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WIND AND ICE LOADING IN CANADA

INDUSTRIAL METEOROLOGY — STUDY II

P.M. CHAÎNÉ, R.W. VERGE, G. CASTONGUAY AND J. GARIÉPY

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INDUSTRIAL METEOROLOGY STUDY I

VARIABILITY OF GLAZE ICE IN QUEBEC – JAMES BAY

by P.M. CHAÎNÉ

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RIVIÈRE PENTECÔTE – MANIC 3, APRIL 29, 1973
PHOTOS COURTESY OF QUEBEC HYDRO

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WIND AND ICE LOADING IN CANADA

P.M. Chaîné
R.W. Verge
G. Castonguay
J. Gariépy

INTRODUCTION

Ice accretion and wind are important factors which place additional loads on structures and must be considered in design specifications. Electrical transmission and communication systems are especially vulnerable to these weather elements. Failures of towers and lines may render communities without heat or light for hours or even days. The ever-expanding network of power and communication systems is demanding more usable and more up-to-date information on extreme wind and ice accumulation. Up to twenty years of hourly weather records are now available for the analysis of the characteristics of these hazards. The purpose of this paper is to present probability maps and values developed from these data.

ASSUMPTIONS

In this study freezing rain and freezing drizzle are defined as liquid precipitation which falls when air temperatures are 32°F or less. There are other damaging icing situations which are not discussed here, such as those caused by wet snow which freezes after contact, or by persistent fog or cloud. It is assumed that the precipitation amount is measured accurately, and that all of it accretes as ice with a density of about 1.0 gm cm^{-3} when air temperatures are below freezing. Furthermore, it is assumed that the wind speed, as measured, is accurate and representative. These assumptions introduce many elements of doubt in the estimates, for reasons such as those noted below:

1) As a result of turbulence over the rain gauge caused by wind, the captured precipitation may be as much as 50% less than the actual amount (see Wilson, 1954).

2) Towers, buildings and transmission lines distort the wind flow in their own peculiar fashion so that the precipitation falling on their surfaces is difficult to estimate. Also the wind, which is an important factor in estimating accretion amounts, is highly dependent on local topography and the nature of the ground cover.

3) Because of the release of the latent heat of fusion depending on atmospheric conditions, considerable amounts of precipitation may not accrete as ice.

4) While 20 years of records are available for many locations, in some instances the period is much shorter. It was necessary to consider records of only nine years in many instances. There is certainly considerable doubt about the validity of quoting return periods of 50 and 100 years for winds on a data base of only nine years; usually about 30 years of records are desired to obtain a stable sample for predictions of up to 50 years. So that the reader may better judge the quality of estimates presented here, the length of the data base for each station in the analysis is included. (Figs. 25-26).

The validity of extrapolated values can be completely resolved only by time, with the resultant extensions of the data bases. Although the above limitations are significant, the estimates compare favourably with observed storms and are therefore considered to have predictive value.

ANALYSIS OF WIND DATA

Extreme wind values for all stations with at least nine years (see Fig. 25) of data were analyzed statistically assuming that they fit the Gumbel Extreme Value Distribution. In this manner values were calculated for 10, 30, 50 and 100 year return periods, and these are shown in Figures 1, 2, 3, 4, respectively. They are expressed in terms of wind pressure on flat and cylindrical surfaces by applying equations (1) and (2) to the extreme wind value estimates.

$$P_F = 0.0042\ V^2 \qquad (1)$$

where P_F is the wind pressure on a flat surface in pounds per square foot and V is the wind speed in miles per hour,

$$P_C = 0.0026\ V^2 \qquad (2)$$

The results of these calculations are shown in Figures 5 to 12 inclusive.

The computed values of P_F and P_C can be entered directly into the calculations for total load (L_T) on transmission lines as indicated by the following equations:

$$L_T = L_W + 6\ L_C \qquad (3)$$

$$L_W = f \quad (P_F,\ \ldots,\ldots,\ldots,) \quad \text{(Load on Tower)}$$

$$L_C = f \quad (P_C,\ \ldots,\ldots,\ldots,) \quad \text{(Load on Cable)}$$

ANALYSIS OF ICE ACCRETION

McKay and Thompson (1969) described a method for combining occurrences of freezing rain or drizzle and temperatures recorded in hourly reports with precipitation amounts as recorded in synoptic reports to produce mass curves. Estimates were made of clear ice accumulation thicknesses for horizontal surfaces from the mass curves. By combining wind speed and precipitation rate, the authors obtained estimates of the ice thickness accumulating on a vertical surface.

In 1972, P.M. Chaîné extended the estimates of McKay and Thomspon. Using their estimates as a data base, regression equations were developed to determine the effect of certain parameters, such as distance from a body of water, elevation of location, presence of a topographical barrier upwind of the icing location, under favourable ice storm conditions. Data from weather stations were augmented in the analysis by ice accretion reports from power companies and newspaper files.

The previous studies were restricted to a 10-year data base. In the present study the data base has been extended to include up to 20 years of information.

While the criteria used in previous studies were retained and are repeated below, the regression equation techniques were found to be inapplicable on a Canada-wide scale and have not been used in this study. The criteria used were:

1) The mass curves of precipitation occurring at air temperatures less than 33°F were used as the basis for analysis.

2) In constructing the mass curves, distinctions were made between the types of precitation (rain or drizzle) and the intensities (light, moderate or heavy).

3) Extremes obtained for specific durations from the mass curves were analyzed using Gumbel Extreme Value Distributions.

4) Contingent winds as measured at the weather observation site were used to estimate the accretion on lines and towers.

ESTIMATES OF ICE ACCRETION ON HORIZONTAL AND VERTICAL SURFACES

It is assumed that the total precipitation falling while the air temperature is less than 33°F is equivalent to the accumulation on a horizontal surface (A_h).

The accumulation on a vertical surface (A_v) is a function of A_h and the wind speed V.

McKay and Thompson (1969) show that the mass of liquid water per unit volume of falling precipitation is proportional to the measured precipitation rate

$$A_v = (0.063V)(1.24\, A_h^{\,0.88}) \tag{4}$$

for wind speed in mph and A_h and A_v in inches per hour.

When integrated over the duration of a storm the formula can be used to estimate total ice accretion on vertical surfaces from hourly wind data and hourly precipitation rates.

However, rigid application of the above formula for a storm of 10 or 12 hours involves cumbersome calculations. It has been found in practice that the following approximation gives useful and meaningful results when applied to a complete storm, and can be used for rapid on-the-spot estimations:

$$A_v = \frac{V\,A_h}{10} \tag{5}$$

where A_v is the accumulation on a vertical surface during the duration of the storm, A_h is the accumulation on a horizontal surface and V is the mean wind speed during the storm.

Table 1 gives an indication of the estimates obtained from use of the above formula (5) compared to those obtained by integrating hourly values by means of formula (4).

Ten- and twenty-year return period values (probabilities 1/10 and 1/20) for accumulation on horizontal and vertical surfaces have been calculated using the above procedures and are shown in Figures 13 and 16. The accumulation on a horizontal surface can be interpreted as the thickness of ice on a road, roof, etc., and the accumulation on a vertical surface as the thickness of glaze ice on a tower or pylon.

EQUIVALENT RADIAL THICKNESS

It has been determined that when the ice accretes about a conductor, the equivalent radial thickness of the ice, A_r, is a function of the estimated accumulation on a horizontal surface A_h, the diameter of the conductor d, the air temperature T expressed in degrees F, and wind speed V in miles per hour.

$$A_r = \sqrt{\frac{rK}{2}\sqrt{A_h^{\,2} + A_v^{\,2}} + r^2} - r \tag{6}$$

where: A_r = equivalent radial thickness (in.)

A_h = horizontal accretion (in.)

A_v = vertical accretion (in.)

r = radius of the conductor (in.)

K = correction factor

This method is explained in the paper, A New Approach to the Estimation of Radial Thickness of Accreted Ice, by P.M. Chaîné and G. Castonguay, which is in preparation.

Usually the accumulation of ice on conductors is irregular, but for the purpose of calculating ice loads it is convenient to express it as an "equivalent radial thickness", i.e. the thickness that would accrue if the ice accreted uniformly about the conductor. For the purpose of calculation, a cable of 1" diameter was considered. The estimates derived using equation (6) results are shown in Figures 17 and 18.

GUSTS

Several severe ice storms would have been relatively insignificant had the wind during or after the storms remained light. The combined effect of ice and wind produces additional load on the towers and/or the wires, frequently resulting in a failure, which would not have occurred as a result of ice accretion alone. Figures 19 and 20 show the maximum computed gust for ice storms. The gust was calculated for either the period ending 24 hours after the ice stopped accreting, or before the air temperature rose to 34°F, whichever was the shorter.

The following formula developed by D.W. Boyd (1970) was used to calculate the maximum gust

$$G = 1.29V + 5.8 \tag{7}$$

V = wind speed in mph

G = gust speed in mph

PEAK GUST AT MAXIMUM ACCUMULATION

The maximum wind is not likely to occur at maximum accumulation. Since the statistics for Figures 13 to 20 are independent of each other, a new set of statistics was established which shows estimated peak gust for periods of maximum accumulation.

These are presented in Figures 21 to 24 which show the probable storm characteristics (wind and accumulation) likely to occur once every twenty years. It is important to note that values taken from Figure 21 must be used in conjunction with comparable values from Figures 22 to 24.

CONCLUSION

The accompanying charts provide a fairly comprehensive interpretation of the ice accretion hazard, based on presently available climatological records. The user is cautioned that the values are estimates for specific locations, and often are based on relatively short records – as low as nine years of observations. Ice accumulations and wind intensities are subject to vagaries due to terrain or abnormal conditions which can produce unusual results. Interpolations between plotted values should therefore be examined from the point of view of possible variations in meteorological conditions due to topography. Long series of in-field measurements are needed to authenticate these estimates, and to show the nature of the variations which may result from local topographic conditions.

TABLE 1

Comparison of estimates obtained using formulae (4) and (5)

$\bar{V}$	A_h	$A_{v(4)}$	$A_{v(5)}$
8.4	1.70	1.56	1.43
33.0	1.43	3.73	4.72
12.3	1.23	1.76	1.51
16.5	0.75	1.28	1.24
21.0	0.60	1.24	1.26
23.3	0.39	0.99	0.92
24.7	0.31	0.85	0.77
13.5	0.28	0.42	0.38
8.6	1.24	1.02	1.07
16.9	0.97	1.58	1.64
11.5	0.95	1.20	1.09
15.2	0.82	1.02	1.25
13.6	0.77	1.20	1.05
18.3	0.78	1.31	1.42
19.3	0.71	1.66	1.37
13.7	0.70	0.92	0.96
7.5	0.65	0.55	0.49
12.1	0.64	0.91	0.78

$\bar{V}$ = mean wind during freezing precipitation (mph)

A_h = horizontal accretion (inches)

$A_{v(4)}$ = vertical accretion estimated using equation (4) (inches)

$A_{v(5)}$ = vertical accretion estimated using equation (5) (inches)

