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The probability of climatically derived seasonal surface runoff in southern Ontario.

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THE PROBABILITY OF CLIMATICALLY DERIVED SEASONAL SURFACE RUNOFF IN SOUTHERN ONTARIO

by

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ABSTRACT

This thesis presents maps of the probability of climatically derived seasonal surface runoff in southern Ontario for the four seasons based on climatic data of temperature and precipitation from about forty-one climatic stations. The method, which is based on the Phillips modification to the Thornthwaite-Mather water balance model is discussed and tested in a small watershed, Duffin Creek. From the correlations obtained between measured runoff and runoff computed by means of the Thornthwaite-Mather and Phillips models, it was found that the Phillips model is a better estimator of runoff for southern Ontario.

The resulting runoff probability maps based on the Phillips model indicate that highest probable amount of runoff is likely to occur in the spring season. In all seasons, the maximum probable runoff is likely to occur in the areas to the east of Georgian Bay and Lake Huron.

ACKNOWLEDGMENTS

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Gratitude is also extended to Professor John D. Jacobs and to Professor S. P. Chee (Civil Engineering) for their many suggestions. Special appreciation is expressed to Professor Frank C. Innes for his cooperation in providing necessary facilities.

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CHAPTER 1

1.1 Introduction

It is well known that runoff at a place varies from year to year and month to month. For agricultural and hydrological purposes it is desirable to know the variability of such runoff as well as its average amount. For any area, it is important to express runoff in terms of its probabilistic occurrence.

Precipitation probabilities which have been studied by many authors, are usually derived from measured data of precipitation. Similarly, it would be desirable to use actual measured values of runoff for constructing maps of runoff probability. However, this ideal is difficult to achieve. For example, in southern Ontario only twenty-four drainage basins have runoff records of more than 15 to 20 years duration. The climatological stations for the same period of record outnumber by three to one the number of hydrometric sites with comparable records. Besides being more numerous, climatological installations have the additional advantage of being more uniformly distributed and less subject to instrumental failure in their measurement. Thus, one of the classical techniques in hydrometeorology is the augmentation of short streamflow records by interpolation from climatological and hydrometeorological data. Where streamflow records are inadequate, estimates of runoff can be obtained by comparing precipitation with evaporation losses.

Studies of runoff are of importance for planning irrigational schemes, water resource management, water transportation and agricultural operations. Especially in Canada, which has about 10 per cent of the world's fresh water resources, water surplus, that amount of water that annually and seasonally runs off the surface of the land, and its time and probability of occurrence is of importance to industry and agriculture. At the present time in southern Ontario, information on runoff is desirable because of its importance to the pollution flowing from agricultural and forest lands into the boundary waters of the Great Lakes System. In addition, the province is one of the most densely populated and highly industrialized areas in Canada. Although it contains only 11 per cent of the total improved farmland, the area produces about 30 per cent of the total value of farm products, ranking first in agricultural production on a per unit basis. Approximately half of the fruit, two-thirds of the vegetables and over 40 per cent of Canadian dairy products come from this area.

The International Joint Commission of the United States and Canada has set up an International Reference Group on Great Lakes Pollution from Land Use Activities, PLUARG. One of the tasks of this group (Task C) is to carry out intensive studies of a small number of representative watersheds, selected and conducted to permit some extrapolation of data to the entire Great Lakes basin and to relate contamination of the water quality, which may be found at river mouths on the Great Lakes, to specific land uses and practices. The present study is part of this task.

For the quantitative estimation of runoff the use of information collected from the hydrological network provides a new dimension for the climatologist. No longer are the studies on runoff limited to gauged networks or where streamflow records are numerous; however, climatological parameters in computing runoff have their own limitations, as these parameters cannot take into account all the factors that contribute to runoff. The present study makes use of climatological data in an effort to obtain information on seasonal runoff.

1.2 The problem and study area

Runoff probabilities on a seasonal basis are unknown in the southern Ontario region. In the present study, an attempt is made to construct maps of runoff probabilities for the four seasons. It is hoped such maps will be useful to resource planners, engineers involved in the construction of dams and water power developments, both for domestic and industrial purposes, and to assess the amounts of pollutants entering into the Great Lakes System.

The study area for the present investigation is southern Ontario as defined by Brown (1968). The region is bounded by the Great Lakes on the south, west and northwest, and the Ottawa and St. Lawrence Rivers on the east. From the level plains bordering Lakes Erie and Huron, there is a gradual rise in elevation in a generally northeasterly direction to the Dundalk uplands. The crown of this upland stands about 300 meters above the lakes and terminates at the brow of the Blue Mountain section of the Niagara Escarpment, overlooking the lower lands to the east and Georgian Bay to the north.

1.3 Water holding capacity of soils

In order to compute the water balance at a place it is necessary to know information on the water holding capacity of the depth of soil for which the balance is to be computed. The Soil Association of Southern Ontario map (John, 1971) shows eight major divisions and sixty-eight minor ones in the region. Many of the southern Ontario soils have been grouped and reclassified by John (1971) according to Laboratory of Climatology system using the Thornthwaite-Mather (1957) water balance model. His classification shows five major types, fine sandy loam in the northwest and toward the south, silt loam soils around the Dundalk uplands and part of Muskoka area, clay loam and clay type of soils on the bordering areas on the east and western portions of the region.

Soil and vegetation are the determining factors of the water holding capacity of soil at a place. Sandy soils hold less water per unit depth than clay soils. Based on the soil types and the land use patterns in southern Ontario earlier workers (Sanderson, 1966; John, 1971 and Phillips, 1975) used soil capacities ranging from 152mm. to 330mm.

1.4 Climatic conditions in southern Ontario

Climate varies considerably across the whole region because of the nature of the climatic controls and physiographic setting in the distribution of land and water bodies.

Precipitation

Brown (1968) reported the mean annual precipitation distribution in southern Ontario. The areas of highest precipitation are found at elevations of 360 to 420 meters on the slopes east of Lake Huron and Georgian Bay and receive 1020 millimeters. The average precipitation ranges from about 660 in the southwest (Essex County) to 1020 millimeters in the area west of Georgian Bay.

Snowfall in southern Ontario is one of the elements that affect the seasonal distribution of the runoff pattern. The frequency of shifting low pressure systems, cold arctic air masses in winter, and the extent of ice cover over the lakes are important controls in determining the amount of snow. In southern Ontario, snowfall accounts for about 30 per cent of total annual precipitation in the Leamington region (Brown, 1968). The mean annual snowfall in the region ranges from over 2790 millimeters in the Huron, Georgian Bay and Muskoka regions to less than 1220 millimeters near Hamilton and to about 890 millimeters in the Kent-Essex region.

Evapotranspiration and the water balance

The concept of potential evapotranspiration, the amount of water loss due to evaporation and transpiration from an extensive, closed homogeneous cover of vegetation that never suffers from a lack of water, was introduced to the climatic literature by Thornthwaite (1948) and subsequently used to define other water budget and moisture parameters.

Potential evapotranspiration, when expressed in terms of depth of water alone, is an index of both thermal efficiency and water needed for growth of plants. Average annual potential evapotranspiration and mean annual actual evapotranspiration for southern Ontario as reported by

Brown (1968) according to the 1948 system of Thornthwaite indicate that most of southern Ontario has an annual potential evapotranspiration of at least 530 millimeters with a maximum of about 660 millimeters over the Leamington region, while lowest values are found in the Dundalk upland and the Algonquin Park region.

Variations in actual evapotranspiration occur when soil moisture is depleted by evapotranspiration and subsequently replaced by precipitation. The soil supply is at potential rate only during periods of rain or irrigation; at other times it is less than potential rate. By assuming a soil moisture holding capacity, Thornthwaite obtained actual annual estimates of water used by crops from a simple accounting of evapotranspiration. The mean values of actual evapotranspiration in southern Ontario are about 530 millimeters and show regional variation. The highest value, 580 millimeters, is found just northwest of London.

In southern Ontario during the cool half-year precipitation greatly exceeds water need and, after the soil moisture has been recharged, moisture surplus occurs. During the periods of rain, rainfall replenishes soil moisture until the soil moisture holding capacity is reached. Precipitation in excess of that needed to saturate the soil is considered as a surplus which runs off and is available as surface runoff, or percolates to the water table. Much of the surplus water in southern

Ontario is deposited on the ground as snow and usually runoff does not take place in large quantities until the spring season. Table 1 illustrates the bookkeeping procedure for computing the monthly estimates of actual evapotranspiration and climatic water budget for Pickering, Ontario, as described by Thornthwaite and Mather (1955) and the details of the computational procedure may be obtained from "Instructions and Tables for Computing Potential Evapotranspiration and the Water Balance" (Thornthwaite and Mather, 1957).

Figure 1 indicates the water surplus map according to Sanderson and Phillips (1967). One can observe great differences in annual water surplus, from 150 millimeters in Essex County to more than 500 millimeters in the Algonquin Park uplands.

Month to month variation in runoff across southern Ontario can be seen in Figure 2, representative hydrographs based on hydrometric data (Surface Water Data) for Duffin Creek above Pickering and the Thames River at Ingersoll. The hydrographs indicate that highest runoff occurs during the winter and spring seasons (29 and 48% respectively) while summer and fall seasons have low runoff (11 and 12% respectively). Winter and spring runoff together account for about 74 per cent of the total annual runoff, while summer and fall amounts constitute for only 26 per cent.

The spatial variability of runoff is due to the

TABLE 1

CLIMATIC WATER BALANCE (THORNTHWAITE AND MATHER, 1955)

PICKERING, ONTARIO - 1970

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
TEMP	-8.30	-6.10	0.80	7.10	11.20	18.20	20.60	20.70	16.10	10.90	5.30	-4.00	7.71
UNPE	0	0	0	1.0	1.8	3.0	3.3	3.5	2.5	1.8	0.7	0	
ADPE	0	0	0	34.0	67.3	117.0	128.0	128.0	79.2	50.5	18.5	0	622.5
PCPN	51.7	31.8	50.2	84.6	62.7	30.0	86.9	49.5	65.0	77.2	46.0	73.4	709.0
P-PE	51.7	31.8	50.2	50.6	-4.6	-87.0	-41.1	-78.5	-14.2	26.7	27.5	73.4	
APWL	0	0	0	0	-4.6	-91.6	-132.7	-211.2	-225.4	-138.6	-82.3	0	
STOR	251.1	282.9	152.4	152.4	148.2	83.6	64.0	38.1	34.8	61.5	89.0	158.2	
DST	0	0	0	0	-4.2	-64.6	-19.6	-25.9	-3.3	26.7	27.5	69.2	
AEV	0	0	0	34.0	66.9	94.6	106.5	75.4	68.3	50.5	18.5	0	514.7
DEF	0	0	0	0	0.4	22.4	21.5	52.6	10.9	0	0	0	107.8
SURP	0	0	180.7	50.6	0	0	0	0	0	0	0	0	231.3
ROFF	0.2	0.1	18.0	106.7	53.4	26.7	13.3	6.7	3.3	1.7	0.8	0.4	231.3

TEMP	Monthly mean daily temperature °C
UNPE	Unadjusted potential evapotranspiration
ADPE	Adjusted potential evapotranspiration
PCPN	Precipitation in millimeters
P-PE	Precipitation minus potential evapotranspiration
APWL	Accumulated potential water loss
STOR	Storage
DST	Change in storage
AEV	Actual evapotranspiration
DEF	Water deficiency
SURP	Water surplus
ROFF	Runoff

All values except temperature are in millimeters.

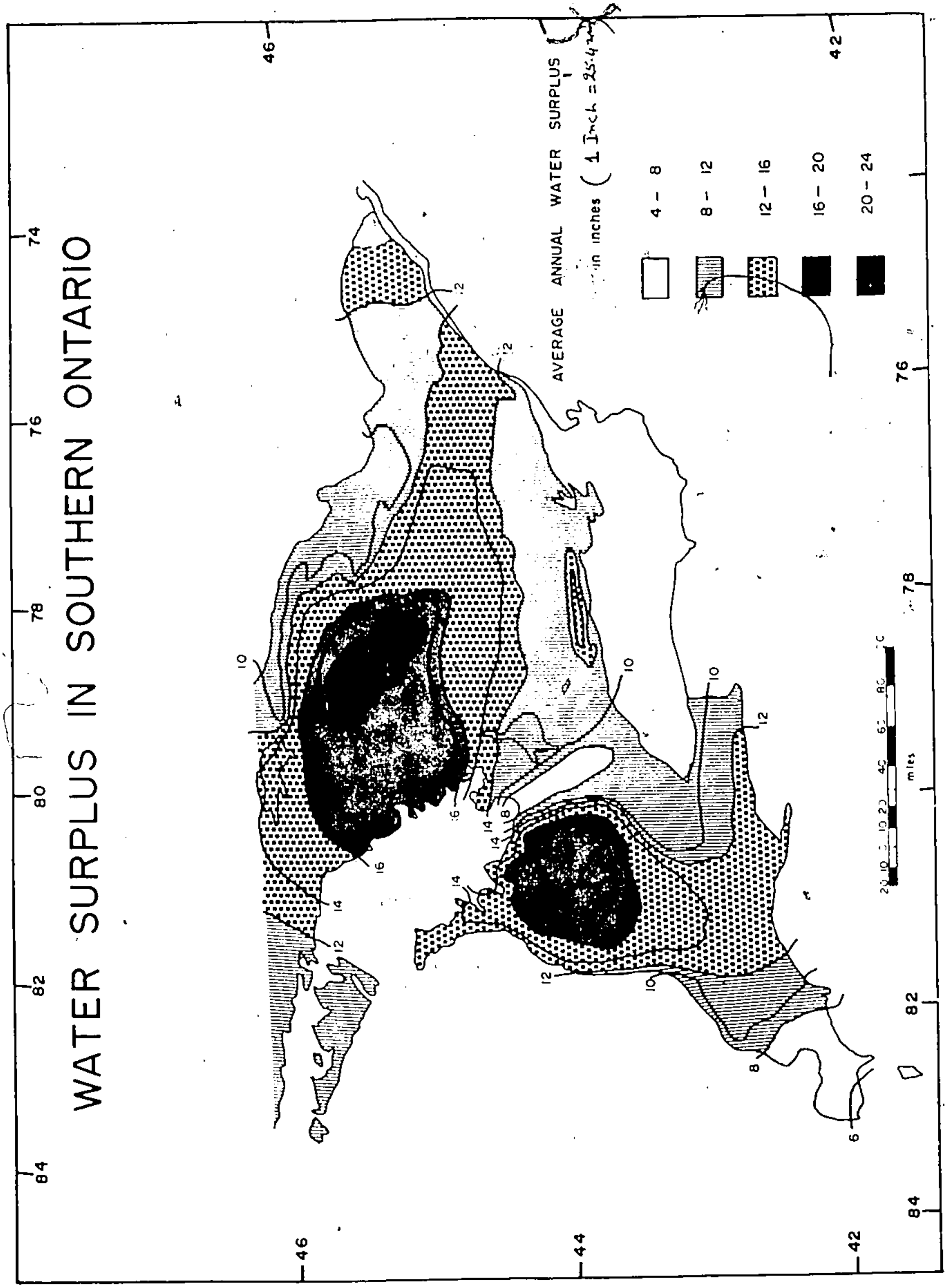
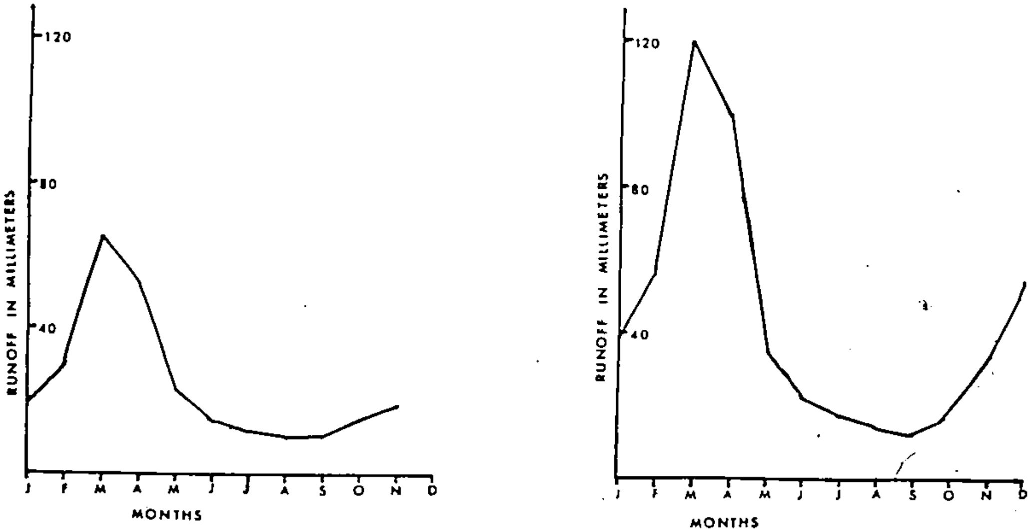

WATER SURPLUS IN SOUTHERN ONTARIO
AVERAGE ANNUAL WATER SURPLUS
in inches (1 Inch = 25.4 mm)
4 – 8
8 – 12
12 – 16
16 – 20
20 – 24
miles
20 10 0 10 20 40 60 80 100
46
44
42
74
76
78
80
82
84
6
8
10
12
14
16
18

Figure 1

REPRESENTATIVE HYDROGRAPHS IN SOUTHERN ONTARIO



a) DUFFIN CREEK AT PICKERING

b) THAMES RIVER AT INGERSOLL

SEASONAL RUNOFF DATA (IN MILLIMETERS)

	RUNOFF								
	WINTER		SPRING		SUMMER		FALL		YEAR
	TOTAL	PERCENT	TOTAL	PERCENT	TOTAL	PERCENT	TOTAL	PERCENT	
a) DUFFIN CREEK	75·2	25	142·5	47	37·2	12	46·2	15	301·1
b) THAMES RIVER	151·9	29	255·2	48	56·8	11	64·7	12	528·6

Figure 2.

various factors such as climatic and physiographic controls. Only after the factors responsible for the seasonal fluctuation have been ascertained is it possible to design a suitable technique to compute runoff theoretically.

CHAPTER 2

2.1 Runoff theory

Ward (1967) defined runoff as "the gravity movement of water over the earth," and further stated that it is the amount which remains from precipitation when allowance is made for evapotranspiration and storage both above and under the ground surface. Runoff can be better understood from a comprehensive description of the hydrologic cycle in terms of three principal phases - precipitation, evaporation and runoff, both surface and subsurface. In the hydrologic cycle, water evaporates from the oceans and the land, and becomes a part of the atmosphere. The evaporated moisture is lifted and carried in the atmosphere until it precipitates to the earth, either on land or in the oceans. The precipitated water may be intercepted or transpired by plants, may run over the ground surface and into streams to oceans, or may infiltrate into the ground. Much of the intercepted and transpired water and some of the surface runoff returns to the air through the process of evaporation and transpiration. The infiltrated water may percolate downward to be temporarily stored as ground water which later flows out of rocks as springs or seeps into streams as runoff to oceans, or evaporates into the atmosphere to complete the cycle.

Surface runoff is mainly derived from precipitation through three main component sources. First, runoff from rainfall, which is intermittent with its occurrence dependent entirely on the rate of rainfall being in excess of the loss rate due to evaporation, transpiration and percolation. Secondly, there is the snowmelt runoff from accumulated snowfall, which is an important source in colder climates. Lastly, there is a contribution to runoff from ground water storage and it is replenished by infiltration which constitutes a loss from the rainfall and snowmelt contributions to the runoff.

Climate and physiography are the important factors that influence the distribution of surface runoff. Under climate the parameters that influence runoff are precipitation, interception, evaporation and transpiration. Of these, probably the most important factor governing runoff is the precipitation - form and type, intensity and duration, time and areal distribution, frequency and storm movement and direction. In southern Ontario, during winter and spring months, precipitation in the form of snow poses problems. If temperatures are cold enough, the atmosphere supplies the moisture both for snowfall and for condensation of water vapour on the snow surface, while meteorological factors control the interchange of energy in the basin snowpack. During the snowmelt period, much water from the snow surface will begin to move downward into the lower layers of the snowpack where, since temperatures are usually below the freezing point, refreezing of the meltwater will occur. Additional heat will be added to the snowpack both from the air above and from the ground below so that after a period the temperature of the entire pack will approach $0^{o}C$. Meltwater continues to be absorbed by the snowpack until the liquid water-holding capacity of the pack is reached and the snow is defined as ripe. The density of the snowpack which has been increasing remains fairly constant after the water holding capacity is reached. Additional melt water now moves downward through the snow to the ground surface and, depending on the infiltration capacity of the soil and the rate of melting of the snow, the melt water will either a) enter soil and move through it, or b) form a slush layer at the surface that will both contribute to moisture infiltrating the soil surface, or to the overland runoff from the area.

Any attempt to estimate runoff theoretically, in particular in southern Ontario, must take into account the vital contribution of snowmelt to the spring and winter season runoff, or its potential for storage and subsequent appearance as runoff.

Generation of snowmelt at a point location in a snowpack is mainly due to thermodynamic processes, although travel of the melt water to another point in the pack depends on physiographic (gradient, depth, etc.) and hydrodynamic (porosity, structure, storage, etc.) properties. The important sources and processes influencing heat transfer to or from a snowpack are listed below:

Absorbed short wave (solar) radiation, R_s

Net long wave (terrestrial and atmospheric) radiation, R_b

Condensation (or vaporization) from the air, R_h

Heat content of rain water, H_r

Conduction of heat from ground, H_g

The melt water produced by the net transfer of heat from all sources to the snowpack may be obtained as

$$M = H/80B$$

where

M - water equivalent of snowmelt (Cms.),

H - algebraic sum of all heat contributions (cal/cm^2), and

B - thermal quality of the snowpack, defined as the ratio of heat required to melt a unit weight of snow to that of ice at 0°C (average from 0.95 to 0.97, for 3 to 5 per cent liquid water).

