Final Report

METEOROLOGICAL STUDY
OF THE
GULL ISLAND-STEPHENVILLE-HOLYROOD
TRANSMISSION LINE ROUTES

Prepared for

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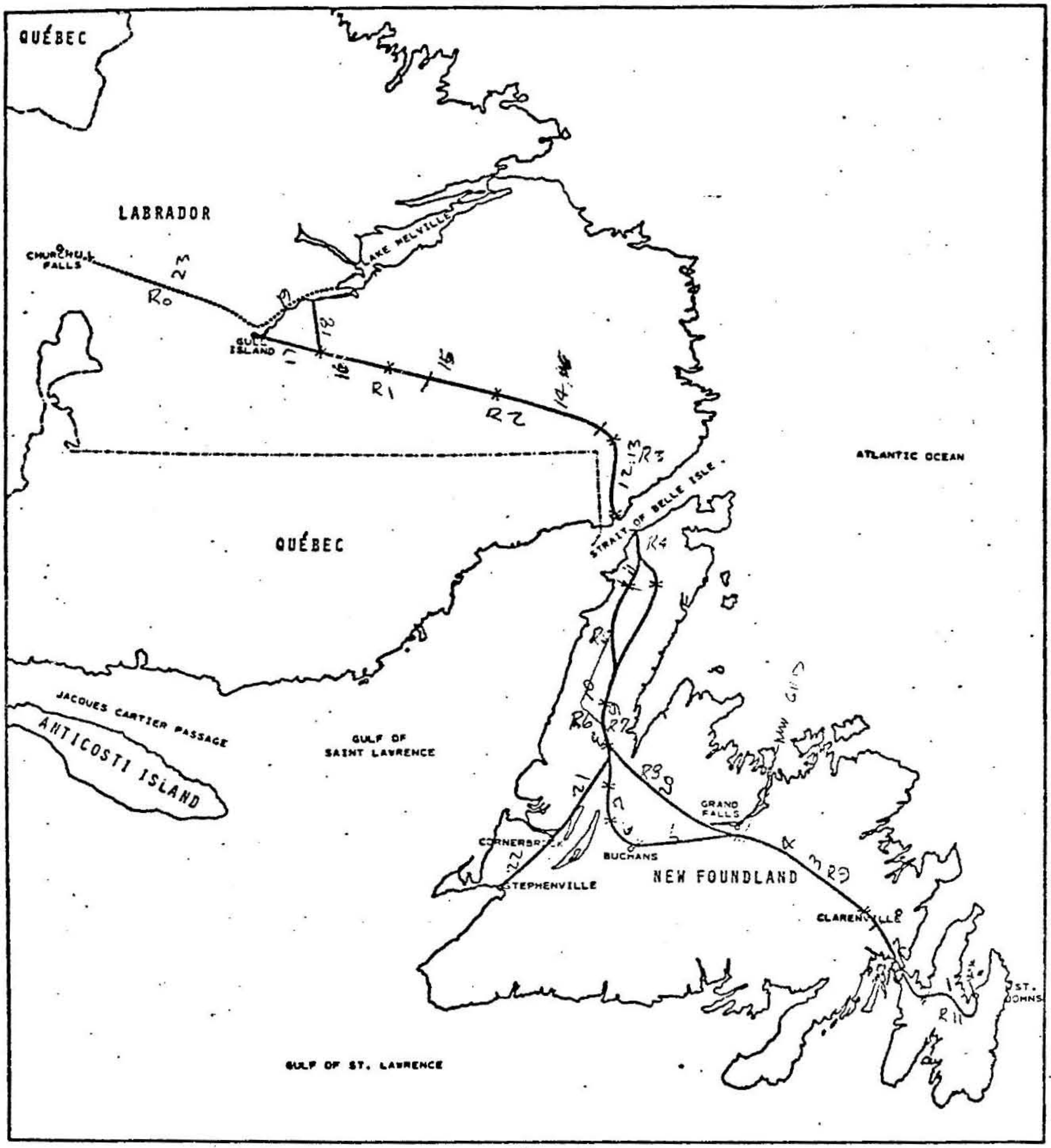
30 November 1973

MRI 73 FR-1131



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SUMMARY

A meteorological study was conducted to determine the extreme values of ice loading, wind loading, and ice and wind loading likely to be experienced along proposed transmission line routes in Labrador and Newfoundland. The study consisted of three phases: a field survey, a climatology study, and the analysis of data and application of results to the proposed routes.

In the field survey, terrain and route exposure were studied, and personal interviews of people who live and work in the areas were conducted. Much first-hand knowledge and some additional weather records, not available through the Atmospheric Environment Service (AES) were acquired on the trip.

In the climatology study, all pertinent materials available in the MRI library as well as a very large volume of processed data from the AES were reviewed. The AES data included summaries of available hourly data tapes for twelve reporting stations in Newfoundland, Labrador, and eastern Quebec. The periods of available records for these stations ranged from 6 to 19 years with the average period being over 14 years.

All data were analyzed and recurrence probabilities of maximum winds and ice accumulations were developed for the reporting stations. These values, tempered by known incidents of damaging icing, were extrapolated, based on route exposure, to route segments.

Freezing precipitation occurs frequently throughout Newfoundland and in the coastal areas of Labrador. Maximum accumulations of glaze icing are expected to reach four radial inches in a 25-year return period near the isthmus to the Avalon Peninsula and along the ridge of the Long Range Mountains.

The heaviest icing expected will be rime (in-cloud) icing along the ridge of the Long Range Mountains on the northwest peninsula. Extreme values near 8.5 radial inches are likely in a 25-year return period. Smaller but still significant amounts of rime will be received on the higher exposures of Newfoundland and in Labrador near the Strait of Belle Isle.

Wet snow will occur and will adhere to the conductors, but accumulations will not be great enough to be the limiting design values.

Wind gusts exceeding 120 mph in a 25-year return period will occur over some of the most exposed terrain of Newfoundland. High wind speeds will occur both during and following icing storms and combined wind and ice loadings will be very great.

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I. INTRODUCTION

Teshmont Consultants Ltd., is in the process of designing a transmission line for the Newfoundland and Labrador Power Commission. The proposed line will extend from the Gull Island Hydro Site southwest of Goose Bay, Labrador to near Holyrood on the Avalon Peninsula of Newfoundland and possibly to Stephenville on the southwest coast of Newfoundland. These proposed routes traverse some of the most severe wind and icing areas known to exist in North America. In recognition of the need for quantitative meteorological information on which to base the design, Meteorology Research, Inc., (MRI) was commissioned to conduct the study reported herein.

It was known that large portions of the proposed routes might be subjected to significant ice loadings. In the last 15 years, several icing storms in Newfoundland had resulted in extensive and costly damage to transmission lines. Various studies of icing in Canada (Austin, 1956; Boyd, 1965a, 1965b, and 1970; Mckay and Thompson 1969; Young and Schell, 1971) all agreed that the northeastern part of Newfoundland had experienced the greatest accumulations of glaze icing reported in Canada. The new routes were proposed to cross through that area as well as uninhabited areas where no past experience or reports were available.

A meteorological study was conducted to determine the probabilities of occurrence (or return periods) of extreme values of ice loading, wind loading, and ice and wind loading. In conjunction with the study, several case histories of past damaging storms were studied also.

This report presents the results of that study. The scope of the study and the regional meteorological characteristics are discussed in Sections II and III. Data sources are outlined in Section IV and the winds, temperatures, and icing are analyzed in Sections V, VI, and VII. The probability of simultaneous occurrence of maximum wind and ice loading is discussed in Section VIII and precipitation and salt contamination are commented on in Section IX. Previous damaging storms are reviewed in Section X and the line segment load values tabulated in Section X I. Finally, conclusions are summarized in Section XII.

II. SCOPE OF STUDY

This transmission line study consisted basically of three phases as follows:

- A field survey
- A climatology study
- Analysis of data and application to route segments.

The field survey consisted of an on-site route familiarization and information gathering visit to Newfoundland and Labrador. The terrain and exposure of the proposed routes were studied and evaluated. Personal interviews were conducted with both professional meteorologists from the area and with engineers and maintenance personnel who lived and worked in the local area and were familiar with the winds and icing storms which have occurred there in recent years. Some wind records not available through the Atmospheric Environment Service (AES) were acquired on this trip along with detailed damage reports of several icing storms in Newfoundland.

The climatology study consisted of a review of all pertinent material available in-house at MRI as well as a large volume of processed data from the AES. The AES data included summaries of available hourly data tapes for twelve reporting stations in Newfoundland, Labrador, and eastern Quebec. The period of data for these stations ranged from 6 to 19 years with the average period being over 14 years.

The final phase consisted of analyzing the data to determine the probabilities of occurrence (or return periods) of specific ice, wind, and combined ice and wind loads for the reporting stations and projecting these results to the proposed line routes.

Case histories of several storms which have resulted in damage to transmission lines in Newfoundland were researched and brief summaries of these storms are included in this study.

III. REGIONAL METEOROLOGICAL CHARACTERISTICS

The climate of Newfoundland is influenced by its latitude, maritime location, and its position relative to storm tracks. A large percentage of all low pressure storm systems moving across North America pass over or near Newfoundland and the heavy snowfalls, periods of freezing rain, and extreme wind speeds are almost invariably associated with these low pressure systems. The east coast of Labrador is exposed to much the same meteorological conditions as insular Newfoundland; however, inland the maritime climate is replaced by the near continental climate of the Labrador-Ungava peninsula.

One of the effects of this transition from maritime to continental climate is apparent in the temperature regimes of representative stations across the area. Based on ten years of hourly observations (1957-1966), 18 percent of the January temperatures at St. John's were above 32°F. During the same period, Gander recorded 12 percent, Goose Bay five percent, and Knob Lake, Quebec, less than one percent. Of course, the continentality is strengthened in this case by the effect of latitude and altitude. Another difference between the maritime and continental regimes is apparent in the frequency of low clouds. In the same 10-year period, March records show that 45 percent of the hourly observations at St. John's reflected ceilings ≤900 ft. Gander records show 39 percent for the same period, while Goose Bay and Knob Lake each show only 16 percent. For the three-month period January through March, the records show ceilings ≤400 ft 26 percent of the time at St. John's while only four percent at Goose Bay.

Precipitation records do not show the same contrast. Nearly all the reporting stations in Newfoundland and Labrador average between 35 and 40 inches of precipitation per year. The exception to this is the eastern side of the island where Argentia and Gander average 42 inches and St. John's-Torbay averages 60 inches. Local topography has a great influence on precipitation and the higher terrain of western Newfoundland undoubtedly receives significantly more precipitation than the recording stations which are all at low elevations. Snowfall is heavy throughout the area with most reporting stations averaging in excess of 100 inches per year and several over 150 inches per year. Once again, these are records from low-level stations and the higher elevations would be expected to receive much greater totals.

Freezing precipitation occurs throughout both Newfoundland and Labrador; however, it is reported most frequently in the northeastern portion of Newfoundland. In the 19-year period 1953 through 1971, freezing drizzle was reported on five percent of all the hourly observations taken during January, February, and March at St. John's-Torbay and at Gander. Farther to the west, Buchans' records reflect only two percent as does Battle Harbour on the coast of Labrador. The frequency then decreases to one percent at Goose Bay.

Strong winds are also most apparent in the records of the stations in northeastern Newfoundland with both St. John's-Torbay and Gander having recorded gusts of 100 mph or greater. Gusts are not recorded at Battle Harbour; however, a sustained wind speed of 80 mph was recorded there in February 1967 and gusts exceeding 100 mph probably occurred at that time. It is likely that gusts of 100 mph have occurred at all well exposed locations in Newfoundland and along the coast of Labrador. Most of the reporting stations are sheltered by nearby higher terrain. No wind records are available from the ridges and plateaus of the region.

IV. DATA SOURCES

A. Climatological Data

The basic data available for study of the proposed transmission line route came from long-term records at a number of locations in the area. Observations of wind speed, direction, temperature, precipitation, and cloud conditions are reported by these stations to the Atmospheric Environment Service (AES). These data form the basis of the route study but are not normally available in the form required for this type analysis. In previous projects, the AES has developed special computer programs for us to summarize the long periods of data in more usable forms for this analysis. These were used once again in this project.

Summarized data was acquired for twelve stations in the area of the proposed routes. The summaries include:

- Annual extreme wind speed analysis.
- Absolute frequency matrix of precipitation type vs wind speed for various temperature ranges.
- Duration of precipitation periods with dry bulb temperature less than 35°F.
- Duration of periods with ceiling below 1000 ft, temperature below 33°F, and visibility less than 3/4 mile.

For the eight stations closest to the proposed routes, more extensive summarizations were acquired. These summaries included thirteen classes of data:

- CIG 1000 ft or less, Temp. 28 to 38 degs, Wind Speed 10 mph or greater
- CIG 1000 ft or less, Temp. 28 to 38 degs, Wind Speed 15 mph or greater
- CIG 1000 ft or less, Temp. 28 to 38 degs, Wind Speed 20 mph or greater
- CIG 800 ft or less, Temp. 27 to 37 degs, Wind Speed 10 mph or greater
- CIG 800 ft or less, Temp. 27 to 37 degs, Wind Speed 15 mph or greater
- CIG 800 ft or less, Temp. 27 to 37 degs, Wind Speed 20 mph or greater

- CIG 300 ft or less, Temp. 25 to 35 degs, Wind Speed 10 mph or greater
- CIG 300 ft or less, Temp. 25 to 35 degs, Wind Speed 15 mph or greater
- CIG 300 ft or less, Temp. 25 to 35 degs, Wind Speed 20 mph or greater
- Temp. greater than 28 degs with moderate or heavy snow
- Freezing rain or drizzle
- Freezing rain
- Freezing drizzle.

The twelve stations for which summarized data were acquired and their length of record included:

St. John's-Torbay, Nfld.	1953-1971
Argentia, Nfld.	1953-1969
Gander, Nfld.	1953-1971
Buchans, Nfld	1953-1964
Deer Lake, Nfld.	1966-1971
Stephenville, Nfld.	1953-1971
Daniels Harbour, Nfld.	1966-1971
Battle Harbour, Labrador	1958-1971
Goose Bay, Labrador	1953-1971
Wabash Lake, Labrador	1961-1971
Schefferville (Knob Lake), Quebec	1953-1971
Lake Eon, Quebec	1961-1971

In addition to these special summaries, published Hourly Data Summaries were available for five of the stations, Wind Speed Summaries for nine, and Temperature and Precipitation Summaries for all twelve. Also available were several papers, studies, and reports dealing with various aspects of the climatology of the area.

B. Data Acquired by Personal Contact

A trip was made to Newfoundland and Labrador for route familiarization and to interview personnel with first-hand experience with the winds and icing of the area. The most senior people available in the weather stations at St. John's-Torbay, Gander, and Goose Bay airports were interviewed and a great deal of insight into the local weather was acquired. Construction and maintenance engineers from the Power Commission and from the Canadian National's microwave system were consulted as to their experiences and problems with ice and wind damage. Files at the Shawmont and Power Commission offices were reviewed for storm damage accounts and wind records for Sunnyside were borrowed.

V. WINDS

A. General Considerations

Strong winds are relatively common in Newfoundland. Of the eleven reporting stations for which wind records are readily available, only Deer Lake and Stephenville have not reported hourly wind speeds of at least 65 mph. Six of the eleven stations have reported hourly wind speeds of at least 70 mph. Only six of the stations have records of wind gusts; however, five of those six have recorded gusts of 85 mph or higher. At St. John's-Torbay Airport, gusts exceeding 100 mph have been recorded several times and 120 mph has been reached at least twice. Gander International Airport has also recorded gust speeds of 100 mph and unofficial reports place winds of this magnitude several places on the island.

Inland in Labrador, the winds tend to be somewhat lighter; however, Battle Harbour on the coast has reported hourly wind speeds up to 80 mph. Once again, no gust records were available there, but 100 to 110 mph is a reasonable estimate. The maximum hourly wind reported at Goose Bay was only 52 mph and the maximum gust was 80 mph; however, the site is sheltered by high terrain on three sides.

When used for maximum wind speeds, "hourly-wind" values are usually conservative. The hourly-wind recorded in the hourly weather observation consists of a one-minute average wind speed observed during the 10 minutes prior to the hour. Thus, if the actual maximum one-minute average does not occur in that 10 minutes, it is not recorded. Wind gust records are normally available only for locations with full scale weather facilities.

In both Newfoundland and Labrador, most of the extreme wind speeds occur during the winter months and are associated with deep low pressure systems and/or frontal systems. Wind directions of the strong winds, being dictated by the location of the low center or orientation of the front, show little pattern except where local exposure or local channeling limits the possible directions.

B. Wind Data Analysis

In this study, the annual maximum recorded hourly wind speeds for each of twelve stations were used to develop return period values for these stations. These values were then related to the proposed routes taking into consideration the local terrain, forest cover, and exposure.

The first step in the analysis was to rank all yearly extreme speeds for a given station in ascending order, compute the probability of occurrence of each speed and plot the points on extreme probability paper of the Fisher-Tippett Type I or Gumble distribution (Fisher and Tippett, 1928; U. S. Department of Commerce, 1953). This is a symmetric, extreme-probability distribution cited by Court (1953) as particularly applicable to extreme surface winds and the distribution adopted by the Canadian Department of Transport (1968). Figures 1 through 12 show these plots.

The mean and standard deviations of each station's extreme wind distribution were then calculated and the characteristic line drawn using the relationship given by Weiss (1955). The lines are shown in Figs. 1 through 12 (if the data points in a particular figure had a truly normal distribution, they would all fall on the line). The speed to be equalled once in a given return period can be determined from these lines.

The 10-, 25-, 50-, and 75-year return-period wind speeds for the twelve stations were extracted from the graphs and appear in Table I along with the number of years of record used and the anemometer heights. The maximum hourly wind (and its direction) and the maximum wind-gust reported for each station from the beginning of record to 1966 were extracted from "Climatic Normals, Vol. 5" (Canadian Department of Transport, 1968) and entered in Table I for comparison with the projected return-period winds. These data are also included for four additional Newfoundland locations. The distribution of annual-extreme winds by month and by direction were extracted from the data and appear summarized in Tables II and III, respectively. When in a particular year the annual-extreme wind speed occurred in more than one month and/or from more than one direction, each occurrence was counted. Thus the totals for each station do not necessarily equal the years of data.

The most important aspect of the analysis is the type of wind-speed parameter used as a data base. When dealing with analysis for structural design winds, such analyses should be based upon either the "fastest mile" or the "fastest minute" values of wind extracted from continuous anemometer records. The "fastest mile-of-wind" represents the mile of wind that took the shortest time to pass at any time during the year. The "fastest minute-of-wind" represents the strongest one-minute average wind speed at any time during the year. These two are equal at 60 mph and very nearly equal at all high speeds. Unfortunately, neither fastest-mile nor fastest-minute values of wind was available for the stations in the vicinity of the proposed transmission lines.