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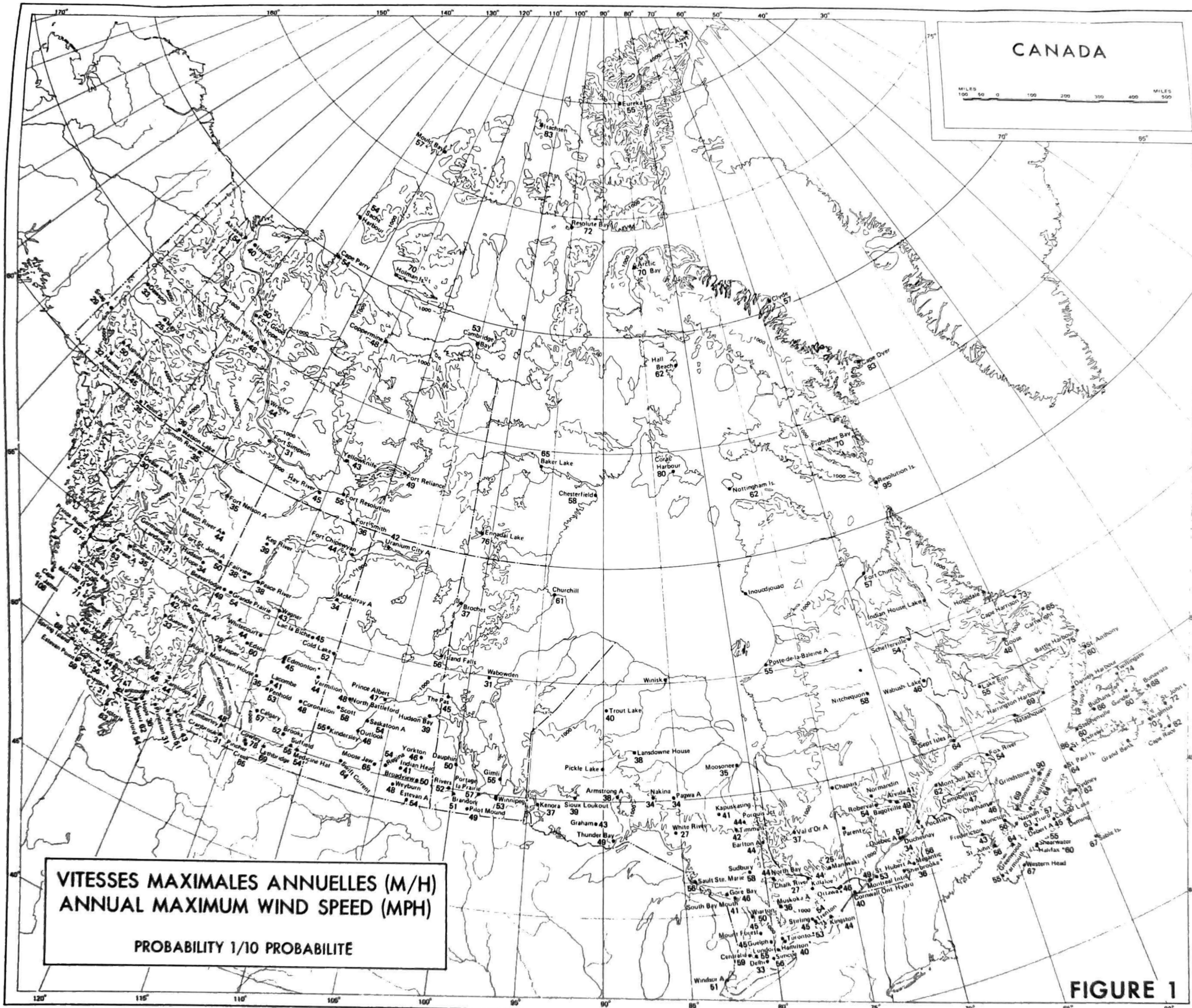
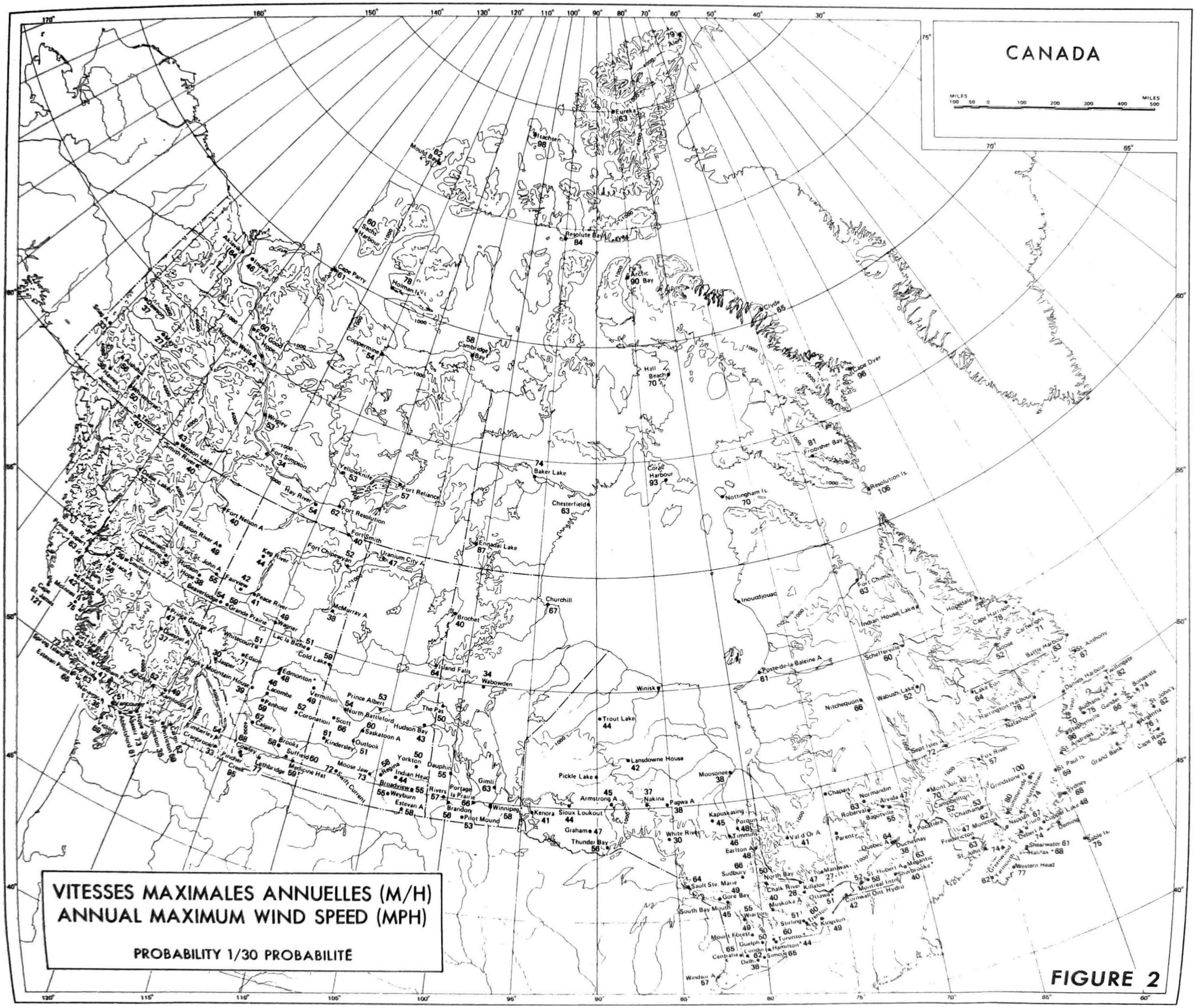
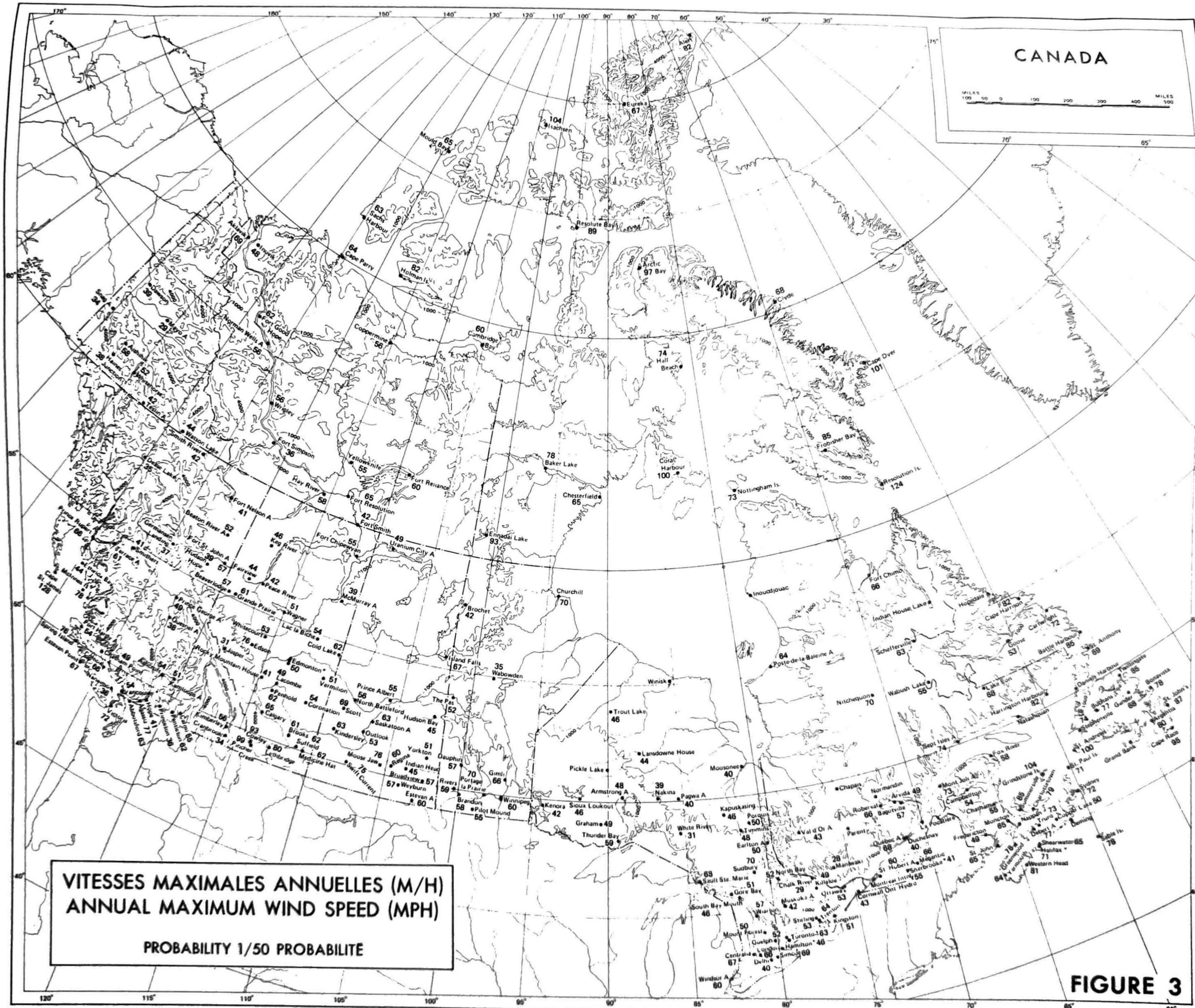

