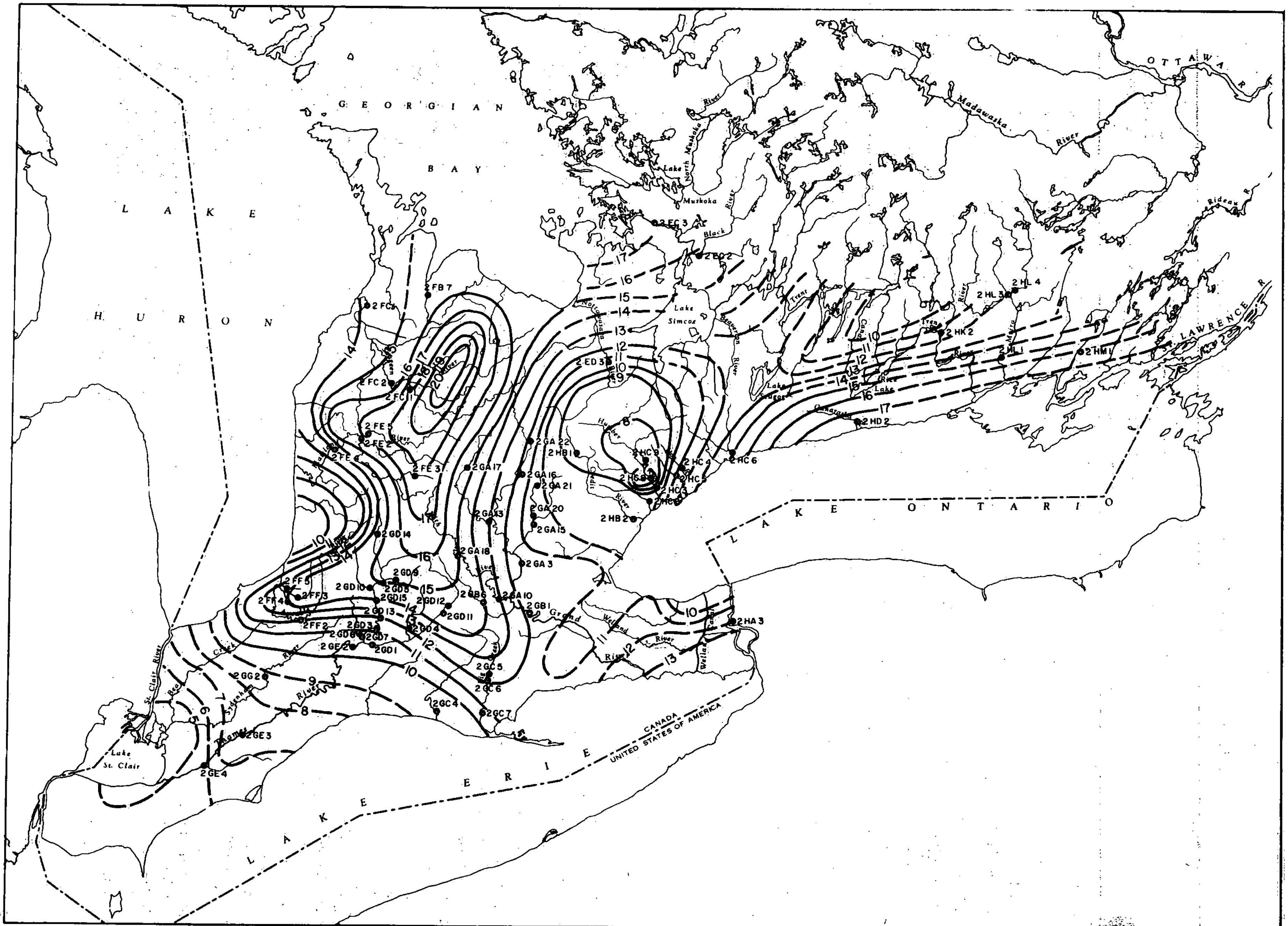


Figure 4. Mean annual runoff in inches for the period 1952 to 1961.