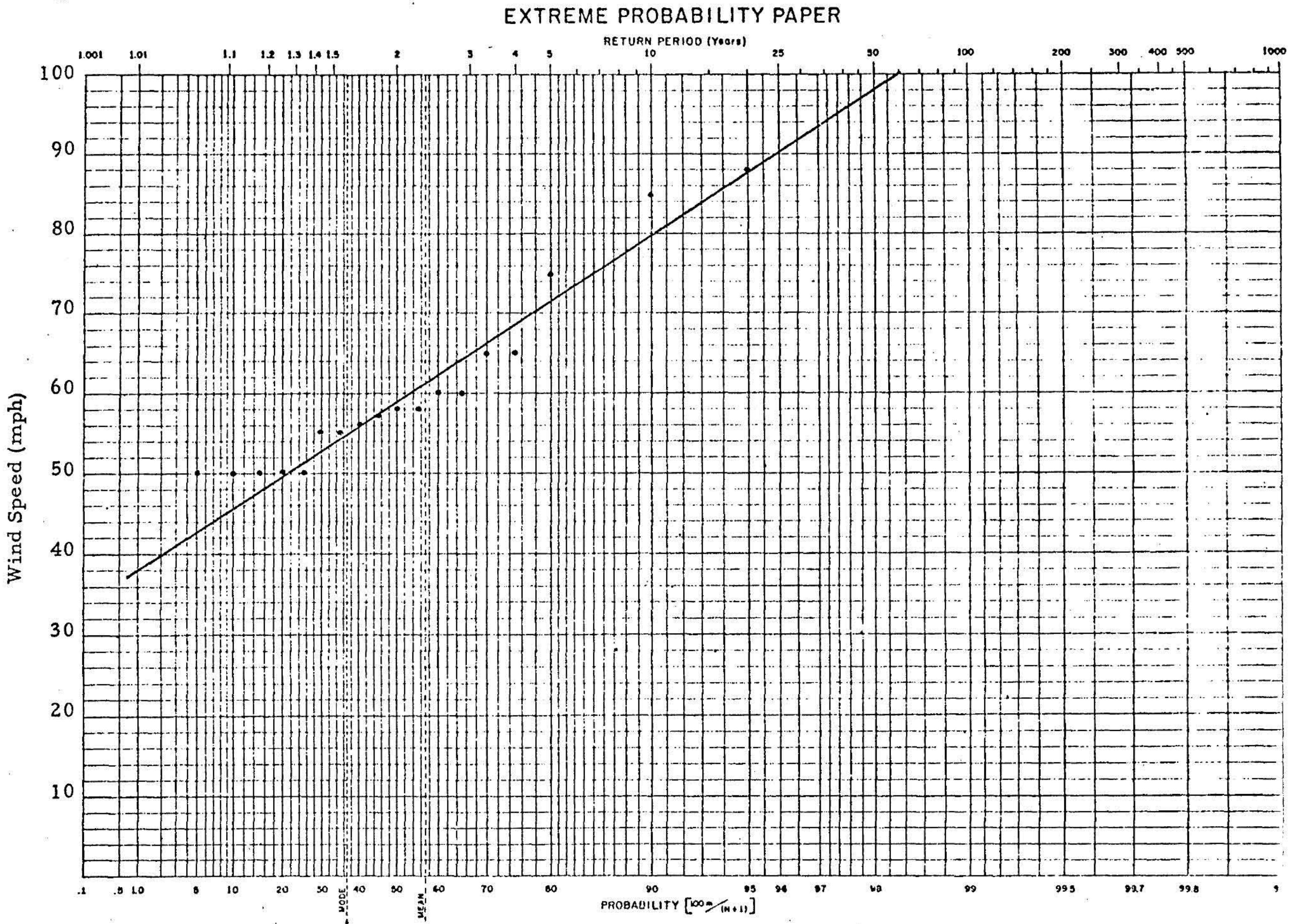

Fig. 1. WIND SPEED PROBABILITIES FOR ST. JOHNS-TORBAY, NFLD.

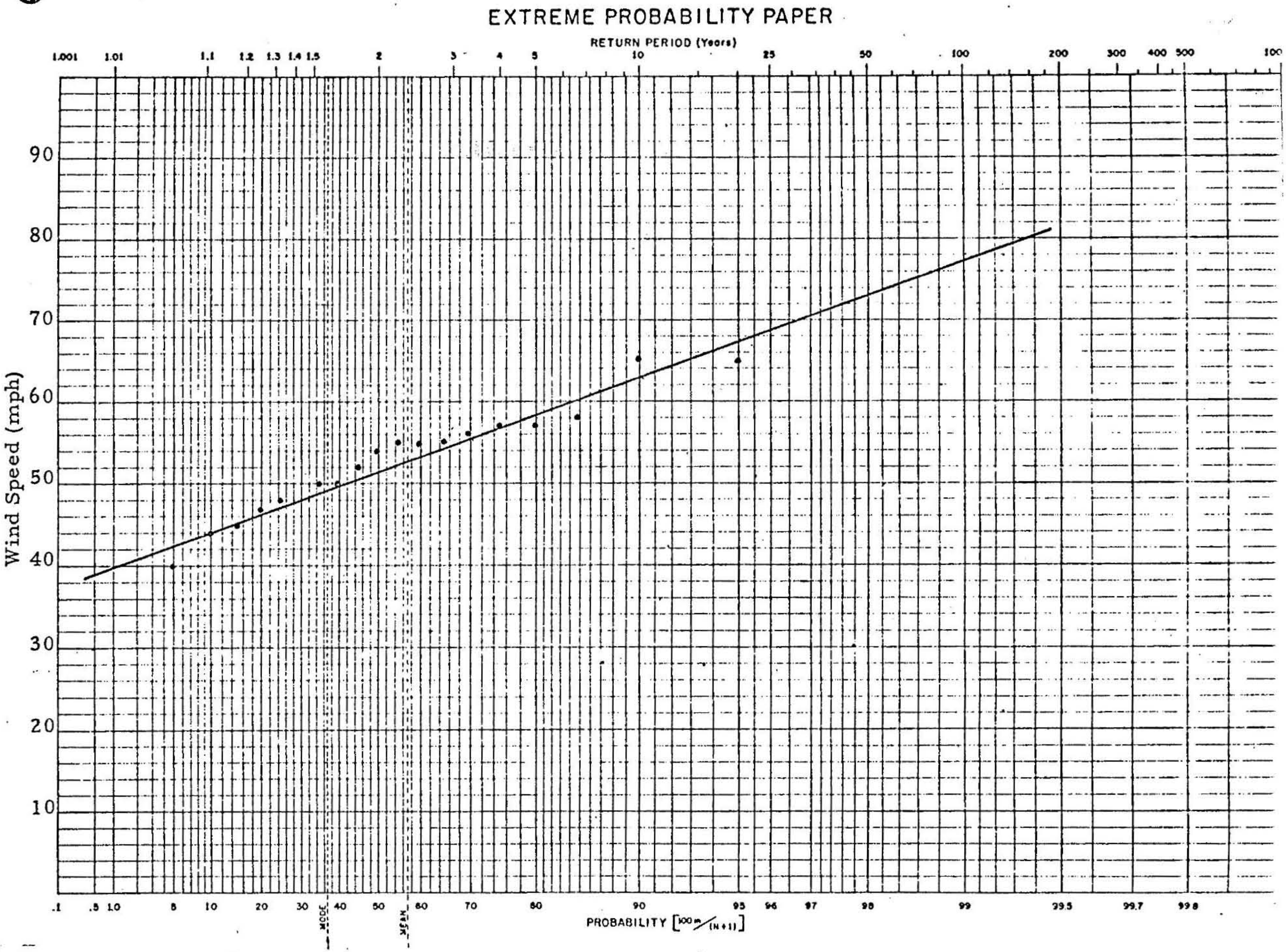

Fig. 2. WIND SPEED PROBABILITIES FOR GANDER, NFLD.

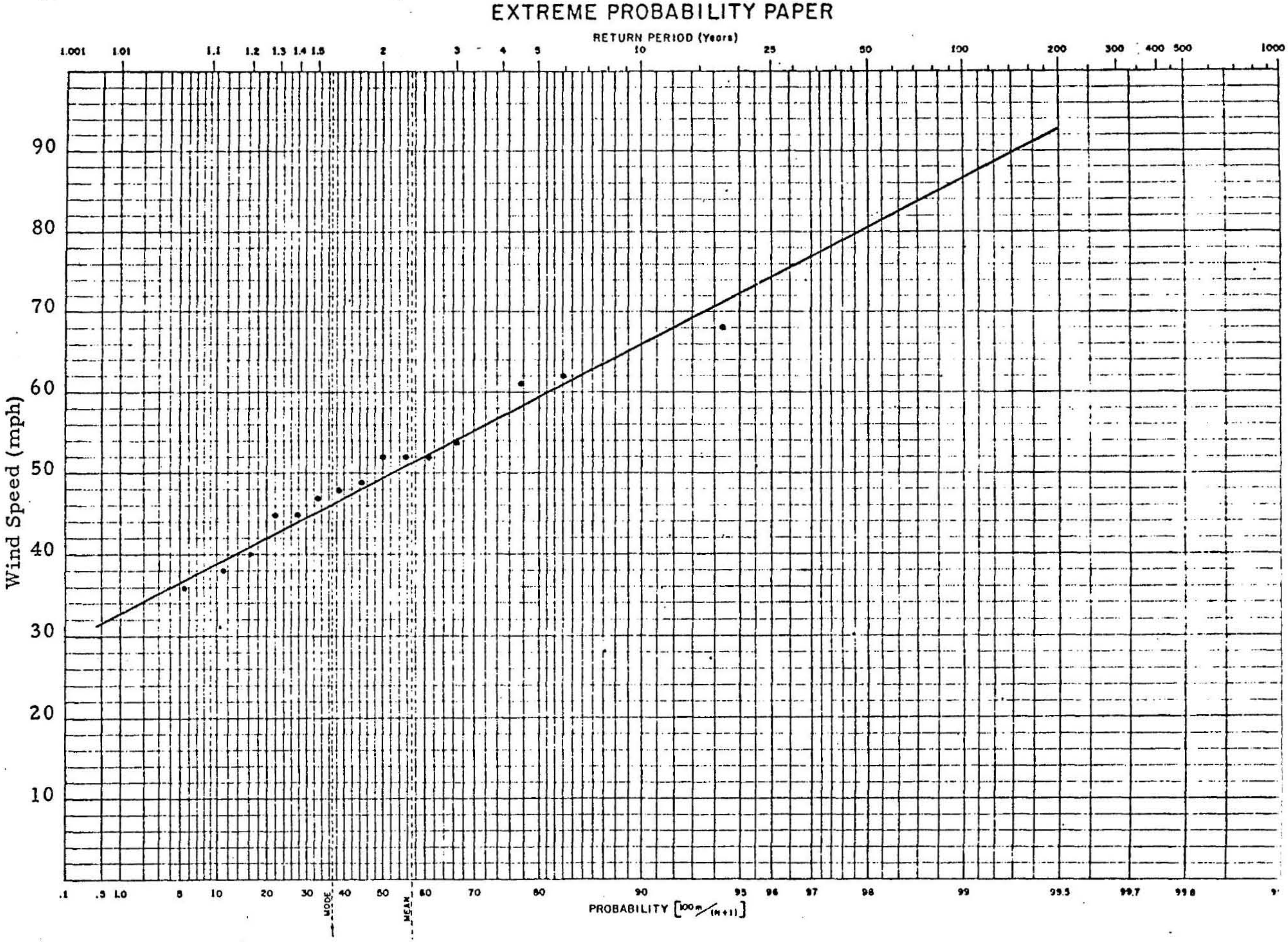

Fig. 3. WIND SPEED PROBABILITIES FOR ARGENTIA, NFLD.

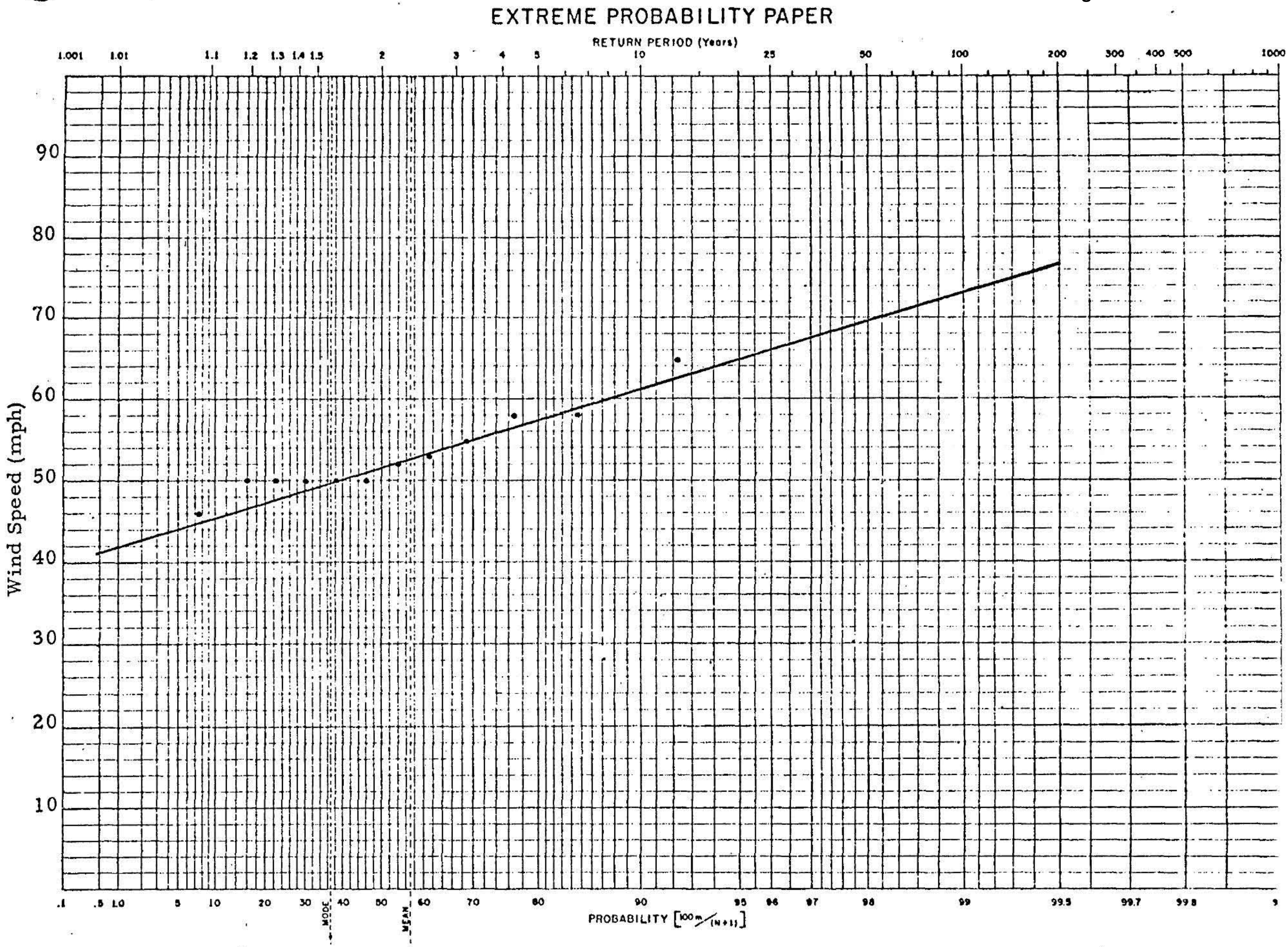

Fig. 4. WIND SPEED PROBABILITIES FOR BUCHANS, NFLD.

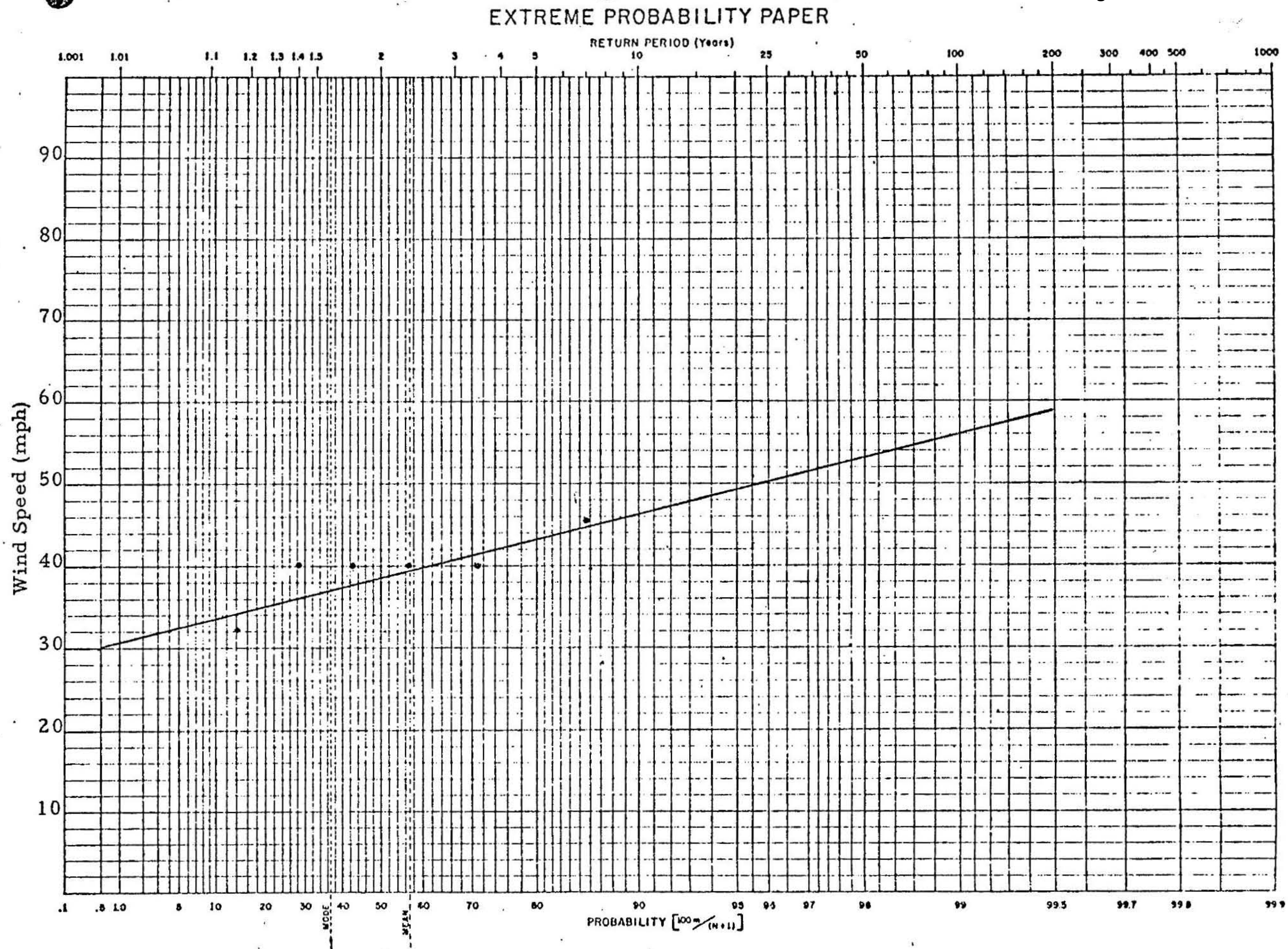

Fig. 5. WIND SPEED PROBABILITIES FOR DEER LAKE, NFLD.

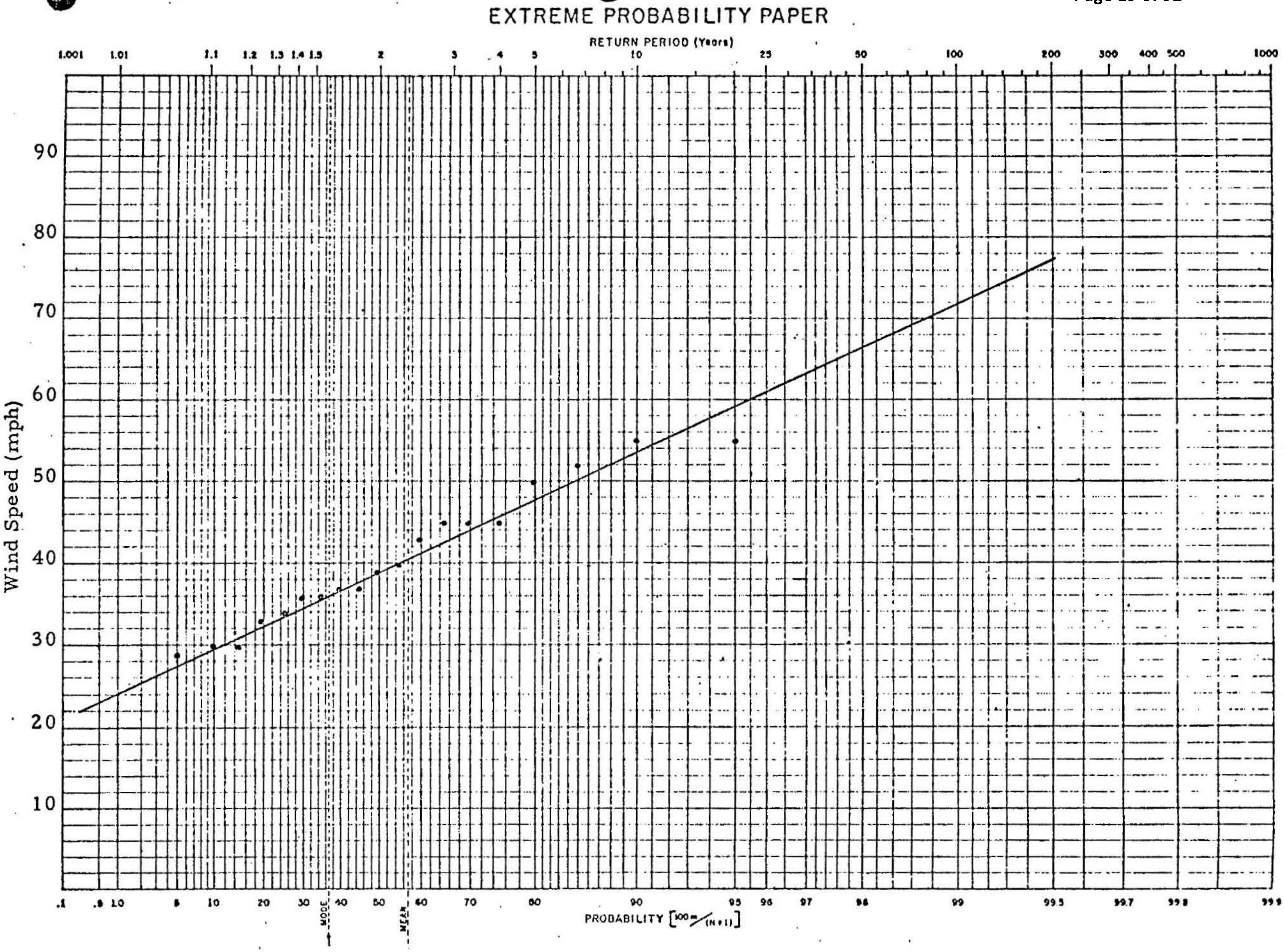

Fig. 6. WIND SPEED PROBABILITIES FOR STEPHENVILLE, NFLD.