The constant 80 is the heat input in Cal/sq.cm required to produce one inch of water (25mm.) from ice at 0°C.

While the individual physical relations can be utilized to determine the effect of different meteorological, ground and vegetation conditions on the snowmelt and consequent runoff at a point, they are hardly satisfactory to apply over a large area because of the myriad of complex factors involved.

The physiographic characteristics are the second major factor influencing surface runoff. These include a) geometric influences - size, shape, slope, orientation, elevation, stream density, b) physical factors such as land use, soil cover and type, topographical features, and c) channel characteristics such as storage capacity of the soil, discharge capability, bed slope, channel roughness, and braiding and meandering tendencies.

In the climatological studies of runoff, among the several physiographic factors that influence runoff, soil moisture storage is of importance. Soil moisture may be determined simply as a result of a bookkeeping procedure in which all precipitation occurring when the soil moisture content is below field capacity is treated as a moisture increment and moisture is lost from the soil only by evapotranspiration. Precipitation occurring when the soil is above field capacity is treated as surplus; some of it is lost as percolation to contribute to ground water storage to appear as springs and underground streams, some flows out as surface runoff. All of this surplus available for runoff in a particular month may not be lost in that month, as some of the surplus water is often detained on the watersheds past the end of the month and will run off in succeeding months.

2.2 Methods of estimating runoff

The construction of runoff probability maps on a monthly or seasonal basis would be simple if the gauged values of runoff covered extensive areas with long periods of record or if a perfect technique to estimate runoff were available.

In recognition of the role of climatic parameters in runoff distribution, several attempts have been made in the past to develop simple annual yield expressions incorporating mean temperature and precipitation.

Theoretically, runoff at a place can be estimated from the water balance equation

$$R = (r + s) - (E + T + S_t + U)$$

where

R - Runoff from drainage area
r - Precipitation in the form of rainfall
s - Precipitation in the form of snowfall
E - Direct evaporation
T - Transpiration from plants and vegetation
S_t - Change in storage
U - All other factors (Underground flow, etc.).

In the above equation, only precipitation both in the form of snow and rainfall can be measured accurately. If it is possible to estimate precisely evaporation, transpiration and all other factors, one can compute runoff at a place using the above relation. However, in actual practice, the limiting factors are the measurement of evaporation, transpiration and underground flow.

Realizing the above relationship between runoff, precipitation and evapotranspiration, several workers (Bruce and Rodgers, 1954; Carter, 1955; Morton and Rosenberg, 1959; Brunk, 1961; Bruce, 1962; Derecki, 1964; Sanderson, 1966 and 1971; Pentland, 1968, and Phillips, 1975) have attempted to calculate runoff from climatic data by energy budget and degree-day methods.

In recent years, climatic estimation of runoff gained new popularity after Thornthwaite (1948), who formulated a bookkeeping model as the basis of his climatic classification. Later it was modified by Thornthwaite and Mather (1955) to make it more meaningful under a wide range of soil and vegetation conditions. Table 1 illustrates the procedure for computing the monthly climatic water balance for Pickering, Ontario. The advantage of Thornthwaite's water balance model is its relative simplicity of computation requiring data only on air temperature, precipitation and latitude.

Muller (1966) used Thornthwaite's water balance model as one of the approaches in his study of the effect of reforestation on water yield and computed the annual runoff from four small watersheds in the Allegheny Uplands of New York State for each year from 1935 to 1957. He reported that measured runoff tended to be greater than computed runoff at the beginning of the study when forests covered 20 to 50 per cent of the watersheds; measured runoff was less than computed in the latter years when forests covered 80 to 90 per cent of three watersheds.

Recently, Solomon (1967) calculated runoff both on an annual and long term basis, taking into account the difference between recorded precipitation and computed evaporation.

Mather, et. al. (1972) applied the climatic water budget bookkeeping technique in Delaware and New Jersey in the eastern United States to compute net flow figures for a 20-year period starting in 1949 and concluded that the calculated values of net flow are quite consistent with other available meteorologic and hydrologic information.

Many of the above studies employ the climatic bookkeeping approach either directly or with slight modification. Where studies of streamflow are based on the original Thornthwaite climatic water balance model, estimated streamflow values fluctuate markedly from measured values particularly in spring and winter months. This discrepancy between computed and measured values might be because

Thornthwaite, in his original scheme, has made no allowance to account for runoff resulting when precipitation occurs as snow when mean monthly temperature remains at or close to $0^{o}C$. Also, in the original model developed by Thornthwaite, no allowance was made for accounting for the effect due to convective summer storms. As a result of snow accumulation, runoff occurrence is from the delayed surplus which collects during spring and winter months. Furthermore, winter months have little flow and runoff is sufficiently delayed so as not to correspond with measured values in the spring.

Realizing the drawbacks in the Thornthwaite bookkeeping model, Van Hylckama (1958) developed nomograms to account for direct runoff by planimetering the areas between runoff and base flow curves for each month. These amounts were then subtracted from precipitation amounts, to arrive at effective precipitation. He then applied the technique to the Delaware Valley basin, giving due weight to the occurrence of snow and the rate of snowmelt, the amount and nature of direct runoff from intense precipitation and the influence of local characteristics such as soil depth, average slope and stream density on the rate of runoff. Compared to the Thornthwaite model, the Van Hylckama modification to account for snow runoff to the original Thornthwaite water balance model is a significant advance with improved estimates in every season. However, the difficulty in his system is in the additional computations making the system tedious to use.

Using Thornthwaite's climatic bookkeeping model, Sanderson (1966) evaluated each of the factors of the water budget for the Lake Erie basin for the period 1958 to 1963. Comparing these results with average conditions over the lake basin, she sought new understanding of the factors responsible for changing lake levels. During her investigations she suggested modification to the original climatic model in an attempt to arrive at a simple method for determining winter runoff based on two assumptions: a) that snowmelt runoff during the months with mean temperature -0.9°C need not be considered zero but modified by the number of days with maximum temperature greater than 0°C; b) that runoff in the first month with mean temperature greater than 0.9°C be considered as 50 per cent of available water surplus. Employing these assumptions, Sanderson found a 0.99 correlation between measured and computed annual runoff for the Grand River basin.

In an unpublished B.A. thesis, Phillips (1967) used runoff records at seven drainage basins in southern Ontario for a ten year period to compare with the computed annual water surplus. Using only one station in each basin, he obtained a correlation coefficient of 0.86 between measured and computed annual runoff. One obvious drawback in the above two studies is that in dealing with snowmelt similar weight is given to all days with the same mean temperatures. This might result in overestimation of the energy available for snowmelt in cold months and underestimation during the warm periods.

Using five different drainage basins in southern Ontario, John (1971) reported that the Thornthwaite water balance model overestimates runoff in the high runoff period (January to June), and underestimates it in the low runoff period (July to December) and further indicated the model yields good results when applied to large basins. His computed values of runoff based on three stations in the Duffin Creek basin overestimated runoff, with correlation of 0.75 for the January to June period while in the period July to December the underestimated values yielded 0.81 correlation. On an annual basis he obtained a high correlation of 0.90. The overestimation and underestimation during periods of high and low runoff periods may be because the Thornthwaite model uses only temperature in estimating evaporation. Basically, evaporation is a function of radiation rather than temperature and in most of southern Ontario, the amount of incoming insolation is highest during May, June and July, while air temperature reaches a maximum only in July and August. Also, although there could be days within a month with above or below freezing temperatures, the Thornthwaite model assumes no resulting runoff for a month when the average temperature is below 0°C.

A heat related unit sometimes used in hydrometeorology to account for snowmelt is the degree-day, a unit expressing the amount of heat in terms of a twenty-four hour period. The degree-day or degree-hour values (temperature summation above a base temperature) can be correlated with runoff values. The approach is only a rough estimate as many other factors besides temperature influence snowmelt. Several workers have given values ranging from 1.27mm. to 5mm. of snowmelt per degree-day under conditions of continuous snow cover and with temperatures above freezing (Collins, 1934; Bruce, 1962).

Garstka, et. al. (1958) in their studies on snowmelt in Colorado, observed that a daily maximum temperature was a better reference point than mean, since a mean temperature of 0°C need not necessarily indicate that melting would not occur. Similarly, Collins (1934) attempted to forecast runoff based entirely upon degree days above freezing.

Generally, applications of the climatic bookkeeping approach for theoretical estimation of runoff have dealt with large areas and average conditions with emphasis on annual yields. For yields in specific years, Sanderson (1966) in southern Ontario and Mather (1969b) in Delaware, found correlations ranging from 0.90 to 0.99 between computed and measured runoff. However, when small areas or seasonal or monthly time periods are considered, the results are less reliable.

In order to test the applicability of the Thornthwaite climatic bookkeeping approach for estimating runoff on a monthly and seasonal basis, the model has been applied to a small watershed in southern Ontario, Duffin Creek gauged at Pickering.

CHAPTER 3

3.1 The Duffin Creek watershed

The watershed, Duffin Creek(at Pickering) has an area of about 176 sq. killometers and it is drained by natural water courses. This watershed was selected out of several small watersheds in the southern Ontario area after a careful examination of their climatic record of data, and based on the following criteria:

a) the drainage water flow at the measuring site should be natural,

b) watersheds selected should lie within southern Ontario and the period of record of gauged runoff should be continuous during the period of study, and

c) the selected watershed should be nearly representative of the rest of southern Ontario. The representative characteristic of the selected watershed to the rest of southern Ontario has been established by comparison of the moisture index of Thornthwaite (1948), which represents both thermal and moisture conditions at a place. According to Sanderson's (1950) moisture relationships in southern Ontario, most of the region falls within the fourth humid to first humid category, and the selected watershed at Pickering has a moisture index of 45.6 and can be classified as second humid, a characteristic which indicates a resemblance to the rest of southern Ontario. Figure 3 shows the location of the watershed and the locations of the meteorological stations used to test the model.

Elevations in the watershed generally increase northwards, reaching a height of about 360 meters in the extreme north, while the lowest elevations in the south are at 87 meters around Pickering. The watershed has a much varied topography which approximately resembles the rest of southern Ontario. The northern section is part of the Peel plain physiographic region and the extreme southern tip is also plain area.

The surface soils in the Duffin Creek watershed, like all those of southern Ontario, are the result of glacial action (Report on Flood Control and Water Conservation, 1962). In the northeast and south central parts of the basin, the prevailing soil is Fox grey-brown podzolic

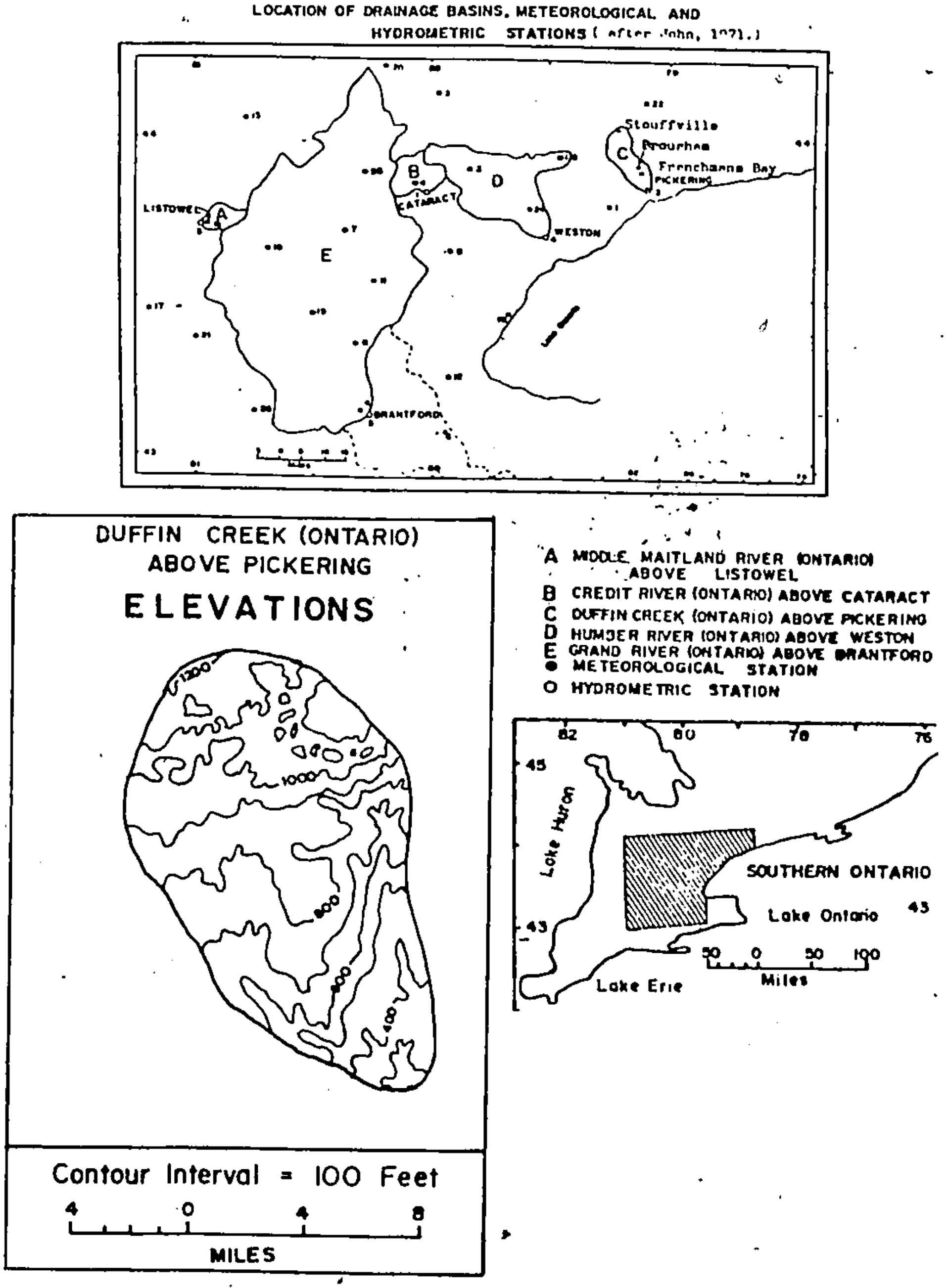

LOCATION OF DRAINAGE BASINS, METEOROLOGICAL AND HYDROMETRIC STATIONS (after John, 1971.)
Stouffville
Frenchmans Bay
PICKERING
LISTOWEL
A
B
C
D
E
CATARACT
WESTON
BRANTFORD
Lake Ontario
DUFFIN CREEK (ONTARIO) ABOVE PICKERING
ELEVATIONS
1200
1000
800
600
400
Contour Interval = 100 Feet
4
0
4
8
MILES
A MIDDLE MAITLAND RIVER (ONTARIO) ABOVE LISTOWEL
B CREDIT RIVER (ONTARIO) ABOVE CATARACT
C DUFFIN CREEK (ONTARIO) ABOVE PICKERING
D HUMBER RIVER (ONTARIO) ABOVE WESTON
E GRAND RIVER (ONTARIO) ABOVE BRANTFORD
● METEOROLOGICAL STATION
O HYDROMETRIC STATION
82
80
78
76
45
43
Lake Huron
SOUTHERN ONTARIO
Lake Ontario
Lake Erie
50
0
50
100
Miles

Figure 3

sandy loam. In the northeast it is coupled with the Guelph grey-brown podzolic sandy loam, while in the south it is coupled with the Granby dark grey gleisolic sandy loam on level stone-free topography.

The variation in the permeability of these soils is considerable. Pervious type of soils consisting of kame moraine, beach, boulder, and sand plain are prevalent in the upper and lower parts of the watershed and account for 36 per cent. Semipervious soils of drumlinized till plain soil type appear in the central part of the basin and constitute 44 per cent. About 20 per cent of the soil in the basin consists of bevelled till, plain and clay plain varieties and these impervious soils appear in the central and lower parts.

According to the land use maps prepared by the Canada Land Inventory, ARDA Branch (1968), there are nine different land use types in the watershed. Most of the natural vegetation within the study area has been destroyed for developing farms and land lying fallow. Approximately 13 per cent of the total area of the drainage basin is forested.

In order to compute the water balance for the watershed, it is necessary to have the following information: a) mean monthly air temperature, b) total monthly precipitation, and c) information on the water holding capacity of the depth of soil for which the balance is to be computed.

Mean monthly air temperature and total monthly precipitation for each of the years from 1966 to 1973 at four climatic stations within the watershed, namely Brougham (43°55'N, 79°07'W), Frenchmans Bay (43°49'N, 79° 05'W), Pickering (43°51'N, 79°03'W), and Stouffville (44°00'N, 79°03'W) were obtained from the Monthly Record. Information on the water holding capacity of the soil within the watershed is not directly available, but can be assessed from the soil types and land use patterns. Water holding capacity of a soil depends basically on two different factors - the soil type and structure, and the type of vegetation growing on the surface. Also, different species of vegetation will send roots down into the soil to different depths. Cultivated crops such as peas or spinach are very shallow rooted and so the depth of the root zone in which water can be stored in the soil is quite small. Tables for use in the computations of the water balance have been prepared for different soils and vegetation types by Thornthwaite and Mather (1957). Detailed information on water holding capacities may be obtained from the Instructions and Tables for Computing Potential Evapotranspiration as referenced earlier in Chapter 1.

Since in the southern Ontario region and in the chosen watershed, the crop pattern ranges from moderately deep rooted crops to deep rooted crops and the soils from fine sand to silt loam type, an average water holding capacity of 152.4 millimeters (6 inches) was chosen for the present study.

3.2 The Thornthwaite-Mather model

Using the mean monthly temperature and monthly total precipitation and assuming a water holding capacity of 152.4 millimeters, monthly potential evapotranspiration, actual evapotranspiration and direct runoff were calculated according to the standard Thornthwaite and Mather (1957) procedure. Calculated total runoff was then summed on a three month basis, based on the simple arithmetic averages obtained from the four climatic stations within Duffin Creek watershed. The computational procedure for Pickering is presented in Table 1.

Eight years (1966-1973) of streamflow records for the watershed were obtained from the Water Survey of Canada, Surface Water Data, Ontario (1974). Water yield at Pickering is measured with current meters and the reliability of the data according to the Water Survey of Canada lies between ± 2 to 5 per cent. In general, data measured during periods of ice conditions are less reliable and subject to error.

A measure of the relationship between computed and measured water yield on a seasonal basis for the Duffin Creek watershed can be assessed by calculating the coefficient of correlation. If 'r' is called the correlation coefficient,

$$r = \frac{\sum xy/n - \bar{x}.\bar{y}}{\sigma_x \sigma_y} \qquad (3.2.1)$$

where

x - Individual seasonal computed runoff

y - Individual seasonal measured runoff

n - Number of seasons

$\bar{x}$ and $\bar{y}$ - Mean runoff of computed and measured

σ_x and σ_y - Standard deviation of computed and measured runoff.

The monthly correlations between measured runoff and that computed using the Thornthwaite and Mather approach were found to be of low order, ranging from 0.13 to 0.44. Consequently, the seasonal correlations were obtained considering the Winter to be from December to February, Spring from March to May, Summer from June to August and Fall from September to November. These values are summarized in Table 2. The correlations tabulated in Table 2 differ from season to season remarkably. The correlation coefficient +0.53 for the summer season while the correlation obtained in winter and fall seasons showed that there was little agreement between measured and computed runoff. A comparison of the correlations at the 5% and 1% level of significance indicates that significant correlation exists in summer and spring seasons while winter and fall seasons show least correlation. The

TABLE 2

SEASONAL CORRELATIONS BETWEEN COMPUTED AND MEASURED RUNOFF FOR DUFFIN CREEK AT PICKERING (1966-1973)
(Thornthwaite and Mather, 1957)

Season	Correlation Coefficient r	Coefficient of Determination r^2	t-Statistic	Level of Significance
WINTER	+0.23	0.08	1.09	greater than 10%
SPRING	+0.47	0.22	2.49	5 to 10%
SUMMER	+0.53	0.28	2.92	1 to 5%
FALL	+0.29	0.08	1.42	greater than 10%

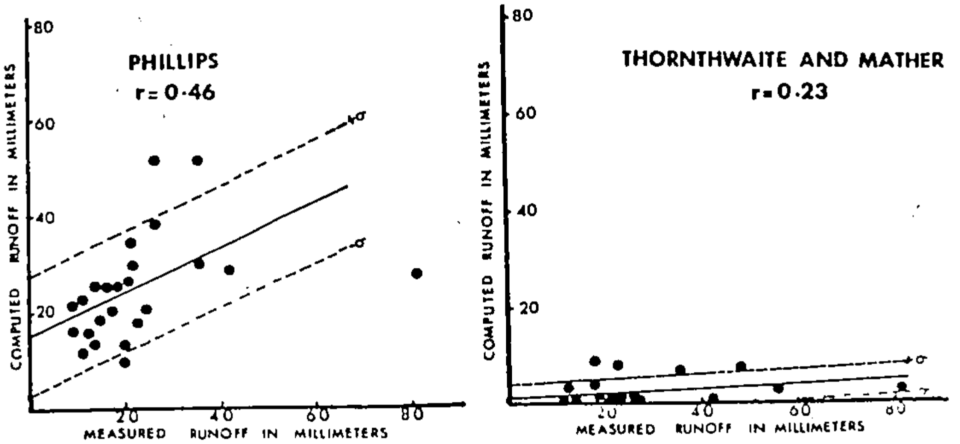
Significance levels: At 5% = 0.40; 1% = 0.51

(Snedecor and Cochran, 1968)

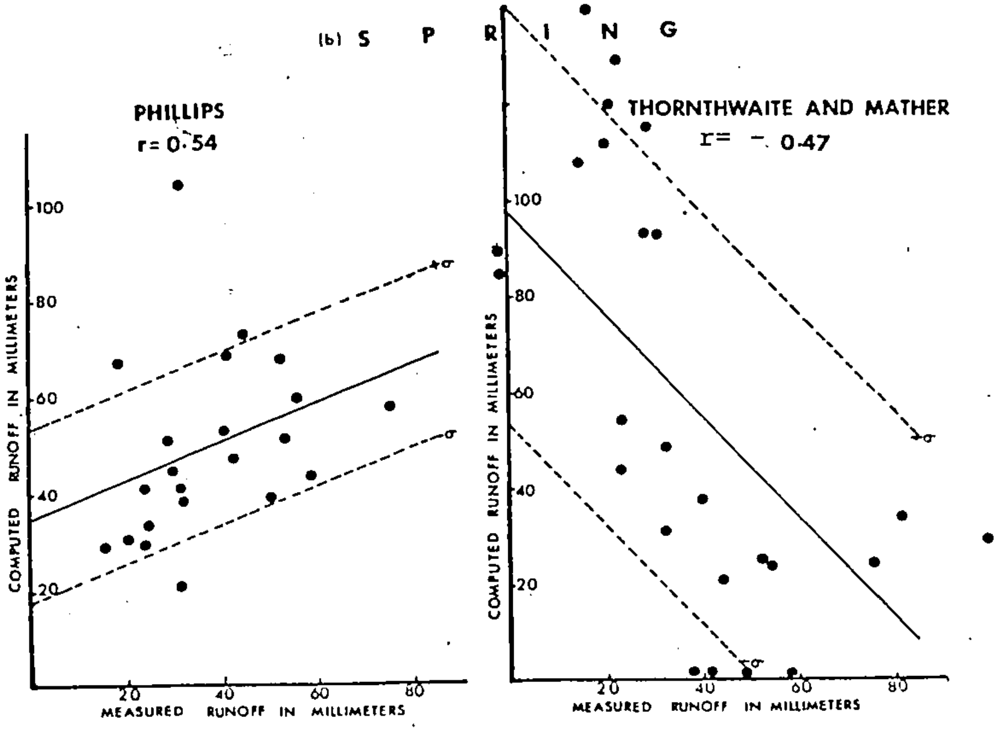
coefficient of determination calculated for the seasons indicate that only in spring and summer seasons the Thornthwaite model accounts for 22 and 28 per cent of the runoff while winter and fall seasons account for only 8 per cent. Figure 4 shows the scatter diagrams of computed and measured runoff and the continuous lines are regression lines. On the scatter diagram, the confidence limits, i.e., the standard deviation lines (dotted lines) can be used to assess how closely the computed runoff approximates measured value. These lines indicate that in all seasons, about 68.3 per cent of the computed values lie within ± one standard deviation.