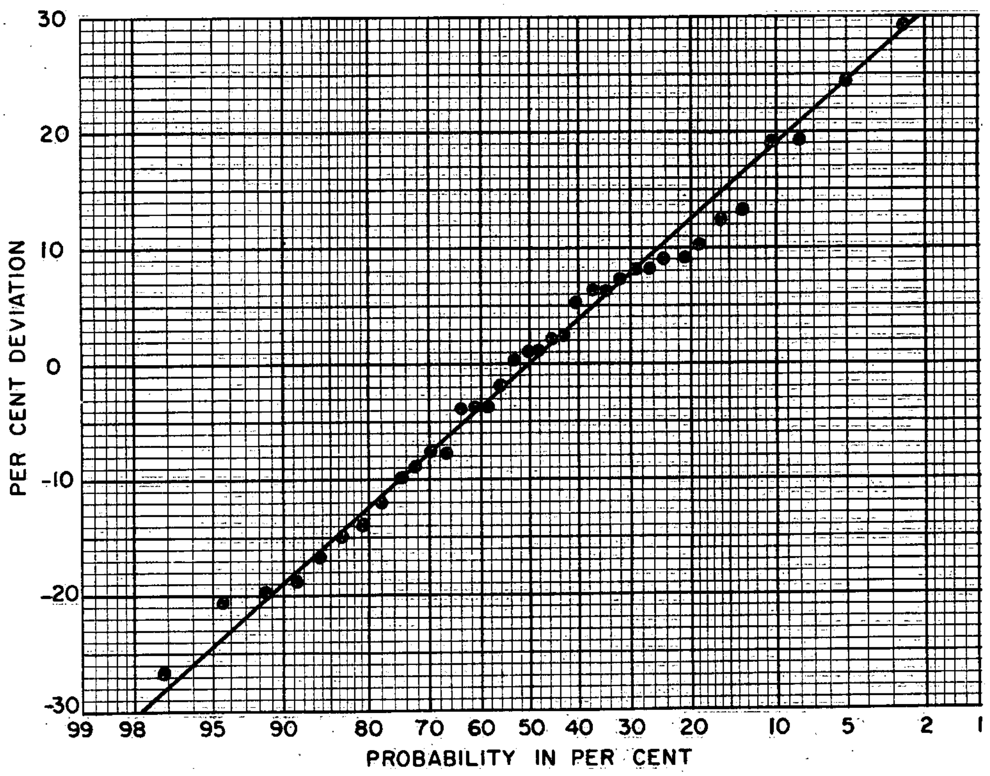


Figure 5. Deviations in per cent of computed mean flow from recorded mean flow.

COEFFICIENT OF VARIATION OF ANNUAL FLOW

The coefficient of variation of the annual flow (C_V) is defined as the standard deviation of the annual flow (S_Q) divided by the mean flow ($\overline{Q}$):

$$C_V = \frac{S_Q}{\overline{Q}} \qquad (1)$$

The coefficient of variation is a dimensionless ratio which has a low value when there is little variation of the annual flow from year to year and a high value when the variation is large.

The coefficient of variation is known to change but little within a particular region (Langbein 1960, Kalinin 1960). When values of C_V for the 59 stations in Southern Ontario were computed and plotted on a map at the centres of the drainage basins, no change in value with geographical location was apparent. It has been assumed, therefore, that the whole of Southern Ontario may be treated as one region.

Langbein (1960) suggests the possibility of correlating the coefficient of variation with the annual runoff and the catchment area. A graphical multiple correlation of these parameters for the Southern Ontario stations, however, gave very poor results. This may have

TABLE 3

COMPARISON OF COMPUTED MEAN FLOW WITH RECORDED MEAN FLOW

Station	Mean Annual Flow 1952-61			
	Recorded cfs	Computed cfs	Deviation	
			cfs	Per cent
Saugeen River near Walkerton	1,080	1,100	+10	+ 1.0
Saugeen River near Port Elgin	1,940	1,860	-80	- 4.1
Carrick Creek near Carlsruhe	68	88	+20	+29.4
Maitland River above Wingham	257	274	+17	+ 6.6
Maitland River below Wingham	709	800	+91	+12.8
Maitland River near Donnybrook	812	862	+50	+ 6.2
Middle Maitland River near Listowel	36	39	+ 3	+ 8.3
Ausable River near Springbank	313	314	+ 1	+ 0.3
Parkhill Creek at Parkhill	42	47	+ 5	+11.9
Sydenham River at Alvinston	262	208	-54	-20.6
Thames River at Woodstock	91	108	+17	+18.7
Thames River near Ealing	478	509	+31	+ 6.5
Cedar Creek at Woodstock	34	37	+ 3	+ 8.8
Trout Creek near St. Mary's	62	61	- 1	- 1.6
Fish Creek near Prospect Hill	52	62	+10	+19.2
Medway River near London	75	66	- 9	-12.0
Big Otter Creek near Vienna	256	232	-24	- 9.4
Big Creek near Walsingham	209	212	+ 3	+ 1.4
Conestogo River at Drayton	123	134	+11	+ 8.9
Speed River above Guelph	88	81	- 7	- 8.0
Speed River below Guelph	199	172	-27	-13.6
Luttrells Creek near Oustic	22	16	- 6	-27.3
Nith River at New Hamburg	198	245	+47	+23.8
Nith River near Canning	370	400	+30	+ 8.1
Horner Creek near Princeton	61	64	+ 3	+ 4.9
Credit River near Cataract	65	54	-11	-16.9
Credit River near Erindale	262	213	-49	-18.7
Etobicoke Creek near Summerville	41	42	+ 1	+ 2.4
Humber River at Weston	204	174	-30	-14.7
East Humber River near Pine Grove	42	43	+ 1	+ 2.4
West Humber River near Thistletown	40	44	+ 4	+10.0
Don River at York Mills	25	23	- 2	- 8.0
Little Don River at Lansing	41	33	- 8	-19.6
Duffin Creek at Pickering	104	100	- 4	- 3.8
Ganaraska River near Dale	129	115	-14	-10.8
Moira River near Foxboro	989	850	-139	-14.1
Black River near Actinolite	157	117	-40	-25.5
Skootamatta River at Actinolite	260	210	-50	-19.2
Napanee River near Napanee	303	301	- 2	- 0.7