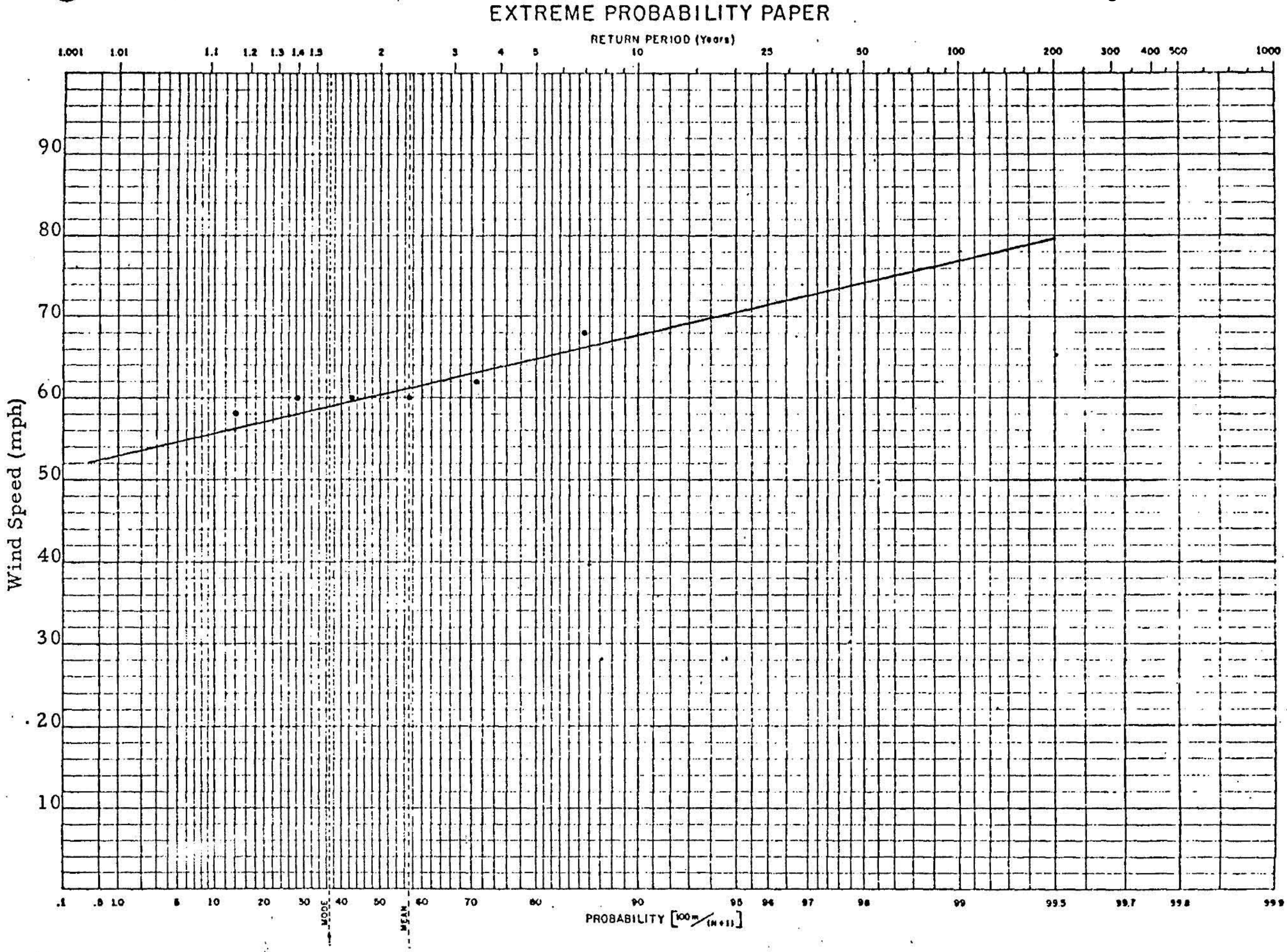

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Fig. 7. WIND SPEED PROBABILITIES FOR DANIELS HARBOUR, NFLD.

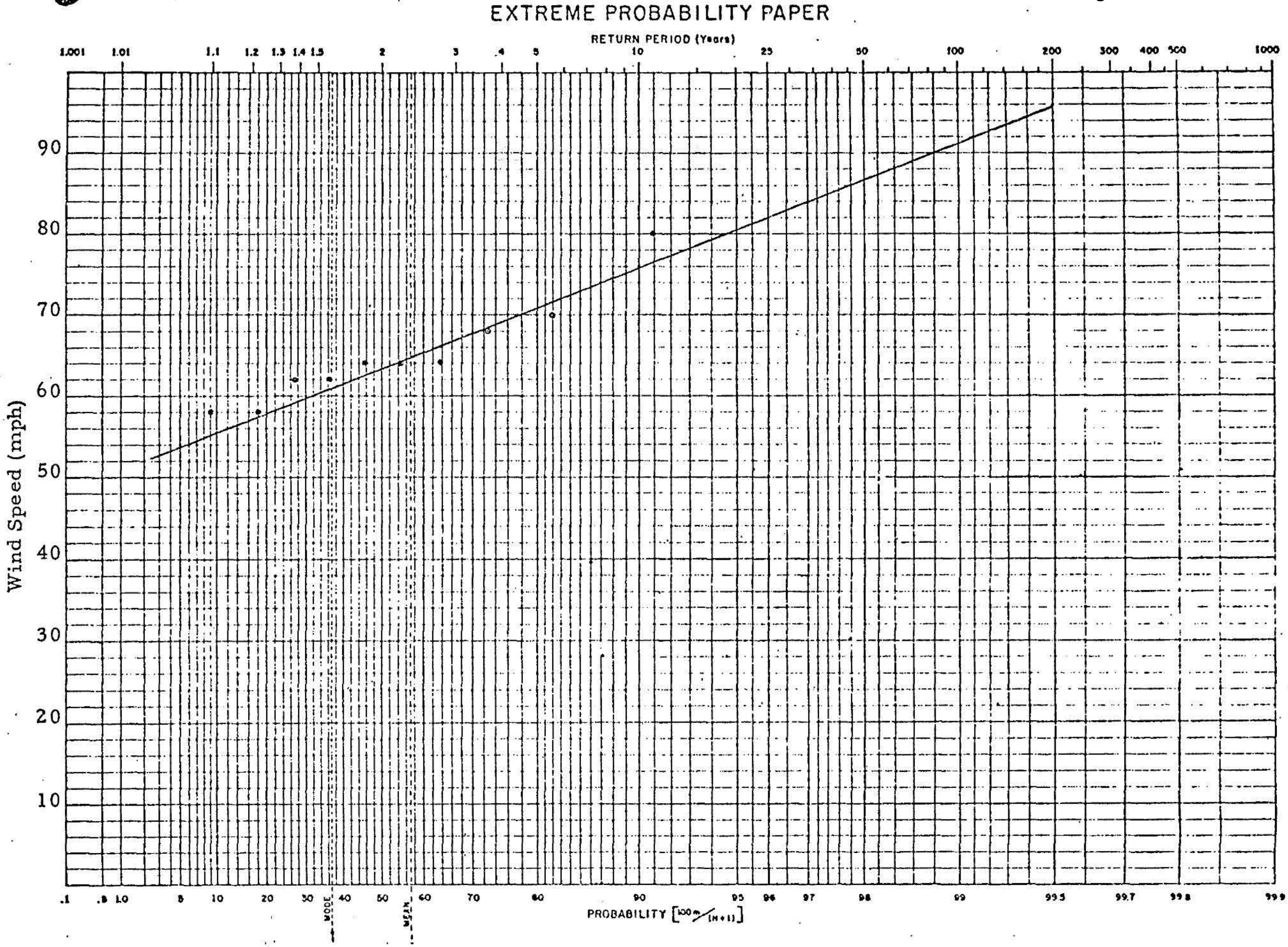

Fig. 8. WIND SPEED PROBABILITIES FOR BATTLE HARBOUR, LABRADOR

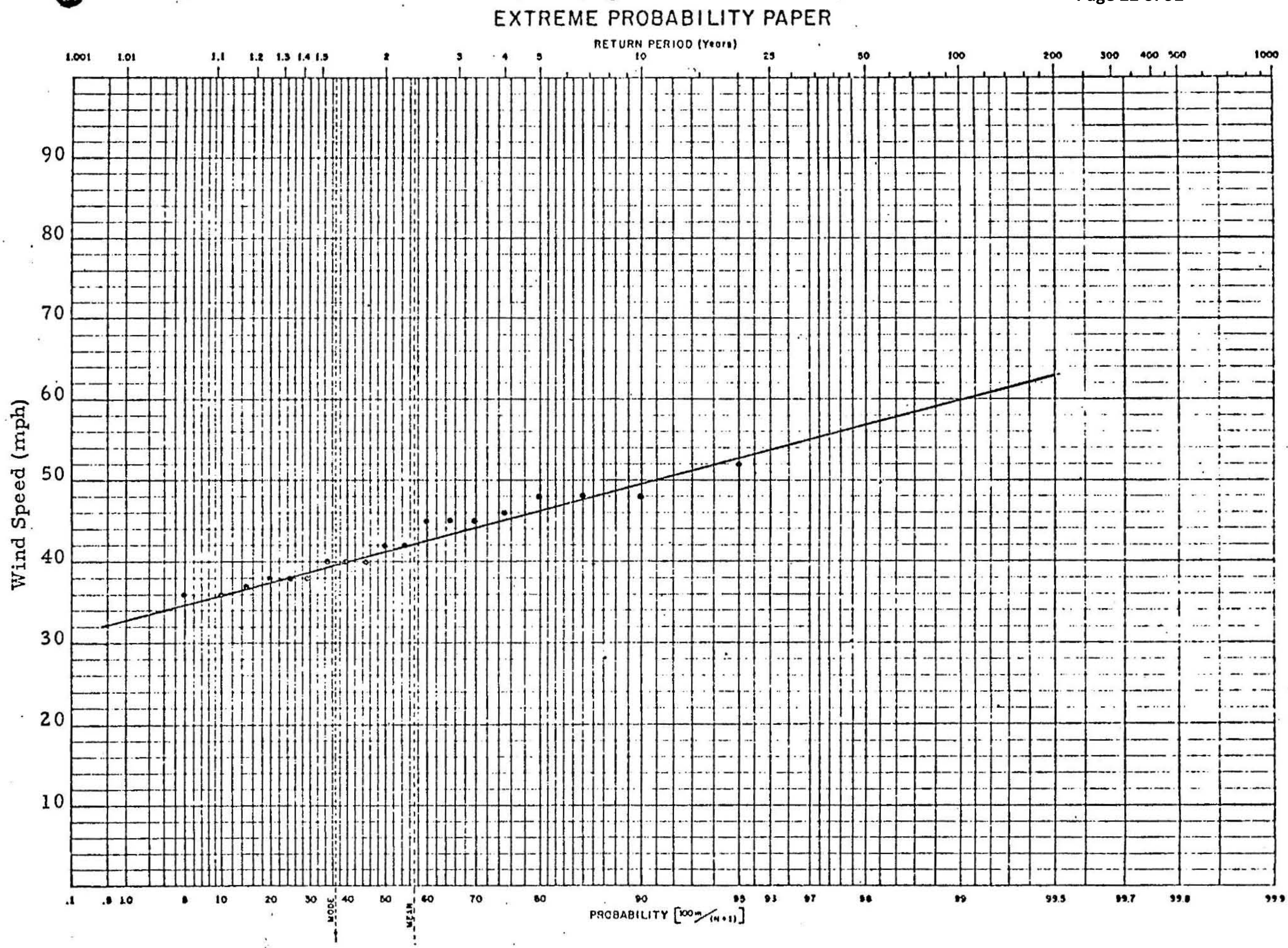

Fig. 9. WIND SPEED PROBABILITIES FOR GOOSE BAY, LABRADOR

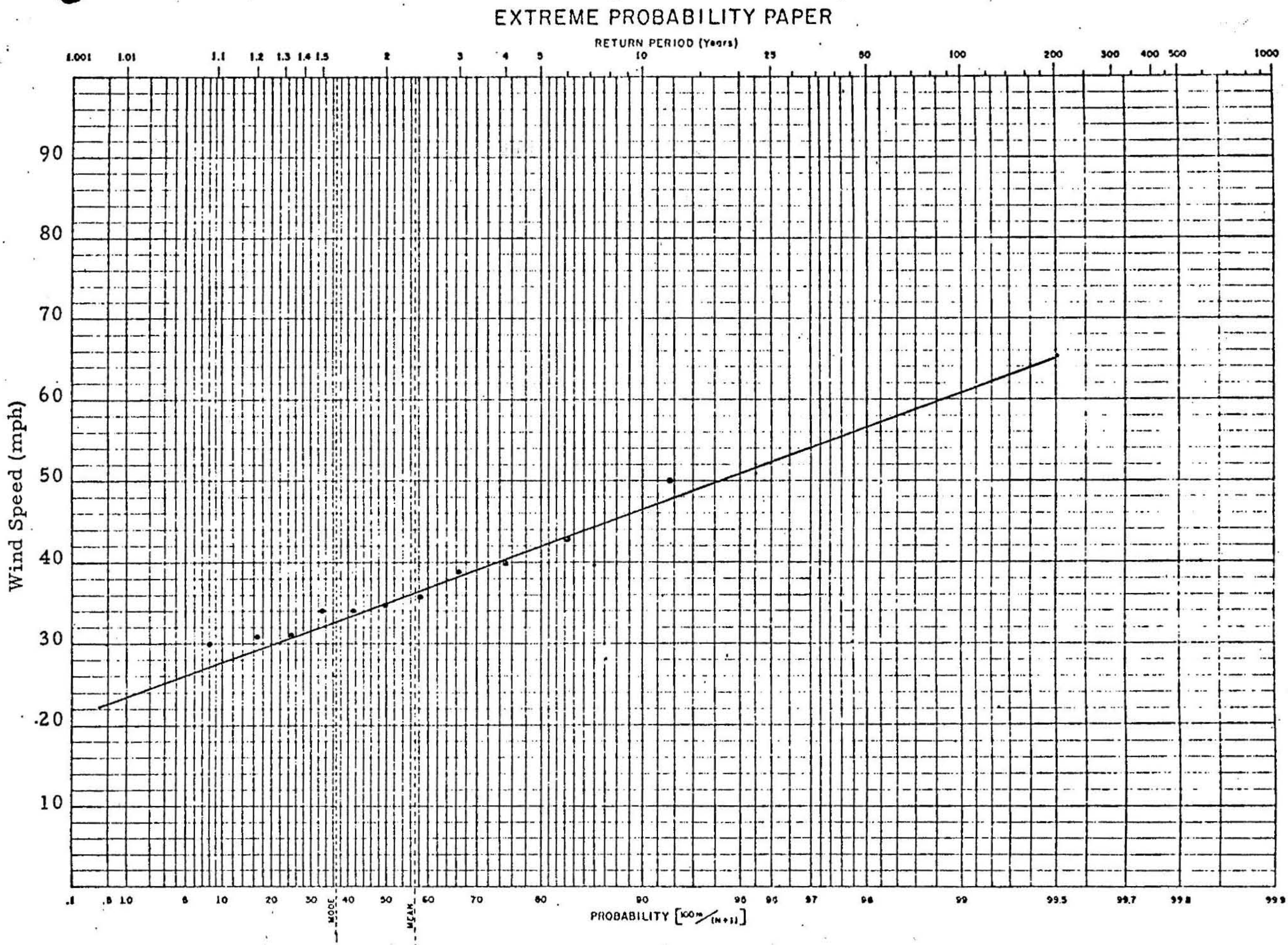

Fig. 10. WIND SPEED PROBABILITIES FOR WABUSH,LAKE, LABRADOR

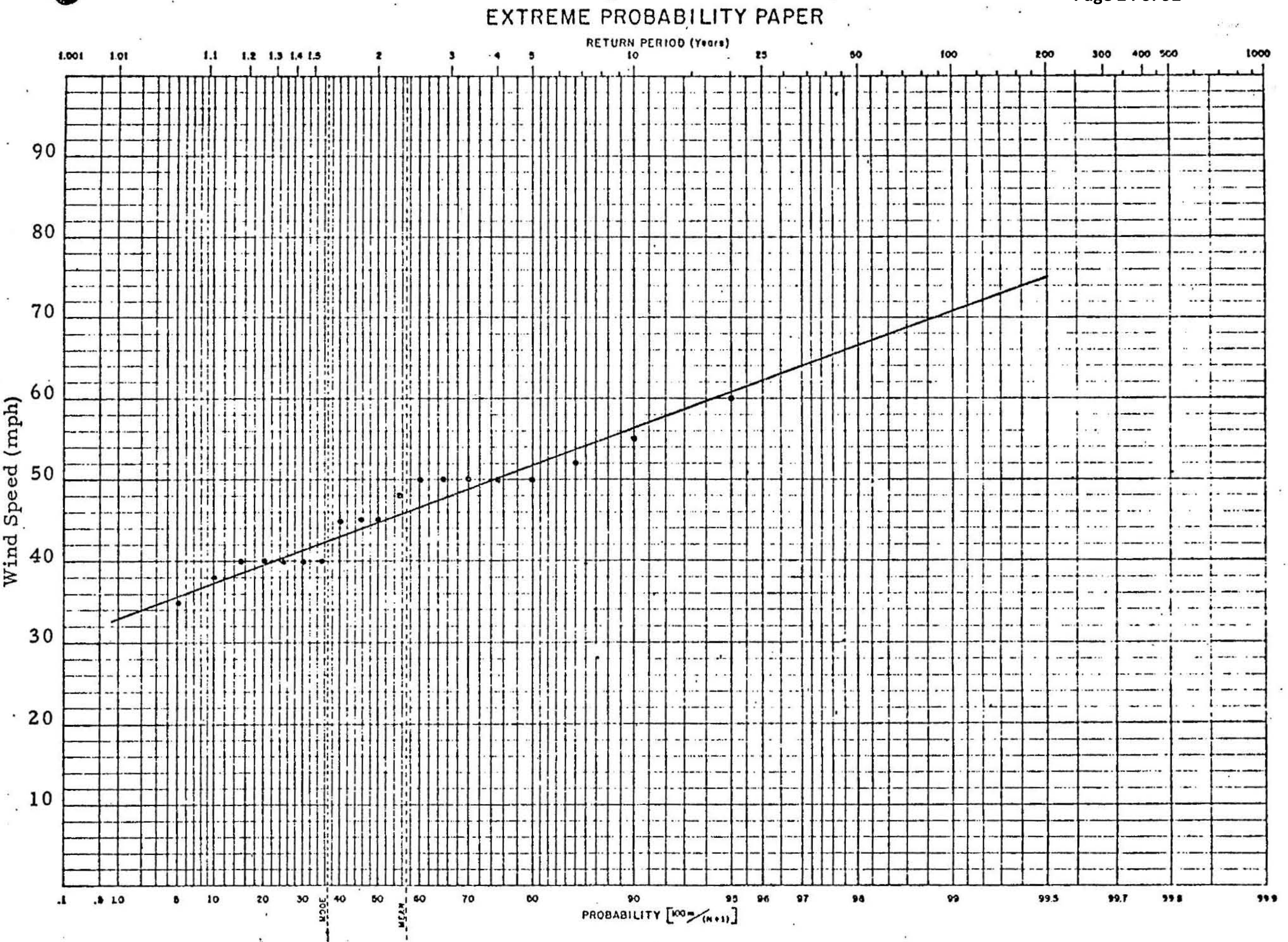

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Fig. 11. WIND SPEED PROBABILITIES FOR SCHEFFERVILLE (KNOB LAKE), QUEBEC