The low correlation in winter and fall is mainly because in many parts of southern Ontario during the period November through February, temperature will be below freezing and precipitation will be deposited in the form of snow. The Thornthwaite-Mather model assumes both evapotranspiration and runoff to be zero during low temperature periods when precipitation is in the form of snow. Under these conditions, total storage may exceed the water holding capacity of the soil, with the excess being deposited as snow or surface storage. When the temperature rises above freezing level in the spring, the snow accumulated above the ground is allowed first to replenish the soil moisture and the excess treated as snowmelt runoff.

(a) W I N T E R



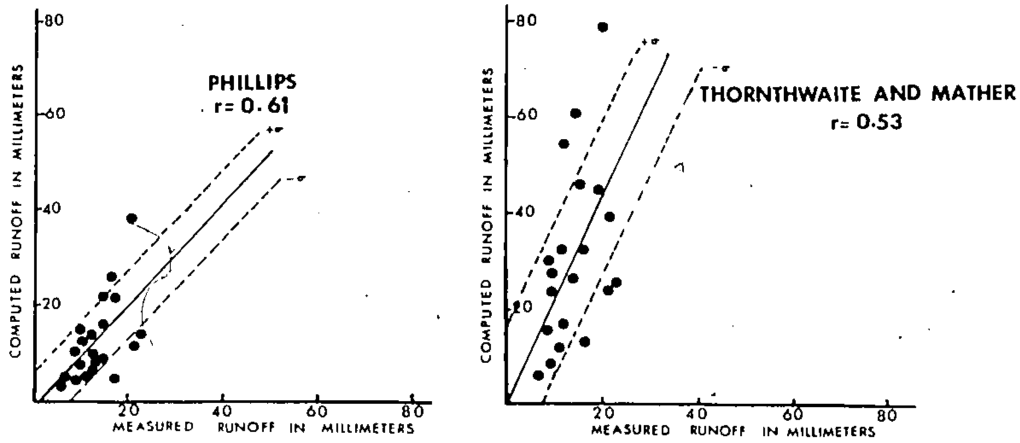
(b) S P R I N G



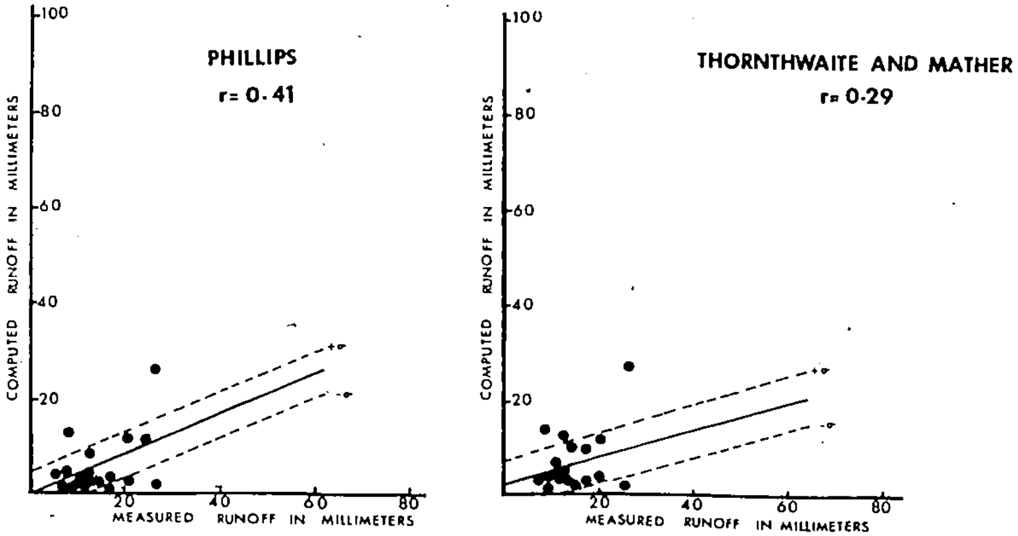
SCATTER DIAGRAMS OF COMPUTED AND MEASURED SEASONAL RUNOFF

Figure 4.

(c) S U M M E R



(d) F A L L



SCATTER DIAGRAMS OF COMPUTED AND MEASURED SEASONAL RUNOFF

Figure 4(cont'd)

3.3 The Phillips model and methodology

Many investigators have criticized the Thornthwaite and Mather model and have attempted to modify the assumptions for snow accumulation and melt. Phillips (1975) introduced a modification to the original Thornthwaite and Mather bookkeeping approach to account for winter and spring runoff. The Phillips modification of the water balance in cold climates is mainly an empirical system which is designed to account for seasonal and annual variation of precipitation, evapotranspiration loss, soil moisture storage, and surplus water for runoff from snow.

Using the total number of melting degree days above base temperatures, Phillips obtained a ratio of runoff to potential runoff. Potential runoff, for this purpose, he defined as the positive difference between the storage term and its water holding capacity expressed as a percentage. The variables involved in the Phillips modification are a) the total number of melting degree days above base temperature of $0^{\circ}C$ for the month under consideration, b) accumulated total precipitation from December to the end of the month in consideration, c) accumulated melting degree days for the various temperature bases including the month under study, d) precipitation of the month, e) mean temperature of the month, and f) potential runoff, the positive difference between the storage term and its water holding capacity or surface storage. Using these variables, Phillips chose a multivariate technique of step-wise multiple regression to determine the significant factors by generating a series of regression equations. The following equations have been suggested by Phillips to be added to the Thornthwaite-Mather model for computing snowmelt runoff in spring and winter months:

Month	Regression Equation	
December	$\% = 82.5 + 10.3\ T$	(3.3.1)
January	$\% = 37.1 + 2.5\ T$	
February	$\% = 35.7 + 1.6\ T - 0.8\ (X-Y)$	
March	$\% = 50.1 + 3.6\ T - 1.0\ (X-Y)$	

where

T - is the mean monthly temperature in $^{\circ}C$

X - is the storage value for the month

Y - is the assumed water holding capacity

% - is the ratio of actual runoff to potential runoff expressed as a percentage.

In the modified version, computation of the climatic water balance is similar to that of the Thornthwaite-Mather approach until the storage line, as can be seen from a comparison of Tables 1 and 3. Then, for each month when mean monthly air temperature is at or below freezing, precipitation is temporarily added to the soil moisture storage of the present month. When the soil moisture storage is at field capacity or above, the ratio of actual to potential runoff expressed as a percentage is calculated from the corresponding month's regression equation. Actual runoff is computed as a product of the runoff ratio and potential runoff and entered as snowmelt runoff. The difference (potential-actual runoff) is added to the water holding capacity as the revised storage term for that month. Again in the following month, the Thornthwaite-Mather method is followed until the storage line is reached, and the revised storage and snowmelt runoff and total runoff according to the Phillips modification. Once the surplus has been entered, the next step is to determine the amount of surplus which appears as direct runoff. For southern Ontario, it has been found that 50% of the surplus will appear as runoff in each of the following months until it is all gone (Phillips, 1975). The final calculation is to enter the result (Direct runoff plus snowmelt runoff) as total runoff.

For formulating the above modification, Phillips used twenty-four years of streamflow records (1947-1973) for the Sydenham River at Owen Sound, which has a drainage area of about 110 sq. km., and temperature and precipitation records of two climatological stations, Wiarton and Owen Sound. In order to test these empirical adjustments, Phillips tested his model in the Thames River at Woodstock (drainage area of about 150 sq. km.) using temperature and precipitation from one station for the period 1952 to 1973, and reported good correlations on a monthly basis (Phillips, personal communication).

A computer listing of the Phillips modification of the climatic water balance was made available to the author and used to compute the water yield in the present study. The program with examples of the computations for some climatic stations are presented in Appendices 1 and 2.

Using the above assumptions and assuming a water holding capacity of 152.4mm. (6 inches), the Phillips modification of the bookkeeping approach for cold climates was tested in the Duffin Creek watershed using streamflow records and climatic data from four stations for the period 1966-1973. A model computation using the Phillips technique, for Pickering, Ontario, is presented in Table 3 and yearly computations for the four climatic stations within the watershed are presented in Appendices 2 and 3. Total runoff in Table 3 was obtained by summing the direct runoff and snowmelt runoff.

Scatter diagrams have been constructed for seasonal computed and measured runoff data to indicate relationships and possible patterns of clustering among some of the data. Figure 4 shows scatter diagrams between measured and computed runoff according to the Thornthwaite and Mather approach as well as with Phillips' modification. The diagrams for all the seasons show less scatter in the case of Phillips' computed runoff verses measured, while the scatter is higher for the Thornthwaite and Mather method.

The regression intercept (a) and coefficient (b) describe how closely the computed runoff approximates the

TABLE 3

CLIMATIC WATER BALANCE (Phillips, 1975)

PICKERING, ONTARIO – 1970

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
TEMP	-8.30	-6.10	0.80	7.10	11.20	18.20	20.60	20.70	16.10	10.90	5.30	-4.00	7.71
UNPE	0	0	0	1.0	1.8	3.0	3.3	3.5	2.5	1.8	0.7	0	
ADPE	0	0	0	34.0	67.3	117.0	128.0	128.0	79.2	50.5	18.5	0	622.5
PCPN	51.7	31.8	50.2	84.6	62.7	30.0	86.9	49.5	65.0	77.2	46.0	73.4	709.0
P-PE	51.7	31.8	50.2	50.6	-4.6	-87.0	-41.1	-78.5	-14.2	26.7	27.5	73.4	
APWL	0	0	0	0	-4.6	-91.6	-132.7	-211.2	-225.4	-138.6	-82.3	0	
STOR	251.1	282.9	152.4	152.4	148.2	83.6	64.0	38.1	34.8	61.5	89.0	158.2	
DST	0	0	0	0	-4.2	-64.6	-19.6	-25.9	-3.3	26.7	27.5	69.2	
AEV	0	0	0	34.0	66.9	94.6	106.5	75.4	68.3	50.5	18.5	0	514.7
DEF	0	0	0	0	0.4	22.4	21.5	52.6	10.9	0	0	0	107.8
SURP	0	0	130.0	50.6	0	0	0	0	0	0	0	0	180.6
ROFF	0	0	65.0	57.8	28.9	14.5	7.2	3.6	1.8	0.9	0.5	0.2	180.4
WSMRO	13.5	22.6	0	0	0	0	0	0	0	0	0	3.8	39.9
TOTRO	13.7	22.6	65.0	57.8	28.9	14.5	7.2	3.6	1.8	0.9	0.5	4.0	220.5

TEMP	Monthly mean daily temperature in °C
UNPE	Unadjusted potential evapotranspiration
ADPE	Adjusted potential evapotranspiration
PCPN	Precipitation in millimeters
P-PE	Precipitation minus potential evapotranspiration
APWL	Accumulated potential water loss
STOR	Storage
DST	Change in storage
AEV	Actual evapotranspiration
DEF	Water deficiency
SURP	Water surplus
ROFF	Direct runoff
WSMRO	Snow melt runoff
TOTRO	Total runoff

All values except temperatures are in millimeters measured runoff. The regression equations obtained from the plots of computed and measured runoff for each of the seasons in the Duffin Creek watershed using the Phillips and the Thornthwaite and Mather models are presented in Table 4 along with the corresponding standard deviations.

Monthly correlations worked out using the Phillips modification are of low order (from 0.33 to 0.74) and statistically insignificant and will not be discussed here. The seasonal correlations obtained are presented in Table 5.

The highest correlation is for the summer season (+0.61), while the fall season has the lowest correlation. For all the seasons, the correlations obtained are statistically significant at the 5% level, but only spring and summer seasons reach the 1% level of significance. A further test was performed on the data, to test the possibility that these correlations obtained for the seasons could have occurred by chance as a result of sample size. Therefore, the significance of correlation was tested by the use of the Student's t- distribution, using the following formula:

$$t = \frac{r \times \sqrt{n-2}}{\sqrt{1 - r^2}} \qquad -(3.3.2)$$

where

n - Number of pairs of data studied

r - Correlation coefficient of the data

The degrees of freedom for the distribution is n - 2.

TABLE 4

Regression Equations to the Scatter Diagrams

	Winter	Spring	Summer	Fall
Phillips	$y = 0.43x+17.23$ $\sigma = 12.7$	$y = 0.41x+35.31$ $\sigma = 17.8$	$y = 1.08x-2.03$ $\sigma = 6.7$	$y = 0.42x-1.78$ $\sigma = 5.6$
Thornthwaite and Mather	$y = 0.05x+1.52$ $\sigma = 3.3$	$y = -0.82x+95.0$ $\sigma = 43.3$	$y = 2.20x$ $\sigma = 16.9$	$y = 0.30x+2.03$ $\sigma = 5.9$

y - computed runoff

x - measured runoff

σ - standard deviation

TABLE 5

SEASONAL CORRELATIONS BETWEEN COMPUTED AND MEASURED RUNOFF FOR DUFFIN CREEK AT PICKERING (1966-1973)

(Phillips)

Season	Correlation Coefficient r	Coefficient of Determination r^2	t-Statistic	Level of Significance
WINTER	+0.46	0.22	2.45	1 - 5%
SPRING	+0.54	0.30	3.06	1%
SUMMER	+0.61	0.38	3.64	0.1 - 1%
FALL	+0.41	0.17	2.11	5%

Significance levels: At 5% = 0.40; 1% = 0.51

(Snedecor and Cochran, 1968)

The computed t- statistic values for each season are presented along with the correlation coefficients and it can be seen that the percentage probability that these correlation coefficients could have occurred by chance is of the order of 0.1 to 5%. In other words, these coefficients are significant indicating good agreement between runoff computed with Phillips modification and measured runoff.

For fall and winter seasons, the coefficients 0.41 and 0.46 do not reach the 1% level of significance. These low correlations might be because Phillips (1975), in his modification, has made no allowance for accounting runoff due to snowmelt in certain fall months during which period some precipitation will occur as snow. Also, Phillips' modification is based mainly on temperature to determine snowmelt runoff. As discussed earlier, snowmelt at a point location depends upon thermodynamic processes, but the travel of melt water and its time distribution from point to point depends upon both physiographic and hydrodynamic properties and these are not accounted in Phillips' modification.

A comparison of correlation coefficients obtained between measured and computed due to the original Thornthwaite and Mather bookkeeping approach and Phillips modification indicates that, in spite of low correlations in certain seasons, water yield calculated according to the

Phillips modification is a better estimator of water yield on a season to season basis, than the Thornthwaite and Mather climatic water balance model.

However, the coefficient of determination obtained from the correlations suggest that the Phillips model accounts for only 40 per cent of the runoff. Although there is a significant correlation between computed and measured runoff, it is obvious from the scatter diagrams in Figure 3 that the relationship is neither regular nor clear-cut. For this reason, regression lines were calculated in order to obtain the best estimated value from the Phillips values of computed runoff. The following are the regression equations for the Phillips modification and are based on the Duffin Creek basin data.

Season	Regression Equation	
Winter	$R_{est} = 2.35\ R_p - 40.81$	
Spring	$R_{est} = 2.46\ R_p - 86.58$	(3.3.3)
Summer	$R_{est} = 0.93\ R_p + 1.96$	
Fall	$R_{est} = 3.34\ R_p - 6.90$	

where

R_{est} - Runoff estimated by regression

R_p - Computed runoff from Phillips modification.

On the basis of these results in the Duffin Creek watershed, assumed to be representative of the southern Ontario area, the modifications suggested by Phillips were, therefore, incorporated in the Thornthwaite and Mather approach and used in the present study. For the construction of seasonal runoff probability maps, estimated runoff evaluated from the regression equations of 3.3.3, based on the computed runoff according to the Phillips modification, were used.

3.4 Seasonal runoff probabilities

Probabilistic analysis of various climatic and weather elements including synoptic patterns of climate, gained increasing popularity after the 1950's with the work of Gregory (1955), Manning (1956 and 1958), Glover, et. al. (1954), Strommen and Horsfield (1969), Sanderson (1974), and Knowles (1974). Using precipitation records of varying lengths, different workers have attempted the probabilistic analysis for constructing maps of probable maximum and minimum values. In all such studies, the basic assumption usually made is that the given set of observations conform to a normal distribution. For testing the normality criteria, a simple method has been proposed by Stidd (1953) who found that for a wide range of periods and localities, rainfall series could be normalized by a cube root transformation. Kendall (1975) used Stidd's hypothesis for monthly rainfall totals for ten Canadian cities for a thirty year period (1921 to 1950) and concluded that the asympotically normal distribution of a function of sample moments can be used to give approximate confidence intervals for the estimates made.

Based on either normal distribution or normalized distribution, the probability function is obtained from the following expression:

$$d = \frac{x - \bar{x}}{\sigma} \qquad 3.4.1$$

where

d - Required figure

x - Critical value

$\bar{x}$ - Mean value of the distribution

σ - Standard deviation of the distribution.

The above expression indicates the extent to which the critical value differs from the mean expressed in terms of so many standard deviations. Based on the above concept, Glover, et. al. (1954) produced maps of rainfall probabilities for East Africa to indicate the probability of receiving thirty inches of rainfall on an annual basis. Bruce (1968) constructed an atlas of probability rainfall intensity, duration and frequency maps for Canada and pointed out the usefulness of these maps for design engineers. Monthly precipitation probabilities for eleven different levels ranging from five per cent to ninety-five per cent, for the eastern United States were reported by Strommen and Horsfield (1969) based on the assumption that precipitation data fit into a gamma distribution.

In Canada, Sanderson (1974) demonstrated the usefulness of the probability analysis for precipitation, and her results are discussed in terms of confidence limits for the frequency with which minimal totals of monthly precipitation will be exceeded or maxima fail to be reached. Sanderson's work is mainly based on the technique outlined by Gregory (1964), but she has drawn isoline patterns of equal probabilities instead of representing probabilities as dots on the map. More recent work in this direction in southern Ontario is due to Gomes (1975) who reported that monthly precipitation during May to September fit into a normal distribution. He drew precipitation probability maps for southern Ontario for the period May to September. Brown, et. al. (1968) constructed graphs showing the probability of exceeding various amounts of precipitation for ten-day periods at sixteen stations in southern Ontario and a similar study was made by Chapman and Thomas (1968) in northern Ontario.

Because of the small number of runoff measuring stations and the problems involved in the theoretical computation of runoff from measured climatological data, studies on runoff probabilities are meagre and non-existent in southern Ontario, and the present study is aimed at partially filling this gap.

Regional historical monthly precipitation and temperature records of 41 climatic stations obtained from the Monthly Bulletin of the Atmospheric Environment Service, Canada for the period 1938 to 1967 were used to compute runoff using the Phillips modification. The estimated runoff from the regression equations, based on the Phillips computed runoff values, were used to map the seasonal runoff probabilities which can be anticipated in the region.

Location and elevations of the 41 climatic stations used in the study appear in Appendix 4 and Figure 5. All the climatic stations have periods of record ranging from 25 to 30 years. For the region as a whole, the selected climatological station coverage is adequate, although it is desirable to have data from a greater number of stations, especially in the northern section of southern Ontario where the distribution of the selected stations is uneven.

Having calculated the runoff for each of the selected stations, two stations, Beatrice and Orono, were used to test whether the computed runoff fits the normal distribution, in order to justify using the runoff values in the computation of runoff probabilities. Seasonal runoff is slightly higher at Beatrice, among the selected stations, while Orono represents stations with average amounts of seasonal runoff.