CANADA
MILES
VITESSES MAXIMALES ANNUELLES (M/H)
ANNUAL MAXIMUM WIND SPEED (MPH)
PROBABILITY 1/10 PROBABILITE

FIGURE 1

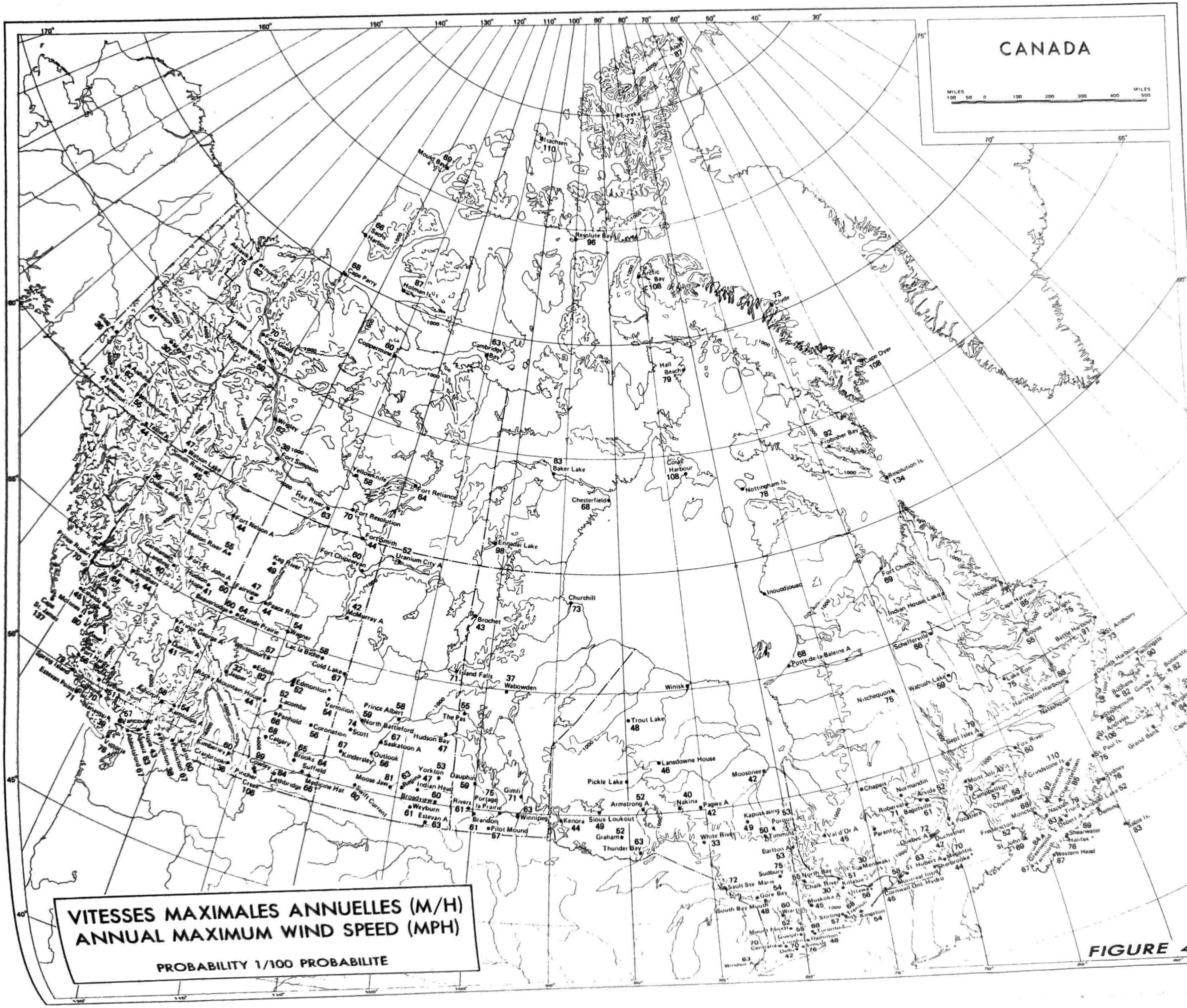

CANADA
VITESSES MAXIMALES ANNUELLES (M/H)
ANNUAL MAXIMUM WIND SPEED (MPH)
PROBABILITY 1/30 PROBABILITÉ
Resolute Bay 84
Arctic Bay 90
Clyde 85
Cape Dyer 96
Hall Beach 70
Frobisher Bay 81
Resolution Is. 106
Coral Harbour 93
Nottingham Is. 70
Baker Lake 74
Chesterfield 63
Churchill 67
Yellowknife 53
Fort Reliance 57
Cambridge Bay 58
Coppermine 54
Cape Parry 61
Eureka 63
Isachsen 98
Fort Chimo 63
Winnipeg 58
Kenora 41
Thunder Bay 56
Moosonee 38
Edmonton 48
Calgary 67
Prince Albert 53
Regina 58
Moose Jaw 72
Medicine Hat 59
Lethbridge 77
Brandon 56
Sault Ste. Marie 49
North Bay 50
Timmins 48
Ottawa 28
Kingston 49
Toronto 60
Windsor A 67
Fredericton 63
Sable Is. 75
St. John's 82
Cape Race 92
Western Head 77
Halifax 68
Sydney 68
Grindstone Is. 100
FIGURE 2



VITESSES MAXIMALES ANNUELLES (M/H)
ANNUAL MAXIMUM WIND SPEED (MPH)

PROBABILITY 1/50 PROBABILITÉ

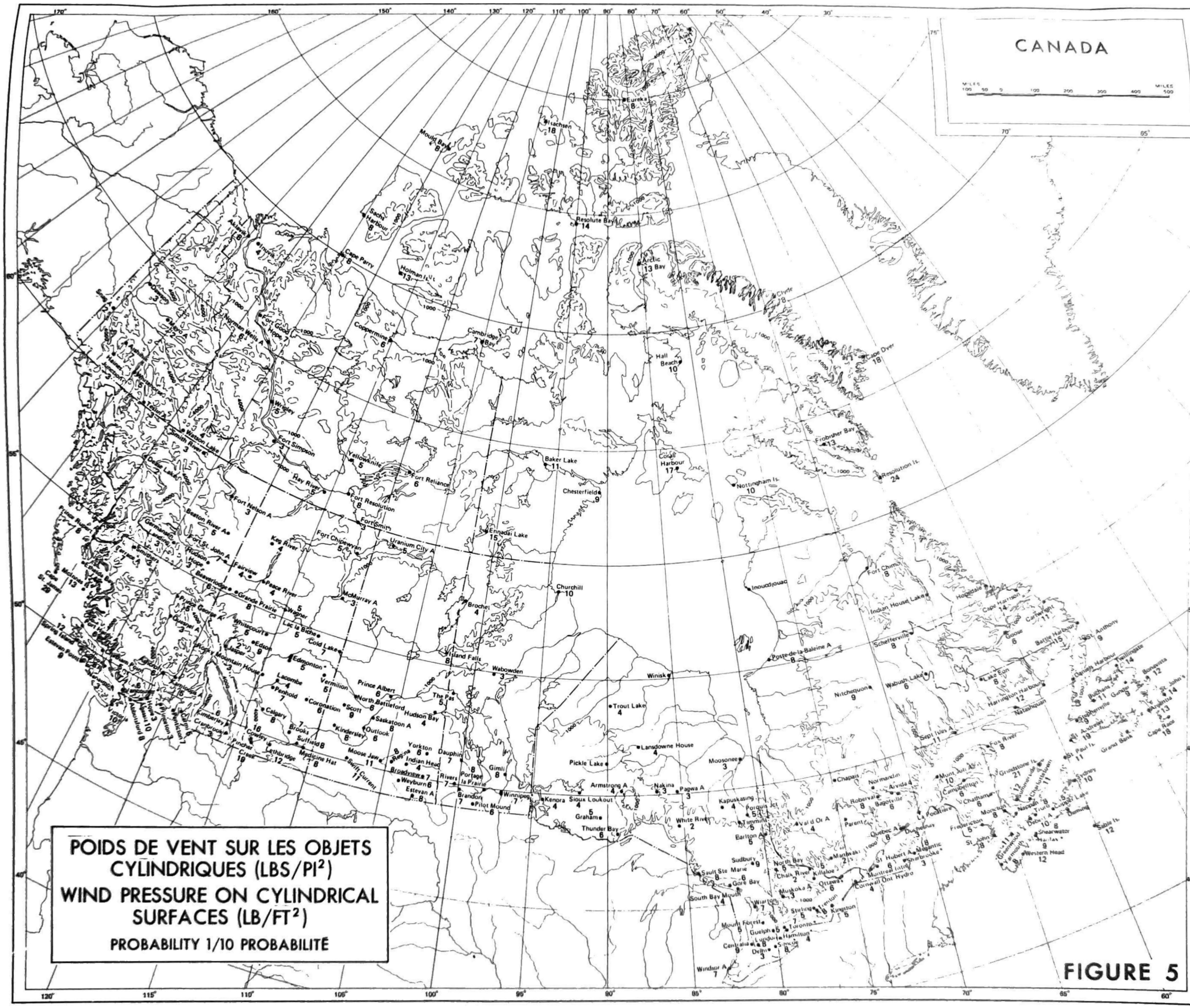
FIGURE 3



VITESSES MAXIMALES ANNUELLES (M/H)
ANNUAL MAXIMUM WIND SPEED (MPH)

PROBABILITY 1/100 PROBABILITE

FIGURE 4

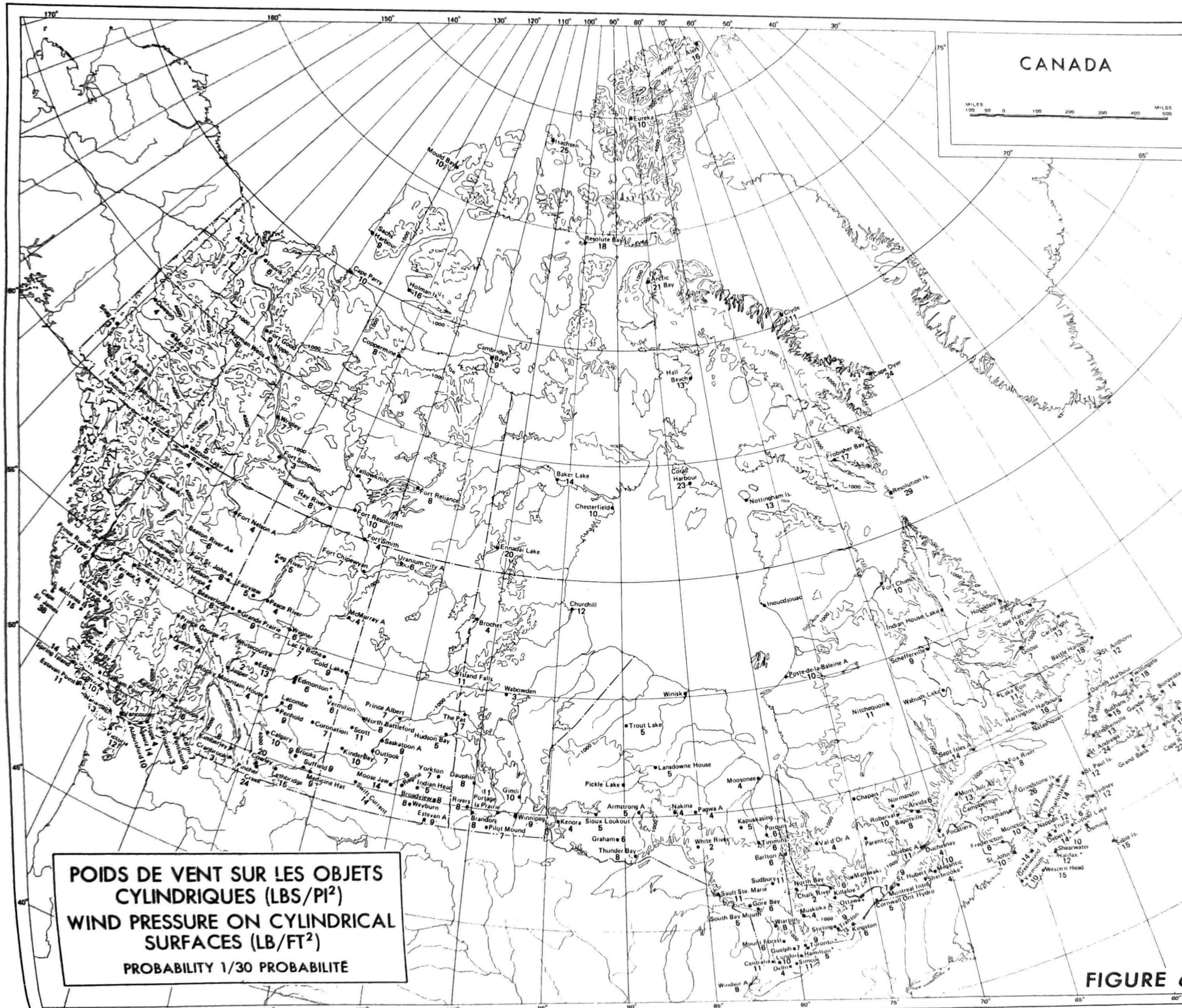


POIDS DE VENT SUR LES OBJETS CYLINDRIQUES (LBS/PI^2)

WIND PRESSURE ON CYLINDRICAL SURFACES (LB/FT^2)

PROBABILITY 1/10 PROBABILITÉ

FIGURE 5



POIDS DE VENT SUR LES OBJETS CYLINDRIQUES (LBS/PI²)

WIND PRESSURE ON CYLINDRICAL SURFACES (LB/FT²)