been due to very large errors in some of the values of C_V derived from the station records. This is to be expected when C_V is computed from short periods of record.

Kalinin (1960) suggests a relationship between the coefficient of variation and the catchment area only. A graphical correlation between C_V and the drainage area (A) in square miles gives the following relation for Southern Ontario:

$$C_V = 0.35 - 0.03 \log (A + 1) \qquad (2)$$

While there is a considerable scatter of the points, the majority fall within one standard error of their computed value from the line of relation.

In computing a frequency curve of annual flow, it should be noted that a large error in the assumed value of C_V will result in relatively small errors in flow for probabilities of exceedance between 10 per cent and 90 per cent. Where estimates of flow in this range of probabilities are required, it will generally be satisfactory to use equation (2) to estimate the value of the coefficient of variation for any drainage basin in Southern Ontario. Where it is necessary to use the equation to estimate flows with extremely high or low probability, the results should be treated with caution.

COEFFICIENT OF SKEW

The coefficient of skew (C_S) depends on the third power of the deviations and, therefore, the computation of C_S from a series of hydrologic observations, even a long series, is subject to very large errors. In practice, a value for C_S is usually derived by assuming successive values and testing the resulting theoretical curves for goodness of fit with the observed data. The value of C_S which gives the best fit is adopted. This procedure was carried out for the long-term stations in Southern Ontario and it was found that a coefficient of skew equal to twice the coefficient of variation gave a good fit to the recorded annual flow series in all cases.

$$C_S = 2\ C_V \qquad (3)$$

For Southern Ontario, therefore, it is suggested that equation (3) be used for annual flow distributions, since this will probably give a more reliable theoretical curve than one obtained by fitting a curve to a short period of observed data.

CONSTRUCTION OF FREQUENCY CURVES

In this study, the Pearson Type III curve has been used exclusively for the theoretical distribution of annual flows. Table 20-4 in Applied Hydrology (Linsley, Kohler and Paulhus 1949) gives the skew factor (ϕ) for various frequencies and coefficients of skew. A more detailed table is given by Kalinin (1960). The factors given in these tables, when multiplied by the standard deviation and added to the mean, define the frequency curve. Thus the flow (q), at a given probability of exceedance, is given by:

$$q = \phi\ C_V\ \overline{Q} + \overline{Q} \qquad (4)$$

$$= \overline{Q}\ (\phi\ C_V + 1) \qquad (5)$$

The examples which follow show how these equations are used in computing frequency curves.