The Chi-square test for the goodness of fit to the normal curve is used to test seasonal runoff for normality at the two stations. From the cumulative normal frequency distribution, (Z) tables (i.e., area under the standard normal curve from 0 to Z), the areas are read from 0 to z_1, 0 to z_2, etc., to calculate the expected frequencies

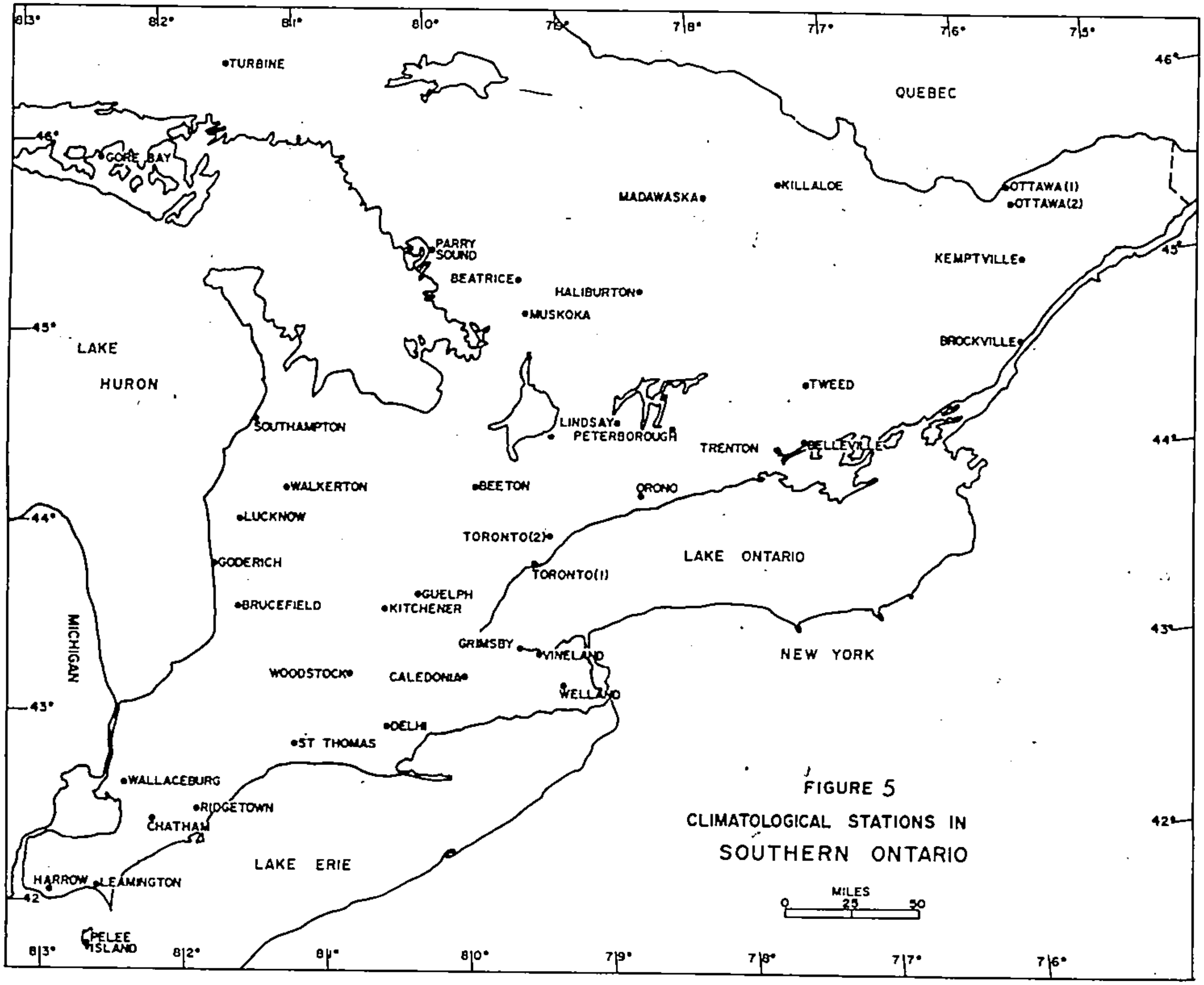


FIGURE 5

CLIMATOLOGICAL STATIONS IN SOUTHERN ONTARIO which are used to compute the X^2 - statistic as follows:

If 'O' is the observed frequency of a distribution and 'E' the expected frequency of the distribution, then the deviation is given by (O-E). Contribution to X^2 for each of the observed frequencies is then given as $(O-E)^2/E$. Summation of all the contributions to the X^2 gives the total X^2 which can be tested for a given degrees of freedom from the number of classes minus the number of estimated parameters minus one. Table 6 summarizes the summed X^2 values for each of the four seasons at the two stations.

From the table it can be seen that at 5% level of significance, winter, spring and summer seasons runoff at Beatrice and Orono approximate the normal distribution. However, for the fall season at Beatrice, the computed X^2-statistic exceeds the value at 5% level of significance by 0.2 and this might indicate high seasonal variability from year to year. The interpretation of these results is a matter of judgment. It seems justifiable to assume that the hypothesis of normality is not disproved by the occurrence of one or two random occurrences and the hypothesis of normality is accepted.

For computing the runoff probabilities, equation 3.4.1 is rewritten as $x = d(\sigma) + \bar{x}$. Since seasonal runoff approximates a normal distribution, sixty-eight and three-tenths per cent of the occurrences must lie between $+\sigma$ and $-\sigma$, and ninety-five per cent of the

TABLE 6

CHI-SQUARE VALUES FOR THE GOODNESS OF FIT

Season	WINTER		SPRING		SUMMER		FALL	
Station	X^2 Values	D.F.	X^2 Values	D.F.	X^2 Values	D.F.	X^2 Values	D.F.
BEATRICE	4.7	12	4.3	12	4.6	12	5.4	12
ORONO	5.6	13	4.9	12	3.9	12	5.2	12

D.F. = Degrees of Freedom

Significant levels of X^2; At 12 degrees of freedom

(Spiegel, 1961) $X^2_{.05} = 5.2$ $X^2_{.10} = 6.3$

At 13 degrees of Freedom

$X^2_{.05} = 5.8$ $X^2_{.10} = 7.0$

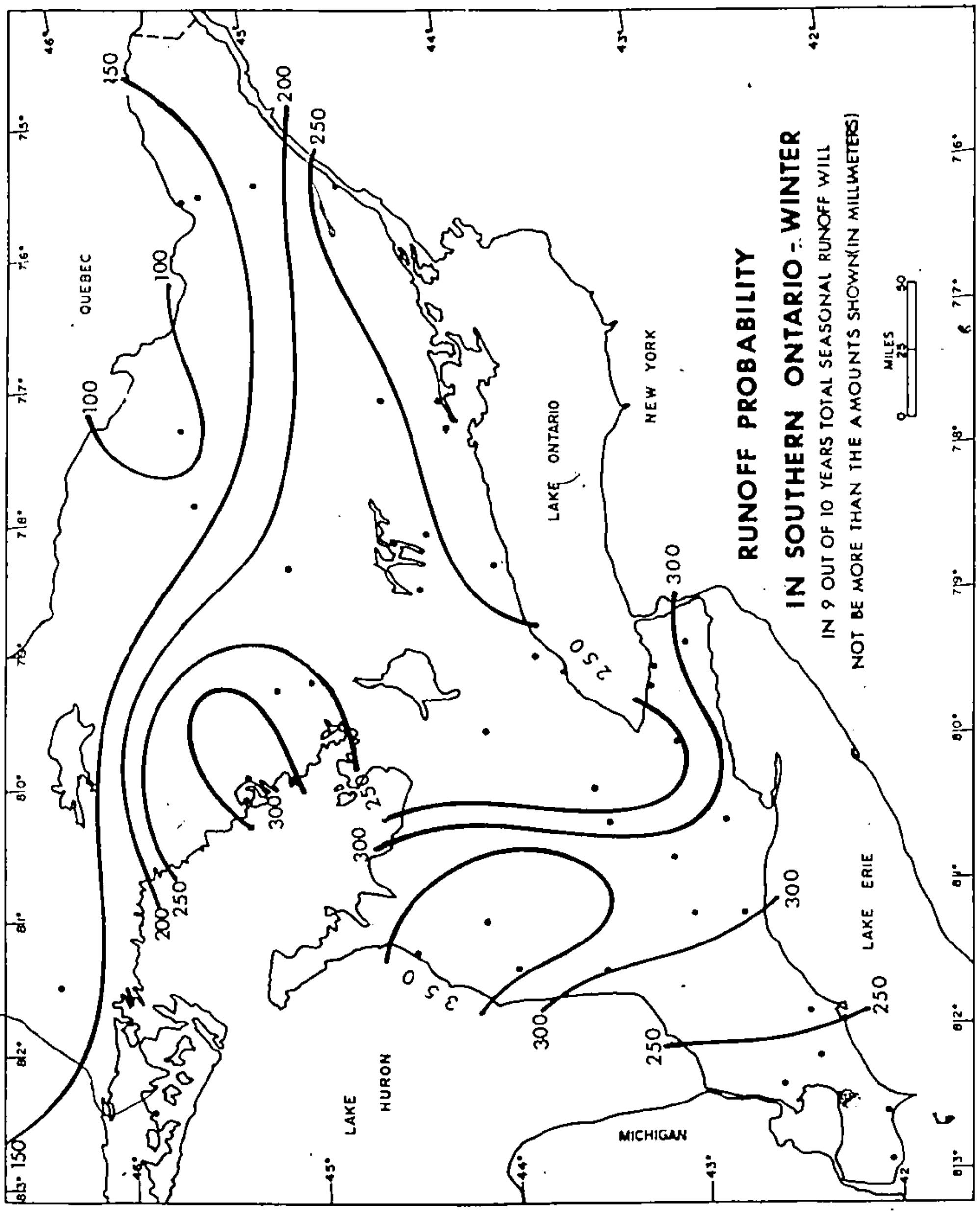
occurrences must lie above or below $\pm 1.28\ \sigma$. In the equation, when the number of standard deviations that the critical value is above the mean is held constant then the critical values computed at each station is only a function of the mean and standard deviation.

For this study, the appropriate values of 'd' is taken as ± 1.28 to compute critical upper and lower runoff limits that will not be exceeded in 9 out of 10 years.

Probability Runoff Maps

Using the computed runoff values from the 41 stations, runoff probabilities were computed for each of the stations on a monthly basis and are summed on a three month basis to obtain seasonal probabilities. The computer program for the runoff probabilities for the months and the print outs obtained for the climatic stations are presented in Appendix 5.

The probability runoff obtained with $+ 1.28\sigma$ indicate the amounts of highest seasonal runoff expected in nine out of ten years, whereas the computations with $- 1.28\sigma$ indicates the lowest probabilities, and these values in nine out of ten years will not be less than the computed amounts. These computed values were plotted on a contoured base map and isopleths of equal runoff probabilities drawn using the contour lines as reference. The resulting maps for the four seasons in southern Ontario are presented in


RUNOFF PROBABILITY
IN SOUTHERN ONTARIO - WINTER
IN 9 OUT OF 10 YEARS TOTAL SEASONAL RUNOFF WILL
NOT BE MORE THAN THE AMOUNTS SHOWN (IN MILLIMETERS)
MILES
0
25
50
QUEBEC
NEW YORK
LAKE ONTARIO
LAKE ERIE
LAKE HURON
MICHIGAN
150
100
100
200
250
300
250
350
300
250
300
300
250
250
300
300
200
250
150
46°
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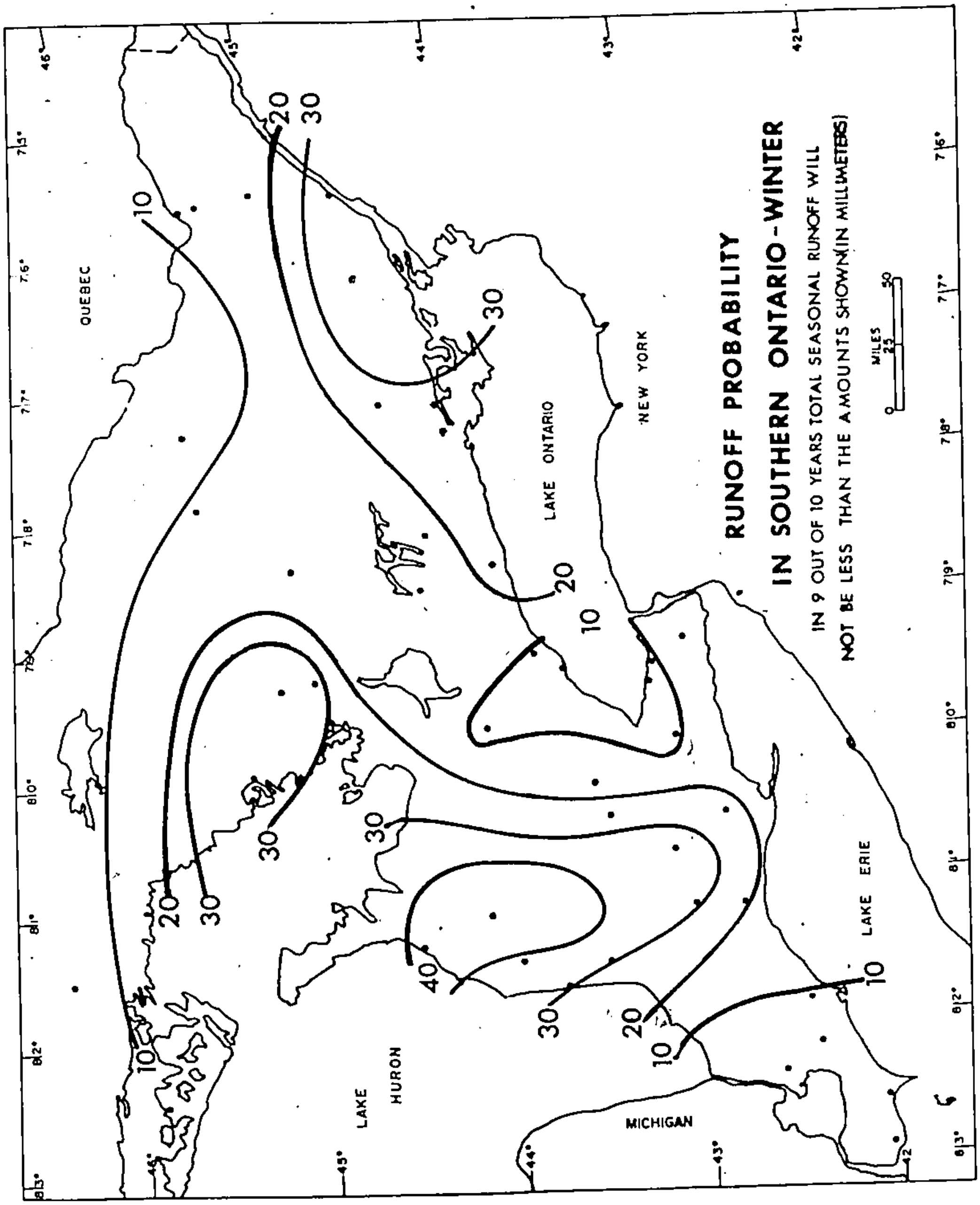
80°
81°
82°
83°

Figure 6



RUNOFF PROBABILITY IN SOUTHERN ONTARIO-WINTER

IN 9 OUT OF 10 YEARS TOTAL SEASONAL RUNOFF WILL NOT BE LESS THAN THE AMOUNTS SHOWN (IN MILLIMETERS)

Figure 7

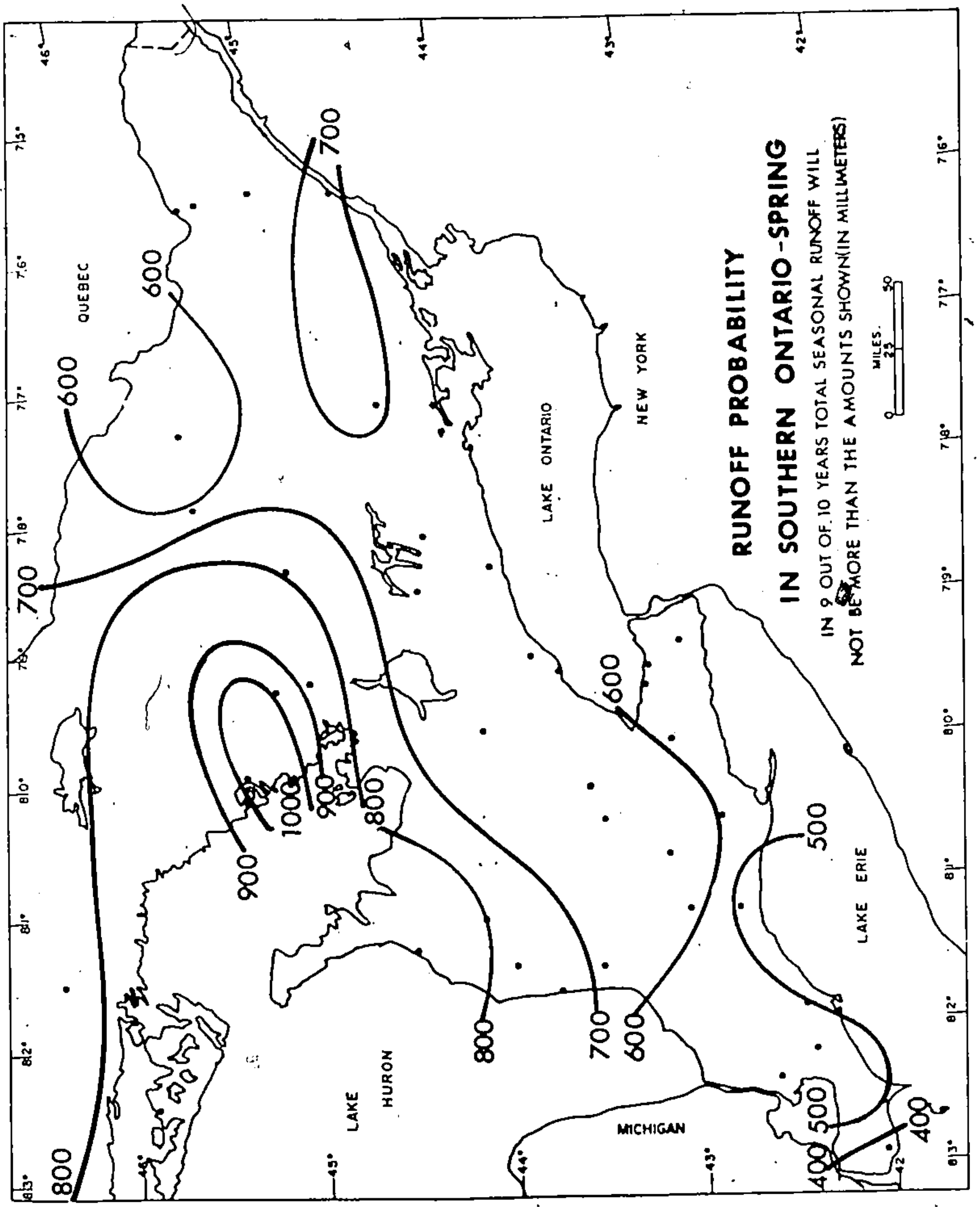

RUNOFF PROBABILITY
IN SOUTHERN ONTARIO-SPRING
IN 9 OUT OF 10 YEARS TOTAL SEASONAL RUNOFF WILL
NOT BE MORE THAN THE AMOUNTS SHOWN (IN MILLIMETERS)
MILES
0
25
50
QUEBEC
NEW YORK
LAKE ONTARIO
LAKE ERIE
LAKE HURON
MICHIGAN
400
500
600
700
800
900
1000
46°
45°
44°
43°
42°
75°
76°
77°
78°
79°
80°
81°
82°
83°

Figure 8

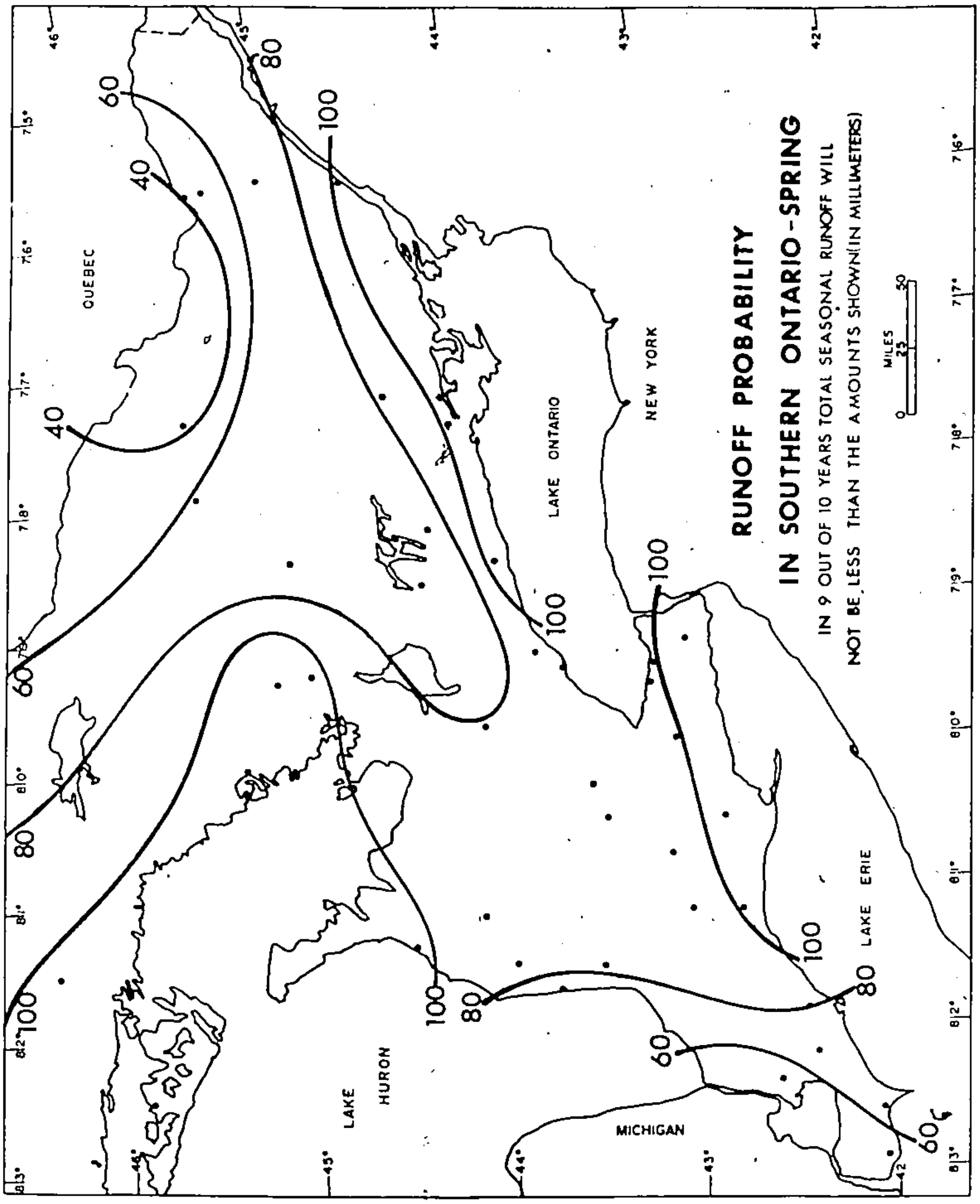

RUNOFF PROBABILITY
IN SOUTHERN ONTARIO-SPRING
IN 9 OUT OF 10 YEARS TOTAL SEASONAL RUNOFF WILL
NOT BE LESS THAN THE AMOUNTS SHOWN (IN MILLIMETERS)
MILES
0
25
50
QUEBEC
NEW YORK
LAKE ONTARIO
LAKE ERIE
LAKE HURON
MICHIGAN
40
40
60
60
60
60
80
80
80
80
100
100
100
100
100
100
46°
45°
44°
43°
42°
75°
76°
77°
78°
79°
80°
81°
82°
83°