PROBABILITY 1/30 PROBABILITÉ

FIGURE 6

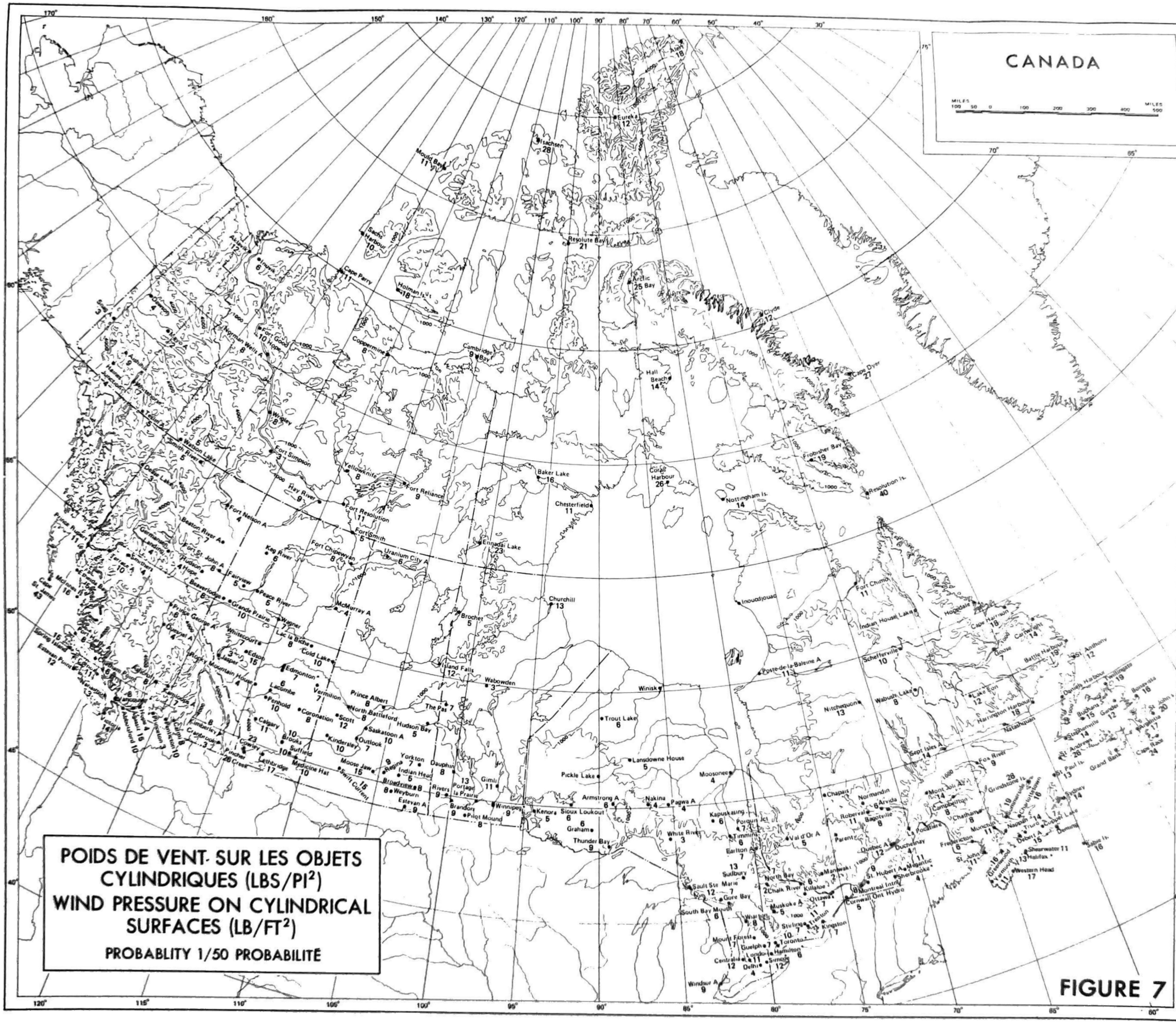
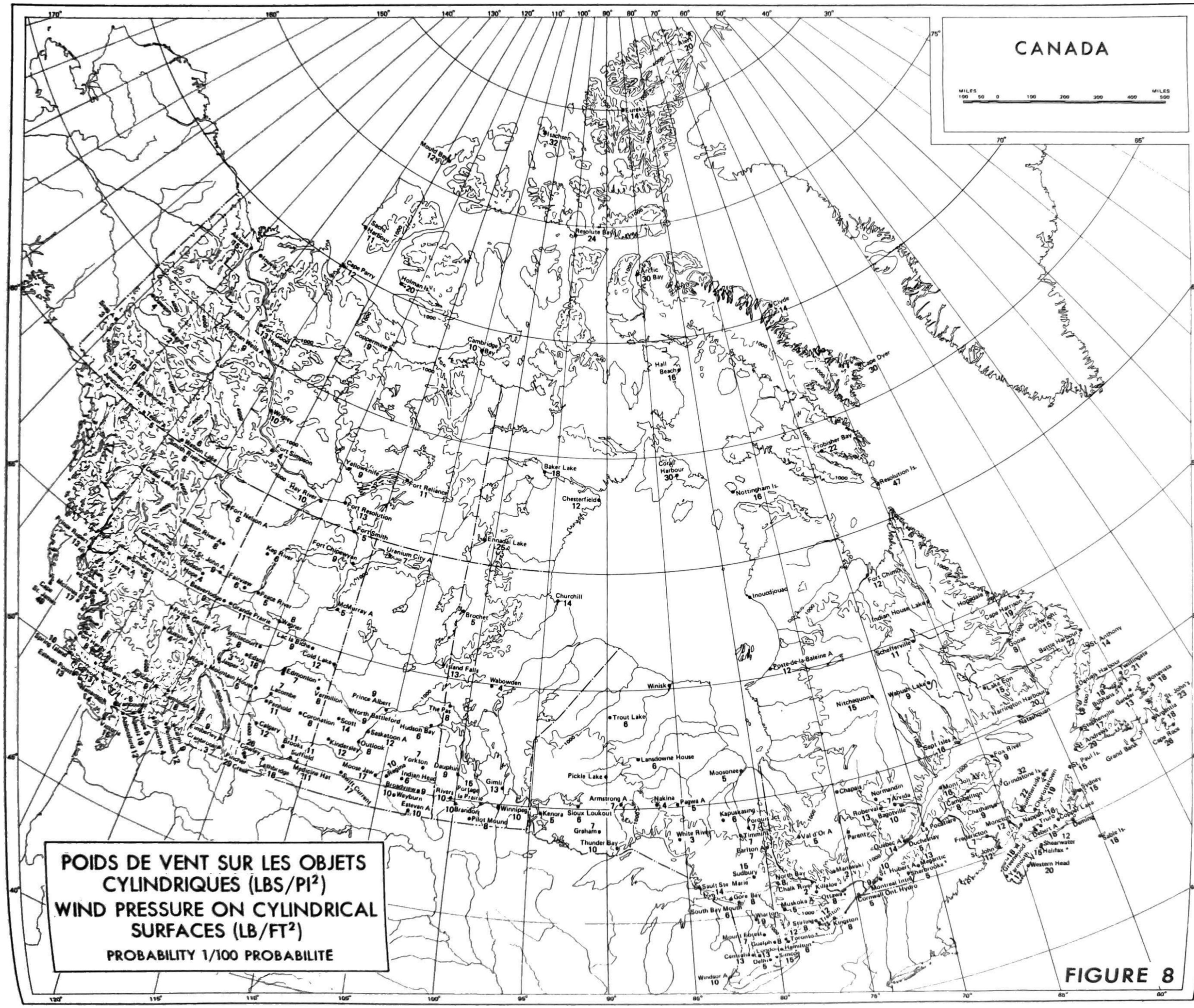
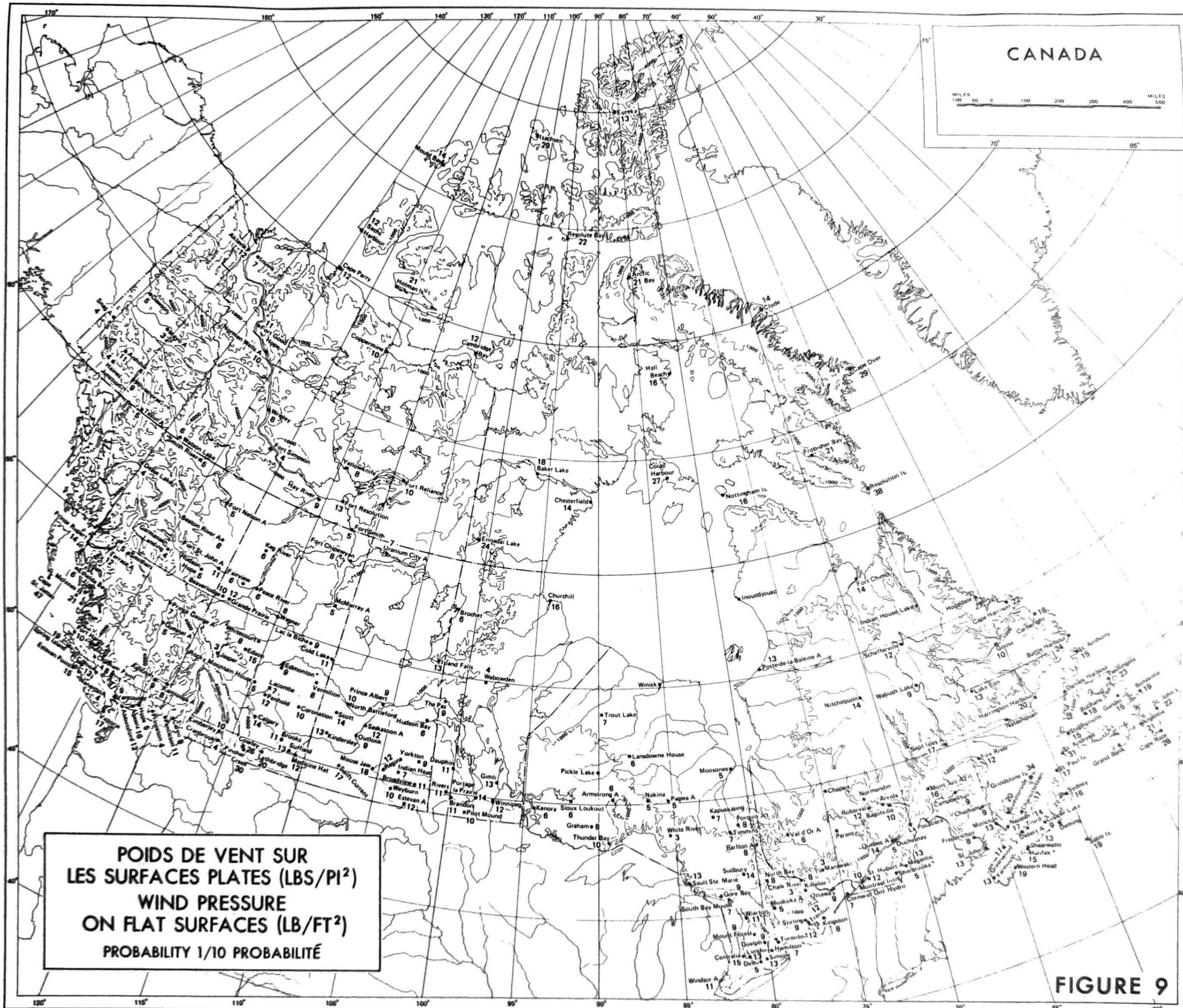

CANADA
MILES
POIDS DE VENT SUR LES OBJETS
CYLINDRIQUES (LBS/PI²)
WIND PRESSURE ON CYLINDRICAL
SURFACES (LB/FT²)
PROBABLITY 1/50 PROBABILITÉ