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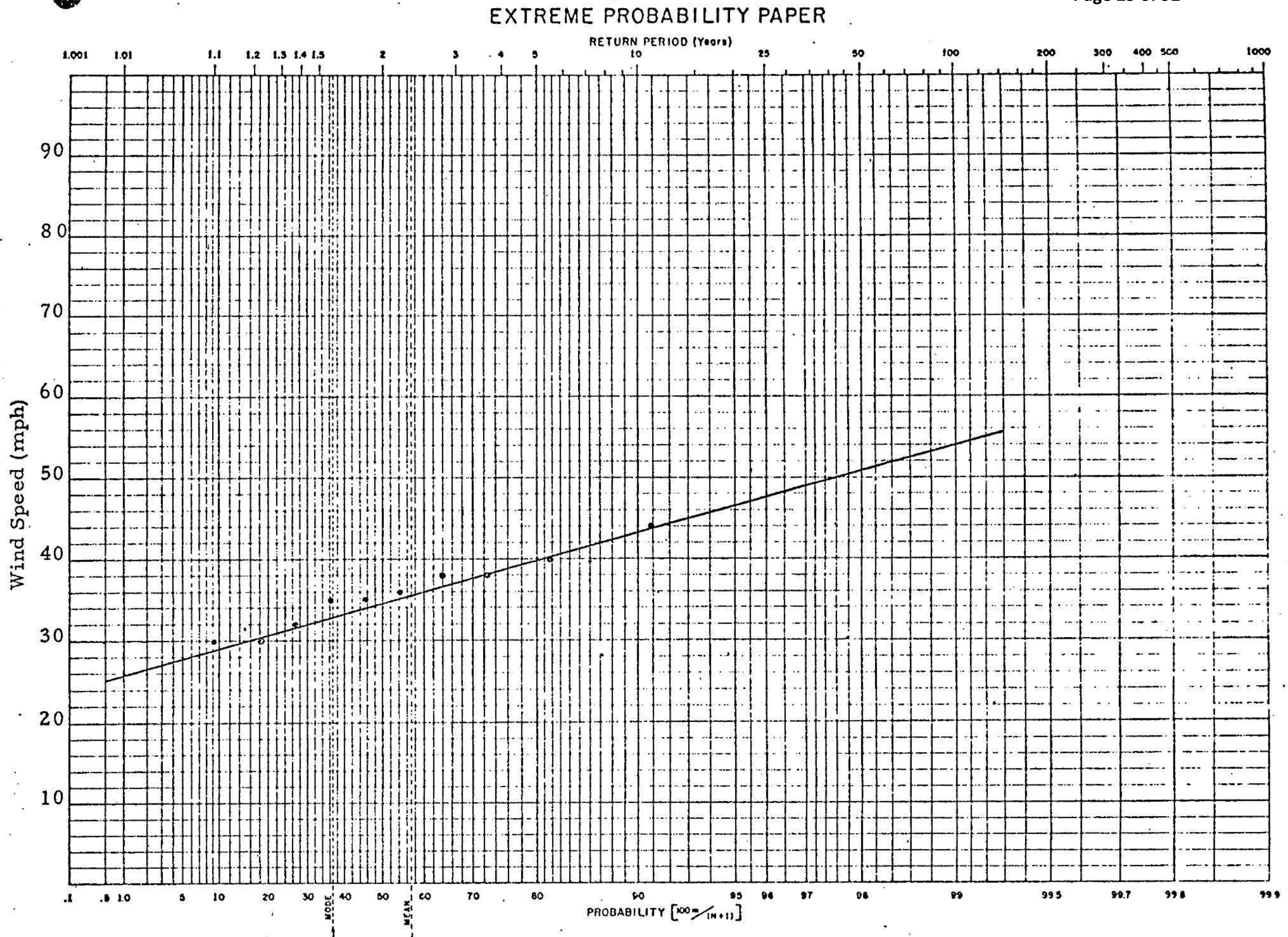

Fig. 12. WIND SPEED PROBABILITIES FOR LAKE EON, QUEBEC

Table I

RETURN PERIOD VALUES OF MAXIMUM WIND SPEEDS

Stations	Elevation (ft)	Anemometer Height (ft)	Return Periods 10-yr (mph)	25-yr (mph)	50-yr (mph)	75-yr (mph)	Maximum Hourly Wind (mph)		Maximum Gust (mph)
St. John's-Torbay	463	45	80	90	98	102	W	88	120
Gander	496	62	63	69	73	76	E	65	100
Argentia	45		66	75	80	84	N	70	85
Buchans	920		62	67	70	72	SSE	65	
Deer Lake	57		46	50	53	55	SW	45	
Stephenville	44		54	61	67	70	NNW	61	71
Daniels Harbour	64		68	71	74	76	SSW	68	
Battle Harbour	55	35	76	82	87	89	NNE	80	
Goose Bay	144	62	50	54	57	59	SW	52	80
Wabush Lake	1807	33	47	53	57	59	W	50	65
Schefferville, P.Q.	1681	35	56	62	66	69	S	60	92
Lake Eon, P.Q.	1840	20	43	48	51	53	SSE	44	55
Bonavista	82	17					WSW	70	88
St. Andrews	35	30					SE	90	
St. Anthony	57	40					NNW	70	85
Twillingate	16	65					SSW	72	

Table II

THE DISTRIBUTION OF EXTREME WINDS BY MONTH

Station	Month J	F	M	A	M	J	J	A	S	O	N	D
St. John's-Torbay	5	3	1	1	1		1		1		3	3
Gander	6	7	1						1	2		6
Argentia	9			1					2		1	2
Buchans	4	2	2	1					2		1	2
Deer Lake	1	1	1	1	1					1	1	
Stephenville	7	6	4	1					1	1	1	3
Daniels Harbour	1	1	1						1	1	1	
Battle Harbour	3	4	1						1		2	2
Goose Bay	5	2	1	2	1				5	2	2	4
Wabush Lake	3	1				1		1	1	1	3	
Schefferville (Knob Lake), P. Q.	3	2	3	1		1			3	2	6	4
Lake Eon, P. Q.	1	3	2	3	1	1					2	1

Table III

THE DISTRIBUTION OF EXTREME WINDS BY DIRECTION

Station	Direction															
	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
St. John's-Torbay	2	1							1	1	4	3	6	2	2	
Gander			1		2	1		2	4	1	1	3	5	1		3
Argentia	2						4	2	3	3	2	2	1			
Buchans			1					1			1	1	2	2	6	
Deerlake			1			1					2	2	1			
Stephenville	1		1	2	11	4					1	1	5			
Daniels Harbour								1		2	1	2				
Battle Harbour	6	1												1	1	5
Goose Bay	2	1	3					1			2	1	8	2	1	4
Wabush Lake			2								1		6	2		1
Schefferville (Knob Lake), P. Q.	1					1		1	1	1	4	8	8	2	3	2
Lake Eon, P. Q.	1	1			1		1	2	3	2				1	2	

The fastest hourly-wind values used in Table I represent only samples of the wind conditions for each hour. The sample covers a period of from one to ten consecutive minutes just before the hour, depending upon the observer and the recording or indicating equipment used for the observation. Such a sample ignores the winds that occur during at least 5/6 of each hour and possibly as much as 59/60 of each hour. Thus there is a consistent tendency for hourly-wind values to understate the fastest wind occurrence during the hour. The degree of underestimate is directly proportional to the variability of the wind speed.

The relation of wind gusts to prevailing wind speeds has been the subject of several studies. Values generally used vary from 1.1 to 1.4 times the prevailing wind speed. In actuality, the magnitude of wind gusts is dependent on several factors such as type of terrain, stability of the air mass involved, local obstructions which result in eddies, height above terrain, and speed of the gradient wind over the area. In station records, the maximum wind speed and maximum peak gusts frequently did not occur in the same storm and are related only in a qualitative sense. Maximum wind speed and peak gust values shown in Table I demonstrate this with factors ranging from 1.16 at Stephenville to 1.54 at Goose Bay. For most of the terrain and exposures represented by the proposed transmission line routes in Newfoundland and Labrador, factors of 1.3 to 1.4 should be appropriate.

Wind records from the Sunnyside Station were available for 17 months between October 1971 and May 1973. Wind speeds in excess of 50 mph were recorded on two occasions. A deep low pressure center moving northeastward across the Avalon Peninsula on February 1, 1973, resulted in seven hours of wind speeds above 50 mph at Sunnyside. Since the wind records there are apparently taken from wind-run charts which record the number of miles of air passing the site each hour, the reported values are actually hourly average wind speeds. The highest one-hour value reported was 58 mph. If we use the formula developed by Boyd (1965b) for computing probable maximum gusts ($G = 5.8 + 1.29\ V$), we have gusts to 81 mph which seem quite realistic. Considering the number of storm centers which pass over the area, it is likely that winds of this magnitude occur each year someplace along the Newfoundland portion of the proposed route.

Both numerical and descriptive information acquired during our visit to Newfoundland and Labrador and information provided by the Newfoundland and Labrador Power Commission were studied for insight into wind patterns and extreme values along the proposed transmission line routes.

C. Application of Wind Data to the Proposed Routes

The proposed routes from Gull Island to Soldiers Pond traverse a variety of terrain and the exposure to the full impact of the strong winds which occasionally sweep over the region is equally varied. The portion of the route from near Soldiers Pond to west of Clarenville lies nearly equidistant from St. John's and Argentia; however, the 45-ft elevation at Argentia resulted in that station being sheltered by the high terrain to the east, northeast, and northwest. The exposure at St. John's-Torbay airport is more representative of this portion of the route. From west of Clarenville northwestward to Grand Falls, the most representative station is Gander International Airport. The average elevation of the route as it crosses the open, rolling wasteland is slightly higher and more exposed than Gander. West of Gander Lake, the elevations above 800 ft will be vulnerable to wind speeds higher than those expected at Gander.

West from Grand Falls, the Buchans' wind will be reasonably representative of the area between Grand Falls and Buchans; however, north from Buchans to east of Sandy Lake, northwest winds will be channeled southward along the west side of the Topsails and across Hinds Lake. This will result in a significant increase in wind speeds through that area. From east of Sandy Lake to the north end of the Humber Valley, the route crosses through low sheltered terrain. Wind speeds will be relatively low and best represented by Deer Lake winds. As the route climbs from the valley floor to the top of the ridge of the Long Range Mountains, wind speeds will be moderated by surrounding higher terrain and forest cover. Along the top of the ridge of the mountains, the proposed line will be exposed to maximum winds from the west through north and east to south. Along the west coastal plain, the possible routes will be exposed to winds from the southwest through northwest except in the canyon east of the highlands near Barr'd Harbour. Northwest through north-northeast winds will be funneled through that canyon as will southwest winds. This funneling will increase the wind speeds significantly. The flat coastal plain at the north end of the peninsula is well exposed to extreme winds from the west, north, and east and will be best represented by the Battle Harbour winds.

West of the Strait of Belle Isle, Battle Harbour winds will be representative for about 30 miles inland except for the protected elevations below 500 ft near the bay. The balance of the route to Gull Lake will be through an area of moderate wind speeds somewhat greater than the Goose Bay records because of greater exposure, but less than Battle Harbour values. A 20-mile stretch across the Kenamee River Valley and the 45 miles along the Churchill River from Gull Lake to Goose Bay will be quite protected from extreme winds. Goose Bay winds will be used as the basis for these areas. Channeling along the Churchill River will increase wind speeds in that area slightly.

VI. TEMPERATURES

As would be expected in a maritime climate, the temperatures in Newfoundland are cool in the summer compared with inland areas at the same latitude. Temperatures at the coastal stations rarely exceed 85°F and even the stations in the interior parts of the island seldom reach 90°F. Even in Labrador, the summer temperatures do not reach the extremes which might be expected. As far inland as Schefferville and Wabush Lake, the maximum temperatures recorded are below 90°F. The record 100°F temperature at Goose Bay is a record which has stood for many years. During the 1957-1966 10-year period for which such data are readily available, the maximum temperature recorded was 92°F and only eight hours exceeded the 90°F mark. Record high temperatures for several stations in the Newfoundland-Labrador area are listed in Table IV.

In the late winter, most of Newfoundland is surrounded by pack ice and the moderating effect of open water is attenuated although not completely lost. The St. John's-Torbay area rarely has temperatures below -5°F in contrast to mainland temperatures below -30°F. Even the northwestern sections of the island have significantly colder temperatures than the eastern or southern sections which are closer to open water. During January and February, thawing of hard ice or deep snow occurs only during brief periods with less than 10 percent of the total hours exceeding 32°F in the northwestern sections of the island and less than five percent in Labrador.

As Table IV shows, Schefferville, Wabush Lake, and Lake Eon all have record low temperatures below -50°F. Extreme low temperatures are very terrain dependent and vary considerably over short distances. The lowest values normally occur in terrain depressions where cold air becomes trapped. It is unlikely that temperatures below -40° to -45°F will occur at conductor level. The extremes would have been measured near the four-foot level and the temperature should have increased with height under the inversion conditions that probably existed to reach these record low temperatures.

The extreme low temperatures (-40°F or lower) rarely occur with strong winds. Strong winds result in mixing of the air and only moderately low temperatures (above -40°F) occur. A McGill University study for the U. S. Army (Rayner, 1960) showed that for nine years of hourly reports of winds and temperatures during the months of December, January, February, and March at Goose Bay, 11.4 percent of the reports reflected wind speeds above 18 mph; but none of these occurred with temperatures below -30°F. During the nine years, wind speeds greater than 24 mph

Table IV

EXTREME TEMPERATURES

Station	Record High Temperatures (°F)	Record Low Temperatures (°F)	Months With Mean Temperature Below 32° F
St. John's-Torbay	87°	-13°	Dec. through Mar.
Gander	96°	-17°	Dec. through Mar.
Grand Falls	94°	-28°	Dec. through Mar.
Buchans	94°	-28°	Dec. through Apr.
Deer Lake	96°	-35°	Dec. through Mar.
Daniels Harbour	84°	-39°	Dec. through Mar.
St. Anthony	88°	-26°	Nov. through Apr.
Battle Harbour	87°	-30°	Nov. through Apr.
Cartwright	97°	-36°	Nov. through Apr.
Goose Bay	100°	-38°	Nov. through Apr.
Lake Eon	84°	-51°	Nov. through Apr.
Wabush Lake	88°	-52°	Oct. through Apr.
Schefferville	89°	-59°	Oct. through Apr.

with temperatures below -15°F occurred for a total of 66 hours. Of those 66 hours, 15 were below -20°F and only one below -25°F. During the same nine-year period, temperatures below -15°F were reported for a total of 1918 hours, below -20°F for 751 hours, and below -25°F for 220 hours.

In summary, the lowest winter temperatures along the proposed route will occur in protected valleys in inland Labrador, probably in the Kenamee River Valley south of Goose Bay. Extremes in this area will be near -50°F. In the more exposed areas of Labrador and northwestern Newfoundland, extreme low temperatures near -40°F should be expected. East of Grand Falls, minimum temperatures below -25°F are unlikely.

Maximum temperatures near 100°F are possible along most of the route, but temperatures above 95°F will be rare.

35°C

VII. CONDUCTOR ICING

A. General Considerations

The basic theory of ice growth and the accretion of snow on cylinders (transmission lines) was developed by Langmuir and Blodgett (1945) from studies conducted on Mt. Washington. Additional studies of icing of transmission lines during various meteorological conditions have been conducted by the Japanese (Kuroiwa, 1965), the Germans (Leibfried and Mors, 1964), the Americans (Leavengood and Smith, 1968), the Russians (Bourgsdorf et al., 1968), and the Canadians (McKay and Thompson, 1969; and Young and Schell, 1971).

Basically four types of frozen deposits will accumulate on transmission lines. These are classified according to the density of the ice accreted as: glaze, soft rime, hard rime, and wet snow.

1. Glaze: density 0.9 to 0.92 g/cm^3 is equal to pure ice. Glaze grows in a clear smooth structure with no air bubbles. For this case, the freezing rate of the droplets is less than the impingement rate, which allows part of the drop to splash or flow around the conductor before freezing. Glaze is usually formed from freezing precipitation, rain or drizzle, or from clouds with large liquid water content and large drop sizes.

2. Soft rime and hoar frost: density less than 0.6 g/cm^3. Soft rime grows in a granular structure that is white and opaque with many air bubbles within the structure. It grows in a triangular or pennant shape pointed into the wind. The granular structure results from the rate of freezing of the individual droplets, each droplet freezing completely before another one impinges on the surface. Ice that forms with less than 0.3 g/cm^3 density, in a feathery structure, during a period of little or no wind is usually called hoar frost.

3. Hard rime: density 0.6 to 0.9 g/cm^3. Hard rime grows in a layered structure with glaze ice alternating with ice containing air bubbles. The freezing rate of the droplets is equal to the impingement rate of the droplets.

4. Wet snow: density 0.4 to 0.7 g/cm^3. According to Kuroiwa (1965), the conditions necessary for the accretion of wet snow are air temperatures between -2 to +1 °C, and wind speeds less than 5 mph. At temperatures colder than about -2 °C, snow particles are usually "dry" in that no liquid water drops are attached to them, and they will not stick to the surface. More recent experiences and studies

Indicate that wet snow will accumulate on conductors with wind speeds up to 45 mph and temperatures up to near +2 °C. Cases of cohesive wet snow building up to a symmetrical thickness of 4 inches radially have been documented (Higuchi, 1973).

In Newfoundland and Labrador, all four types of ice accretion will occur. In Newfoundland, with the exception of the high terrain in the northwest, glaze will be the dominating type; while in Labrador, rime will dominate in most areas.

B. Icing Data Analysis

1. Glaze

In Newfoundland and the coastal area of Labrador, glaze icing results from three basic mechanisms or combinations thereof. The first and most obvious is freezing rain from warm frontal overrunning. This is the classical picture of warm air from the south or southeast riding up over cold air on the surface. As the rain from the warm air falls into the subfreezing air, it freezes on the surface of anything it contacts. In a no-wind condition, the precipitation impacts on the top surface and freezes there or partially runs off and freezes on the sides or forms icicles. The maximum total accretion rate of ice under this circumstance is equal to the rainfall rate. When horizontal air motion (wind) is introduced into the problem, drops will impact on vertical surfaces or sides of objects as well and freeze there and/or run down and form icicles. The higher the wind speed, the faster the horizontal component of the raindrop's motion and the greater the number of drops impacting in a given time period will be. For a known drop size distribution, rainfall rate can be expressed in terms of liquid water content per unit volume of the air above the surface. As wind speed increases, more unit volumes will be intercepted by the object (conductor) in a given time period and more liquid water will impact on the object. As a result, the ice accretion rate on a conductor during high wind speeds can be many times the rainfall rate.

Rainfall rate and wind speed are, then, two important factors in determining ice accretion rates. A third important factor is temperature. The colder the temperature, the faster the freezing and less "splash-off" will occur. This type of situation may cover a large area or aonly a narrow band and the location of any particular occurrence will be nearly random, depending on the location and orientation of the frontal system.

Closely allied to the warm frontal freezing rain is freezing rain resulting from rain falling into cold air trapped in a valley or depression. Strong winds would not be expected to occur in this type of situation and accretion rates are accordingly slower.

The second mechanism resulting in glaze icing was described in detail by C. H. Sutherland in a study titled "Freezing Precipitation at Gander Airport." This situation results from a well developed onshore circulation of 10 to 20 mph with surface temperatures over the land slightly below freezing. As the saturated air moves inland, it is lifted slightly resulting in cooling and some mechanical mixing over the rough terrain. In the process, the cloud droplets grow sufficiently to precipitate as drizzle which freezes on contact with any cold surface. Even with the moderate winds involved, accumulations from freezing drizzle of this type normally will not result in damaging weights.

The third glaze mechanism is really a special form of in-cloud icing and is most apt to occur along a ridge line at right angles to moderate or strong winds. When cloud droplets impact on structures protruding into the cloud and freeze on contact, normally some form of rime ice will result. However, when there are sufficient updrafts in the cloud to support large droplets or drops and these impact on the object with sufficient frequency to accumulate and spread before they freeze, glaze ice will result. This is likely to happen occasionally on the ridge of the Long Range Mountains on the northwest peninsula of Newfoundland. Heavy clouds being swept in from the water by strong winds will be lifted over the barrier of mountains. Considerable turbulence and mixing will occur in the lifting process resulting in droplet growth and setting the stage for heavy ice accumulations.

In this study, records of freezing precipitation at 12 stations in Newfoundland, Labrador, and eastern Quebec were reviewed. Monthly and annual frequencies of freezing rain and freezing drizzle were derived and tabulated as shown for St. John's-Torbay in Tables V and VI. Care must be exercised in the use of this frequency data because of the extreme variations from year to year. While this information is of interest and valuable in a qualitative sense, there is no direct way to convert these data into ice accumulations. It is possible to make estimations based on hours of freezing rain plus equivalent hours of freezing drizzle (Boyd, 1970); however, in the past these estimates have served to represent regional averages and been well below local accumulations in major storms.