Figure 9

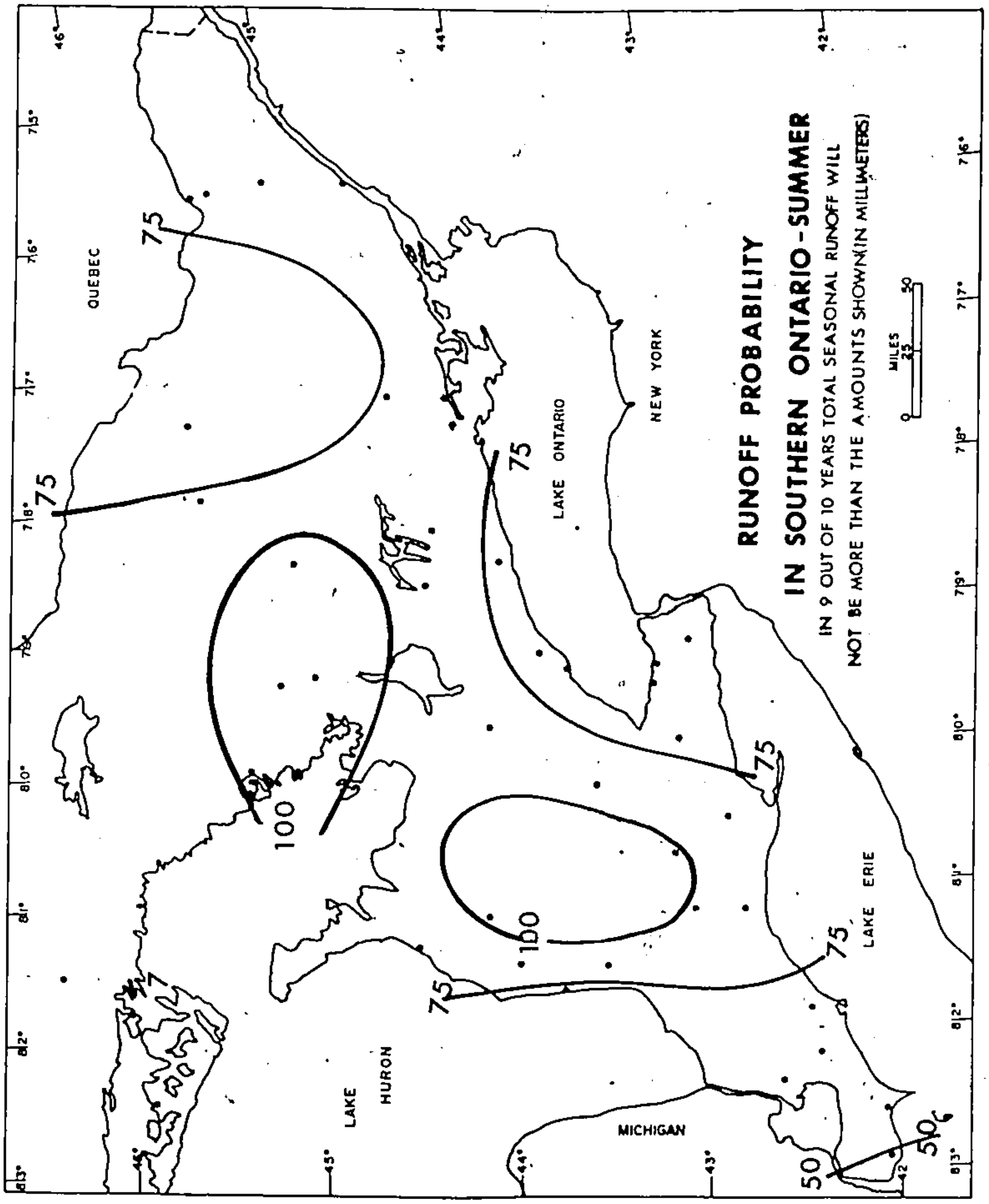

RUNOFF PROBABILITY
IN SOUTHERN ONTARIO-SUMMER
IN 9 OUT OF 10 YEARS TOTAL SEASONAL RUNOFF WILL
NOT BE MORE THAN THE AMOUNTS SHOWN (IN MILLIMETERS)
MILES
0
25
50
QUEBEC
LAKE ONTARIO
NEW YORK
LAKE ERIE
LAKE HURON
MICHIGAN
75
75
75
75
75
75
100
100
50
50
46°
45°
44°
43°
42°
75°
76°
77°
78°
79°
80°
81°
82°
83°

Figure 10

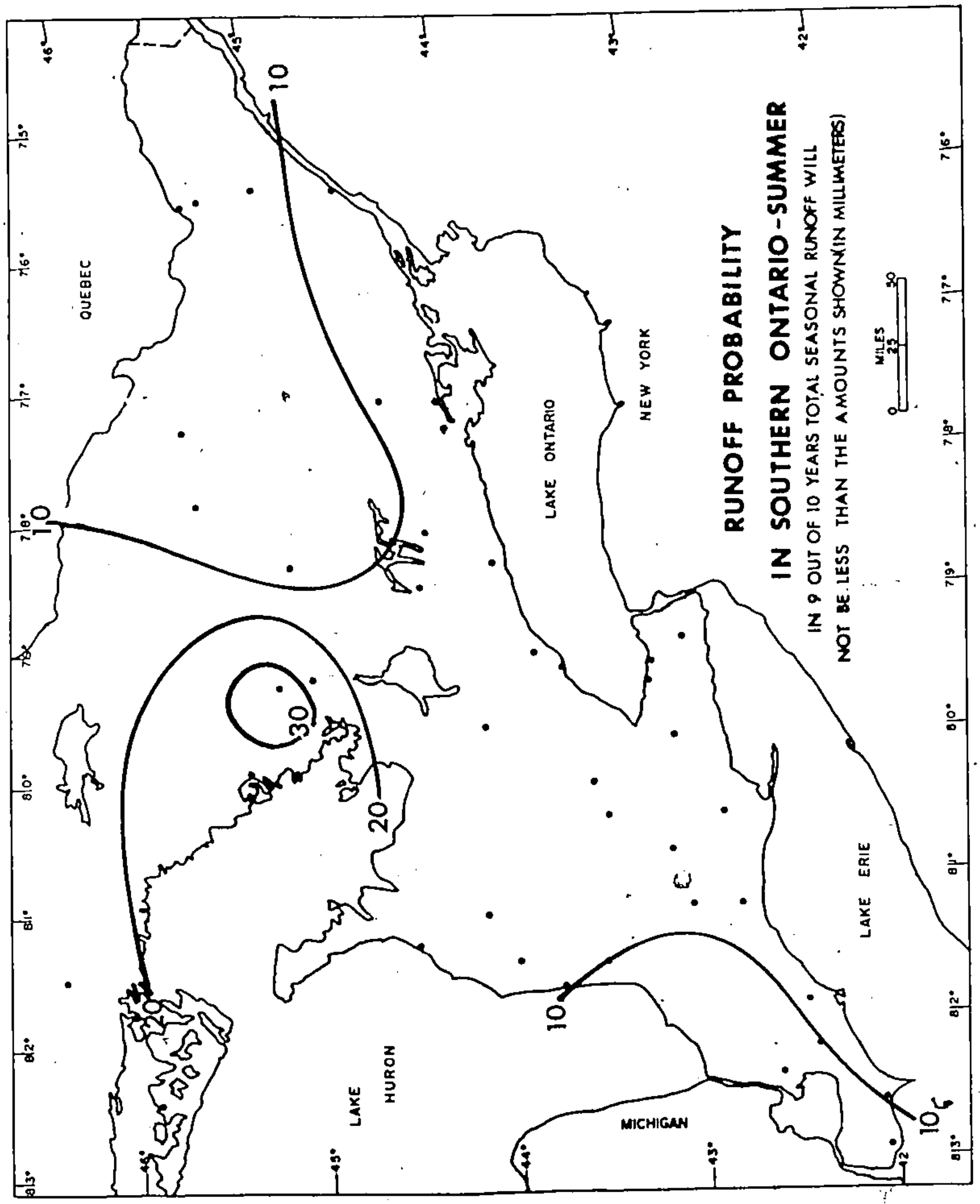
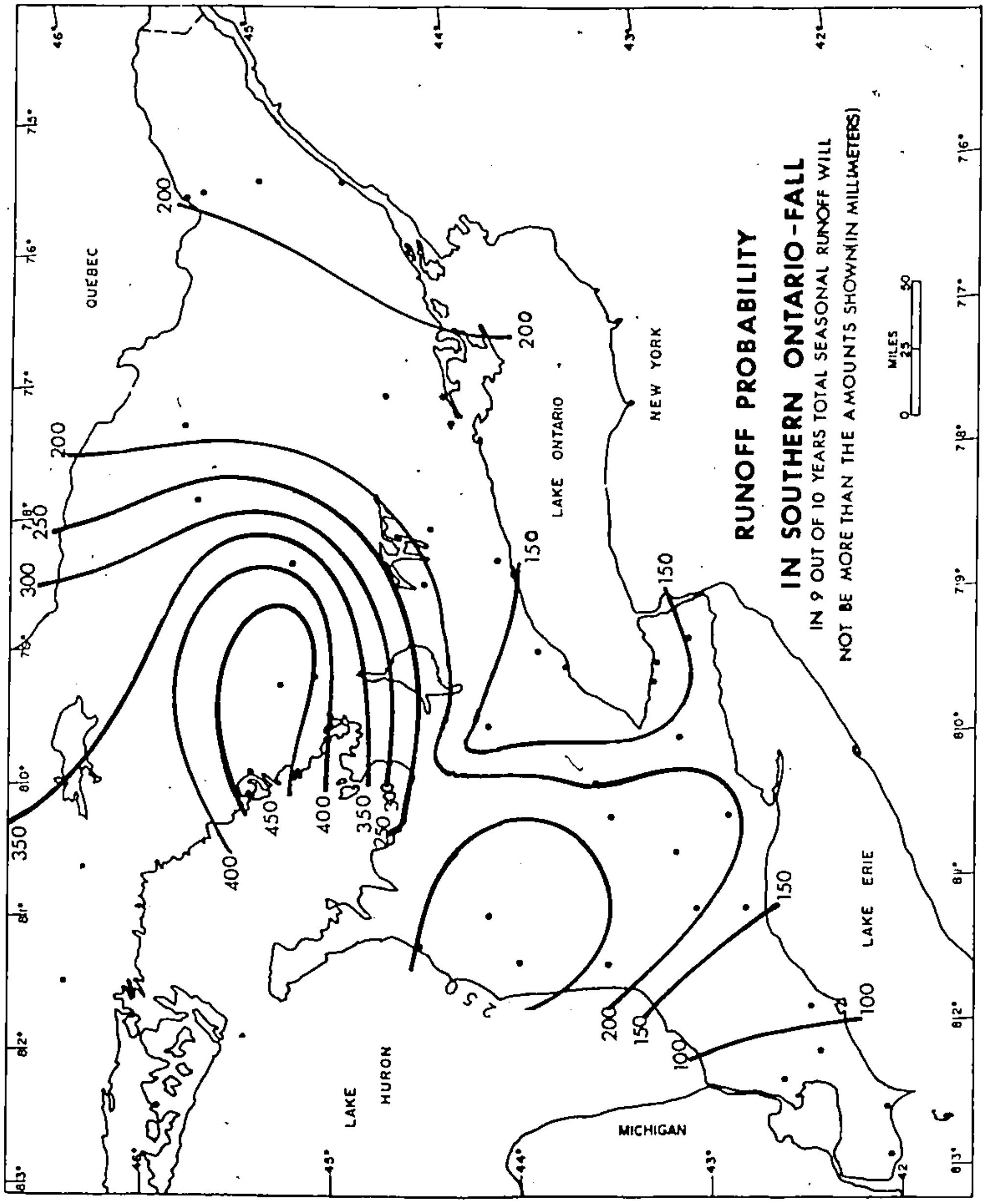

RUNOFF PROBABILITY
IN SOUTHERN ONTARIO-SUMMER
IN 9 OUT OF 10 YEARS TOTAL SEASONAL RUNOFF WILL
NOT BE LESS THAN THE AMOUNTS SHOWN (IN MILLIMETERS)
MILES
0
25
50
QUEBEC
LAKE ONTARIO
NEW YORK
LAKE ERIE
LAKE HURON
MICHIGAN
10
10
20
30
10
10
46°
45°
44°
43°
42°
75°
76°
77°
78°
79°
80°
81°
82°
83°

Figure 11



RUNOFF PROBABILITY IN SOUTHERN ONTARIO-FALL

IN 9 OUT OF 10 YEARS TOTAL SEASONAL RUNOFF WILL NOT BE MORE THAN THE AMOUNTS SHOWN (IN MILLIMETERS)

Figure 12

Figures 6 to 12. No map is presented for minimum fall values since, except for four stations (values ranging from 5mm. to 10mm.), the computed values were zero for all the stations. This is also the season when normality of data is suspect.

In general, the runoff probability maps for all the seasons show that, for the entire southern Ontario region, for all the seasons in 9 out of 10 years, average seasonal runoff will not be more than 460 millimeters and will not be less than 30 millimeters. In all seasons, the maximum probable runoff is likely to occur in the areas to the east of Georgian Bay and Lake Huron.

On a seasonal basis, the spring season (Figure 8) has the highest probable amount of runoff (1000mm.), while for the summer season (Figure 10) in 9 out of 10 years, total runoff will not be more than 100 millimeters. The maps indicating the low probable amounts also suggest that at least 60mm. of runoff should occur for the spring season, while summer and fall are the seasons with low runoff probabilities. Large variations of probability of occurrence of runoff within the region for the same period are quite evident in the spring (Figures 8 and 9).

In order to compare the predicted runoff range obtained from these maps, measured values of runoff results for some representative small watersheds for the year 1970 are tabulated in Table 7. In general, the measured runoff fits the predicted range, although low values of runoff

TABLE 7

Measured and Predicted Seasonal Runoff at
Representative Watersheds for 1970
(in Millimeters)

		Location				Seasonal Runoff			
						Winter		Spring	
Watershed	Drainage Area Sq. Km.	o	Lat 1^N	Long o	1^W	Measured	Predicted Range	Measured	Predicted Range
Castor River at Russell	267	45	15	75	20	35	15-170	413	60-650
Cedar Creek at Woodstock	58	43	07	80	46	13	16-270	31	60-550
Conestogo River at Drayton	200	43	45	80	40	79	40-350	243	100-1000
Don River at Todmorden	178	43	41	79	21	66	12-210	134	100-600
Goldwater River at Todmorden	110	44	42	79	38	45	30-300	101	100-1000
Highland Creek near West Hill	54	43	46	79	10	10	30-300	26	100-1000
Holland River at Holland Landing	108	44	05	79	29	18	15-200	63	80-600
Lynde Creek near Whitby	66	43	52	78	57	14	15-250	52	80-600
Mimico Creek at Islington	39	43	38	79	31	13	10-250	28	100-600
Salmon River near Shannonville	550	44	12	77	12	230	25-250	592	100-670
Thames River at Ingersoll	320	43	02	80	53	103	10-270	181	70-580
Thames River at Woodstock	157	43	08	80	45	56	10-270	103	70-580

TABLE 7 (cont'd)

Measured and Predicted Seasonal Runoff at Representative Watersheds for 1970 (in Millimeters)

		Location				Seasonal Runoff			
		Lat		Long		Summer		Fall	
Watershed	Drainage Area Sq. Km.	°	'N	°	'W	Measured	Predicted Range	Measured	Predicted Range
Castor River at Russell	267	45	15	75	20	8	6-80	64	5-220
Cedar Creek at Woodstock	58	43	07	80	46	6	6-60	11	5-130
Conestogo River at Drayton	200	43	45	80	40	8	25-100	42	10-400
Don River at Todmorden	178	43	41	79	21	73	10-80	76	10-200
Goldwater River at Todmorden	110	44	42	79	38	42	30-100	60	10-450
Highland Creek near West Hill	54	43	46	79	10	12	30-600	15	10-450
Holland River at Holland Landing	108	44	05	79	29	11	10-80	16	10-150
Lynde Creek near Whitby	66	43	52	78	57	6	10-80	10	5-200
Mimico Creek at Islington	39	43	38	79	31	14	10-75	12	5-150
Salmon River near Shannonville	550	44	12	77	12	95	10-75	114	5-200
Thames River at Ingersoll	320	43	02	80	53	83	10-90	73	5-170
Thames River at Woodstock	157	43	08	80	45	26	10-90	40	5-170

from the predicted range are slightly higher than the measured in the spring and summer seasons at five watersheds. This tendency of the predicted range, particularly pronounced in spring and summer, might be because the Phillips modification to the Thornthwaite and Mather approach does not take into account the underestimation of evaporation rate in spring and summer months, and hence the direct runoff resulted from precipitation is likely to result in higher values.

CHAPTER 4

Summary and Conclusions

In this study, the Phillips modification of the Thornthwaite-Mather water balance was examined to determine its applicability as an estimator of seasonal surface runoff probabilities in southern Ontario. The use of the historic records of temperature and precipitation from climatological stations in the region made possible the construction of seasonal runoff probability maps which provide background information on the probabilistic occurrence of runoff in all the seasons.

It is hoped that such maps may be useful to the PLUARG study in obtaining data on the inputs of pollutants into the Great Lakes drainage system which have their origins in the complex land use activities of agriculture. Since studies such as PLUARG involve measurements of precipitation and runoff for two years only, it is necessary to determine how representative these two years are of the precipitation-runoff history of the area. The present study is part of this objective.

On the basis of the study, the following conclusions can be drawn. In southern Ontario, the Phillips modification to the Thornthwaite-Mather model provides a better estimate of seasonal runoff when compared with the original Thornthwaite-Mather model. The seasonal runoff probability maps presented here give quantitative statements of maximum probable runoff that is likely to occur in southern Ontario. On a seasonal basis, the highest probable amount of runoff occurs in the spring. Also, the evaluated range of probable seasonal runoff from the maps shows good agreement with the measured runoff in some representative small watersheds.

Only seasonal runoff probabilities have been considered in the present study, since the Phillips modification failed to give significant correlations when applied on a monthly basis. Further work is needed in the modification of the model to obtain more reliable estimates of monthly runoff.

REFERENCES CITED

Brown, D. M., et al. 1968. The climate of southern Ontario. Climatological Studies. No. 5, Dept. of Transport, Met. Branch, Toronto.

Bruce, J. P., G. K. Rodgers. 1954. Water loss investigations. Lake Hefner studies. Geol. Survey Proc. Paper 269, U. S. Dept. of Interior, Washington.

Bruce, J. P. 1962. Snowmelt contributions to maximum floods. Paper presented at 19th Annual Meeting of Eastern Snow Conference. Yale Univ., New Haven, Conn.

Bruce, J. P. 1968. Atlas of rainfall intensity - duration frequency data for Canada. Climatological Studies. No. 8. Met. Branch. Canada Dept. of Transport, p. 31.

Brunk, I. W. 1961. Changes in the levels of Lake Michigan and Huron. J. Geophys. Res., 66(10):3335.

Canada Dept. of Energy Mines and Resources. 1968. A Guide to the Classification of Land use for the Canada Land Inventory. Policy and Planning Branch, Ottawa.

Carter, D. B. 1955. The water balance of the Lake Maracaibo basin during 1946-'53. Publ. in Climatology, Lab. of Climatology. 8(1):1-104.

Chapman, L. J., M. K. Thomas. 1968. The climate of northern Ontario. Climatological Studies. No. 6. Met. Branch. Canada Dept. of Transport, p. 58.

Collins, E. H. 1934. Relationship of degree days above freezing to runoff. *Trans. American Geophyl. Union*, Part 11, p. 624.

Derecki, J. A. 1964. Variation of Lake Erie evaporation and its causes. *Proc. Seventh Conf. Great Lakes Res*., 217-227.

Garstka, W. V., *et*. *al*. 1958. Factors affecting snowmelt and streamflow. *U. S. Dept. of the Interior*, Bureau of Reclamation, U. S. Govt. Printing, Washington.