FIGURE 7



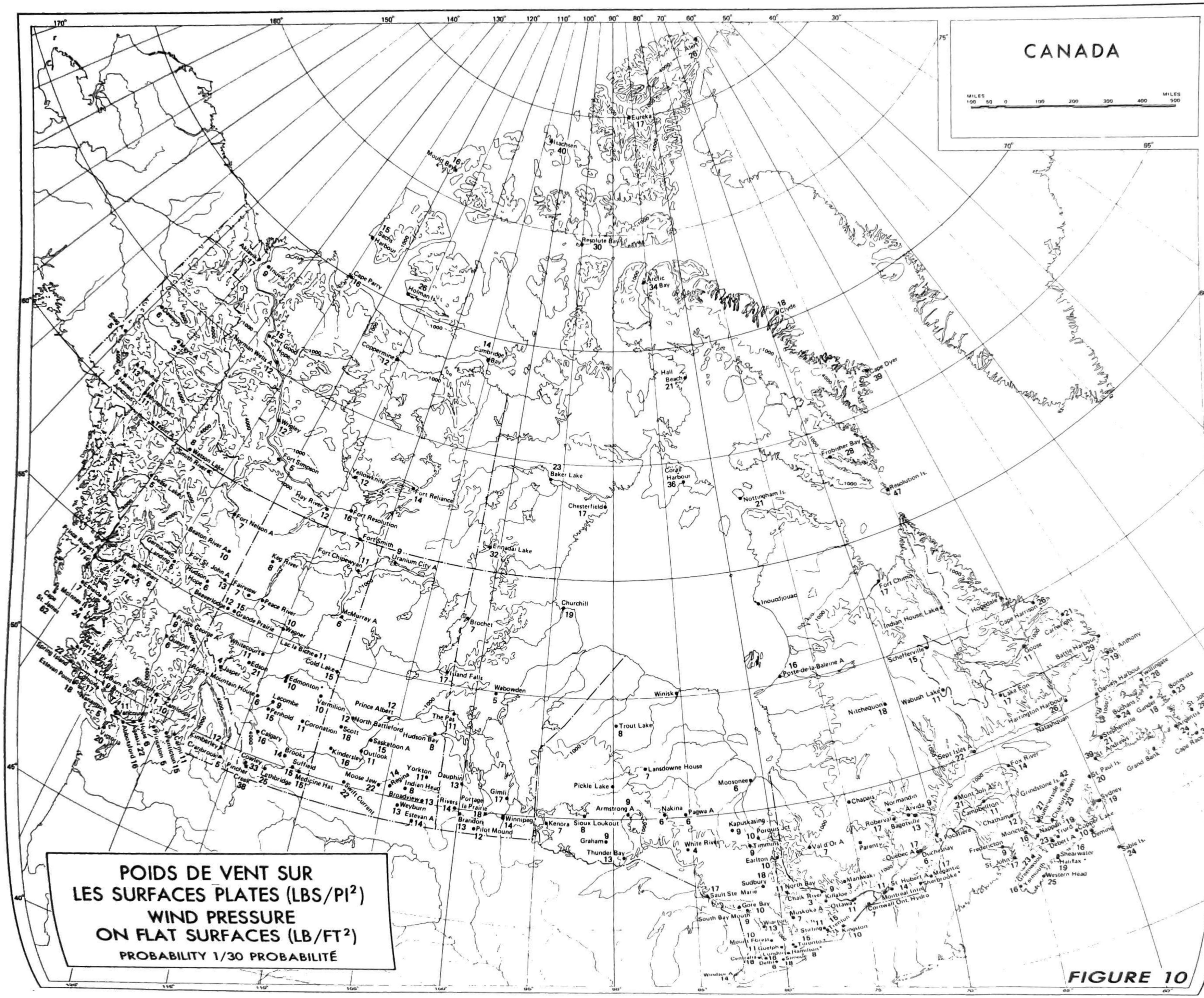
POIDS DE VENT SUR LES OBJETS CYLINDRIQUES (LBS/PI²)
WIND PRESSURE ON CYLINDRICAL SURFACES (LB/FT²)
PROBABILITY 1/100 PROBABILITE

FIGURE 8



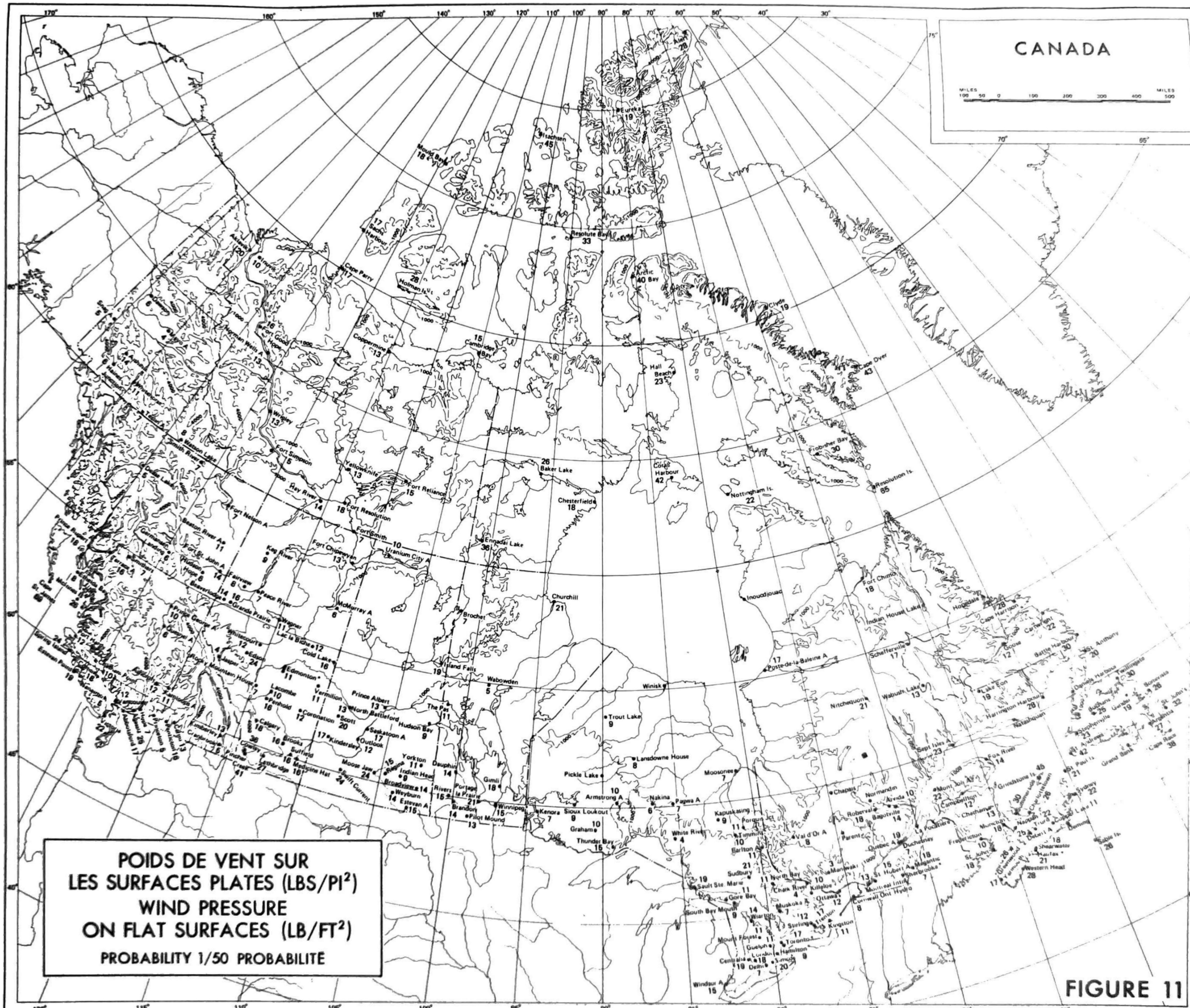
POIDS DE VENT SUR LES SURFACES PLATES (LBS/PI²)
WIND PRESSURE ON FLAT SURFACES (LB/FT²)
PROBABILITY 1/10 PROBABILITÉ

FIGURE 9



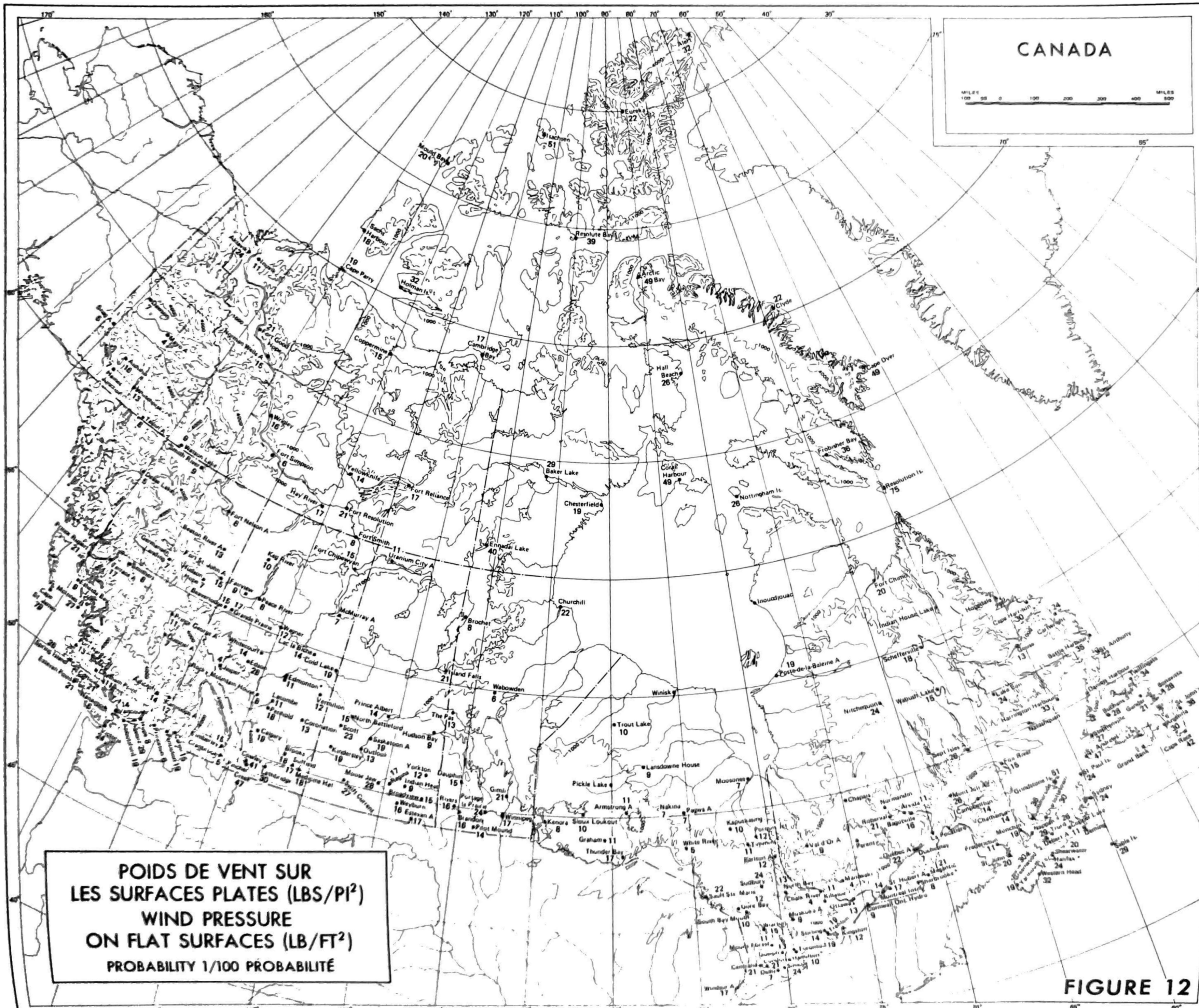
POIDS DE VENT SUR
LES SURFACES PLATES (LBS/PI^2)
WIND PRESSURE
ON FLAT SURFACES (LB/FT^2)
PROBABILITY 1/30 PROBABILITÉ