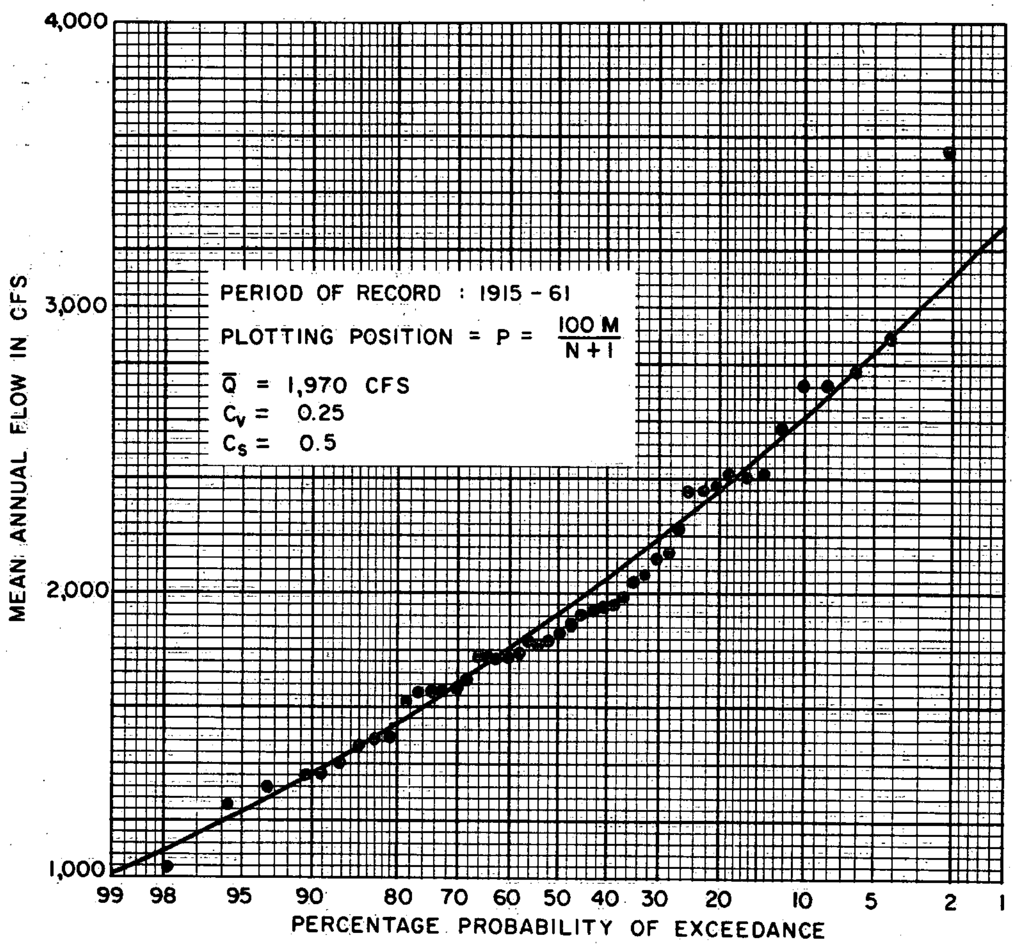


Figure 6. Frequency curve of annual flow for Saugeen River near Port Elgin.

FITTING THE THEORETICAL CURVE TO A LONG SERIES OF OBSERVED DATA

The 47 annual flows recorded on the Saugeen River near Port Elgin are listed in order of magnitude in Table 4. The mean of the 47 annual flows ($\overline{Q}$) is 1970 cfs. The standard deviation (S_Q), computed by the usual statistical methods, is 491 cfs; thus the coefficient of variation (C_V) is 491/1970 or 0.25. By equation (3), the coefficient of skew (C_S) is $2C_V$ or 0.5. Some anchor points for the theoretical frequency curve were computed, using equation (5). The computations are shown in Table 5 and the resulting curve in Figure 6. The recorded annual flows are also shown in Figure 6. Plotting positions for the percentage probability of exceedance (P) of each of the annual flows was computed from the formula $P = 100\ m/(n+1)$, where m = order of magnitude and n = 47 in this example. It may be noted that the curve is a reasonably good fit to the points.

TABLE 4

ANNUAL FLOW DATA FOR THE SAUGEEN RIVER NEAR PORT ELGIN

Mean Annual Flow Q cfs	Order of Magnitude m	Probability of Exceedance P per cent	Mean Annual Flow Q cfs	Order of Magnitude m	Probability of Exceedance P per cent
3,560	1	2.1	1,850	25	52.1
2,900	2	4.2	1,850	26	54.2
2,780	3	6.2	1,840	27	56.2
2,730	4	8.3	1,800	28	58.3
2,730	5	10.4	1,790	29	60.4
2,580	6	12.5	1,790	30	62.5
2,420	7	14.6	1,790	31	64.6
2,420	8	16.7	1,780	32	66.7
2,420	9	18.8	1,700	33	68.8
2,380	10	20.8	1,670	34	70.8
2,370	11	22.9	1,660	35	72.9
2,360	12	25.0	1,660	36	75.0
2,230	13	27.1	1,650	37	77.1
2,140	14	29.2	1,620	38	79.2
2,120	15	31.3	1,510	39	81.2
2,070	16	33.3	1,500	40	83.3
2,050	17	35.4	1,460	41	85.4
1,990	18	37.5	1,410	42	87.5
1,970	19	39.6	1,370	43	89.6
1,960	20	41.7	1,370	44	91.7
1,940	21	43.8	1,320	45	93.8
1,930	22	45.8	1,270	46	95.8
1,890	23	47.9	1,040	47	97.9
1,860	24	50.0			