Glover, J., *et*. *al*. 1954. Provisional maps of the reliability of annual rainfall in East Africa. *Quarterly Journ. of Royal Met. Soc*., 80, 602-611.

Gomes, J. R. 1975. Precipitation probabilities in southern Ontario. Unpublished B.A. Thesis. Department of Geography, Univ. of Windsor.

Gregory, S. 1955. Some aspects of the variability of annual rainfall over the British Isles for the standard period 1901-1930. *Quarterly Journ. of Royal Met. Soc*., 81, 257-262.

Gregory, S. 1964. *Statistical Methods and the Geographer*. Longmans, London.

Kendall, G. R. 1975. The cube-root normal distribution applied to Canadian Monthly Rainfall totals. Unpublished paper. Meteorological Service of Canada, Toronto.

Knowles, H. T. 1974. A central Texas synoptic climatology and its use as a precipitation forecast tool. Atmospheric Sciences Group. Dept. of Civil Eng. The Univ. of Texas at Austin, Texas.

John, C. T. 1971. The Thornthwaite water balance model as an estimator of runoff in southern Ontario. Unpublished M.A. Thesis, Dept. of Geography, Univ. of Windsor.

Manning, H. L. 1956. The statistical assessment of rainfall probability and its application to Uganda Agriculture. Proc. Royal Soc., B.144, 460.

Manning, H. L. 1958. The relationship between soil moisture and yield variance in cotton. Rep. Conf. Directors etc. of Overseas Dept. Col. Office. Misc. 531, p. 47. HMSO, London.

Mather, J. R. 1969b. Factors of the climatic water balance over the Delmarva Peninsula. <u>Publ. in Climatology</u>, Lab. of Climatology. 22(3):129.

Mather, J. R., <u>et</u>. <u>al</u>. 1972. The influence of the climatic water balance on conditions in the Estuarine Environment. <u>Publ. in Climatology</u>, Lab. of Climatology. 25(1).

Morton, F. I., H. B. Rosenberg. 1959. Hydrology of Lake Ontario. <u>Journ. Hydraulics Div</u>., <u>Proc. Amer. Soc. of Civil Eng</u>., 85 (H.Y.5) 2017.

Muller, R. A. 1966. The effects of reforestation on water yield: A case study using energy and water balance models for the Allegheny Plateau, New York. Publ. in Climatology. Lab. of Climatology. 19(3): 251-304.

Pentland, R. L. 1968. Runoff characteristics in the Great Lakes basin. Proc. Eleventh Conf. Great Lakes Res., International Assoc. Great Lakes Res., 326-359.

Phillips, D. W. 1967. Estimating runoff of river basins in southern Ontario. Unpublished B.A. Thesis, Dept. of Geography, Univ. of Windsor.

Phillips, D. W. 1975. Modification of the climatic water balance in cold climates. Unpublished paper. Atmospheric Environment Service, Toronto.

PLUARG. International Reference Group on Great Lakes Pollution from Land Use Activities. Task Group C (Canadian Section). Agricultural Watershed Studies, Great Lakes Drainage Basin. Agriculture Canada and Ontario Ministry of Environment (1975).

Report on Flood Control and Water Conservation. 1962. The Metropolitan Toronto and Region Conservation Authority Duffin Creek. R. K. Kilborn and Associates, Consulting Engineers, Toronto.

Sanderson, M. E. 1950. Moisture relationships in southern Ontario. Scientific Agriculture. 30, 235-255.

Sanderson M. E. 1966. A climatic water balance of the Lake Erie basin, 1958-1963. Publ. in Climatology. Lab. of Climatology. 19(1):1-87.

Sanderson, M. E., D. W. Phillips. 1967. Average annual water surplus in Canada. Climatological Studies. No. 9, Canada Dept. of Transport. Met. Branch.

Sanderson, M. E. 1971. Variability of annual rainfall in the Lake Ontario basin. Water Resources Res. 7(3): 554-565.

Sanderson, M. E. 1974. Maps of temperature and precipitation probabilities for Canada. Unpublished papers. Dept. of Geography, Univ. of Windsor.

Snedecor, W. G., W. G. Cochran. 1968. Statistical Methods. The Iowa State Univ. Press. Ames, Iowa.

Solomon, S. 1967. Relationship between precipitation, evaporation and runoff in tropical equatorial regions. Water Resources Res. 3(1):164-170.

Spiegel, M. R. 1961. Theory and Problems of Statistics. Schaum's outline series. McGraw-Hill. New York, p. 345.

Stidd, C. K. 1953. Cube-root-normal precipitation distributions. Trans. Amer. Geophl. Union. 34(1):31-35.

Strommen, N. D., J. E. Horsfield. 1969. Monthly precipitation probabilities by climatic divisions. U. S. Dept. of Agri. Misc. Publ., No. 1160.

Thornthwaite, C. W. 1948. An approach toward a rational classification of climate. Geogr. Rev. 38(1):55-94.

Thornthwaite, C. W., J. R. Mather. 1955. The water balance. Publ. in Climatology. Lab. of Climatology. 8(1).

Thornthwaite, C. W., J. R. Mather. 1957. Instructions and Tables for computing Potential Evapotranspiration and the Water Balance. Publ. in Climatology. Lab. of Climatology. 9(3).

Van Hylckama, T. E. A. 1958. Modification of the water balance approach for basins within the Delaware Valley. Publ. in Climatology. Lab. of Climatology. 11(3):271-302.

Ward, R. C. 1967. Principles of Hydrology. London Press, London.

Water Survey of Canada. 1974. Historical Streamflow Summary Ontario to 1973. Inland Waters Directorate, Water Resources Branch, Environment Canada, Ottawa.

Appendix 1

Computer program(WATIV)for Phillips modification

```
$JOB    WATFIV  XXXXXXXXXX,TIME=9
C        THIS PROGRAM COMPUTES THE AVERAGE WATER BALANCE BY MONTHS,
C        FOR AS MANY CONSECUTIVE YEARS AS DESIRED.
C
C        FOLLOWING ARE TWO CARD PAIRS, ONE PAIR FOR EACH YEAR OF DATA.
C          FIRST CARD OF PAIR HAS TWELVE MONTHLY AVERAGE TEMPERATURES
C          PUNCHED IN FIVE COLUMN FIELDS, WITH DECIMAL POINT.
C          SECOND CARD OF PAIR HAS TWELVE MONTHLY AVERAGE PRECIPITATION
C          VALUES IN FIVE COLUMN FIELDS, WITH DECIMAL POINTS.
C
C        FOLLOWING THE LAST PAIR OF T-P VALUES, THERE SHOULD BE A PAIR
C        OF BLANK CARDS TO SIGNIFY THE END OF A SET OF DATA.
C        THE PROGRAM IS SET TO PROCESS MULTIPLE SETS OF DATA, UNTIL
C        NO MORE CARDS ARE AVAILABLE.
C
      DIMENSION V(160.10).C(12.50),W(13.12).T(12).P(12)
      DIMENSION TITLE(7),HEAT(12),Z(12)
      DIMENSION PERCNT(12)
      DIMENSION DEGDAY(12)
      DIMENSION NAME(13)
      DIMENSION WSMRO(12).TOTRO(12)
      DATA NAME/'TEMP'.'UNPE'.'ADPE'.'PCFN'.'P-PE'.'APWL'.'STOR'.'D ST'.
     1'A EV'.'DEF '.'SURP'.'ROFF'.'TMDT'/
    2 CONTINUE
      READ (5.908.END=99) WHC
      WRITE(6.909) WHC
    1 DO 1000 ISET=1.10
      READ(5.901) (V(IZ.ISET).IZ=1.160)
 1000 CONTINUE
      DO 1005 ILAT=1.50
      READ(5.907) (C(JZ.ILAT).JZ=1.12)
 1005 CONTINUE
    5 W(7.12)=WHC
   11 CONTINUE
      TSAVE=25.0
      SUM=0.0
      ROS=0.0
      QST=WHC
   13 READ(5.934.END=99)IYR.TITLE.LAT.MIN.LONG,LMIN.LEV
  934 FORMAT(I4.3X.7A4.2I2.I3.I2.I4)
      WRITE(6.911)(TITLE(I).I=1.7).LAT.MIN.LONG.LMIN,LEV
  911 FORMAT('1'.7A4.6X.I2.2X.I2.6X.I3.2X.I2.6X.I4.//)
    9 READ(5.935)(T(K).K=1.12)
      READ(5.936)(P(K).K=1.12)
  935 FORMAT(12F5.2)
  936 FORMAT(12F5.2)
      IF(T(7)) 2.20.29
   20 GO TO 11
   29 ILAT=LAT-40
   10 CONTINUE
      DO 7 IY=1.12
      WSMRO(IY)=0.0
    7 TOTRO(IY)=0.0
      WSMSUM=0.0
      TOTSUM=0.0
   21 THEAT=0.0
      DO 253 J=1.12
      HEAT(J)=(((0.0026*T(J)**2)-(0.0268*T(J)))-2.2587)
      IF(HEAT(J).LT.0.0) HEAT(J)=0.0
      THEAT=THEAT+HEAT(J)
  253 CONTINUE
      IF(THEAT.GE.50.0) ISET=10
      IF(THEAT.GE.45.0.AND.THEAT.LT.50.0) ISET=9
      IF(THEAT.GE.40.0.AND.THEAT.LT.45.0) ISET=8
      IF(THEAT.GE.35.0.AND.THEAT.LT.40.0) ISET=7
      IF(THEAT.GE.30.0.AND.THEAT.LT.35.0) ISET=6
      IF(THEAT.GE.25.0.AND.THEAT.LT.30.0) ISET=5
      IF(THEAT.GE.20.0.AND.THEAT.LT.25.0) ISET=4
      IF(THEAT.GE.15.0.AND.THEAT.LT.20.0) ISET=3
      IF(THEAT.GE.10.0.AND.THEAT.LT.15.0) ISET=2
      IF(THEAT.LT.10.0)                   ISET=1
   14 CONTINUE
   30 STL=W(7.12)
      DO 250 J=1.12
      W(1.J)=T(J)
      W(2.J)=0.0
   35 W(4.J)=P(J)
      W(11.J)=0.0
      W(12.J)=0.0
      IF(T(J)-32.0)50.40.40
```

8

4

```
   40 IT = 2.0*T(J)-62.5
      W(2,J)=V(IT,ISET)
   50 W(3,J)=W(2,J)*C(J,ILAT)
      W(5,J)=W(4,J)-W(3,J)
      W(6,J)=0.0
      IF (W(5,J))60,70,70
   60 CONTINUE
      IF (QST-WHC)65,65,63
   63 W(11,J)=QST-WHC
   65 CONTINUE
      SUM=SUM+W(5,J)
      W(6,J)=SUM
      W(7,J) = WHC*EXP(SUM/WHC)
      W(8,J)=W(7,J)-QST
      QST=W(7,J)
      W(9,J)=W(4,J)-W(8,J)
      W(10,J)=W(3,J)-W(9,J)
      GO TO 200
   70 CONTINUE
      W(7,J)=STL+W(5,J)
      IF(T(J).GT.31.9) GO TO 68
      POT=W(7,J)-WHC
      IF(W(7,J)-WHC)68,68,69
   69 IF(J.EQ.1) GO TO 710
      IF(J.EQ.2) GO TO 711
      IF(J.EQ.3) GO TO 712
  713 PERCNT(J)=(-99.91+5.71*(T(J)))/100.
      GO TO 71
  710 PERCNT(J)=(-7.74+1.41*(T(J)))/100.
      GO TO 71
  711 PERCNT(J)=(6.93+0.87*(T(J))-0.78*(W(7,J)-WHC))/100.
      GO TO 71
  712 PERCNT(J)=(-13.85+1.95*(T(J))-0.95*(W(7,J)-WHC))/100.
      GO TO 71
   71 WSMRO(J)=(PERCNT(J)*(W(7,J)-WHC))-(0.5*ROS)
   72 IF(WSMRO(J).GT.POT) WSMRO(J)=POT
      IF(WSMRO(J).LT.0.0) GO TO 85
      W(7,J)=W(7,J)-WSMRO(J)
      WSMSUM=WSMSUM+WSMRO(J)
      GO TO 68
   85 WSMRO(J)=0.0
   68 CONTINUE
      TSAVE=T(J)
      W(9,J)=W(3,J)
      W(10,J)=0.0
      IF(W(7,J)-WHC)80, 115,90
   80 CONTINUE
      SUM = WHC*ALOG(W(7,J)/WHC)
      W(6,J)=SUM
      W(8,J) = W(7,J)-QST
      QST=W(7,J)
      GO TO 200
   90 CONTINUE
      SUM=0.0
      W(6,J)=0.0
      W(8,J)=WHC-QST
      QST=WHC
      IF(T(J)-31.9) 200,200,110
  110 CONTINUE
      W(7,J)=WHC
  115 CONTINUE
      W(11,J)=W(5,J)+STL-W(7,J)
  200 CONTINUE
      STL=W(7,J)
  210 W(12,J)=0.5*(ROS+W(11,J))
  215 ROS=W(12,J)
  220 IF(J-1)230,230,240
  230 DO 235 I=1,12
  235 W(13,I)=0.0
  240 DO 245 I = 1,12
  245 W(13,I)=W(I,J)+W(13,I)
      TOTRO(J)=W(12,J)+ WSMRO(J)
      TOTSUM=TOTSUM+TOTRO(J)
  250 CONTINUE
      W(13,1)=W(13,1)/12.
      W(13,7)=W(13,7)/12.
      WRITE(6,910)
      DO 270 I=1,12
      DO 265 J = 1,12
  265 T(J) = W(I,J)
```

```
    145           W_ASTA = W(13,I)
    146           WRITE(6,904) T,IYR,WLASTA,NAME(I)
    147       270 CONTINUE
    148           WRITE(6,915) WSMRO,IYR,WSMSUM
    149           WRITE(6,916) TOTRO,IYR,TOTSUM
    150           WRITE(7,917)TOTRO,IYR
    151       917 FORMAT(12F6.2,I5,2X'C')
**WARNING**  EXPECTING COMMA BETWEEN FORMAT ITEMS NEAR ,2X'C
    152           WRITE(6,905)
    153           IYR=IYR + 1
    154           GO TO 9
    155        99 STOP
    156       901 FORMAT (40F2.2)
    157       902 FORMAT (12F5.2)
    158       903 FORMAT(1H1,18A4)
    159       904 FORMAT.(1X,12F6.2,I5,1X,F7.2,2X,A4)
    160       905 FORMAT (1H )
    161       906 FORMAT (I4,18A4)
    162       907 FORMAT(20X,12F5.2)
    163       908 FORMAT(F5.2)
    164       909 FORMAT(' SOIL MOISTURE RETENTION = ',F5.2,' INCHES'//)
    165       910 FORMAT('   JAN   FEB   MAR   APR    MAY    JUN    JUL    AUG    SEP    O
             1CT   NOV   DEC   YEAR      Y  '/)
    166       915 FORMAT(1X,12F6.2,I5,1X,F7.2,2X,'WSMRO')
    167       916 FORMAT(1X,12F6.2,I5,1X,F7.2,2X,'TOTRO')
    168           END
**WARNING**  FORMAT STATEMENT    902 IS UNREFERENCED
**WARNING**  FORMAT STATEMENT    903 IS UNREFERENCED
**WARNING**  FORMAT STATEMENT    906 IS UNREFERENCED

       $ENTRY




SOIL MOISTURE RETENTION =  6.00 INCHES
```

Appendix 2

Model water balance computations based on Phillips model

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BROUGHAM30                                   43  55      79   7        550

  JAN    FEB    MAR    APR    MAY    JUN    JUL    AUG    SEP    OCT    NOV    DEC   YEAR       Y

19.60  19.60  35.00  46.20  49.80  61.20  68.20  67.20  63.20  51.90  38.50  23.50  1968    45.32  TEMP
 0.00   0.00   0.01   0.05   0.06   0.10   0.13   0.13   0.11   0.07   0.02   0.00  1968     0.68  UNPE
 0.00   0.00   0.31   1.68   2.27   3.84   5.03   4.68   3.43   1.99   0.49   0.00  1968    23.72  ADPE
 4.87   3.04   3.47   1.38   3.80   2.74   1.45   2.47   3.02   1.90   4.76   3.86  1968    36.43  PCPN
 4.87   3.04   3.16  -0.33   1.23  -1.10  -3.58  -2.21  -0.41  -0.09   4.27   3.86  1968    12.71  P-PE
 0.00   0.00   0.00  -0.33   0.00  -1.10  -4.68  -6.89  -7.30  -7.40   0.00   0.00  1968   -27.70  APWL
10.75  12.39   6.00   5.68   6.00   4.99   2.75   1.90   1.78   1.75   6.00   8.56  1968     5.71  STOR
 0.00   0.00   0.00  -0.32   0.32  -1.01  -2.24  -0.85  -0.13  -0.03   4.25   0.00  1968     0.00  D ST
 0.00   0.00   0.31   1.67   2.27   3.75   3.69   3.32   3.15   1.93   0.49   0.00  1968    20.56  A EV
 0.00   0.00   0.00   0.01   0.00   0.09   1.34   1.36   0.29   0.07   0.00   0.00  1968     3.16  DEF
 0.00   0.00   9.56   0.00   0.91   0.00   0.00   0.00   0.00   0.00   0.02   0.00  1968    10.49  SURP
 0.00   0.00   4.78   2.39   1.65   0.82   0.41   0.21   0.10   0.05   0.04   0.02  1968    10.47  ROFF
 1.18   1.39   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   1.30  1968     3.88  WSMRO
 1.18   1.39   4.78   2.39   1.65   0.82   0.41   0.21   0.10   0.05   0.04   1.32  1968    14.35  TOTRO
  JAN    FEB    MAR    APR    MAY    JUN    JUL    AUG    SEP    OCT    NOV    DEC   YEAR       Y

24.30  26.50  29.70  44.40  53.10  61.20  69.90  70.80  62.70  49.50  38.90  23.00  1969    46.17  TEMP
 0.00   0.00   0.00   0.04   0.07   0.10   0.14   0.14   0.11   0.06   0.02   0.00  1969     0.68  UNPE
 0.00   0.00   0.00   1.34   2.65   3.84   5.42   5.04   3.43   1.71   0.49   0.00  1969    23.92  ADPE
 2.72   0.34   2.40   3.85   3.21   3.05   2.40   1.83   0.50   2.24   3.94   3.30  1969    29.78  PCPN
 2.72   0.34   2.40   2.51   0.56  -0.79  -3.02  -3.21  -2.93   0.53   3.45   3.30  1969     5.86  P-PE
 0.00   0.00   0.00   0.00   0.00  -0.79  -3.81  -7.02  -9.95  -7.66  -0.94   0.00  1969   -30.17  APWL
 9.89   9.10   9.37   6.00   6.00   5.26   3.18   1.86   1.14   1.67   5.13   7.68  1969     5.52  STOR
 0.00   0.00   0.00   0.00   0.00  -0.74  -2.08  -1.32  -0.72   0.53   3.45   0.87  1969     0.00  D ST
 0.00   0.00   0.00   1.34   2.65   3.79   4.48   3.15   1.22   1.71   0.49   0.00  1969    18.82  A EV
 0.00   0.00   0.00   0.00   0.00   0.05   0.94   1.89   2.21   0.00   0.00   0.00  1969     5.09  DEF
 0.00   0.00   0.00   5.87   0.56   0.00   0.00   0.00   0.00   0.00   0.00   0.00  1969     6.44  SURP
 0.01   0.00   0.00   2.94   1.75   0.88   0.44   0.22   0.11   0.05   0.03   0.01  1969     6.44  ROFF
 1.39   1.12   2.13   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.75  1969     5.40  WSMRO
 1.40   1.13   2.14   2.94   1.75   0.88   0.44   0.22   0.11   0.05   0.03   0.76  1969    11.84  TOTRO
  JAN    FEB    MAR    APR    MAY    JUN    JUL    AUG    SEP    OCT    NOV    DEC   YEAR       Y

17.00  21.10  33.40  44.80  52.20  64.80  69.00  69.30  61.00  51.60  41.60  24.80  1970    45.88  TEMP
 0.00   0.00   0.00   0.04   0.07   0.12   0.13   0.14   0.10   0.07   0.03   0.00  1970     0.70  UNPE
 0.00   0.00   0.00   1.34   2.65   4.61   5.03   5.04   3.12   1.99   0.73   0.00  1970    24.51  ADPE
 2.06   1.64   2.85   3.88   2.15   1.02   4.94   3.42   2.43   3.05   2.35   4.57  1970    34.36  PCPN
 2.06   1.64   2.85   2.54  -0.50  -3.59  -0.09  -1.62  -0.69   1.06   1.62   4.57  1970     9.85  P-PE
 0.00   0.00   0.00   0.00  -0.50  -4.08  -4.17  -5.79  -6.48  -3.98  -1.45   0.00  1970   -26.46  APWL
 9.14   9.75   6.00   6.00   5.52   3.04   2.99   2.28   2.04   3.09   4.71   7.92  1970     5.21  STOR
 0.00   0.00   0.00   0.00  -0.48  -2.49  -0.05  -0.71  -0.25   1.06   1.62   1.29  1970     0.00  D ST
 0.00   0.00   0.00   1.34   2.63   3.51   4.99   4.13   2.68   1.99   0.73   0.00  1970    21.99  A EV
 0.00   0.00   0.00   0.00   0.02   1.10   0.05   0.91   0.44   0.00   0.00   0.00  1970     2.52  DEF
 0.00   0.00   6.60   2.54   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00  1970     9.14  SURP
 0.01   0.00   3.30   2.92   1.46   0.73   0.36   0.18   0.09   0.05   0.02   0.01  1970     9.14  ROFF
 0.60   1.03   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   1.36  1970     2.98  WSMRO
 0.61   1.03   3.30   2.92   1.46   0.73   0.36   0.18   0.09   0.05   0.02   1.37  1970    12.12  TOTRO
  JAN    FEB    MAR    APR    MAY    JUN    JUL    AUG    SEP    OCT    NOV    DEC   YEAR       Y