FIGURE 10



POIDS DE VENT SUR
LES SURFACES PLATES (LBS/PI^2)
WIND PRESSURE
ON FLAT SURFACES (LB/FT^2)
PROBABILITY 1/50 PROBABILITÉ

FIGURE 11

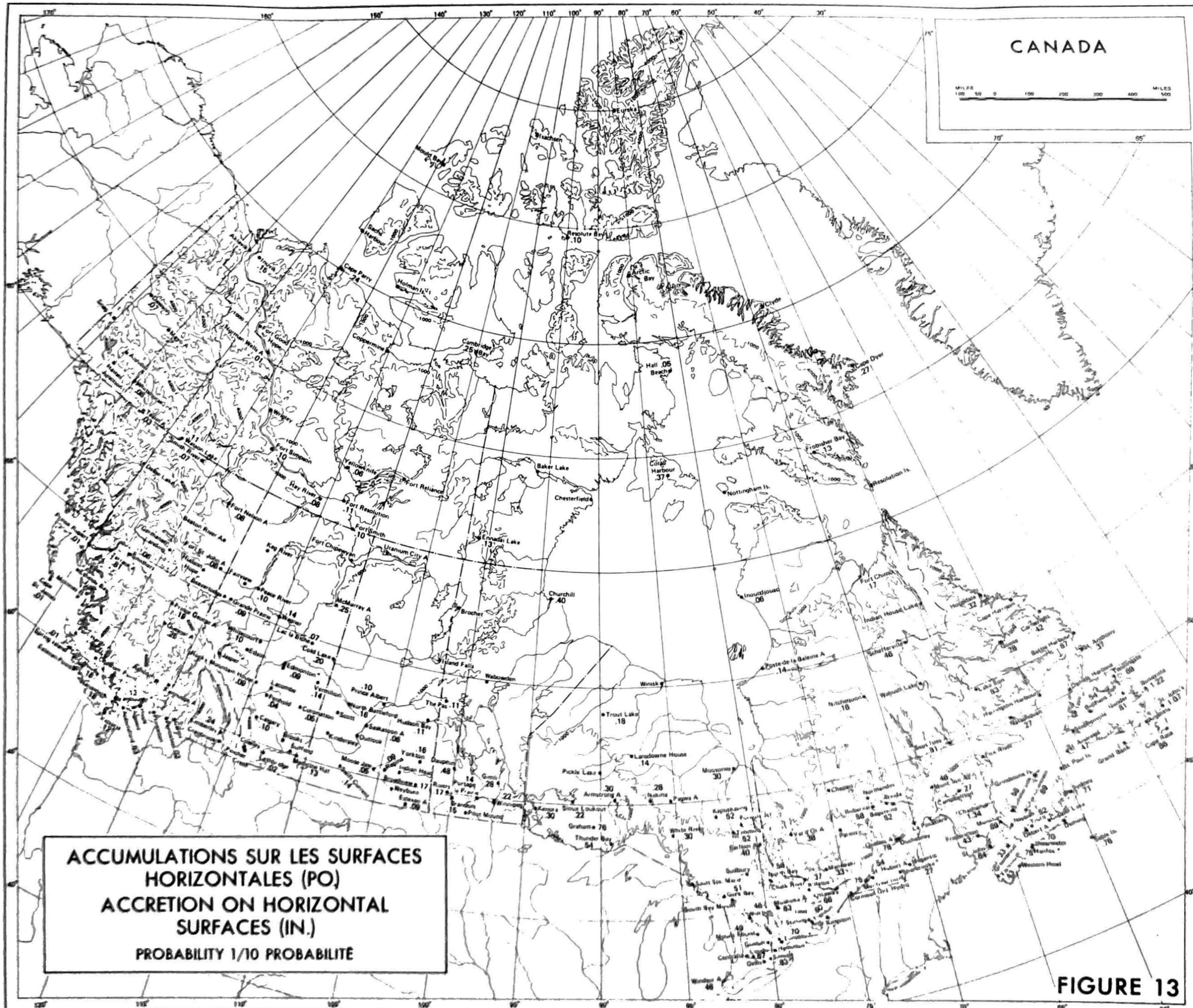


POIDS DE VENT SUR LES SURFACES PLATES (LBS/PI²)

WIND PRESSURE ON FLAT SURFACES (LB/FT²)

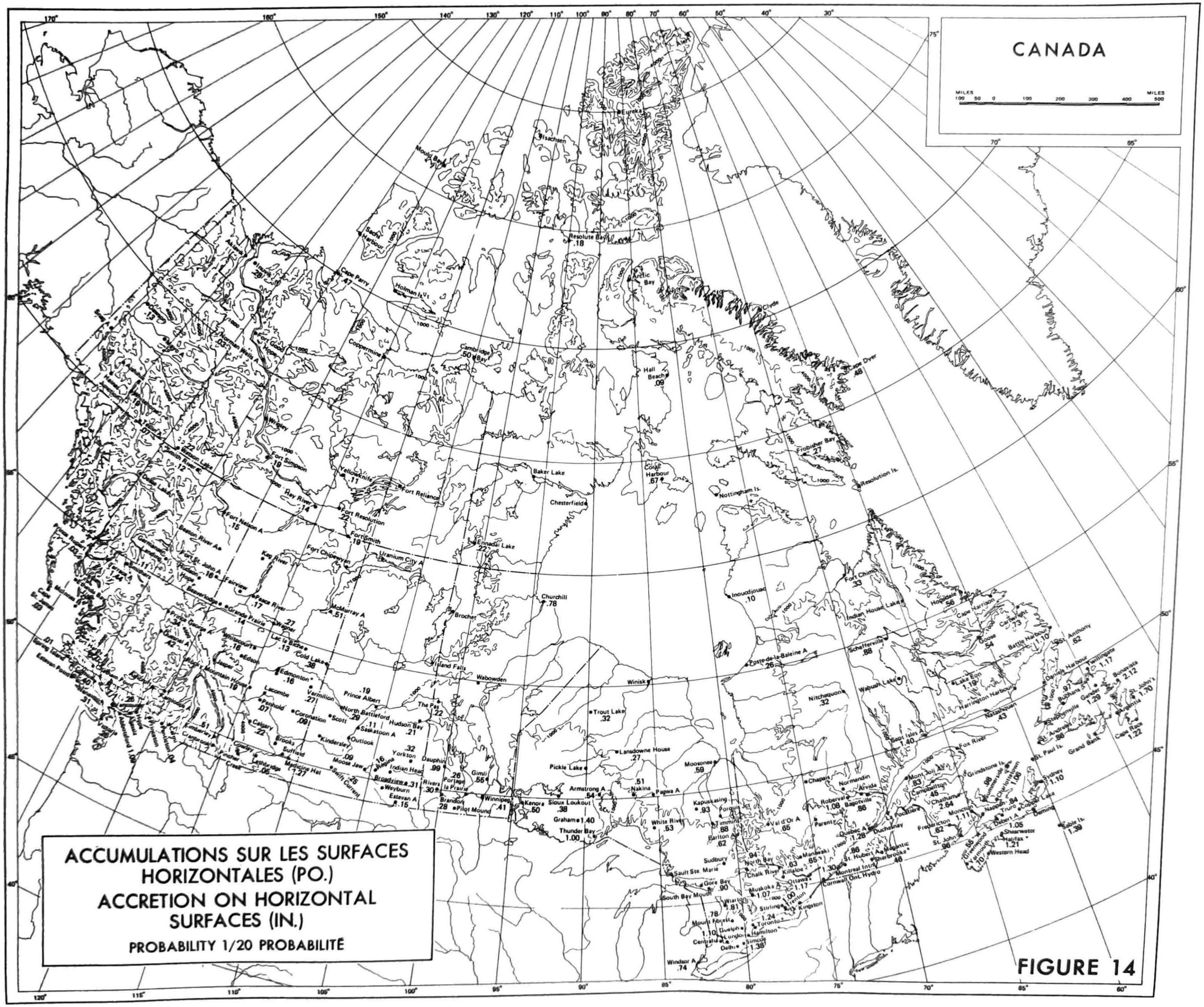
PROBABILITY 1/100 PROBABILITÉ

FIGURE 12



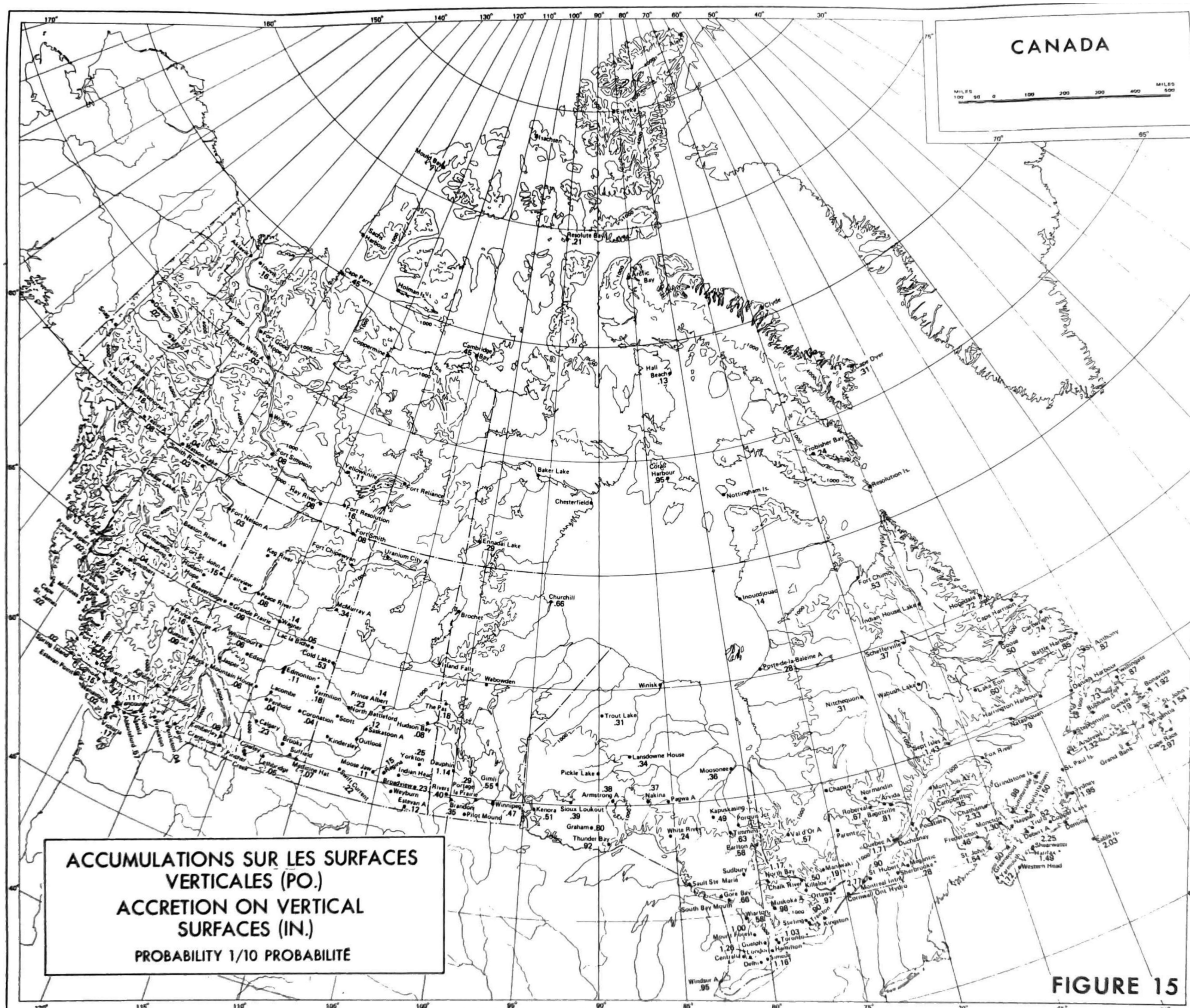
ACCUMULATIONS SUR LES SURFACES HORIZONTALES (PO)
ACCRETION ON HORIZONTAL SURFACES (IN.)
PROBABILITY 1/10 PROBABILITÉ