In an attempt to quantify glaze accumulation which can be expected to occur for various return periods, the MRI icing model computer program was used to determine the maximum ice accumulation which should have resulted from the worst storm each year for seven stations along the proposed route. These values were then arranged in rank order and plotted on extreme probability graphs in the manner described for the extreme wind speeds in Section V, B. The resulting

Table V

MONTHLY FREQUENCY OF FREEZING PRECIPITATION
ST. JOHN'S-TORBAY

Month	Years of Record (yr)	Total Hours Freezing Precip. (hr)	Total Hours Freezing Rain (hr)	Total Hours Freezing Drizzle (hr)	Percent Freezing Rain (%)	Avg. Hr/Yr Freezing Precip. (hr)	Avg. Storm Duration (hr)	Avg. Wind Speed (mph)	Max. Wind Speed (mph)
Jan.	19	536	141	395	26.3	28.2	3.5	17	40
Feb.	19	692	190	502	27.5	36.4	4.4	17	40
Mar.	19	745	256	489	34.4	39.2	4.0	17	40
Apr.	19	585	180	405	30.8	30.8	4.4	16	40
May	19	85	17	68	20.0	4.5	2.9	16	37
June	19	0	0	0	-	0	-	-	-
July	19	0	0	0	-	0	-	-	-
Aug.	19	0	0	0	-	0	-	-	-
Sept.	19	0	0	0	-	0	-	-	-
Oct.	19	1	1	0	100.0	0	1.0	25	25
Nov.	19	27	20	7	74.1	1.4	3.9	19	25
Dec.	19	228	61	167	26.8	12.0	2.7	20	50
Total/ %/Avg.	19	2899	866	2033	29.9	152.6	3.8	17	50

Table VI

YEARLY FREQUENCY OF FREEZING PRECIPITATION
ST JOHN'S-TORBAY

Year	Total Hours Freezing Precipitation (hr)	Total Hours Freezing Rain (hr)	Total Hours Freezing Drizzle (hr)
1953	110	29	81
1954	117	53	64
1955	189	28	161
1956	119	36	83
1957	178	51	127
1958	207	71	136
1959	158	76	82
1960	207	39	168
1961	141	38	103
1962	132	59	73
1963	174	33	141
1964	131	58	73
1965	224	56	168
1966	169	36	133
1967	164	39	125
1968	116	38	78
1969	121	35	86
1970	166	54	112
1971	76	37	39
Total	2899	866	2033
Average	152.6	45.6	107.0

graphs are shown in Figs. 13 through 19. The 10-, 25-, 50-, and 75-year return periods were extracted from these graphs and appear in Table VII.

The yearly maximum values for Buchans include two years which seem disproportionately large for the rest of the values. These values were for 1959 and 1962. On 17 and 18 November 1959, Buchans reported 31 hours of freezing rain with an average wind speed of 18 mph. The maximum hourly wind speed reported was 25 mph. The temperature during the period ranged from 22°F to 29°F. From the MRI model, this should have resulted in 3.7 inches of glaze. On 24 March 1962, Buchans reported nine hours of freezing rain with an average wind speed of 45 mph! The maximum hourly wind speed reported during that period was 50 mph. Temperatures were 31 to 32°F with the exception of one report of 33°F. In this case, the MRI model predicted 3.0 inches of glaze. Neither of these periods are reflected in lists of damage reports which we have seen. This, of course, does not mean that damage did not occur. These two points on the graph, Fig. 15, would seemingly fit better near the 30- and 100-year points. The solid line represents the computed curve using all twelve points. The dashed line fits the ten lower values and has nearly the same slope as the other stations. The values in Table VII are based on the dashed line and consider the 1962 and 1959 points as 30- and 100-year storms, respectively.

2. Rime

In Newfoundland, rime icing has not caused as much damage to transmission lines as glaze icing; however, this does not indicate that rime does not occur in Newfoundland. In fact the higher terrain in Newfoundland is particularly susceptible to this type of icing. Low clouds and strong winds are frequently reported at most of the airport stations. These clouds are often low enough that hilltops are in the clouds. Table VIII shows that at the St. John's-Torbay airport ceilings were at or below 400 ft 26 percent of the time during the January through March period, and at or below 100 ft 11 percent of the time during that period. These data are based on the 10-year period 1957 through 1966. Gander records show that these conditions exist with a slightly lower frequency at that location. Inland in Labrador, Goose Bay and Schefferville have low ceilings much less frequently. Data in this format is not readily available for the smaller stations along the proposed route; however, Table IX presents the frequency of low ceilings with low temperatures and strong winds for those stations. The ≥20 mph columns in Table IX give a subjective feel for the frequency of riming conditions on nearby terrain 300 and 800 ft above the stations listed. Rime will form at speeds less than 20 mph, but accretion rates are low. The low