17.80  25.30  28.60  40.90  53.40  64.20  68.70  68.50  65.20  63.40  45.00  30.40  1971    47.45  TEMP
 0.00   0.00   0.00   0.03   0.07   0.11   0.13   0.12   0.11   0.11   0.04   0.00  1971     0.72  UNPE
 0.00   0.00   0.00   1.01   2.65   4.22   5.03   4.32   3.43   3.14   0.97   0.00  1971    24.77  ADPE
 2.53   3.69   1.42   1.33   1.06   3.94   4.77   5.20   3.08   1.56   2.51   4.38  1971    35.47  PCPN
 2.53   3.69   1.42   0.32  -1.59  -0.28  -0.26   0.88  -0.35  -1.57   1.54   4.38  1971    10.70  P-PE
 0.00   0.00   0.00   0.00  -1.59  -1.87  -2.13  -0.99  -1.34  -2.92  -0.83   0.00  1971   -11.67  APWL
 9.69  11.67  10.60   6.00   4.61   4.39   4.21   5.09   4.80   3.69   5.23   6.96  1971     6.41  STOR
 0.00   0.00   0.00   0.00  -1.39  -0.21  -0.19   0.88  -0.29  -1.11   1.54   0.77  1971     0.00  D ST
 0.00   0.00   0.00   1.01   2.45   4.15   4.96   4.32   3.37   2.67   0.97   0.00  1971    23.90  A EV
 0.00   0.00   0.00   0.00   0.19   0.07   0.07   0.00   0.06   0.47   0.00   0.00  1971     0.87  DEF
 0.00   0.00   0.00   4.92   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00  1971     4.92  SURP
 0.01   0.00   0.00   2.46   1.23   0.61   0.31   0.15   0.08   0.04   0.02   0.01  1971     4.92  ROFF
 0.77   1.71   2.49   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   2.65  1971     7.62  WSMRD
 0.77   1.71   2.49   2.46   1.23   0.61   0.31   0.15   0.08   0.04   0.02   2.66  1971    12.54  TOTRO
  JAN    FEB    MAR    APR    MAY    JUN    JUL    AUG    SEP    OCT    NOV    DEC   YEAR       Y

22.80  20.20  27.00  38.50  54.80  60.00  67.20  65.40  60.40  44.70  36.50  27.90  1972    43.78  TEMP
 0.00   0.00   0.00   0.02   0.08   0.10   0.13   0.12   0.11   0.04   0.02   0.00  1972     0.62  UNPE
 0.00   0.00   0.00   0.67   3.02   3.84   5.03   4.32   3.43   1.14   0.49   0.00  1972    21.94  ADPE
 1.85   2.27   4.08   2.85   1.48   2.44   2.24   4.68   3.41   3.21   3.41   6.02  1972    37.94  PCPN
 1.85   2.27   4.08   2.18  -1.54  -1.40  -2.79   0.36  -0.02   2.07   2.92   6.02  1972    16.00  P-PE
 0.00   0.00   0.00   0.00  -1.54  -2.94  -5.73  -4.86  -4.89  -1.43   0.00   0.00  1972   -21.41  APWL
 8.13   9.47  11.17   6.00   4.64   3.67   2.31   2.67   2.66   4.73   6.00   8.87  1972     5.86  STOR



 0.00   0.00   0.00   0.00  -1.36  -0.97  -1.37   0.36  -0.01   2.07   1.27   0.00  1972     0.00  D ST
 0.00   0.00   0.00   0.67   2.84   3.41   3.61   4.32   3.42   1.14   0.49   0.00  1972    19.89  A EV
 0.00   0.00   0.00   0.00   0.18   0.43   1.42   0.00   0.01   0.00   0.00   0.00  1972     2.05  DEF
 0.00   0.00   0.00   7.34   0.00   0.00   0.00   0.00   0.00   0.00   1.65   0.00  1972     9.00  SURP
 0.00   0.00   0.00   3.67   1.84   0.92   0.46   0.23   0.11   0.06   0.85   0.43  1972     8.58  ROFF
 0.68   0.92   2.39   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   3.15  1972     7.14  WSMRO
 0.69   0.93   2.39   3.67   1.84   0.92   0.46   0.23   0.11   0.06   0.85   3.58  1972    15.72  TOTRO
  JAN    FEB    MAR    APR    MAY    JUN    JUL    AUG    SEP    OCT    NOV    DEC   YEAR       Y

18.50  20.60  38.30  43.70  51.50  65.20  70.20  72.30  61.10  51.80  40.00  26.30  1973    46.62  TEMP
 0.00   0.00   0.02   0.04   0.06   0.11   0.13   0.15   0.10   0.06   0.02   0.00  1973     0.69  UNPE
 0.00   0.00   0.61   1.34   2.27   4.22   5.03   5.40   3.12   1.71   0.49   0.00  1973    24.19  ADPE
 2.09   1.31   5.38   2.17   3.47   2.19   2.03   2.28   1.72   3.68   3.33   3.28  1973    32.93  PCPN
 2.09   1.31   4.77   0.83   1.20  -2.03  -3.00  -3.12  -1.40   1.97   2.84   3.28  1973     8.74  P-PE
 0.00   0.00   0.00   0.00   0.00  -2.03  -5.03  -8.15  -9.55  -3.79   0.00   0.00  1973   -28.57  APWL
10.26  10.54   6.00   6.00   6.00   4.27   2.59   1.54   1.22   3.19   6.00   7.66  1973     5.44  STOR
 0.00   0.00   0.00   0.00   0.00  -1.73  -1.68  -1.05  -0.32   1.97   2.81   0.00  1973     0.00  D ST
 0.00   0.00   0.61   1.34   2.27   3.92   3.71   3.33   2.04   1.71   0.49   0.00  1973    19.42  A EV
 0.00   0.00   0.00   0.00   0.00   0.31   1.32   2.07   1.08   0.00   0.00   0.00  1973     4.78  DEF
 0.00   0.00   9.31   0.83   1.20   0.00   0.00   0.00   0.00   0.00   0.03   0.00  1973    11.37  SURP
 0.21   0.11   4.71   2.77   1.58   0.99   0.50   0.25   0.12   0.06   0.05   0.02  1973    11.77  ROFF
 0.70   1.04   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   1.62  1973     3.36  WSMRO
 0.91   1.14   4.71   2.77   1.58   0.99   0.50   0.25   0.12   0.06   0.05   1.65  1973    15.13  TOTRO
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All values except temperature are in inches.

APPENDIX 3

COMPUTED AND MEASURED SEASONAL RUNOFF - DUFFIN CREEK (PICKERING)

(DEPTH IN MILLIMETERS)

(a) WINTER

Year	Month	a	b	c
1966	Dec.	51.3	1.5	26.2
1966	Jan.	21.3	8.6	17.0
1966	Feb.	26.6	4.3	16.8
1967	Dec.	52.8	13.7	35.1
1967	Jan.	26.9	0.8	20.3
1967	Feb.	19.8	0.5	14.7
1968	Dec.	29.7	6.6	21.6
1968	Jan.	21.6	5.3	23.9
1968	Feb.	27.9	2.5	81.0
1969	Dec.	14.7	1.0	13.2
1969	Jan.	29.5	3.3	35.3
1969	Feb.	25.9	1.5	18.5
1970	Dec.	18.3	0.5	22.4
1970	Jan.	13.2	0.5	11.2
1970	Feb.	22.6	0.3	11.4
1971	Dec.	28.9	0.8	41.9
1971	Jan.	11.2	0.3	19.3
1971	Feb.	38.9	0	26.2
1972	Dec.	71.4	6.9	48.0
1972	Jan.	13.5	0.5	20.1
1972	Feb.	22.6	0.3	14.7
1973	Dec.	35.1	1.0	21.3
1973	Jan.	16.3	3.1	12.2
1973	Feb.	26.0	1.8	14.7

(b) SPRING

Year	Month	a	b	c
1966	Mar.	72.7	20.8	44.5
1966	April	38.6	93.5	31.2
1966	May	21.3	48.8	31.8
1967	Mar.	39.4	0.3	50.8
1967	April	51.0	23.6	53.9
1967	May	31.0	112.0	20.3
1968	Mar.	89.4	34.3	101.1
1968	April	45.2	115.1	29.0
1968	May	32.8	43.7	23.6
1969	Mar.	43.7	0.8	58.2
1969	April	68.1	25.2	51.8
1969	May	41.2	120.4	30.7
1970	Mar.	68.6	38.1	40.6
1970	April	60.2	110.2	54.6
1970	May	30.2	55.1	23.1
1971	Mar.	52.8	0	39.6
1971	April	58.4	24.1	75.2
1971	May	29.2	108.2	15.2
1972	Mar.	56.9	0	42.2
1972	April	83.8	28.7	136.9
1972	May	41.9	129.8	23.4
1973	Mar.	104.1	31.2	32.3
1973	April	67.3	155.2	17.5
1973	May	50.6	92.9	28.5

a = computed runoff (Phillips, 1975)

b = computed runoff (Thornthwaite, 1957)

c = measured runoff

APPENDIX 3 (cont'd)

(c) SUMMER

Year	Month	a	b	c
1966	June	10.7	24.4	21.3
1966	July	5.3	12.2	5.8
1966	Aug.	2.5	6.1	6.4
1967	June	37.9	78.2	20.8
1967	July	19.0	39.4	21.6
1967	Aug.	15.5	25.7	21.6
1968	June	15.2	32.8	14.5
1968	July	7.6	15.5	8.9
1968	Aug.	3.8	8.4	9.4
1969	June	20.6	60.2	14.2
1969	July	10.4	30.2	8.6
1969	Aug.	5.1	15.0	8.4
1970	June	15.2	27.7	9.4
1970	July	7.4	13.7	12.5
1970	Aug.	3.8	6.9	9.9
1971	June	14.5	54.1	11.7
1971	July	7.4	26.9	13.2
1971	Aug.	3.6	13.5	16.5
1972	June	21.1	65.0	17.0
1972	July	10.4	32.5	11.7
1972	Aug.	5.3	16.3	11.7
1973	June	25.2	46.5	15.8
1973	July	12.7	23.1	9.9
1973	Aug.	6.4	11.7	11.9

(d) FALL

Year	Month	a	b	c
1966	Sept.	1.3	3.1	9.7
1966	Oct.	0.8	1.5	9.2
1966	Nov.	2.8	3.3	20.6
1967	Sept.	7.9	13.0	12.7
1967	Oct.	11.2	13.7	24.4
1967	Nov.	26.4	27.4	25.9
1968	Sept.	2.0	4.1	11.4
1968	Oct.	3.6	4.8	11.4
1968	Nov.	12.5	13.0	19.8
1969	Sept.	2.5	7.6	6.9
1969	Oct.	1.3	3.8	10.4
1969	Nov.	0.8	2.0	16.5
1970	Sept.	1.8	3.6	11.9
1970	Oct.	1.0	1.8	14.5
1970	Nov.	0.5	0.8	20.6
1971	Sept.	1.8	6.9	16.5
1971	Oct.	1.0	3.3	12.7
1971	Nov.	0.5	1.5	16.0
1972	Sept.	2.5	7.9	6.1
1972	Oct.	1.3	4.1	7.6
1972	Nov.	12.7	14.0	8.1
1973	Sept.	3.1	5.8	10.7
1973	Oct.	1.5	3.6	14.7
1973	Nov.	1.3	2.0	26.2

a = computed runoff (Phillips, 1975)

b = computed runoff (Thornthwaite, 1957)

c = measured runoff

APPENDIX 4

Climatological stations used in the study

Station	Latitude	Longitude	Elevation (meters)
Beatrice	45°08'	79°23'	288.8
Beeton	44 06	79 47	232.3
Belleville	44 09	77 24	76.0
Brockville	44 36	75 42	91.2
Brucefield	43 33	81 33	258.4
Caledonia	43 05	79 57	205.2
Chatham	42 24	82 12	182.4
Delhi	42 52	80 33	231.0
Goderich	43 43	81 42	220.4
Gore Bay	45 53	82 34	190.0
Grimsby	43 12	79 34	92.7
Guelph	43 31	80 14	332.9
Harrow	42 02	82 54	190.3
Haliburton	45 01	78 33	319.2
Kemptville	45 00	75 38	97.3
Killaloe	45 34	77 25	173.6
Kitchener	43 26	80 30	342.0
Leamington	42 03	82 38	212.8
Lindsay	44 21	78 45	266.0
Lucknow	43 58	81 31	266.0
Madawaska	45 30	77 59	315.6
Muskoka	44 58	79 18	281.5
Orono	43 58	78 37	147.4
Ottawa CDA (1)	45 23	75 43	79.0

Appendix 4 (cont'd)

Station	Latitude	Longitude	Elevation (meters)
Ottawa International A (2)	45°19'	75°40'	125.6
Parry Sound	45 20	80 00	193.0
Pelee Island	41 45	82 41	174.8
Peterborough	44 17	78 19	193.0
Ridgetown	42 27	81 53	205.2
St. Thomas	42 48	81 11	207.3
Southampton	44 30	81 21	199.4
Toronto (1)	43 40	79 24	115.2
Toronto (Agincourt) (2)	43 47	79 16	179.4
Trenton	44 07	77 32	80.9
Turbine	46 23	81 34	205.2
Tweed	44 30	77 17	144.4
Vineland Station	43 11	79 23	79.0
Walkerton	44 08	81 09	243.2
Wallaceburg	42 35	82 24	176.3
Welland	43 00	79 16	174.8
Woodstock	43 08	80 46	281.2

Appendix 5

Computed monthly runoff probabilities

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//RUNOFF JOB (XXXXXXXXXX,8..8888),'C.V.RAMASASTRY',CLASS=A                    JOB 959
// EXEC WATFIV
//GO.SYSIN DD *
IEF142I - STEP WAS EXECUTED - COND CODE 0000
IEF373I STEP /GO       / START 75343.1430
IEF374I STEP /GO       / STOP  75343.1431 CPU   0MIN 11.30SEC MAIN 150K LCS    OK
IEF375I  JOB /RUNOFF   / START 75343.1430
IEF376I  JOB /RUNOFF   / STOP  75343.1431 CPU   0MIN 11.30SEC
```

```
$JOB    WATFIV  XXXXXXXXXX
       DIMENSION   DATA(35,12), VECTOR(35),ITITLE(20)
       REAL    POSVAR, NEGVAR
       INTEGER STOP
       DATA    STOP/'9999'/
       IT=0
   702 READ (5,100)    ITITLE
   100 FORMAT (20A4)
          (ITITLE(1).EQ.STOP)  GO TO 705
       READ (5,102)    N
   102 FORMAT (I2)
       WRITE (6,103)    ITITLE , N
   103 FORMAT (//,5X,'STATION ',20A4,5X,'NUMBER OF YEARS ', I3,//)
       DO 104    I=1,N
       READ (5,105)    (DATA(I,J),J=1,12)
   105 FORMAT (12F6.2)
   104 CONTINUE
       WRITE (6,500)
   500 FORMAT (3X,'MONTH',5X,'MEAN',16X,'ST. DEV.',20X,'POSVAR',20X,'NEGV
      1AR',//)
       DO 1000   J=1,12
       SUMX=0.0
       SUMX2=0.0
       DO 2000   I=1,N
       VECTOR (I)=DATA(I,J)
       SUMX=SUMX+VECTOR(I)
       SUMX2=SUMX2+VECTOR(I)*VECTOR(I)
  2000 CONTINUE
       VAR=(FLOAT(N)*SUMX2-SUMX*SUMX)/FLOAT(N*(N-1))
       STDEV=SQRT(VAR)
       AMEAN=SUMX/FLOAT(N)
       POSVAR=(1.28*STDEV+AMEAN)*25.4
       NEGVAR=(-1.28*STDEV+AMEAN)*25.4
       WRITE (6,201) J,AMEAN,STDEV,POSVAR,NEGVAR
   201 FORMAT (5X,I2,F15.5,5X,F15.5,5X,F20.5,5X,F20.5)
  1000 CONTINUE
       IT=IT+1
       GO TO 702
   705 CONTINUE
       WRITE (6,555)    IT
```

All values in centimeters.

```
      555 FORMAT (///,5X,'NUMBER OF STATIONS TREATED', I5)
          STOP
          END

      $ENTRY


 STATION        ALGONQUIN PARK                     4535 7833 1419

MONTH      MEAN                ST. DEV.                     POSVAR            NEGVAR

   1        0.39955              0.35136                    21.57176          -1.27488
   2        0.84682              0.34743                    32.83481          10.21347
   3        1.87272              1.13604                    84.50214          10.63205
   4        4.54181              2.37606                   192.61220          36.11166
   5        2.07454              0.91902                    82.57249          22.81415
   6        1.14545              0.63463                    49.72760          -8.46124
   7        0.57364              0.31675                    24.86844           4.27226
   8        0.28591              0.15934                    12.41016           2.11399
   9        0.23318              0.28630                    15.23080          -3.38525
  10        0.37227              0.59169                    28.69264          -9.78122
  11        1.16000              1.04735                    63.51547          -4.58761
  12        0.32636              0.39257                    21.05280          -4.47355

 STATION        BEATRICE                           4508 7923 950

MONTH      MEAN                ST. DEV.                     POSVAR            NEGVAR

   1        0.96643              0.58472                    43.55765           5.53673
   2        1.22892              0.37403                    43.37508          19.05426
   3        2.68785              1.35666                   112.37910          24.16360
   4        5.72892              3.16672                   248.47090          42.55821
   5        2.98999              0.92583                   106.04620          45.84541
   6        1.58107              0.58118                    59.05428          21.26389
   7        0.79035              0.29150                    29.55208          10.59790
   8        0.40357              0.15476                    15.28216           5.21924
   9        0.44179              0.42918                    25.17473          -2.73205
  10        0.66786              0.77286                    42.09070          -8.16366
  11        2.13178              1.19137                    92.88112          15.41325
  12        1.23892              0.82127                    58.16968           4.76763

 STATION        BELLEVILLE                         4409 7724 250

MONTH      MEAN                ST. DEV.                     POSVAR            NEGVAR

   1        0.78133              0.42807                    33.76331           5.92826
   2        1.20433              0.26592                    39.23543          21.94447
   3        2.81466              0.82333                    98.26035          44.72433
   4        3.19699              1.27295                   122.58960          35.81754
   5        1.95033              0.93014                    79.77895          19.29762
   6        1.00800              0.54312                    43.26096           7.94519
   7        0.54100              0.41922                    27.37111           0.11162
   8        0.27000              0.20986                    13.68095           0.03503
   9        0.13500              0.10523                     6.85036           0.00762
  10        0.17367              0.52011                    21.32089         -12.49865
  11        0.38533              0.62617                    30.14560         -10.57070
  12        0.99233              0.94461                    55.91618          -5.50589

 STATION        KEMPTVILLE                         4500 7538 320

MONTH      MEAN                ST. DEV.                     POSVAR            NEGVAR

   1        0.52207              0.35481                    24.79602           1.72505
   2        0.94069              0.29412                    33.45596          14.33086
   3        2.36827              0.97801                    91.95110          28.35693
   4        2.83896              1.41778                   118.20430          26.01472
   5        1.79103              1.07817                    80.54543          10.43877
   6        0.93620              0.67669                    45.77791           1.77918
   7        0.48655              0.37407                    24.52023           0.19657
   8        0.24310              0.18790                    12.28393           0.06571
   9        0.14724              0.16217                     9.01237          -1.53253
  10        0.12414              0.19595                     9.52381          -3.21762
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 11        0.50655          0.71116                 35.98749            -10.25470

 12        0.60724          0.50224                 31.75282             -0.90504

 STATION        MADAWASKA                    4530 7759 1038

MONTH      MEAN             ST. DEV.                 POSVAR                NEGVAR

  1        0.28333          0.27385                 16.10014             -1.70683
  2        0.66633          0.30432                 26.81891              7.03069
  3        1.54533          0.67370                 61.15469             17.34792
  4        2.93833          1.34711                118.43050             30.83643
  5        1.62999          0.68549                 63.68855             19.11511
  6        0.89900          0.58196                 41.75523              3.91380
  7        0.46000          0.31248                 21.84319              1.52479
  8        0.22933          0.15587                 10.89275              0.75736
  9        0.20833          0.31608                 15.56790             -4.98458
 10        0.27667          0.63894                 27.80049            -13.74586
 11        0.72433          0.86584                 46.54820             -9.75216
 12        0.26333          0.42777                 20.59634             -7.21904

 STATION        LEMINGTON                    4203 8238 700

MONTH      MEAN             ST. DEV.                 POSVAR                NEGVAR

  1        0.68866          0.56677                 35.91878             -0.93467
  2        0.98800          0.55646                 43.18669              7.00349
  3        2.41366          0.90534                 90.74135             31.87248
  4        2.22866          0.95472                 87.64784             25.56807
  5        1.35699          0.66663                 56.14108             12.79422
  6        0.74333          0.38066                 31.25656              6.50457
  7        0.39233          0.22525                 17.28842              2.64208
  8        0.19567          0.11337                  8.65583              1.28401
  9        0.11300          0.12052                  6.78855             -1.04817
 10        0.10233          0.23981                 10.39590             -5.19738
 11        0.12867          0.34032                 14.33264             -7.79640
 12        0.68867          0.94104                 48.08727            -13.10306

 STATION        PARRY SOUND                  4520 8000 635

MONTH      MEAN             ST. DEV.                 POSVAR                NEGVAR

  1        1.01700          0.55153                 43.76294              7.90046
  2        1.17233          0.39330                 42.56415             16.99007
  3        2.70199          1.21215                108.04010             29.22110
  4        4.76499          2.11239                189.70890             52.35265
  5        2.76099          1.18471                108.64640             31.61186
  6        1.41933          0.59574                 55.41968             16.68217
  7        0.70967          0.29877                 27.73926              8.31173
  8        0.37267          0.20216                 16.03831              2.89311
  9        0.36433          0.52865                 26.44138             -7.93327
 10        0.53167          0.79798                 39.44815            -12.43953
 11        1.85399          1.45120                 94.27296             -0.09009
 12        1.42400          0.83002                 63.15497              9.18405