TABLE 5

COMPUTATION OF FREQUENCY CURVE OF ANNUAL FLOW FOR SAUGEEN RIVER NEAR PORT ELGIN

	Percentage Probability of Exceedance						
	99	95	80	50	20	5	1
ϕ	-1.96	-1.49	-0.85	-0.08	0.81	1.77	2.68
$\phi\ C_V$	-0.490	-0.372	-0.212	-0.020	0.202	0.443	0.670
$\phi\ C_V + 1$	0.510	0.628	0.788	0.980	1.202	1.443	1.670
q	1,010	1,240	1,550	1,930	2,370	2,840	3,290

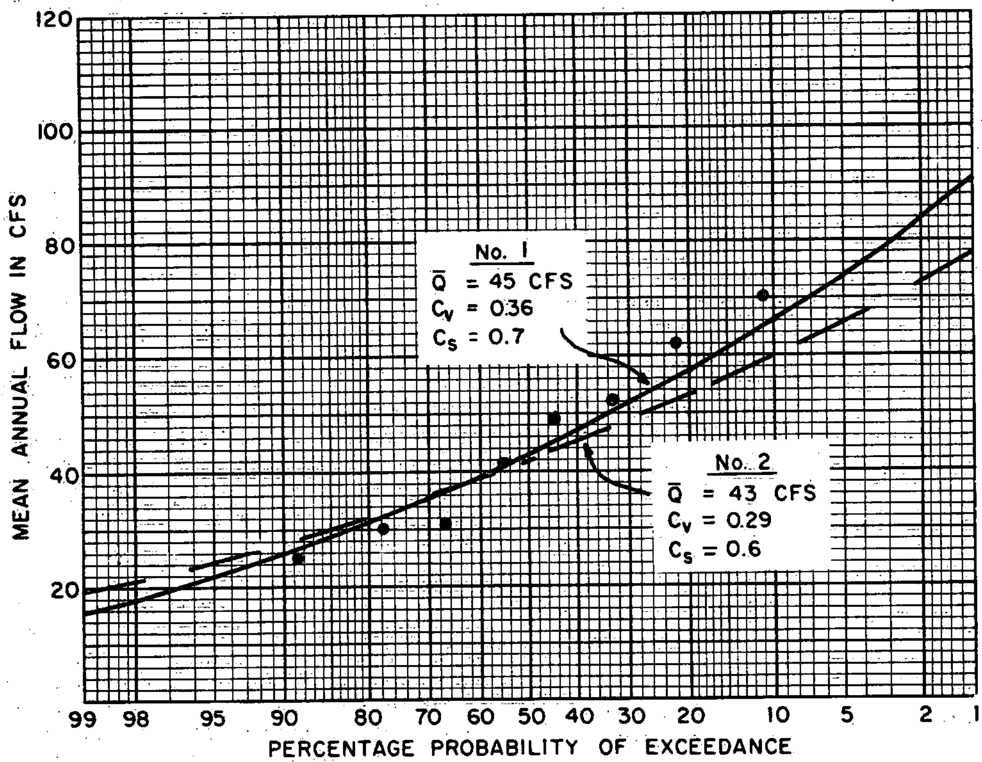


Figure 7. Frequency curve of annual flow for East Humber River near Pine Grove.

FITTING THE THEORETICAL CURVE TO A SHORT SERIES OF OBSERVED DATA

When only a short period of record is available at the point of interest, the following alternatives for constructing a frequency curve for annual flow may be considered:

(a) Use of equation (5) after computing values for $\overline{Q}$ and C_V from the recorded flows, just as described for a long period of record.

(b) Use of equation (5) after determining value for $\overline{Q}$ from Figure 4 and computing value of C_V from equation (2), just as would be done if there were no records.

It remains with the hydrologist to select one of these two alternatives, or perhaps some combination of them, for a specific application.

As an illustration, the frequency curves shown in Figure 7 for the East Humber River near Pine Grove have been developed by the two procedures.

The observed data from the eight years of record on the East Humber River station are listed in Table 6. The mean of the eight annual flows $(\overline{Q})$ is 45 cfs, the coefficient of variation (C_V) is 0.36 and the coefficient of skew (C_S) is taken as 2 C_V or 0.7. The frequency curve based on the recorded flows is computed in Table 7 and is shown in Figure 7. The recorded flows, plotted by the 100 m/(n+1) formula, are also shown. The computed curve (No. 1) must be considered more reliable than a curve drawn by eye through only eight recorded flows. It is doubtful if a significantly better fit could be obtained by assuming other values for the coefficient of skew.