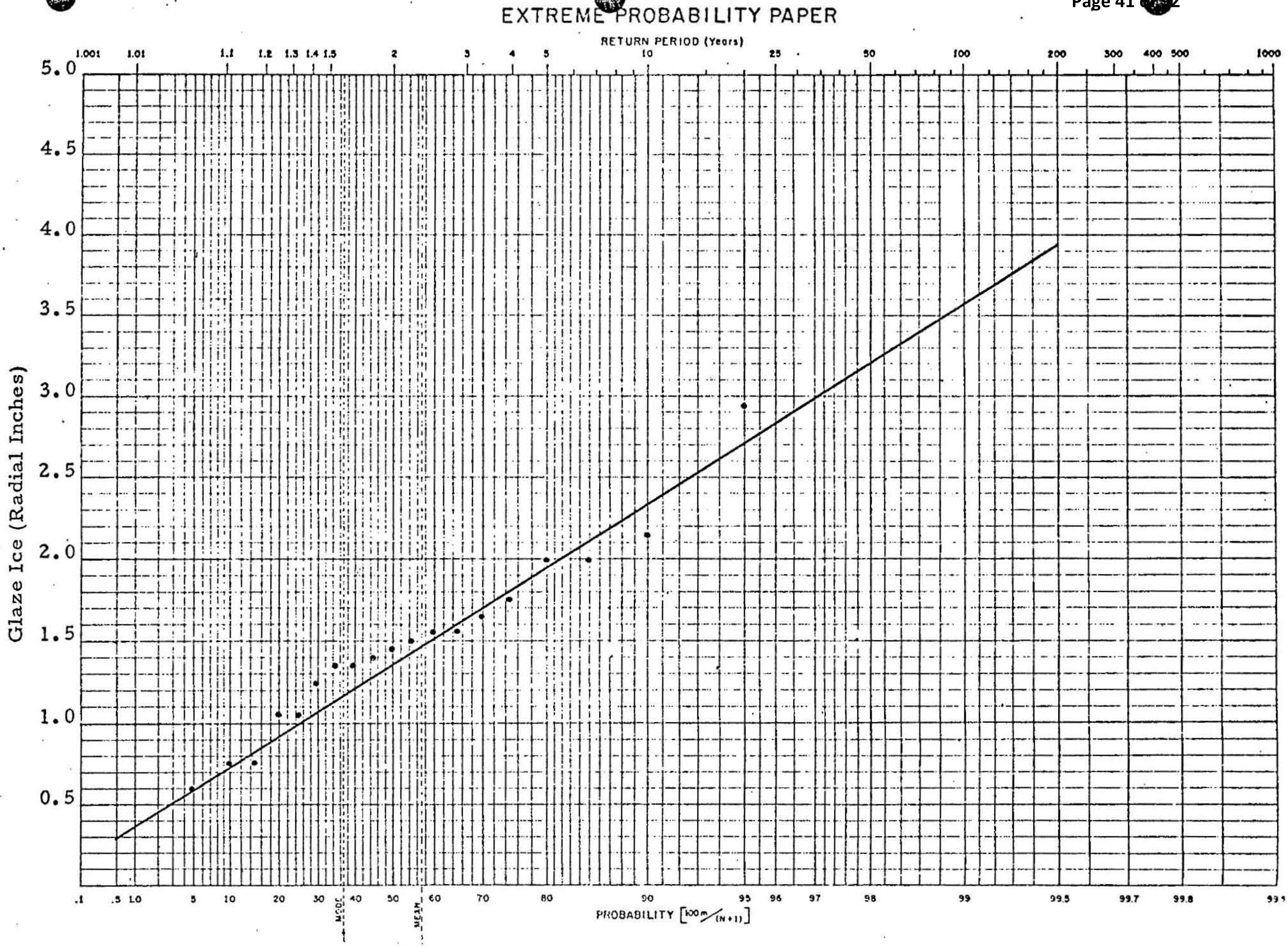

Fig. 13. GLAZE ICE PROBABILITIES FOR ST. JOHN'S-TORBAY

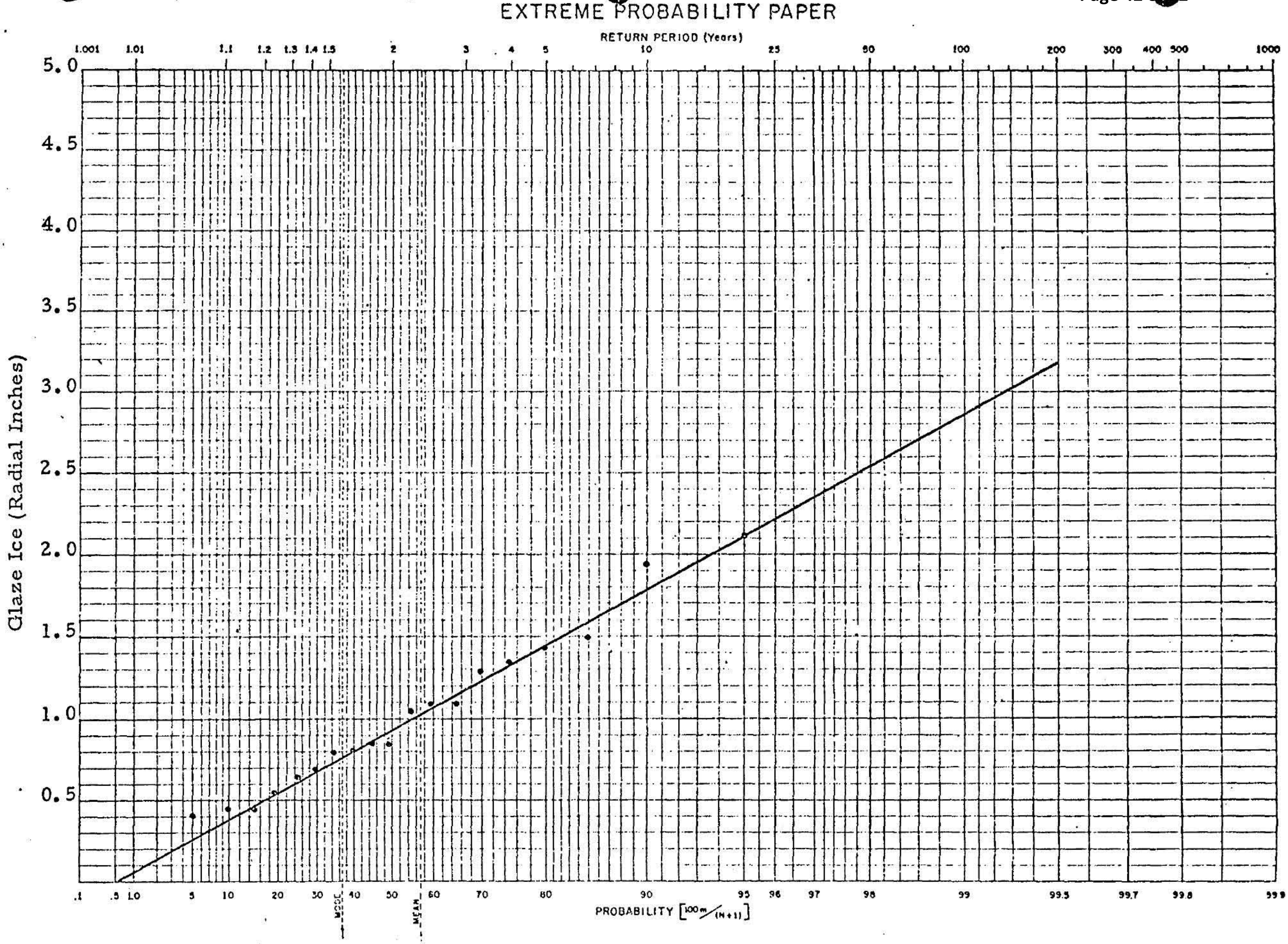

Fig. 14. GLAZE ICE PROBABILITIES FOR GANDER

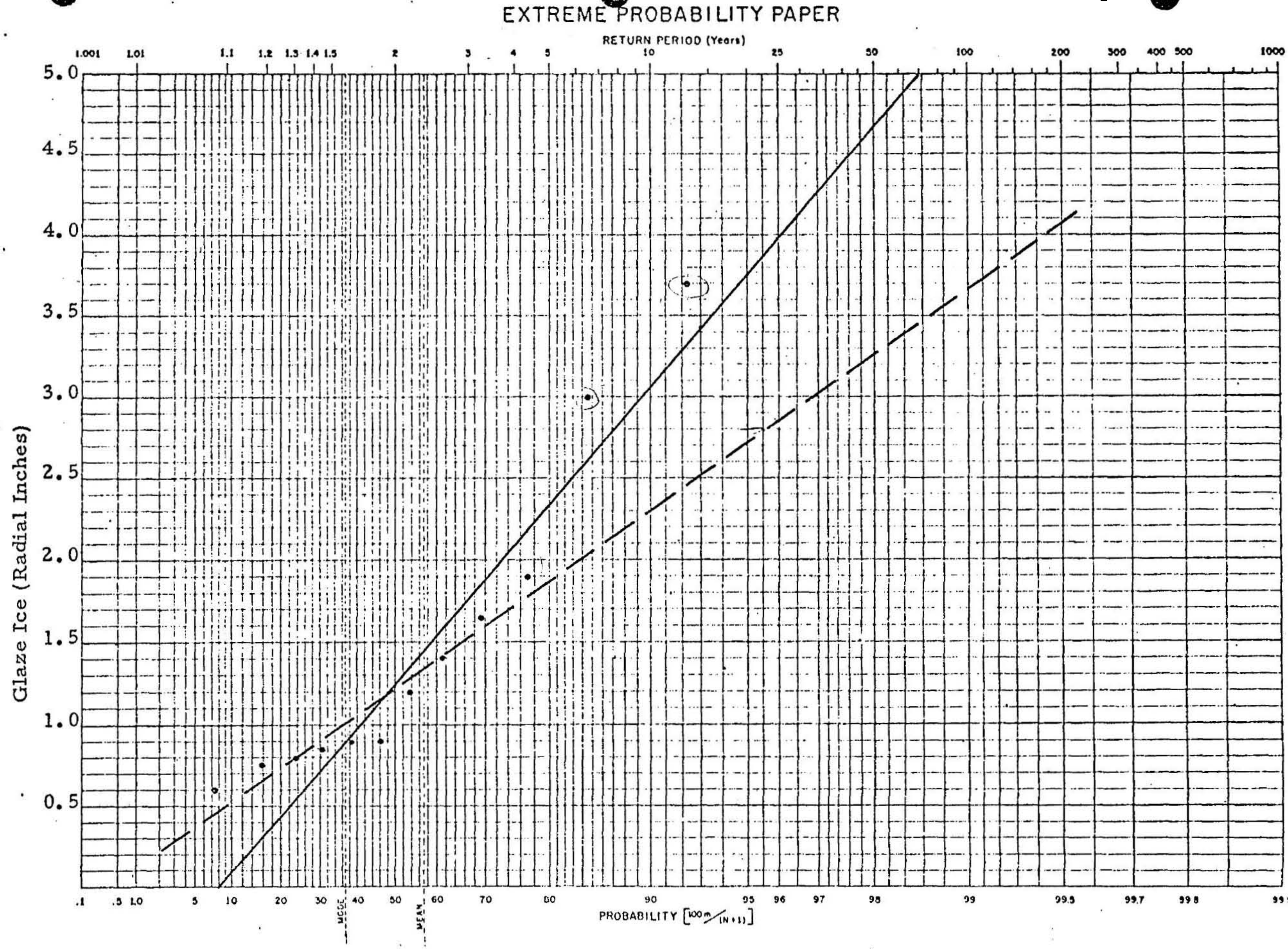

Fig. 15. GLAZE ICE PROBABILITIES FOR BUCHANS

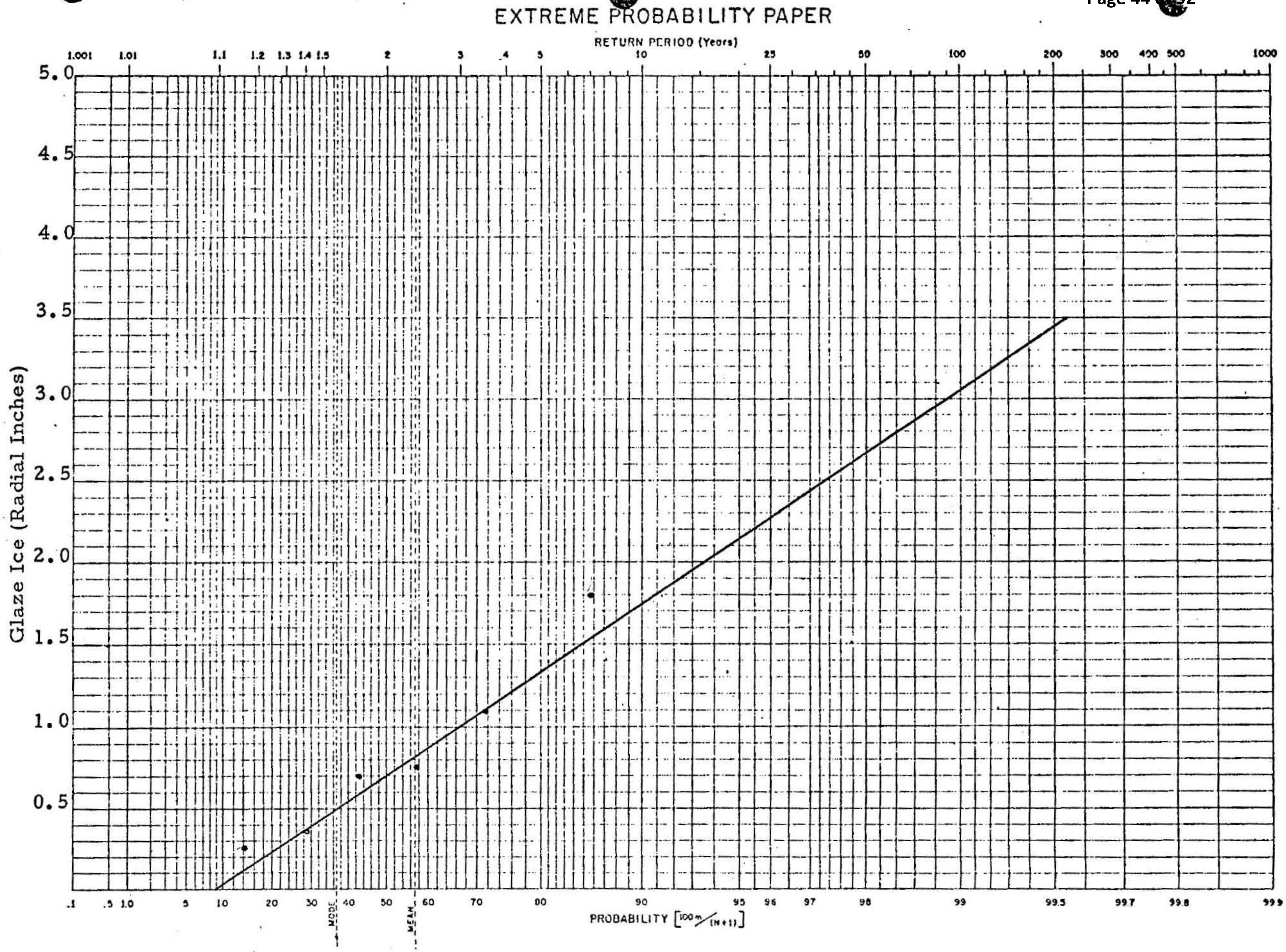

Fig. 16. GLAZE ICE PROBABILITIES FOR DEER LAKE

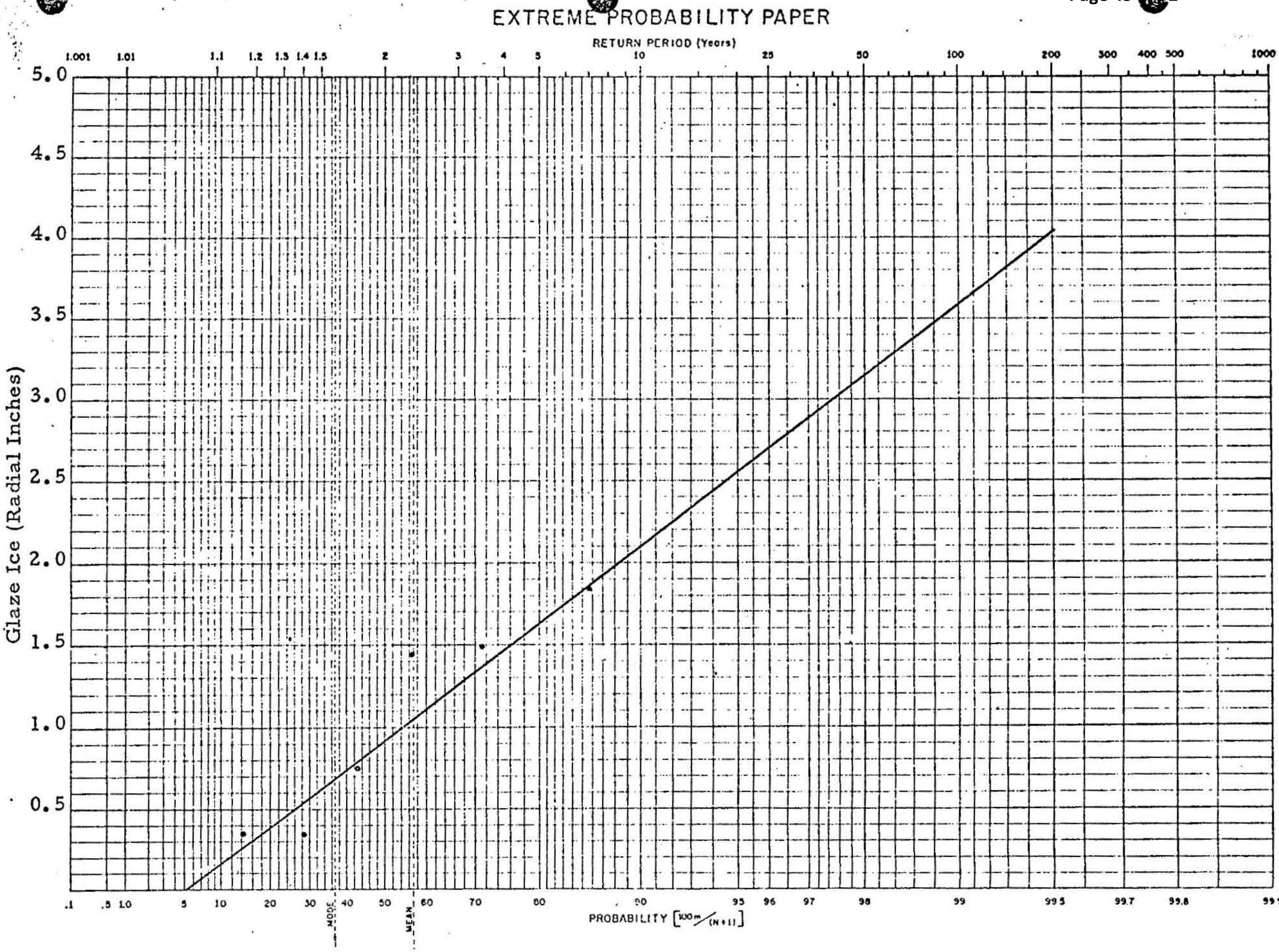

Fig. 17. GLAZE ICE PROBABILITIES FOR DANIELS HARBOUR

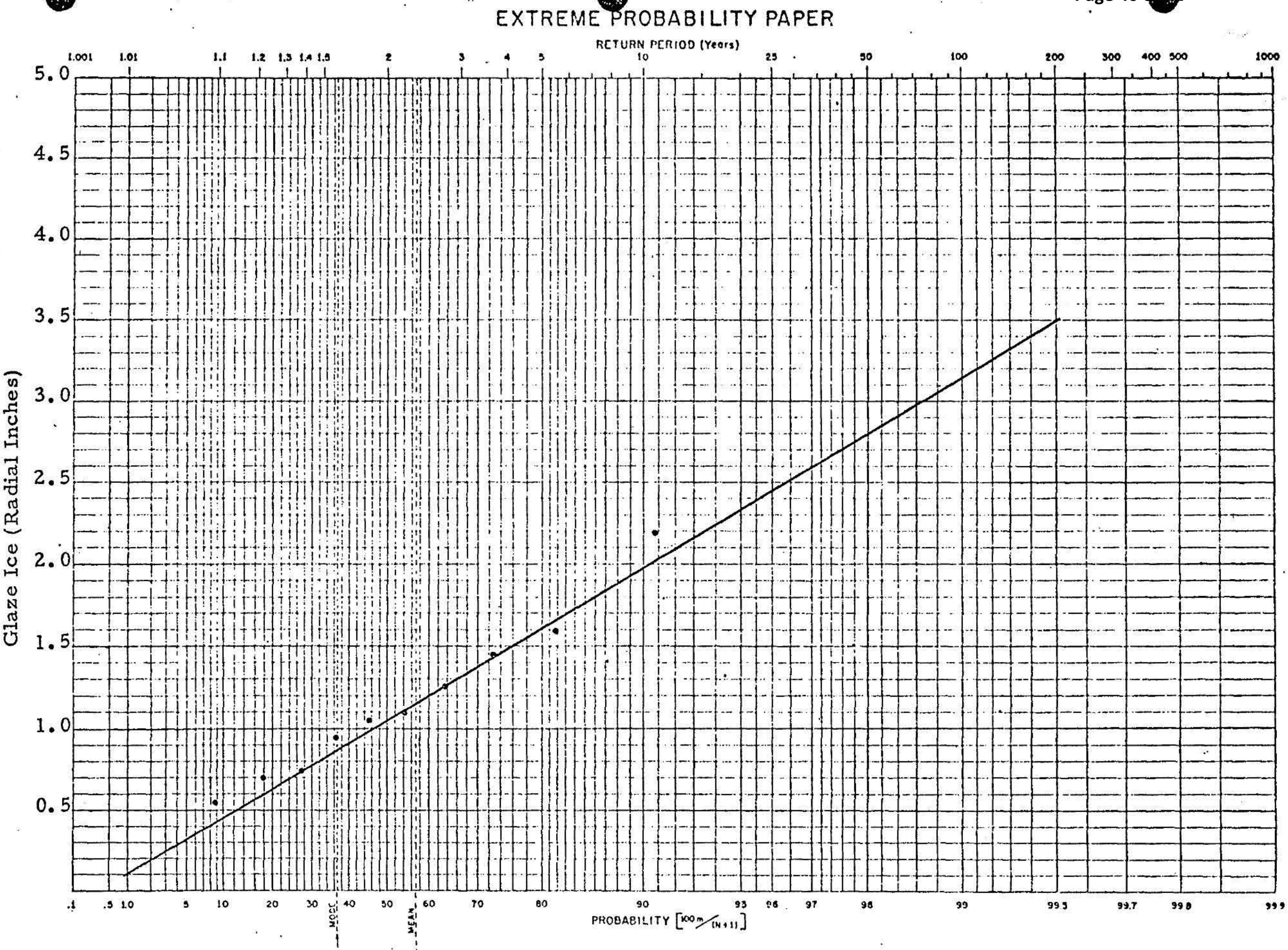

Fig. 18. GLAZE ICE PROBABILITIES FOR BATTLE HARBOUR

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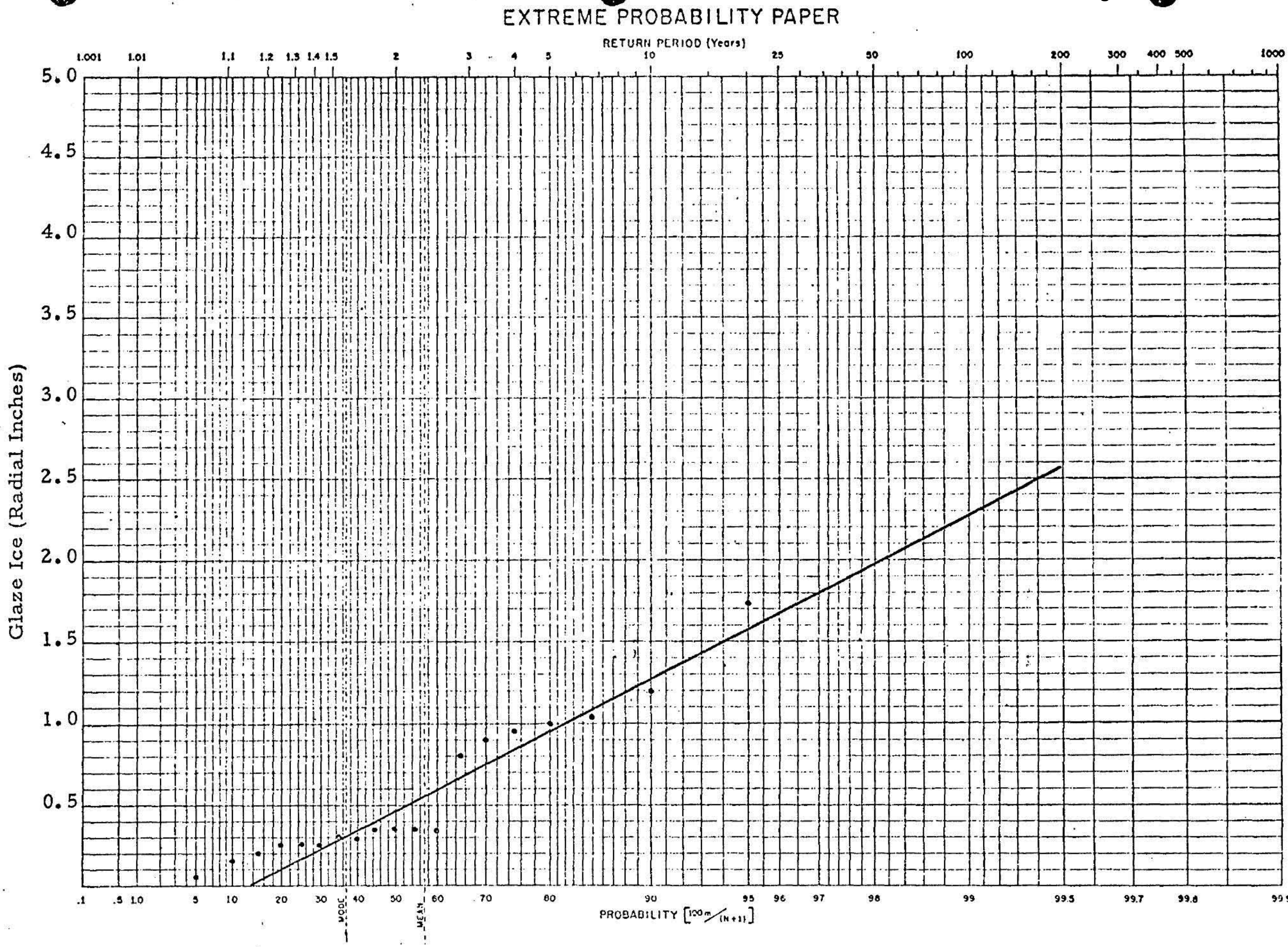

Fig. 19. GLAZE ICE PROBABILITIES FOR GOOSE BAY

Table VII

RETURN PERIOD VALUES FOR GLAZE ICING

Station	Elevation (ft)	Return Period Glaze Amounts (radial in.) 10-yr	25-yr	50-yr	75-yr
St. John's-Torbay	463	2.3	2.8	3.2	3.4
Gander	496	1.8	2.2	2.6	2.7
Buchans*	920	2.3	2.8	3.2	3.5
Deer Lake	57	1.8	2.3	2.7	2.9
Daniels Harbour	64	2.1	2.7	3.2	3.4
Battle Harbour	55	2.0	2.5	2.8	3.0
Goose Bay	144	1.3	1.7	2.0	2.2

*Values based on modified curve Fig. 15.

Table VIII

PERCENTAGE FREQUENCY OF LOW CEILINGS 1957-1966

Station	Month	Cloud Ceiling Frequency in % of Time		
		≤900 ft	≤400 ft	≤100 ft
St. John's-Torbay	Jan.	37%	21%	8%
	Feb.	42	27	11
	Mar.	45	30	14
	Jan-Mar.	41	26	11
Gander	Jan.	34	17	4
	Feb.	36	19	6
	Mar.	39	22	7
	Jan. -Mar.	36	19	6
Goose Bay	Jan.	15	5	1
	Feb.	12	3	1
	Mar.	16	5	1
	Jan. -Mar.	14	4	1
Schefferville	Jan.	22	6	2
	Feb.	18	5	<1
	Mar.	16	5	<1
	Jan. -Mar.	19	5	1

Table IX

FREQUENCY OF SELECTED WIND SPEEDS WITH LOW CEILINGS AND ICING-RANGE TEMPERATURES

Station	Period of Record (yr)	Average Hours per Year: Ceiling ≤300 ft, Temperature 25-35°F, Wind Speed (mph)			Ceiling ≤800 ft, Temperature 27-37°F, Wind Speed (mph)		
		≥200	≥15	≥10	≥20	≥15	≥10
St. John's Torbay	19	207	380	506	460	796	1029
Gander	19	78	153	266	275	505	763
Buchans	12	14	21	37	91	148	257
Deer Lake	6	3	4	5	11	70	117
Daniels Harbour	6	12	19	26	99	143	198
Battle Harbour	12	53	77	156	276	362	509
Argentia	17	28	51	78	115	226	359
Stephenville	19	6	10	17	16	36	77

frequencies at Deer Lake and Stephenville reflect the sheltering at those stations and may not be representative of the surrounding terrain.

The growth of rime ice which will occur in a particular situation can be estimated using an empirical model developed from the combination of the Japanese data as given by Kuroiwa and the Mt. McDill, California, data of Leavengood and Smith (Fig. 20). Dashed lines show extrapolations where no experimental data were available. The shaded area represents regions of uncertainty where the ice accumulations will be affected by the dynamic pressure of the wind, turbulence of the wind, motion of the conductors, and the critical diameter. Figure 20 was derived under the assumptions that the liquid water content in the cloud was 0.5 g/m^3 and the cloud drops were about 15 microns in diameter.

In this study, the maximum rime ice which would have been formed in one icing period was determined for each year of record at appropriate heights above stations along the proposed routes. The heights were chosen to represent surrounding terrain. These maximum yearly values were then arranged in rank order and plotted on extreme probability graphs as described in Section V, B. The resulting graphs are shown in Figs. 21 through 28. The 10-, 25-, 50-, and 75-years return periods were extracted from these graphs and appear in Table X.

The values 1000 ft above Daniels Harbour do not necessarily represent expected conditions on the ridge of the Long Range Mountains. Storms coming in from the east would not have resulted in sufficient wind speeds or low enough ceilings at Daniels Harbour to have been considered.

The period of record at Buchans was 1953 through 1964. If the records had extended through 1967, the January 1967 riming storm west of there would have undoubtedly raised the predicted values somewhat.

3. Wet Snow

In Newfoundland, wet snow has not been reported as a serious problem to transmission lines. Table XI shows the hours of moderate or heavy snow which have occurred at selected stations with temperatures above 28°F. The last column reflects the number of cases during the periods of record that moderate or heavy snow has occurred with air temperatures above 28°F and lasted for more than six hours. Only Battle Harbour averages one such case per year. In actuality, the records show that the 15 cases occurred in seven of the 12 years. Table XII presents more detail about the Battle Harbour storms. It is important to note that nearly all of the cases occurred with strong winds.