 STATION        LINDSAY                      4421 7845 875

MONTH      MEAN             ST. DEV.                 POSVAR                NEGVAR

  1        0.69566          0.48425                 33.41367              1.92605
  2        1.03900          0.24441                 34.33682             18.44412
  3        2.40033          0.92653                 91.09164             30.84496
  4        3.27866          1.27788                124.82440             41.73145
  5        2.01966          1.00210                 83.87955             18.71924
  6        1.05666          0.51031                 43.43047             10.24792
  7        0.58967          0.36101                 26.71466              3.24031
  8        0.29467          0.18137                 13.38118              1.58787
  9        0.19333          0.25053                 13.05602             -3.23472
 10        0.24833          0.46752                 21.50781             -8.89251
 11        0.56033          0.67606                 36.21262             -7.74776
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                                                                   4
 12          0.84000            0.72777                44.99728              -2.32547

 STATION           ORONO                          4358 8783 485

MONTH       MEAN             ST. DEV.                    POSVAR                  NEGVAR

   1         0.87033           0.44740                36.65213                7.56054
   2         1.27600           0.27792                41.44585               23.37466
   3         2.88299           0.89486               102.32160               44.13437
   4         3.33566           1.30212               127.05020               42.39114
   5         2.05666           1.00472                84.90468               19.57359
   6         1.05033           0.53707                44.13943                9.21721
   7         0.52567           0.26902                22.09819                4.60565
   8         0.26300           0.13562                11.08960                2.27078
   9         0.14400           0.10241                 6.93701                0.32817
  10         0.15700           0.33203                14.78265               -6.80707
  11         0.60100           0.75429                39.78876               -9.25801
  12         1.12700           0.88196                57.29982               -0.04850

 STATION           HARROW                         4202 8254 626

MONTH       MEAN             ST. DEV.                    POSVAR                  NEGVAR

   1         0.71000           0.62582                38.38068               -2.31287
   2         0.94666           0.57628                42.78131                5.30912
   3         2.34399           0.91341                89.23430               29.84052
   4         2.09433           1.02001                86.35826               20.03351
   5         1.21466           0.64407                51.79228                9.91248
   6         0.63933           0.33762                27.21570                5.26232
   7         0.33600           0.19956                15.02252                2.04626
   8         0.16833           0.10014                 7.53143        [illegible].01988
   9         0.09400           0.08900                 5.28123               -0.50605
  10         0.08333           0.24206                 9.98665               -5.75333
  11         0.16200           0.41094                17.47523               -9.24567
  12         0.63833           0.93676                46.55962         -14[illegible]4234

 STATION           BROCKVILLE                     4436 7542 300

MONTH       MEAN             ST. DEV.                    POSVAR                  NEGVAR

   1         0.91433           0.50120                39.51891                6.92901
   2         1.31899           0.37041                45.54520               21.45969
   3         3.33466           1.14620               121.96540               47.43524
   4         3.73299           1.50549               143.76450               45.87148
   5         2.24533           1.01790                90.12535               23.93721
   6         1.12333           0.50846                45.06354               12.00154
   7         0.56767           0.27132                23.23973                5.59764
   8         0.29367           0.14789                12.26740                2.65085
   9         0.16467           0.10644                 7.64304                0.72200
  10         0.35533           0.62294                29.27859              -11.22770
  11         0.84400           0.92461                51.49834               -8.62330
  12         1.29566           0.86168                60.92487                4.89473

 STATION           BRUCEFIELD                     4333 8133 850

MONTH       MEAN             ST. DEV.                    POSVAR                  NEGVAR

   1         0.88766           0.47408                37.95993                7.13336
   2         1.17366           0.30265                39.55063               19.97136
   3         2.50933           0.84225                91.12004               36.35367
   4         2.62733           1.17145               104.82030               28.64787
   5         1.57633           0.73282                63.86429               16.21315
   6         0.79200           0.36878                32.10643                8.12699
   7         0.39667           0.18501                16.09045                4.06018
   8         0.25900           0.31059                16.67639               -3.51922
   9         0.12967           0.15873                 8.45427               -1.86722
  10         0.20300           0.40581                18.34995               -8.03757
  11         0.61733           0.82076                42.36488              -11.00440
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  12         1.24966              1.15950                    69.43906                -5.95622

  STATION          TRENTON                        4407 7732 266

MONTH       MEAN                ST. DEV.                         POSVAR                 NEGVAR

    1          0.88814              0.49248                    38.57048                6.54725
    2          1.21370              0.37026                    42.86572               18.79021
    3          2.89703              0.87168                   101.92440               45.24458
    4          2.95592              1.31562                   117.85380               32.30681
    5          1.87407              0.95125                    78.52835               16.67433
    6          0.95703              0.51024                    40.89738                7.71987
    7          0.51222              0.36740                    24.95517                1.06569
    8          0.25667              0.18383                    12.49587                0.54277
    9          0.14741              0.13549                     8.14928               -0.66101
   10          0.13000              0.28188                    12.46631               -5.86232
   11          0.42407              0.74437                    34.97237              -13.42945
   12          1.10185              1.04819                    62.06549               -6.09166

  STATION          TURBINE                        4623 8134 675

MONTH       MEAN                ST. DEV.                         POSVAR                 NEGVAR

    1          0.39615              0.27162                    18.89314                1.23144
    2          0.76577              0.31317                    29.53228                9.26861
    3          1.83153              0.76806                    71.39467               21.64714
    4          3.61576              1.17276                   129.96910               53.71150
    5          2.02692              0.76091                    76.22250               26.74480
    6          1.12000              0.58824                    47.57274                9.32299
    7          0.56077              0.29304                    23.77075                4.71629
    8          0.31808              0.24369                    16.00192                0.15635
    9          0.28308              0.40515                    20.36250               -5.98223
   10          0.49538              0.69629                    35.22038              -10.05489
   11          1.40884              1.23464                    75.92511               -4.35596
   12          0.53769              0.49805                    29.85010               -2.53536

  STATION          TWEED                          4430 7717 475

MONTH       MEAN                ST. DEV.                         POSVAR                 NEGVAR

    1          0.72652              0.39121                    31.17250                5.73476
    2          1.21130              0.30925                    40.82113               20.71284
    3          2.76434              0.92174                   100.18180               40.24658
    4          3.17869              1.54701                   131.03500               30.44231
    5          1.96130              1.10479                    85.73575               13.89820
    6          0.98304              0.55188                    42.91182                7.02658
    7          0.49130              0.27516                    21.42503                3.53320
    8          0.24565              0.13846                    10.74115                1.73796
    9          0.12435              0.06894                     5.39987                0.91698
   10          0.21522              0.57305                    24.09760              -13.16457
   11          0.68000              0.83647                    44.46722               -9.92327
   12          0.95000              0.65777                    45.51537                2.74450

  STATION          WALKERTON                      4408 8109 800

MONTH       MEAN                ST. DEV.                         POSVAR                 NEGVAR

    1          0.90154              0.46020                    37.86095                7.93716
    2          1.19923              0.41648                    44.03090               16.91995
    3          2.56538              1.18765                   103.77360               26.54764
    4          2.63769              1.85857                   127.42310                6.57142
    5          1.55769              1.09298                    75.10043                4.03028
    6          0.78615              0.55298                    37.94691                1.98967
    7          0.39385              0.27657                    18.99559                1.01176
    8          0.19615              0.13967                     9.52340                0.44120
    9          0.09769              0.06858                     4.71089                0.25187
   10          0.36615              0.61119                    29.17143              -10.57084
   11          0.66154              0.73826                    40.80542               -7.19929
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 12         0.84769          0.81079                47.89183            -4.82910

 STATION         WALLACEBURG                4235 8224 580

MONTH      MEAN               ST. DEV.                     POSVAR                 NEGVAR

  1          0.62304          0.53137                33.10101            -1.45044
  2          0.95261          0.52865                41.38377             7.00867
  3          2.27130          1.05181                91.88745            23.49446
  4          2.05130          1.06994                86.39895            17.31696
  5          1.49217          0.95562                68.97011             6.83207
  6          0.75652          0.47635                34.73256             3.72867
  7          0.37739          0.23975                17.34798             1.82346
  8          0.18956          0.12096                 8.74764             0.88225
  9          0.09565          0.05922                 4.35506             0.50405
 10          0.07652          0.11761                 5.76747            -1.88019
 11          0.20956          0.33947                16.35980            -5.71392
 12          0.61739          0.80475                41.84581           -10.48237

 STATION         WELLAND                    4300 7916 575

MONTH      MEAN               ST. DEV.                     POSVAR                 NEGVAR

  1          1.07724          0.62414                47.65372             7.06991
  2          1.47517          0.38848                50.09940            24.83900
  3          3.33999          0.87051               113.13780            56.53369
  4          3.06792          0.99259               110.19610            45.65434
  5          1.94482          0.74464                73.60805            25.18883
  6          0.97207          0.37276                36.80951            12.57141
  7          0.48759          0.18318                18.40514             6.36421
  8          0.24379          0.09348                 9.23156             3.15311
  9          0.14724          0.15741                 8.85759            -1.37774
 10          0.14138          0.32740                14.23543            -7.05339
 11          0.25483          0.63699                29.72235           -11.69714
 12          1.19793          0.93401                60.79387             0.06073

 STATION         WOODSTOCK                  4308 8046 925

MONTH      MEAN               ST. DEV.                     POSVAR                 NEGVAR

  1          0.82556          0.36106                32.70796             9.23021
  2          1.31555          0.29236                42.92030            23.90968
  3          2.62000          0.78575                92.09398            41.00172
  4          3.09055          1.46021               125.97440            31.02548
  5          1.95777          1.02699                83.11690            16.33789
  6          1.10555          0.62931                48.54106             7.62098
  7          0.56444          0.33229                25.14017             3.53358
  8          0.39333          0.37075                22.04460            -2.06330
  9          0.23222          0.25202                14.09199            -2.29512
 10          0.21833          0.31825                15.89270            -4.80138
 11          0.78389          0.71431                43.13426            -3.31276
 12          1.44777          1.05490                71.07030             2.47664

 STATION         VINELAND STATION           4311 7323 260

MONTH      MEAN               ST. DEV.                     POSVAR                 NEGVAR

  1          0.72466          0.56062                36.63329             0.17961
  2          1.16333          0.50574                45.99112            13.10591
  3          2.55066          0.78611                90.34473            39.22876
  4          2.22699          0.92115                86.51398            26.61731
  5          1.44033          0.73621                60.52010            12.64857
  6          0.74700          0.40825                32.24658             5.70078
  7          0.37367          0.20338                16.10327             2.87896
  8          0.18733          0.10171                 8.06495             1.45156
  9          0.12967          0.22415                10.58116            -3.99412
 10          0.12500          0.30096                12.95981            -6.60983
 11          0.20900          0.48857                21.19290           -10.57572
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  12          0.70266            0.99069                 50.05690          -14.36160

  STATION         PETERBOROUGH                  4417 7819 635

MONTH      MEAN             ST. DEV.                       POSVAR                NEGVAR

   1         0.45800          0.32468                 22.19913            1.07723
   2         0.84730          0.26218                 30.03701           12.98960
   3         1.97366          0.81913                 76.76254           23.49937
   4         2.44633          1.20567                101.33540           22.93793
   5         1.55433          0.92521                 69.56021            9.39957
   6         0.80433          0.47041                 35.72380            5.13615
   7         0.41833          0.26597                 19.27275            1.97855
   8         0.20067          0.13338                  9.56187            0.98917
   9         0.14167          0.16626                  9.00373           -1.80708
  10         0.13900          0.29021                 12.96596           -5.90478
  11         0.26933          0.48115                 22.43409           -8.80199
  12         0.51533          0.48025                 28.70329           -2.52440

  STATION         PELEE ISLAND                  4145 8241 575

MONTH      MEAN             ST. DEV.                       POSVAR                NEGVAR

   1         0.64931          0.55511                 34.54019           -1.55534
   2         0.88413          0.52551                 39.54243            5.37156
   3         2.20965          0.88460                 84.88501           27.36508
   4         2.30344          1.08954                 93.93053           23.08429
   5         1.50965          0.74701                 62.63176           14.05843
   6         0.79827          0.40803                 33.54193            7.01035
   7         0.41069          0.20908                 17.22905            3.63395
   8         0.20724          0.10660                  8.72968            1.79816
   9         0.10379          0.05301                  4.35982            0.91285
  10         0.05828          0.04863                  3.06123           -0.10083
  11         0.07483          0.18591                  7.94483           -4.14360
  12         0.49034          0.95486                 43.49915          -18.58966

  STATION         MUSKOKA A                     4458 7918 926

MONTH      MEAN             ST. DEV.                       POSVAR                NEGVAR

   1         0.84866          0.52124                 38.50258            4.60950
   2         1.16666          0.30292                 39.48158           19.78482
   3         2.52033          1.12795                100.68810           27.34438
   4         4.60466          1.95739                180.59680           53.31976
   5         2.74866          1.12899                106.52150           33.11041
   6         1.49600          0.66789                 59.71259           16.28394
   7         0.75033          0.33998                 30.11171            8.00506
   8         0.38667          0.19302                 16.09683            3.54580
   9         0.35067          0.41313                 22.40352           -4.58968
  10         0.77233          1.00797                 52.38814          -13.15376
  11         1.83199          1.22017                 86.20261            6.86266
  12         1.24566          0.72594                 55.24171            9.03792

  STATION         KILLALORE A                   4534 7725 571

MONTH      MEAN             ST. DEV.                       POSVAR                NEGVAR

   1         0.22800          0.20078                 12.31897           -0.73659
   2         0.56900          0.26498                 23.05772            5.83742
   3         1.38866          0.64426                 56.21808           14.32587
   4         2.00800          1.29287                 93.03680            8.96939
   5         1.22766          0.83264                 58.25330            4.11196
   6         0.64200          0.42852                 30.23886            2.37465
   7         0.32433          0.21973                 15.38186            1.09425
   8         0.16233          0.10982                  7.69365            0.55287
   9         0.10067          0.13506                  6.94796           -1.83411
  10         0.09500          0.30614                 12.36625           -7.54025
  11         0.17933          0.32205                 15.02555           -5.91544
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 12        0.14767         0.21907              10.87306          -3.37161

  STATION       ST.THOMAS                   4248 8111 682

MONTH      MEAN            ST. DEV.                  POSVAR
                                                                     NEGVAR

   1         0.89233         0.54406               40.35358
   2         1.22066         0.43337               45.09462         4.97675
   3         2.91133         0.95065              104.85500        16.91493
   4         2.96099         1.20463              114.37410        43.04030
   5         1.85299         0.83350               74.16490        36.04430
   6         1.01933         0.52326               42.90320        19.96715
   7         0.50967         0.26085               21.42636         8.87869
   8         0.31800         0.27941               17.16144         4.46466
   9         0.15933         0.13916                8.57137        -1.00707
  10         0.14167         0.20610               10.29895        -0.47726
  11         0.42500         0.67894               32.86862        -3.10230
  12         1.18366         0.94755               60.87170       -11.27866
                                                                   -0.74167

  STATION       ORILLIA                     4437 7924 735

MONTH      MEAN            ST. DEV.                  POSVAR
                                                                     NEGVAR

   1         0.80333         0.44273               34.79878
   2         1.13291         0.28167               37.93373         6.01045
   3         2.25666         0.92597               87.42438        19.61813
   4         3.87874         1.69582              153.65450        27.21402
   5         2.45208         1.22572              102.13340        43.38554
   6         1.25875         0.61578               51.99225        22.43207
   7         0.63833         0.30082               25.99387        11.95202
   8         0.31833         0.15199               13.02720         6.43341
   9         0.19917         0.12656                9.17344         3.14411
  10         0.49875         0.69362               35.21930         0.94420
  11         0.86583         0.92988               52.19171        -9.88285
  12         0.96791         0.69561               47.20061        -8.20753
                                                                    1.96937

  STATION       SOUTHAMPTON                 4430 8121 656

MONTH      MEAN            ST. DEV.                  POSVAR
                                                                     NEGVAR

   1         1.35143         0.59378               53.63113
   2         1.50428         0.32438               48.75510        15.02127
   3         3.09952         1.20934              118.04560        27.66235
   4         3.98476         1.78528              159.25580        39.40976
   5         2.33190         1.15955               96.92953        43.16968
   6         1.19095         0.59943               49.73863        21.53078
   7         0.59524         0.29901               24.84039        10.76152
   8         0.29809         0.15085               12.47609         5.39766
   9         0.16286         0.09073                7.08630         2.66712
  10         0.24238         0.48966               22.07635         1.18682
  11         0.80905         0.89972               49.90142        -9.76342
  12         2.22857         1.41778              102.73040        -8.70190
                                                                   10.51077

  STATION       RIDGETOWN                   4227 8153 675

MONTH      MEAN            ST. DEV.                  POSVAR
                                                                     NEGVAR

   1         0.75633         0.60410               38.85120
   2         1.10500         0.54030               45.63319        -0.42969
   3         2.57633         0.87465               93.87520        10.50055
   4         2.50333         1.05622               97.92436        37.00214
   5         1.60400         0.82078               67.42668        29.24466
   6         0.85833         0.48753               37.65210        14.05626
   7         0.42933         0.24315               18.81044         5.95103
   8         0.21533         0.12213                9.44009         2.99966
   9         0.10733         0.06186                4.73759         1.49882
  10         0.08567         0.14402                6.85840         0.71492
  11         0.31333         0.50013               24.21896        -2.50655
                                                                   -8.30166
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 12        0.84500          1.08569             56.76093          -13.83506

 STATION       LUCKNOW                      4358 8131 875

MONTH      MEAN             ST. DEV.                POSVAR             NEGVAR

  1        1.22850          0.43177             45.24155           17.16603
  2        1.49100          0.28504             47.13843           28.60413
  3        2.87199          1.25713            113.82030           32.07692
  4        3.17900          1.68453            135.51390           25.97893
  5        1.95800          0.93608             80.15676           19.29936
  6        1.02300          0.50953             42.55008            9.41813
  7        0.54500          0.32150             24.29562            3.39034
  8        0.27250          0.16036             12.13502            1.70795
  9        0.16850          0.20095             10.81324           -2.25346
 10        0.36050          0.67986             31.26016          -12.94679
 11        1.00500          1.16184             63.33074          -12.24685
 12        1.71750          1.23095             83.64496            3.60385

 STATION       HALIBURTON                   4501 7833 1050

MONTH      MEAN             ST. DEV.                POSVAR             NEGVAR

  1        0.61467          0.45727             30.47920            0.74577
  2        0.91800          0.33996             34.36977           12.26442
  3        2.13166          1.01648             87.19196           21.09641
  4        3.87699          2.61642            183.54040           13.41073
  5        2.10566          1.15947             91.18050           15.78711
  6        1.20099          0.80377             56.63734            4.37316
  7        0.62233          0.41220             29.20866            2.40576
  8        0.31200          0.20983             14.71424            1.13534
  9        0.30600          0.43430             21.89238           -6.34762
 10        0.68900          0.81161             43.88768           -8.88657
 11        1.42500          1.04279             70.09819            2.29160
 12        0.83333          0.59843             40.62257            1.71060

 STATION       KITCHENER                    4325 8030 112

MONTH      MEAN             ST. DEV.                POSVAR             NEGVAR

  1        0.76966          0.51202             36.19612            2.90280
  2        1.11466          0.42340             42.07806           14.54679
  3        2.58399          0.79158             91.36922           39.89757
  4        2.82333          1.25705            112.58170           30.84322
  5        1.86833          0.95252             78.42375           16.48723
  6        1.12433          0.75117             52.97980            4.13599
  7        0.62433          0.50645             32.32376           -0.60774
  8        0.35167          0.34817             20.25195           -2.38732
  9        0.22867          0.28995             15.23512           -3.61888
 10        0.24833          0.43875             20.57236           -7.95706
 11        0.63933          0.68058             38.36591           -5.88788
 12        1.08400          0.88059             56.16339           -1.09637

 STATION       OTTAWA EXPT FARM             4523 7543 260

MONTH      MEAN             ST. DEV.                POSVAR             NEGVAR

  1        0.38840          0.31363             20.06209           -0.33140
  2        0.81120          0.31687             30.90628           10.30248
  3        2.13839          0.90569             83.76094           24.86940
  4        2.91920          1.84108            134.00450           14.29052
  5        1.69560          1.24936             83.68733            2.44890
  6        0.88720          0.67038             44.30028            0.73929
  7        0.44400          0.33526             22.17758            0.37759
  8        0.26400          0.33283             17.52649           -4.11533
  9        0.14280          0.17375              9.27590           -2.02169
 10        0.25560          0.47063             21.79332           -8.80886
 11        0.82840          0.82481             47.85750           -5.77486

 12        0.57480          0.43926             28.88115            0.31865
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VITA AUCTORIS

1946	Born on December 10, 1946 in Kakaraparru, India.
1964	Enrolled in first year Science at the Sir C. R. Reddy College, Eluru, India.
1967	Graduated from Andhra University with the degree of Bachelor of Science (Mathematics, Physics and Chemistry).
1970	Graduated from Andhra University with the degree of Master of Science (Technology) in Meteorology and Oceanography. In the same year obtained a Post-Graduate Diploma in Applied Statistics. In September, 1970 enrolled for Doctoral studies in Meteorology at Andhra University, and obtained a Junior Research Fellowship from the Council of Scientific and Industrial Research, India.
1973	Senior Research Fellow in the Department of Meteorology and Oceanography, Andhra University.
1974	In September 1974 enrolled in the graduate program in Geography at the University of Windsor, Windsor, Ontario, Canada.
1975	Graduated from Andhra University with Doctor of Philosophy in Meteorology.
1976	Graduated from the University of Windsor with the degree of Master of Arts in Geography.