FIGURE 13



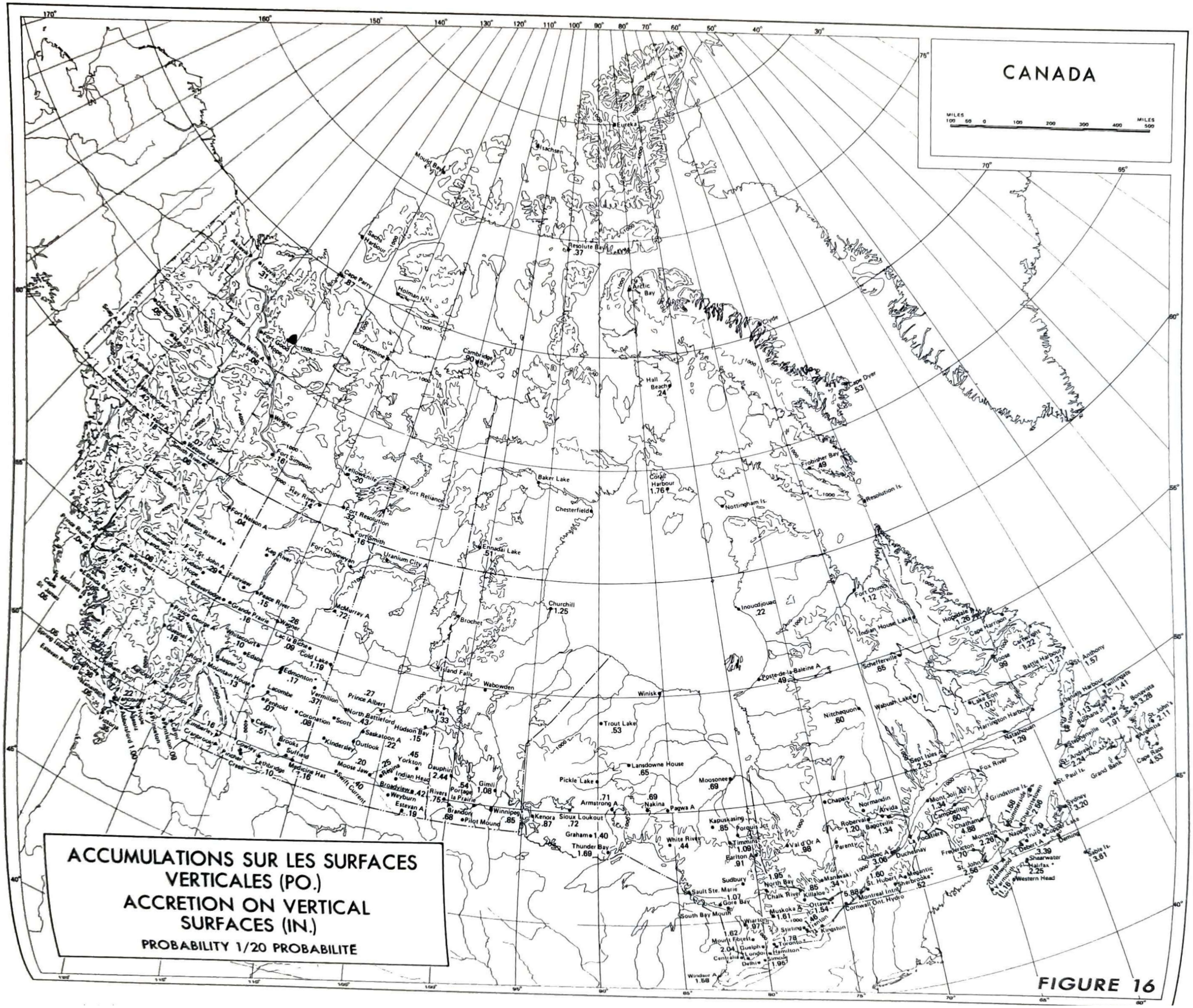
ACCUMULATIONS SUR LES SURFACES HORIZONTALES (PO.)
ACCRETION ON HORIZONTAL SURFACES (IN.)
PROBABILITY 1/20 PROBABILITÉ

FIGURE 14



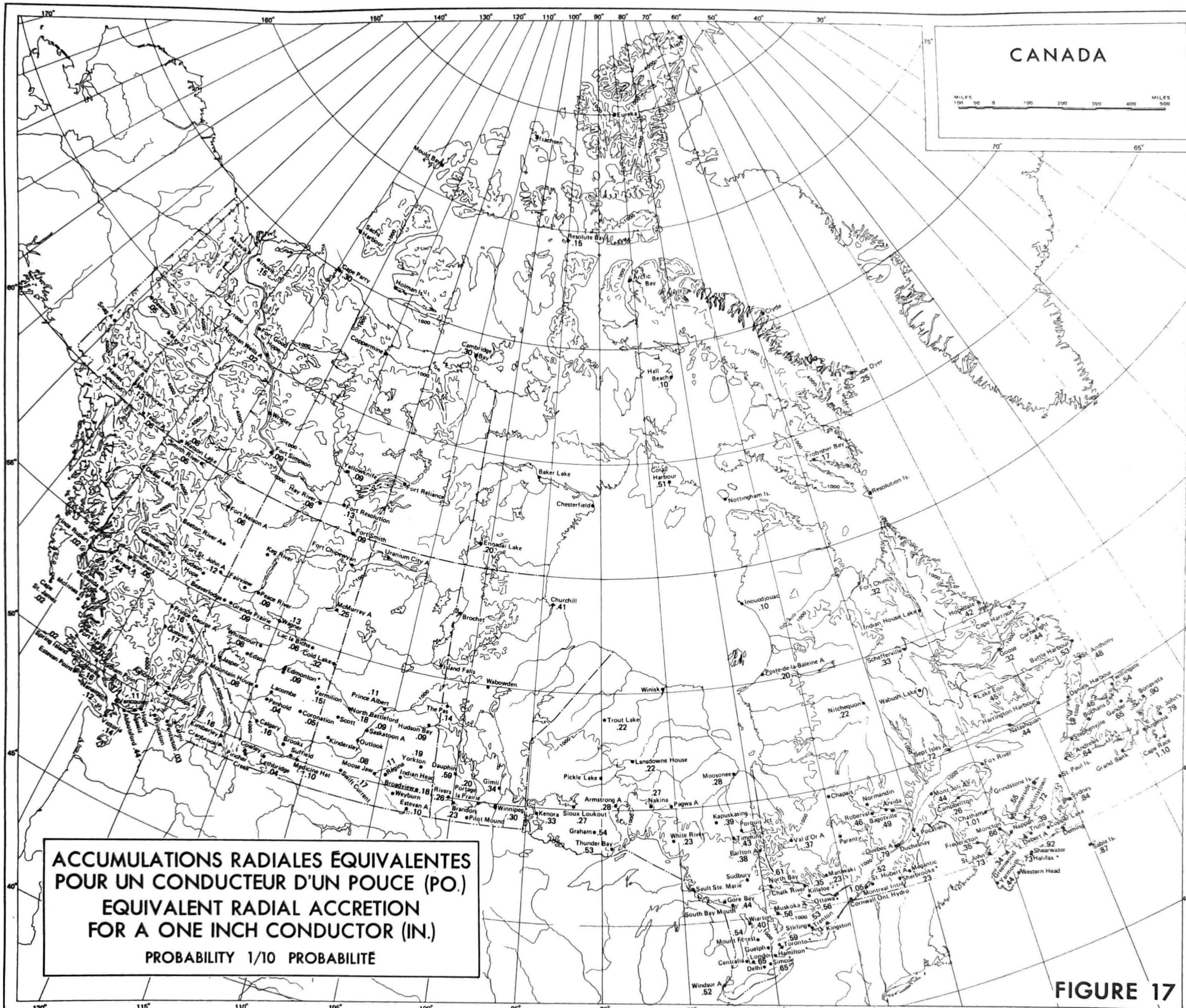
ACCUMULATIONS SUR LES SURFACES VERTICALES (PO.)
ACCRETION ON VERTICAL SURFACES (IN.)
PROBABILITY 1/10 PROBABILITÉ

FIGURE 15



ACCUMULATIONS SUR LES SURFACES VERTICALES (PO.)
ACCRETION ON VERTICAL SURFACES (IN.)
PROBABILITY 1/20 PROBABILITÉ

FIGURE 16



ACCUMULATIONS RADIALES ÉQUIVALENTES POUR UN CONDUCTEUR D'UN POUCE (PO.)
EQUIVALENT RADIAL ACCRETION FOR A ONE INCH CONDUCTOR (IN.)
PROBABILITY 1/10 PROBABILITÉ

FIGURE 17

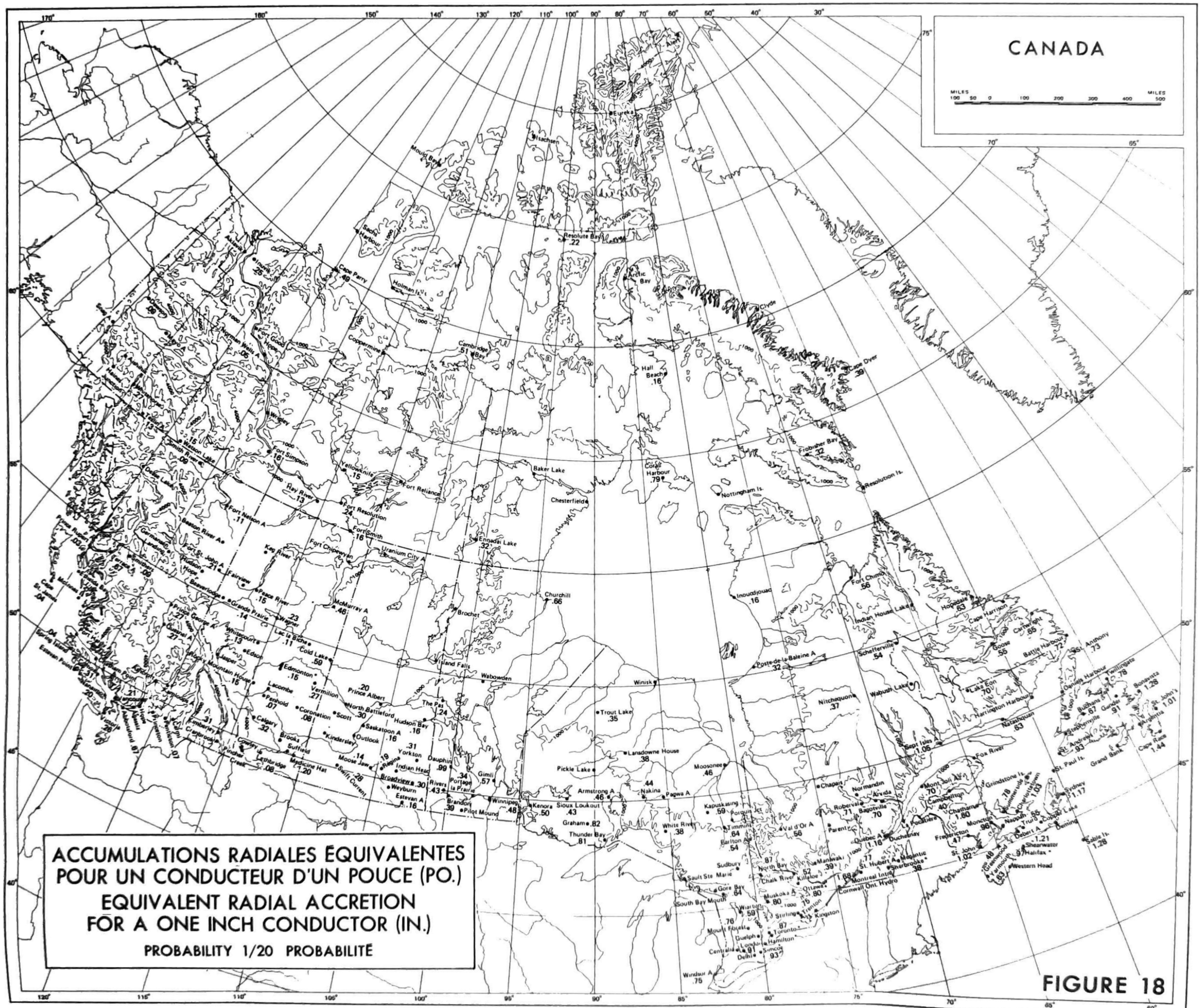
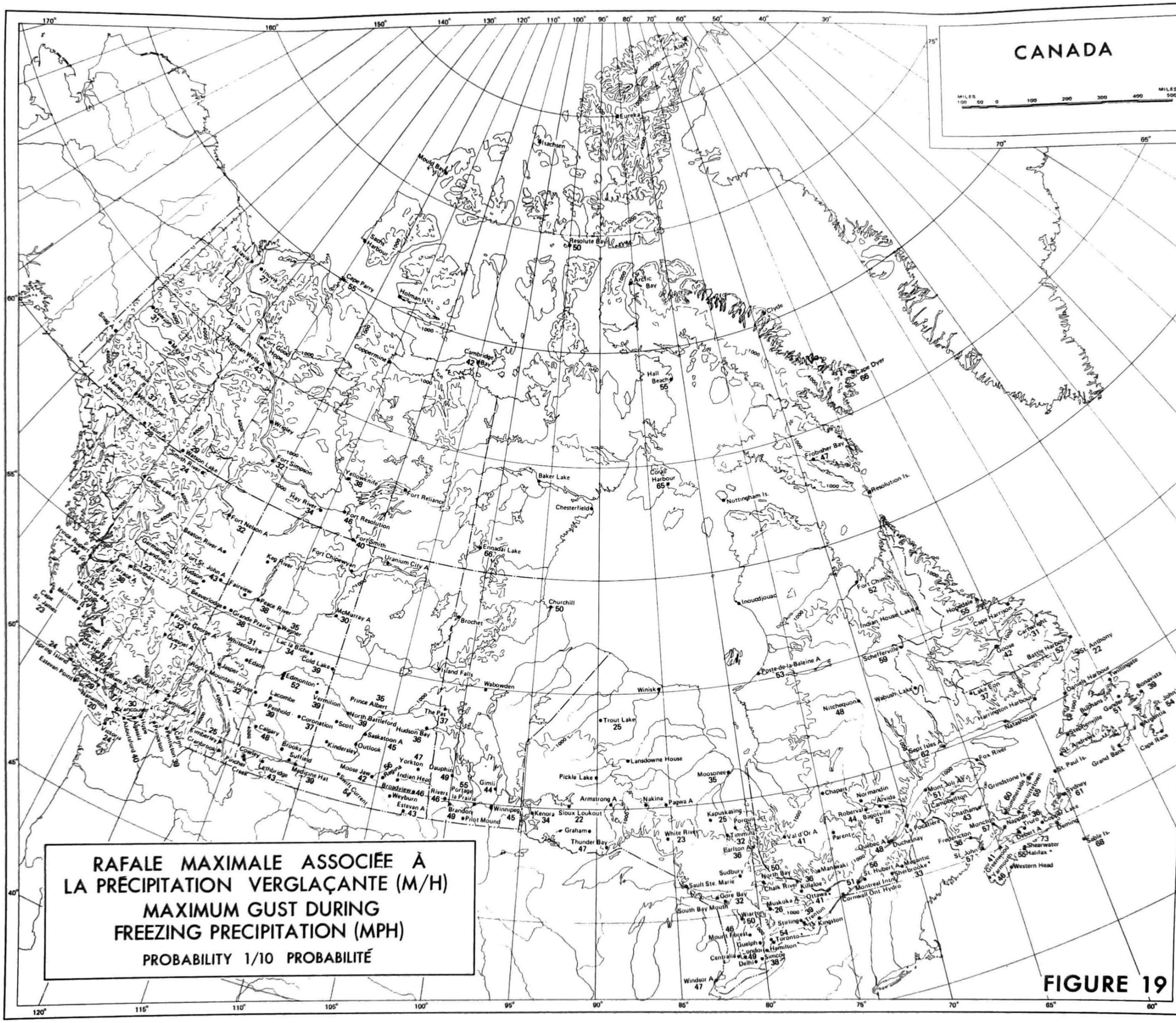