TABLE 6

ANNUAL FLOW DATA FOR THE EAST HUMBER RIVER NEAR PINE GROVE

Mean Annual Flow Q cfs	Order of Magnitude m	Probability of Exceedance P per cent
70	1	11.1
62	2	22.2
52	3	33.4
49	4	44.5
41	5	55.6
31	6	66.7
30	7	77.8
25	8	88.9

To illustrate the alternative procedure for estimating the frequency curve for short-term stations, the existing records for the East Humber River near Pine Grove were ignored.

The first step was to delineate the watershed on a topographic map and determine the area of the drainage basin. The drainage basin boundary was then transferred to the runoff map on Figure 4 and the mean runoff determined by planimetering the areas between adjacent isorunoff lines. The area of drainage basin was found to be 75 square miles and the mean runoff 43 cfs.

The coefficient of variation was computed from equation (2):

$$C_V = 0.35 - 0.03 \log (75 + 1)$$

$$= 0.29$$

The coefficient of skew was computed from equation (3):

$$C_s = 2\ C_V = 0.6$$

Using these values for C_V and C_s, a frequency curve (No. 2) was developed by the computations shown in Table 8. This curve is also shown on Figure 7. It is not a good fit to the points from the eight years of record and does not appear very reliable at first sight. Further study will show, however, that it may in fact be a better curve than the one based on the actual record.

The highest annual flow in the eight years of record, 70 cfs, has a probability of exceedance of about 3 per cent according to the frequency curve No. 2 and the lowest flow of 25 cfs has a probability of 95 per cent. The 70 cfs flow occurred in 1955 and 25 cfs flow in 1958. The nearest long-term station is the Credit River near Cataract, where records have been obtained for 46 years. The best fit frequency curve for the Credit River gives a frequency of exceedance of 4 per cent for the 1955 flow and 98 per cent for the 1958 flow. These percentages agree fairly well with those from the No. 2 curve for the East Humber River. The No. 2 frequency curve for the East Humber River, therefore, is not unreasonable and might be used in preference to the No. 1 curve which is based on the eight years of record.

TABLE 7

COMPUTATION OF FREQUENCY CURVE OF ANNUAL FLOW FOR EAST HUMBER RIVER NEAR PINE GROVE FROM RECORDED FLOWS (Curve No. 1 on Fig. 7)

	Percentage Probability of Exceedance						
	99	95	80	50	20	5	1
ϕ	-1.81	-1.42	-0.85	-0.12	0.79	1.82	2.82
$\phi\ C_V$	-0.651	-0.510	-0.306	-0.043	0.284	0.655	1.015
$\phi\ C_V + 1$	0.349	0.490	0.694	0.957	1.284	1.655	2.015
q	15.7	22.1	31.2	43	58	74	91

TABLE 8

COMPUTATION OF FREQUENCY CURVE OF ANNUAL FLOW FOR EAST HUMBER RIVER NEAR PINE GROVE ASSUMING NO FLOW RECORDS (Curve No. 2 on Fig. 7)

	Percentage Probability of Exceedance						
	99	95	80	50	20	5	1
ϕ	-1.88	-1.45	-0.86	-0.09	0.80	1.79	2.77
$\phi\ C_V$	-0.545	-0.420	-0.250	-0.026	0.232	0.518	0.803
$\phi\ C_V + 1$	0.455	0.580	0.750	0.974	1.232	1.518	1.803
q	19.6	25.0	32.2	42	53	65	78

ESTIMATING THE FREQUENCY CURVE FOR AN UNGAUGED STREAM

A frequency curve for annual flows may be produced for any catchment area in the region of Southern Ontario covered by the runoff lines in Figure 4, the basic requirement being a topographic map on which the catchment area can be delineated. The procedure to be followed is the same as described in the preceding section for developing Curve No. 2 for East Humber River near Pine Grove.