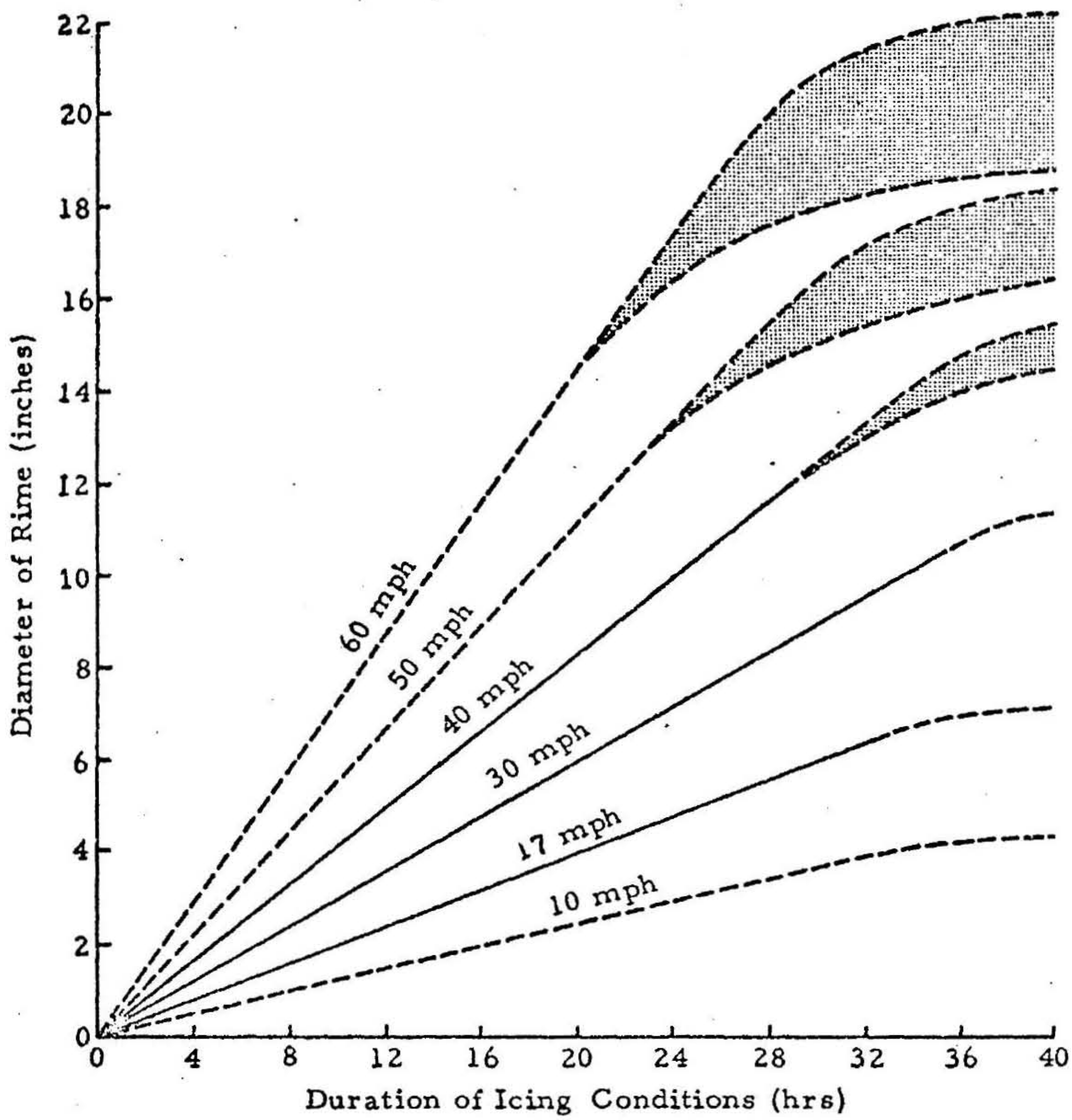

Fig. 20. GROWTH OF RIME FOR VARIOUS WIND SPEEDS AND DURATIONS OF ICING CONDITIONS

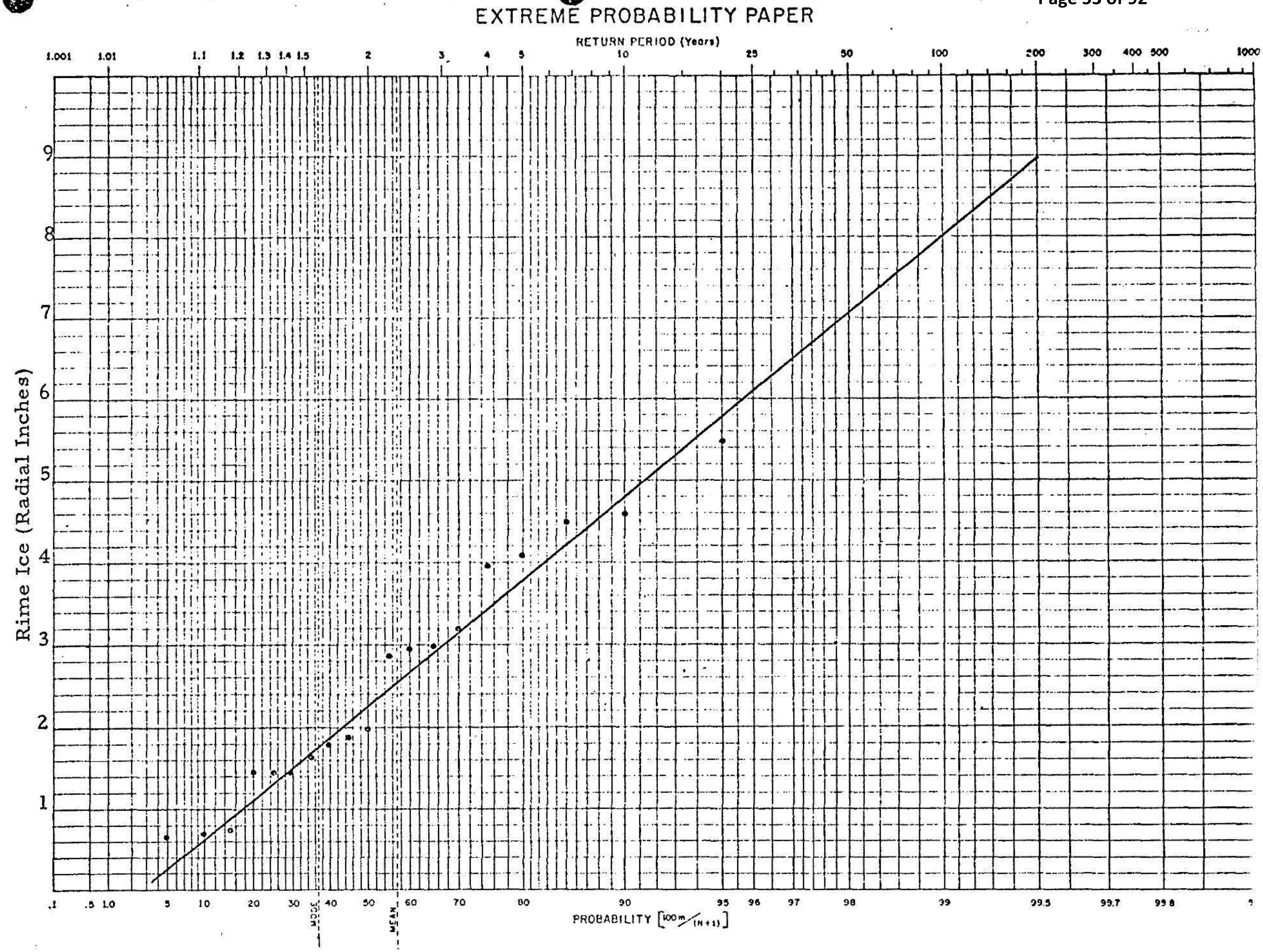

Fig. 21. RIME ICE PROBABILITIES 300 FT ABOVE ST. JOHNS-TORBAY

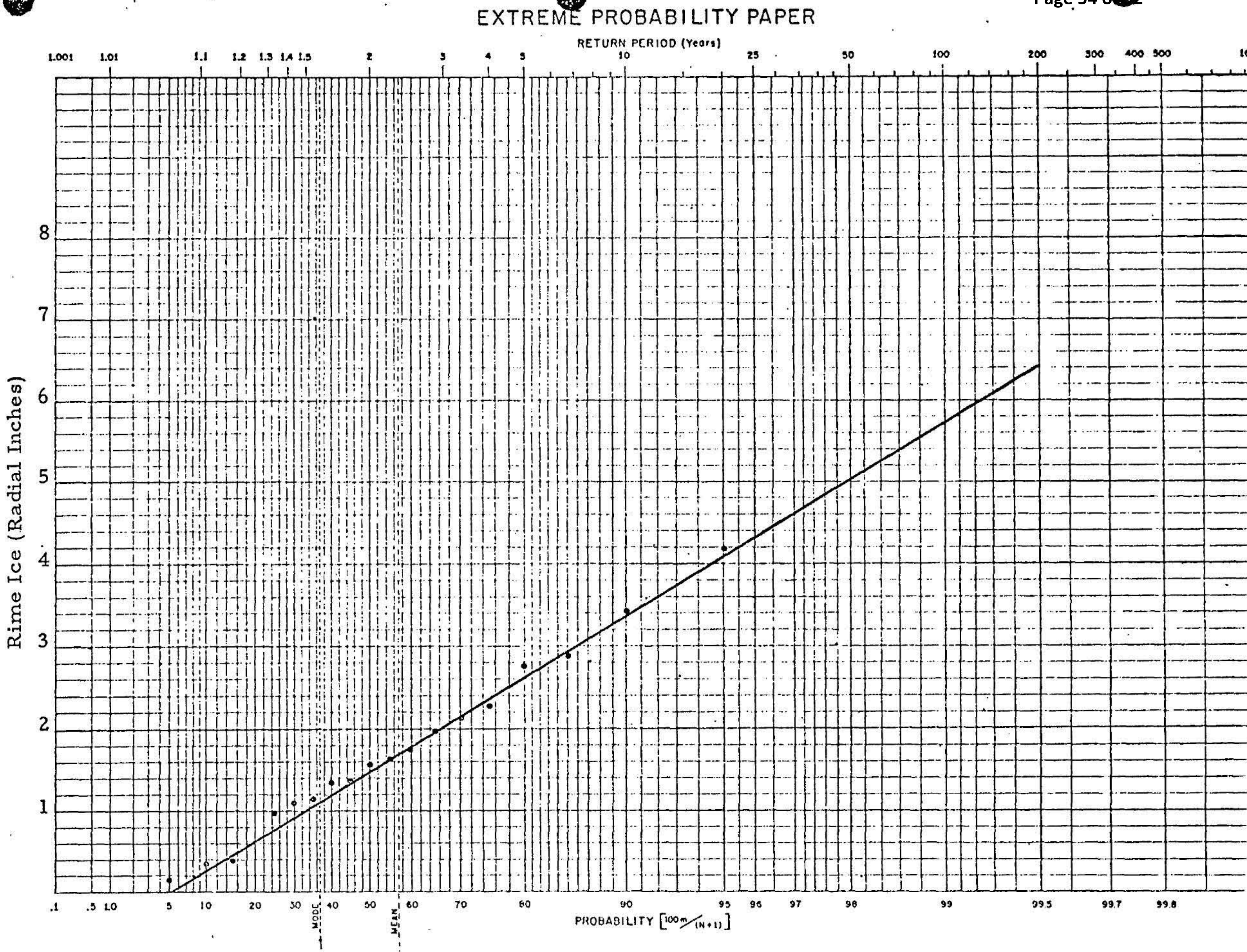

Fig. 22. RIME ICE PROBABILITIES 300 FT ABOVE GANDER

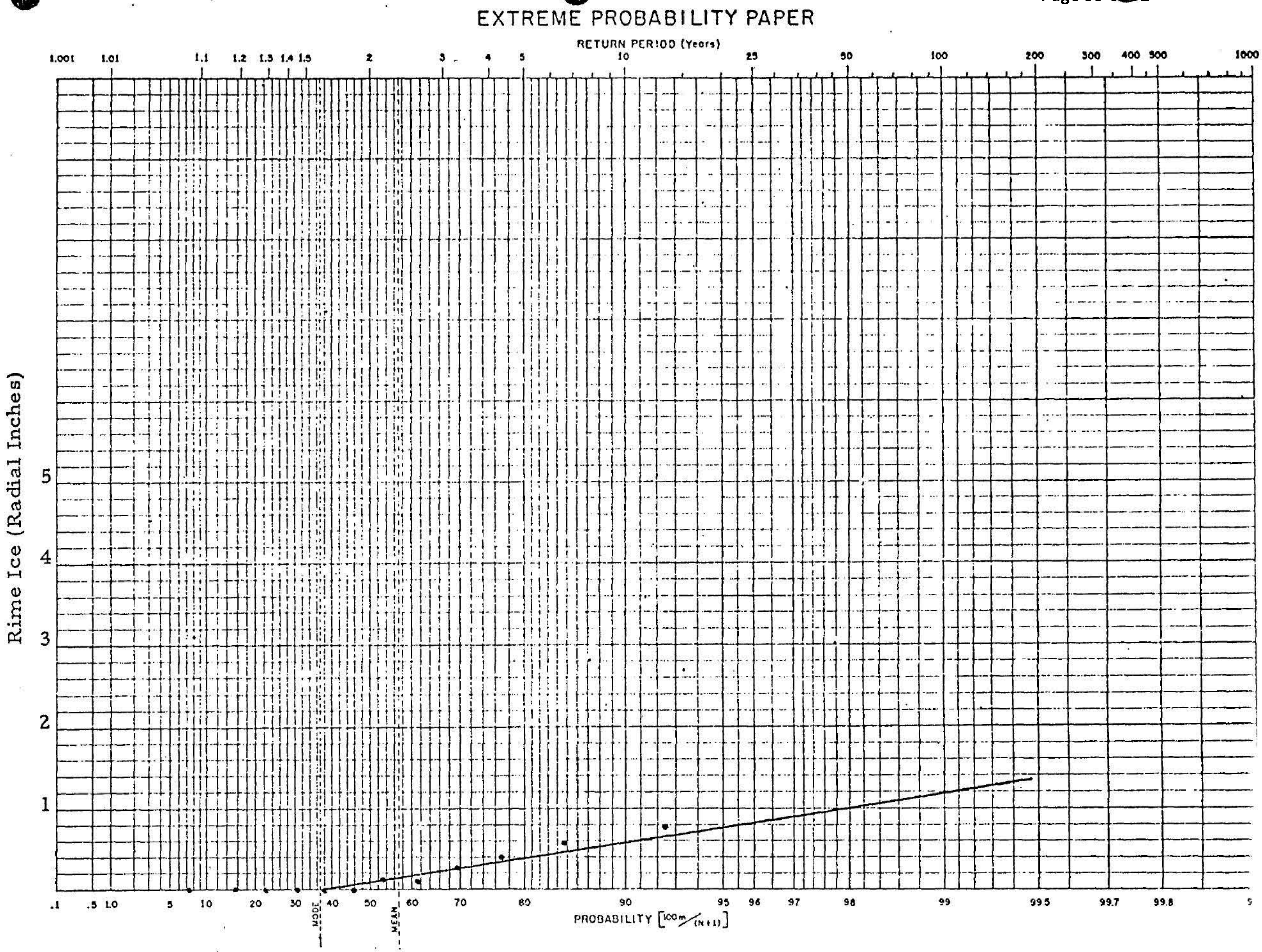

Fig. 23. RIME ICE PROBABILITIES 300 FT ABOVE BUCHANS

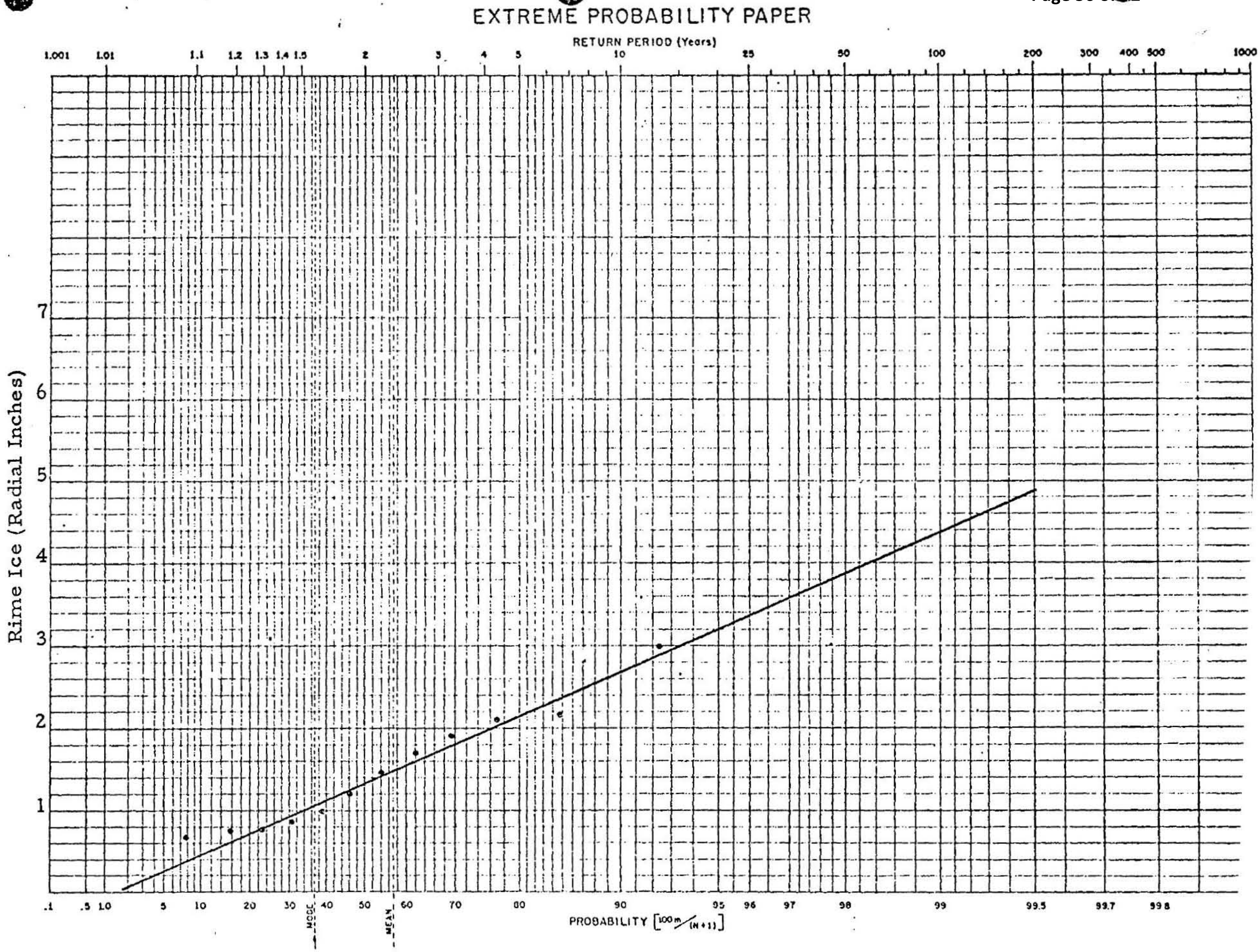

Fig. 24. RIME ICE PROBABILITIES 800 FT ABOVE BUCHANS

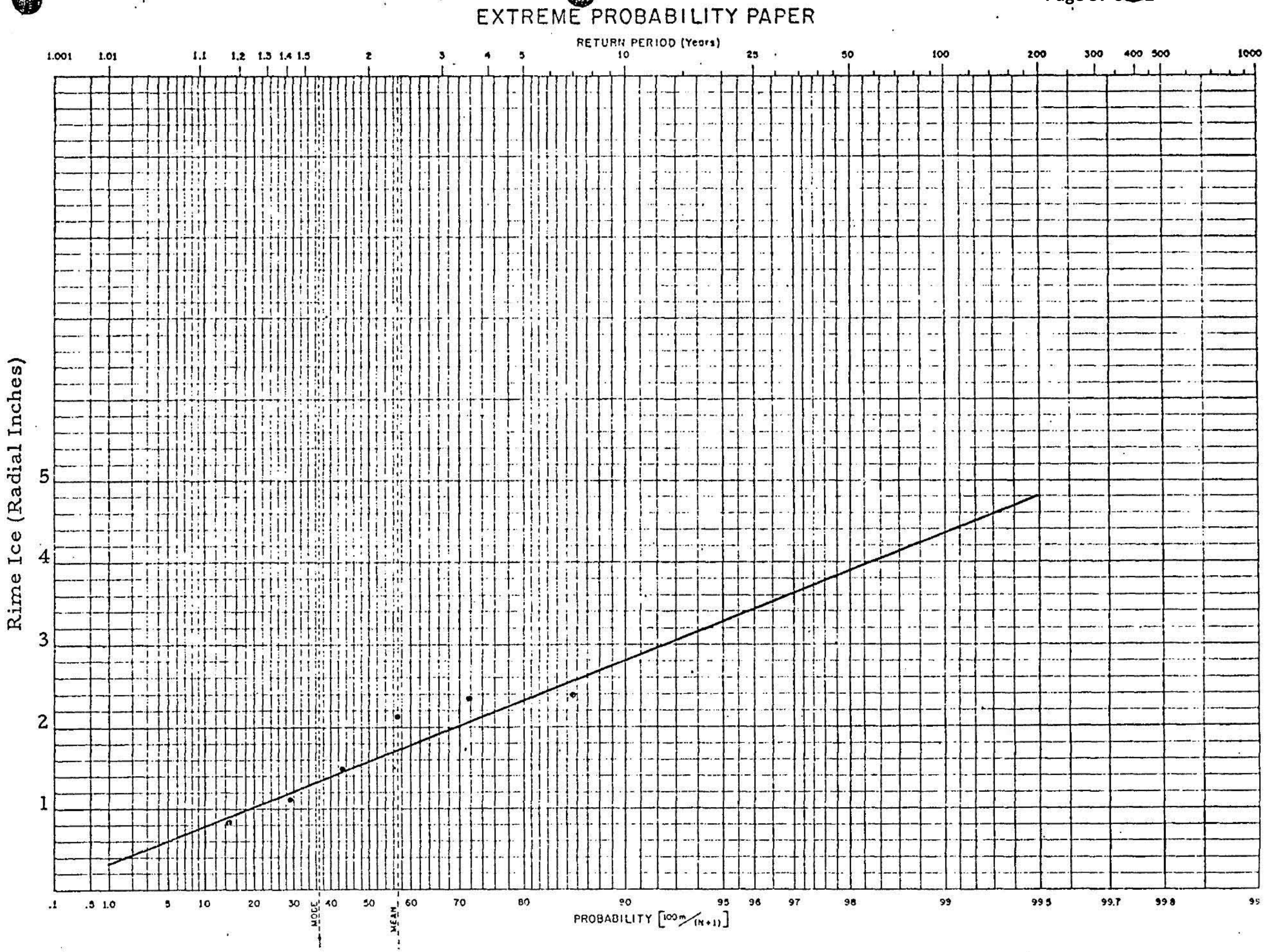

Fig. 25. RIME ICE PROBABILITIES 1000 FT ABOVE DANIELS HARBOUR

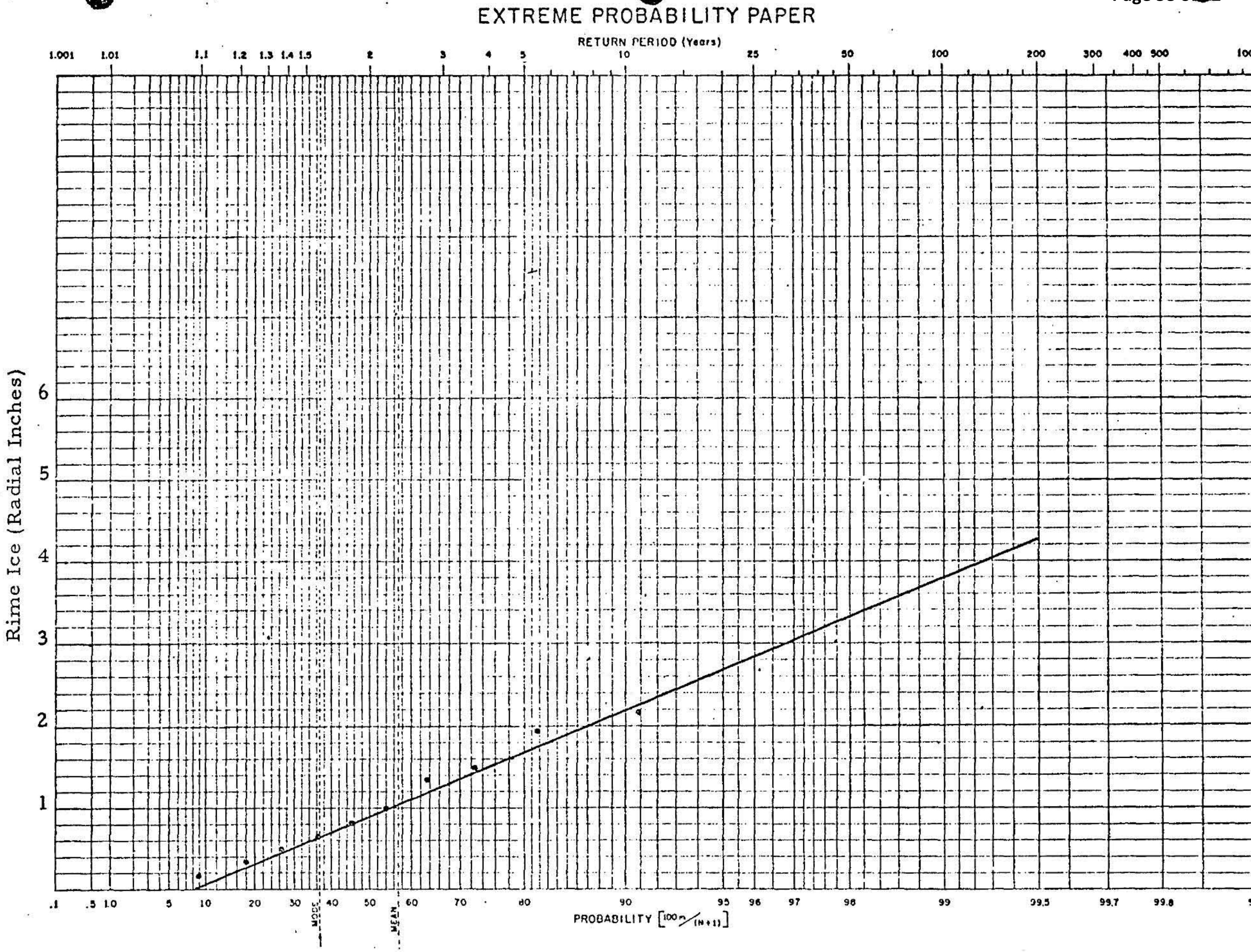

Fig. 26. RIME ICE PROBABILITIES 300 FT ABOVE BATTLE HARBOUR

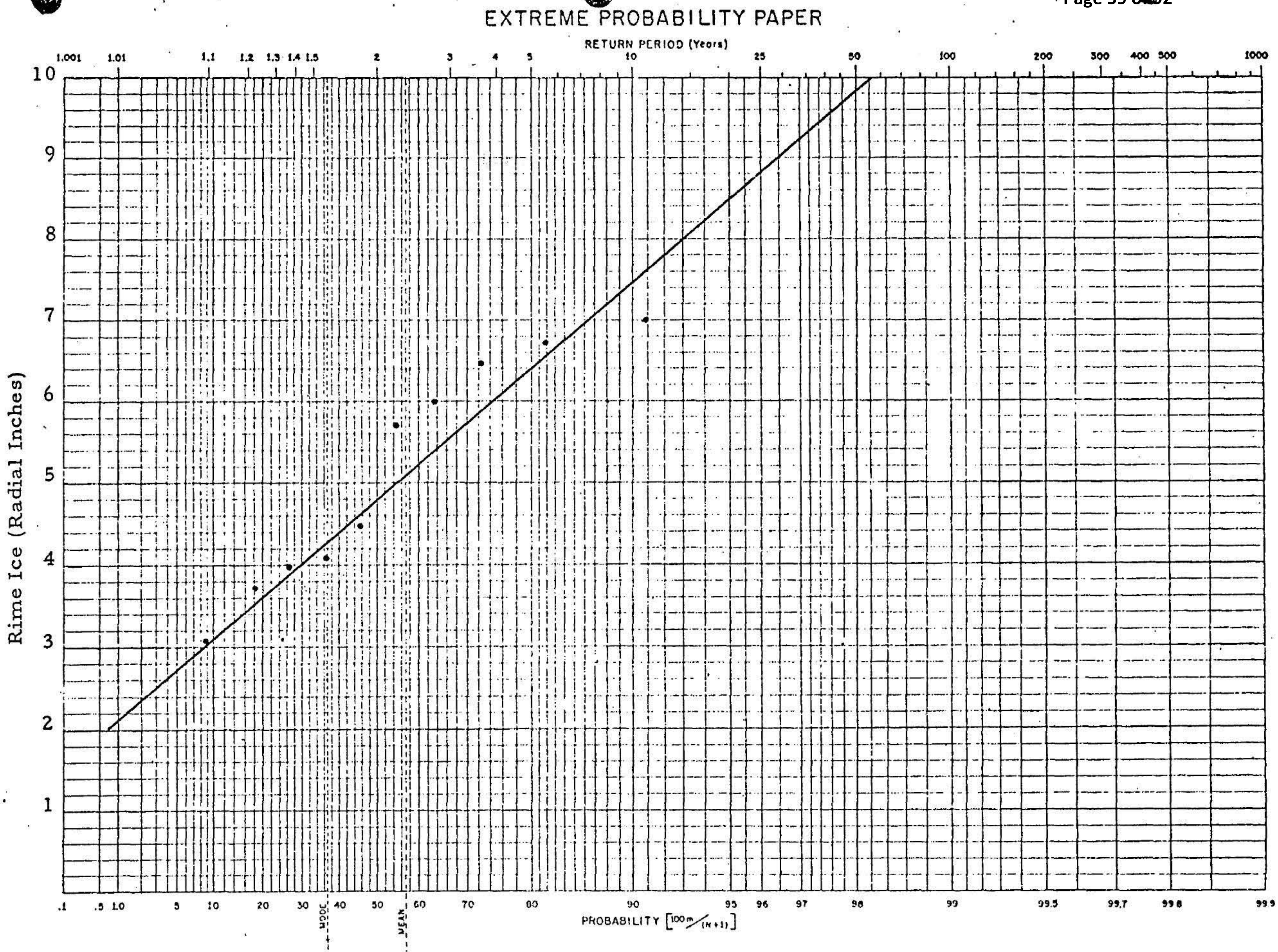

Fig. 27. RIME ICE PROBABILITIES 1000 FT ABOVE BATTLE HARBOUR

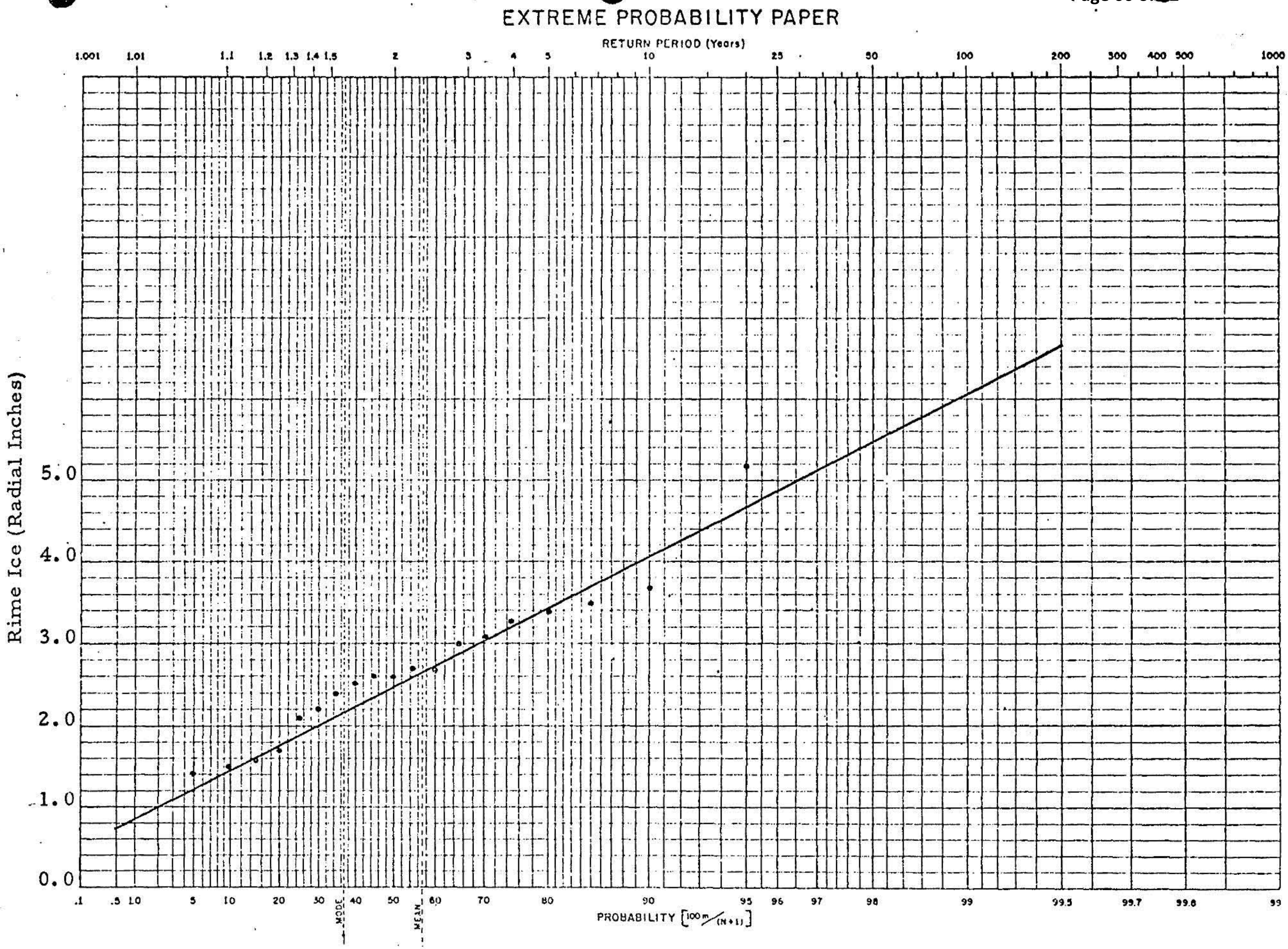

Fig. 28. RIME ICE PROBABILITIES 1000 FT ABOVE GOOSE BAY

Table X

RETURN PERIOD VALUES FOR RIME ICING

Location	Return Period Rime Amounts (radial inches) 10-yr	25-yr	50-yr	75-yr
300 ft above St. John's-Torbay	4.8	6.1	7.1	7.3
300 ft above Gander	3.4	4.3	5.0	5.5
300 ft above Buchans	0.6	0.8	1.0	1.1
800 ft above Buchans	2.7	3.4	3.9	4.2
1000 ft above Daniels Harbour	2.8	3.4	3.9	4.2
300 ft above Battle Harbour	2.2	2.9	3.4	3.6
1000 ft above Battle Harbour	7.5	8.8	9.9	10.4
1000 ft above Goose Bay	4.1	4.9	5.5	5.9

Table XI

FREQUENCY OF MODERATE OR HEAVY SNOW
WITH AIR TEMPERATURE ABOVE 28°F

Station	Period of Record	Total Hours	Avg. Hours Per Year	No. of Cases >6 Hours
St. John's-Torbay	19	297	15.6	1
Gander	19	249	13.1	3
Buchans	12	93	7.8	0
Deer Lake	6	74	12.3	2
Daniels Harbour	6	66	11.0	0
Battle Harbour	12	524	43.7	15
Argentia	17	282	16.6	5
Stephenville	19	112	5.9	0

Table XII

STORMS AT BATTLE HARBOUR WITH MODERATE OR HEAVY SNOW, AIR TEMPERATURES ABOVE 28°F, AND DURATIONS GREATER THAN SIX HOURS

Date	Duration (hr)	Temperature Range (°F)	Avg. Wind Speed (mph)	Max. Wind Speed (mph)	Remarks
12-14-59	12	29-30	39	52	Followed 7 hours of heavy snow <28°F
01-11-60	9	29-31	56	68	Max. wind for year
02-29-60	7	33	27	28	Snow intermittent
01-05-61	9	29-31	34	44	
03-17-61	7	30-31	10	14	Heavy snow followed by rain
05-03-61	7	30-32	16	18	
11-09-61	7	33-35	29	40	Followed by rain
03-24-62	7	32-33	40	44	Followed by rain
12-23-66	7	30-31	28	42	Preceded by freezing drizzle
01-14-70	12	29-31	41	45	Preceded by 5 hours freezing drizzle
04-09-70	8	30-31	37	45	Followed by rain
05-24-70	7	29-31	17	30	
01-07-71	7	29-30	36	45	
03-21-71	16	30-31	32	38	Preceded by 3 hours freezing drizzle
04-07-71	7	29-31	24	33	6 hours were heavy snow

There is strong reason to believe that the damage-causing wet snow occurs with temperatures from 32 to 35°F. If this is true, only three of the storms in Table XII would qualify.

It is very nearly impossible to objectively extrapolate station data to higher terrain in the case of wet snow. Rain occurring with near freezing temperatures at station level will mean that wet snow is occurring at some higher elevation in some cases but not all cases. From historical data, there is no way to differentiate between these cases. Even in real time it is difficult to predict where the sticking snow is occurring without on-site observations.

VIII. COMBINED WINDS AND ICING

Of extreme importance to the design engineer is the maximum effect on towers and conductors resulting from the combined loadings of the weight of the ice plus the pressure of the wind on the increased surface area. The determination of this combined effect is complicated in any specific case by several factors. As the preceding section has indicated, the accretion rate of both glaze and rime ice is a function of wind speed. The faster the wind, the more rapidly ice will build up. To determine the maximum combination, it is necessary to know when during the storm the strongest wind occurred and how much ice had accumulated at that time. If the strongest wind occurred early in the storm, the greatest combined effect may have occurred later with a lesser wind speed and a greater surface area and weight of ice. Superimposed on this is the effect of wind direction both on accretion rate and transverse and longitudinal wind loadings. Going beyond this, we have the problem of how long the ice can be expected to stay on the conductors. The longer the ice stays on, the greater the vulnerability to high winds not associated with the storm which caused the ice.

Not consider

A review of both the glaze and rime producing storm periods at the reporting stations revealed no pattern to the time within the storm period that the maximum wind occurred. The peak wind time appears to have occurred randomly throughout the icing period and up to at least six hours subsequent to the termination of icing conditions. Because of the manner in which the case histories were extracted from the climatological records, no more than six hours of records past the icing termination point were available in most cases. How long the ice will stay on the conductors will vary with each storm. In some cases, the temperature rises immediately and the melting and cracking process starts. At the other extreme, a prolonged cold period may result in the ice remaining for several days or in some locations perhaps weeks.

The possibility that ice may stay on the conductors for several days results in the possibility that the maximum wind speeds experienced by the ice loaded lines occur with a subsequent storm system and the winds and ice loadings then become independent variables. As Table II indicated, the maximum wind speeds throughout the area occur in the winter months. We must then consider the possibility that those maximum winds might occur with ice on the conductors. If we consider the wind and ice loadings to be independent variables, the probability of their occurring simultaneously becomes the product of their individual probabilities of occurrence. For a given combined probability or return period, there are, of course, many combinations of individual probabilities, the product of which would equal the selected combined probability. If we wish to

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consider the same individual probabilities for both variables, the individual probabilities will then be the square root of the combined probabilities. These values were used in this report. In nearly all sections of the proposed route, the direction of the peak winds vary through a wide sector and could be either perpendicular or parallel to the proposed route line.

IX. OTHER METEOROLOGICAL FACTORS

A. Total Precipitation and Snowfall

Total rainfall and rainfall equivalent in the form of snow is plentiful throughout both Newfoundland and Labrador. Total annual average precipitation exceeds 35 inches at all stations in Newfoundland. In most cases, approximately one-third of this comes in the form of snow. Table XIII gives the average annual snowfall and total precipitation for a number of stations in the area. As a rule-of-thumb, 10 inches of snow is the equivalent of one inch of liquid precipitation. This, of course, is an over-simplification and will vary quite widely from storm to storm.

Inland in Labrador, the total precipitation gradually decreases to only 28 inches annually at Schefferville; however, nearly half of the total comes as snow. It is probable that some areas in both Newfoundland and Labrador receive significantly greater amounts, but reports are not taken.

B. Powerline Sea-Salt Contamination