CANADA
ACCUMULATIONS RADIALES ÉQUIVALENTES
POUR UN CONDUCTEUR D'UN POUCE (PO.)
EQUIVALENT RADIAL ACCRETION
FOR A ONE INCH CONDUCTOR (IN.)
PROBABILITY 1/20 PROBABILITÉ

FIGURE 18



RAFALE MAXIMALE ASSOCIÉE À LA PRÉCIPITATION VERGLAÇANTE (M/H)

MAXIMUM GUST DURING FREEZING PRECIPITATION (MPH)

PROBABILITY 1/10 PROBABILITÉ

FIGURE 19

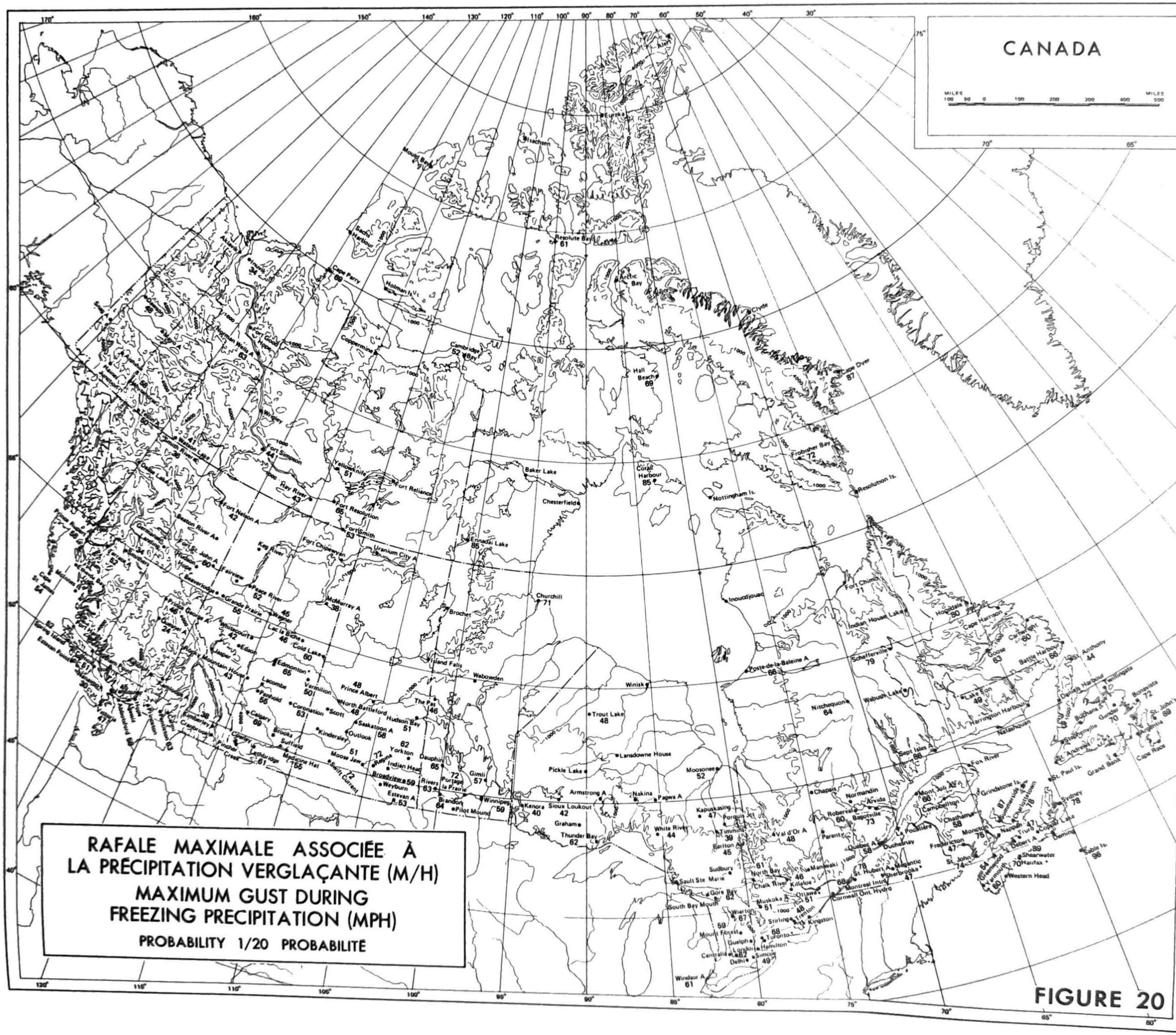
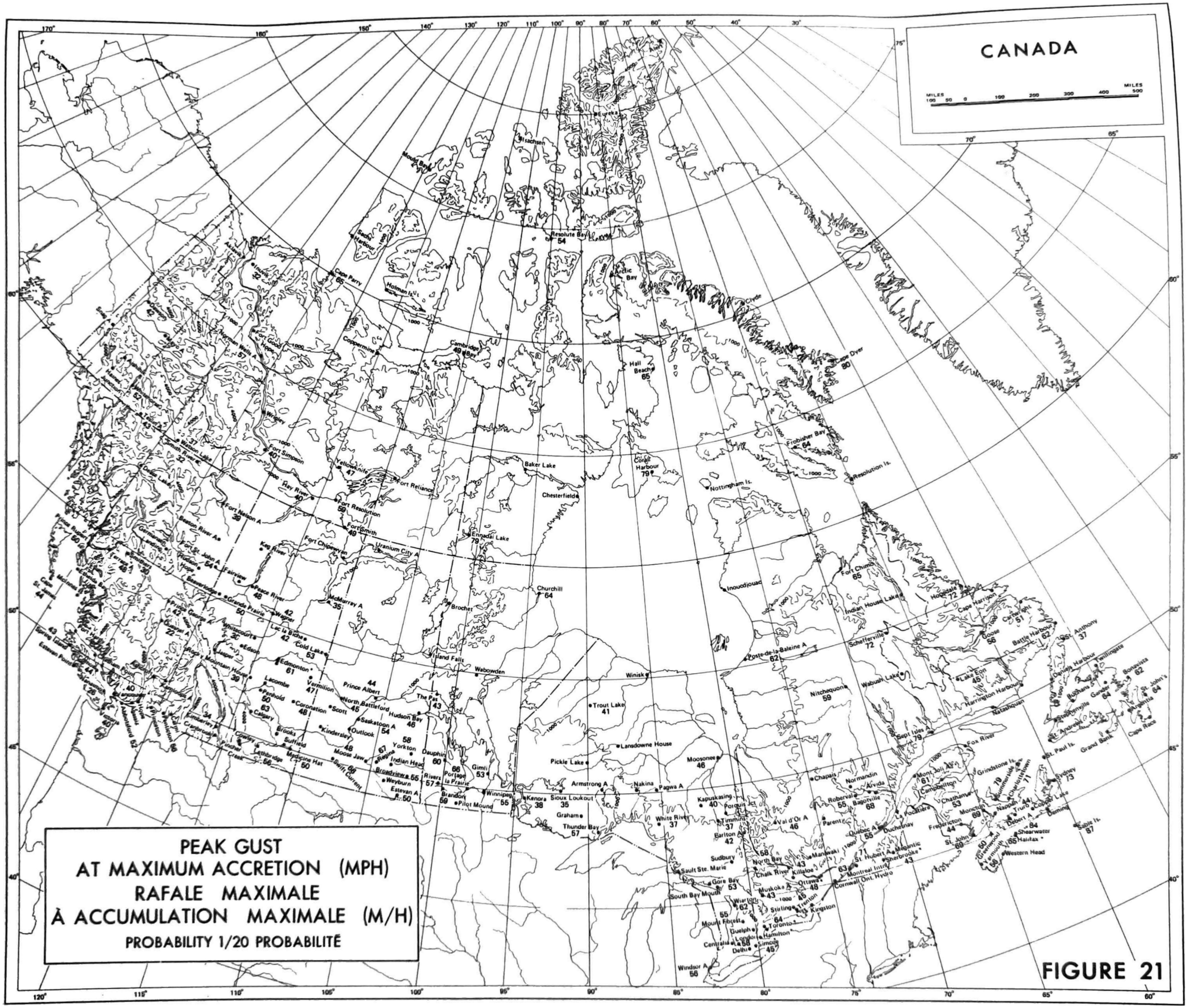

CANADA
MILES 100 50 0 100 200 300 400 500 MILES
RAFALE MAXIMALE ASSOCIÉE À
LA PRÉCIPITATION VERGLAÇANTE (M/H)
MAXIMUM GUST DURING
FREEZING PRECIPITATION (MPH)
PROBABILITY 1/20 PROBABILITÉ

FIGURE 20


CANADA
MILES
MILES
PEAK GUST
AT MAXIMUM ACCRETION (MPH)
RAFALE MAXIMALE
À ACCUMULATION MAXIMALE (M/H)
PROBABILITY 1/20 PROBABILITÉ
FIGURE 21