DISTRIBUTION OF FLOW WITHIN THE YEAR

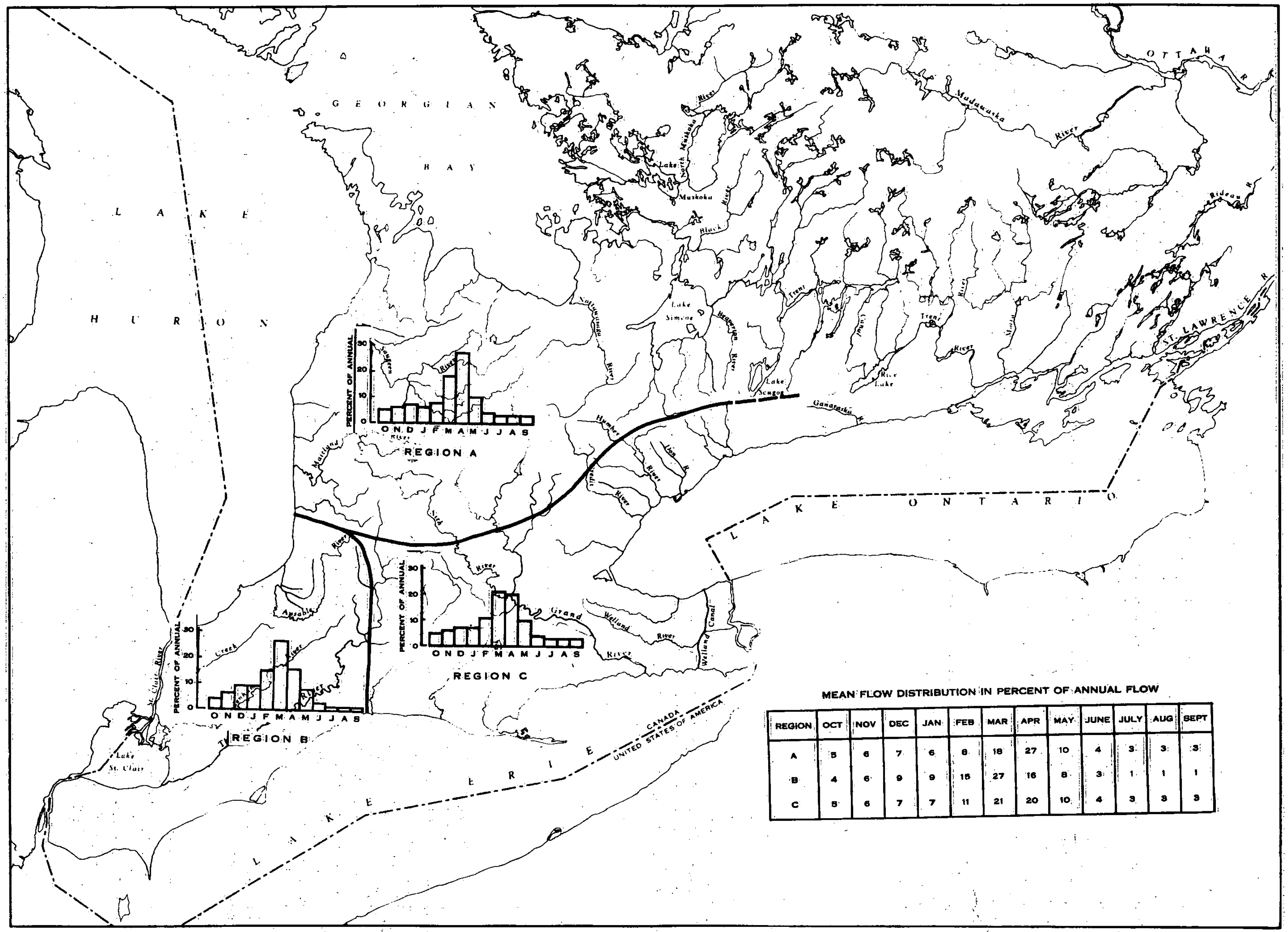
In general, the pattern of flow within the year tends to be uniform throughout Southern Ontario. The highest flows usually occur in March or April and lowest flows in July, August and September. However, there is a discernible difference in the time of occurrence of the high flows during March and April in different areas of Southern Ontario. In the northern area, the highest flow usually occurs in April; in the southwest, in March; in the southeast, March and April flows are usually of about the same magnitude. These areas have been designated on Figure 8 as Region A, Region B and Region C, respectively.

Figure 8 also shows the typical hydrographs of monthly flow for the three regions and a table giving the mean monthly flow distribution as a percentage of annual flow. These flow distributions were obtained by computing, region by region, the means of the distributions for the gauging stations not affected by major regulation.

Although the table of mean flow distribution can be used to derive a fairly reliable estimate of the average monthly hydrograph on any stream in the area, it must be emphasized that the actual hydrograph in any particular year may differ very considerably from the mean hydrograph.

A typical monthly hydrograph of any desired frequency of occurence may be obtained from the average hydrograph and the frequency curve of annual flow. It is possible also to construct a duration curve of monthly flow from the same data, although this is a somewhat laborious procedure.

It should be borne in mind that the typical hydrograph is applicable only to streams which are not subject to major regulation.



MEAN FLOW DISTRIBUTION IN PERCENT OF ANNUAL FLOW

REGION	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT
A	5	6	7	6	8	18	27	10	4	3	3	3
B	4	6	9	9	15	27	16	8	3	1	1	1
C	5	6	7	7	11	21	20	10	4	3	3	3

Figure 8. Mean flow distribution as a percentage of annual flow.

HYDROMETRIC NETWORK EXPANSION

There are areas in Southern Ontario for which very little streamflow information is available. While the results of the study described in this report may be used to estimate flow in these areas, hydrometric data should be gathered to confirm the estimates. Accordingly, it is recommended that streams in the following areas or categories be considered when any expansion of the existing hydrometric network is planned:

(a) The area south and west of London.

(b) The Niagara Peninsula and adjoining areas west to Brantford and north to Guelph.

(c) Smaller streams draining into Lake Huron and Georgian Bay.

(d) Streams draining into Lake Simcoe, particularly from the south.

(e) The area between Oshawa and Kingston south of the Shield.

(f) The Muskoka area and Algonquin Park.

Because of the extremely complex physiography of Southern Ontario resulting from repeated glaciation, a more complete knowledge of streamflow in the region demands that greater attention be paid than heretofore to small basins with drainage areas in the range of about 10 to 100 square miles. Recording gauges, rather than manual gauges, should be installed in these small drainage basins, if worthwhile records are to be obtained. Whereas it is true that streamflow from a large drainage area is the integration of the effects of all the runoff producing characteristics of that area, it is also true that separating the different characteristics in such basins can be a difficult process. A better knowledge of the hydrology of some of the smaller basins would be of assistance in this problem.

CONCLUSION

In designing a water-use project, probably the fundamental element which will contribute most to a successful design is a sound knowledge of the quantity of water available to the completed project and the characteristics of flow of that water.

Ideally, of course, the data upon which the hydrologist's calculations are based should be derived from actual hydrometric records extending over very lengthy periods. In practice, this is not often possible.

The method of estimating runoff data outlined in this study is offered to the hydrologist faced with the problem of meagre or non-existent streamflow records as a possible working alternative.

REFERENCES

Kalinin, G.P. 1960. Calculation and Forecasts of streamflow from scanty hydrometric readings. Hydrometric Networks and Methods. WMO Flood Control Series No. 15.

Langbein, W.B. 1960. Hydrologic data networks and methods of extrapolating or extending available hydrologic data. Hydrometric Networks and Methods. WMO Flood Control Series No. 15.

Linsley, R.K., M.A. Kohler and J.L.H. Paulhus. 1949. Applied Hydrology. McGraw-Hill.

Other TECHNICAL BULLETINS issued:

No. 1 E. P. Collier and A. Coulson, October 1965. Natural flow of North Saskatchewan River at Alberta - Saskatchewan boundary by the rim station method.

Discusses methods of estimating the natural flow of the North Saskatchewan River at the provincial boundary by simple regression with the flow at Rocky Mountain House and also by multiple regression techniques involving precipitation.

No. 2 R. O'N. Lyons, November 1965. LACOR - Program for streamflow correlation.

A program for the IBM 1620 computer to correlate streamflow records in terms of deviations in log units from the geometric mean of each calendar month's discharges.

No. 3 A. Coulson, 1966. Tables for computing and plotting flood frequency curves.

A compilation of tables for the computation and plotting of flood frequency curves according to the first asymptotic distribution of extreme values (the Gumbel method). A worked example of the use of the tables is included.

No. 4 A. Coulson, 1967. Flood frequencies of Nova Scotia streams.

Recorded flood flows have been analysed on a regional basis and a method for estimating the flood frequency curve for any stream in Nova Scotia is outlined.

No. 5 A Coulson and P. N. Gross, 1967. Measurement of the physical characteristics of drainage basins.

Methods of obtaining quantitative descriptions of certain physical characteristics of drainage basins are outlined using as examples Marmot Creek and Streeter Creek, two of the experimental basins of the East Slopes (Alberta) Watershed Research Program.

No. 6 D. A. Davis and A. Coulson, 1967. Hydrologic zones in the headwaters of the Saskatchewan River.

The Saskatchewan River headwaters area of Alberta has been divided into seven by hydrologically similar zones, based on correlations of mean monthly recorded stream discharge.

Copies of the technical bulletins are available free from:

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