An important consideration to be made in the placement of powerlines in a coastal environment is the degree to which the lines will be affected by sea-salt contamination. The sea-salt contaminant becomes very conductive when the relative humidity reaches about 74 percent, a value not uncommon in coastal areas. Abrupt increases in insulator leakage current result, and in many cases visible arcs develop which in turn cause severe power losses.

The physics of the sea-salt contamination problem can be analyzed in terms of four relatively distinct phenomena:

(1) the production of sea-salt particles
(2) the transport of sea-salt particles inland
(3) the deposition of sea-salt particles on insulators
(4) the electrodynamics of contaminated insulators.

Present knowledge of the first three phenomena are discussed in the following paragraphs. The electrodynamical phenomena caused by various contaminants are described to some extent in literature published through various utility companies and are not described here.

Table XIII

ANNUAL AVERAGE PRECIPITATION 1941-1970

Station	Snowfall (in.)	Total Precipitation (in.)
St. John's-Torbay	143	60
Gander	140	42
Argentia	69	42
Grand Falls	105	39
Buchans	123	38
Deer Lake	103	39
Stephenville	129	43
Daniels Harbour	110	37
St. Anthony	132	36
Battle Harbour	155	38
Goose Bay	161	35
Cartwright	171	37
Schefferville	132	28
Wabush Lake	171	35
Lake Eon	165	35

1. Production

The source of sea-salt particles is believed to be associated with the bursting of small air bubbles that reach the surface of the water. These bubbles are formed when breaking and choppy waves capture air at the surface. It is not surprising, therefore, that the concentration of sea-salt particles near the ocean surface correlates with wind speed.

To some extent, the time history of an air mass arriving in a given locality will also determine its sea-salt concentration, but MRI studies have suggested that when local wind speeds exceed 12 mph the previous identity of the air mass is lost and local meteorological conditions dominate. In the same vein, local shoreline topology will also have some bearing on the sea-salt concentration.

Limited field data indicates that the size distribution of sea-salt particles is bimodal, the mean sizes being somewhat dependent on wind speed but averaging 1 and 10 microns. It is the larger mode that contributes most of the sea salt mass and is therefore of prime interest in powerline contamination studies.

2. Transport

Recent literature has suggested that when transported inland from the coast, the large mode of salt particles is quickly depleted relative to the smaller mode. This occurs more by impaction with trees, buildings, and other obstacles near the ground than by simple sedimentation. Limited MRI field data in one locality have indicated that the mean size of the large particle mode at a point over 3 miles from the shore does not vary significantly from that at the shoreline, while over 75 percent of the sea-salt mass has been lost between the two points. This would tend to support the impaction theory, at least for the nominal wind speeds (<20 mph) observed in the locality mentioned.

All of this implies that salt transport is largely a locality specific phenomenon. Hence, an open area near a coastline would certainly allow more salt to be transported inland than a forested area would. This would be true even in an area where vertical cliffs form the shoreline, since 10 micron particles can be easily carried along the wind streamlines. A gauge of the quantity of salt transported inland is provided by the fact that serious salt contamination problems have been observed at a distance 5 miles inland in a heavily populated urban area where local wind speeds seldom exceed 20 mph.

Finally, it must be noted that inland from the coast the number concentration of sea-salt particles first increases and then decreases with altitude, reaching a maximum at about 50 to 100 meters. This is a direct result of the loss of particles near the ground while the smaller particles higher in the atmosphere remain at a nearly constant concentration (neglecting washout by rain or their use as condensation nuclei in clouds). Hence, salt contamination of unusually high structures could occur much farther inland than the 5-mile figure quoted above.

3. Deposition

The actual deposition of sea-salt particles on insulators and other objects is the least documented phenomenon of those discussed here. Little experimental data are available to determine the efficiency of sea-salt collection on insulators as a function of particle size, density, and chemical behavior. The problem is complicated by the fact that sea-salt deliquesces in an anomalous fashion. Depending on whether the relative humidity is increasing or decreasing, a given salt particle will absorb moisture and assume one of two different sizes.

In being transported inland, the sea-salt particles generally encounter decreasing humidities, but the 5-mile band discussed previously normally represents such a short residence time that they do not equilibrate with their environment. However, when the relative humidity reaches 74 percent, the sea salt is no longer a particle as such, but is perhaps best represented as a droplet, which will have a much higher likelihood of sticking to any object it should encounter regardless of its size.

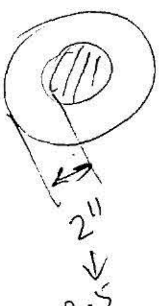
C. Areal Extent of Storms

The area covered by any one storm may vary from approximately one square mile in a moderate thunderstorm to thousands of square miles in a well developed low-pressure center-frontal system complex. Icing storms are somewhat more restricted in extent than storms defined only on the basis of wind and/or precipitation. Freezing precipitation resulting from the chemical overrunning situation will tend to occur in a band parallel to the front. This band may be a mile deep and 30 miles long or it may be 300 miles deep and 400 miles long. The average extent of a freezing rainstorm is probably near 5 to 10 miles deep and 30 to 60 miles long. Within this area there will be small pockets of heavy icing and larger areas of lesser icing. These are functions of terrain as well as the natural variability in rainfall intensity and wind speeds. In the case of extreme icing loads, it is unlikely that the maximum loads will affect more than a few miles (five to seven) of any one transmission line. In most cases, only a few spans will receive the maximum loadings with somewhat lesser amounts on neighboring spans. The same variability occurs in riming situations, probably due to local variations in wind speeds.

X. DISCUSSION OF ICE STORM TRANSMISSION LINE FAILURES IN NEWFOUNDLAND

In their paper "Icing Damage to Transmission Facilities in Newfoundland," presented at the Canadian Electrical Association Transmission Section Meeting in October 1971, Young and Schell included the following history of recent ice storms in Newfoundland:

"February 27, 1958 Up to four inch diameter glaze ice occurred on conductors in the St. John's area as a result of over one inch of freezing precipitation which fell during a six day period. During this time air temperatures ranged between 28°F and 33°F and the winds were generally greater than 20 mph with a peak gust of 45 mph. It was reported as the worst storm to hit St. John's since the 1920's and damage to overhead lines was extensive.
February 10-11, 1962 3/4 inch thick glaze ice deposited on structures in the St. Lawrence area. Forests in the Avalon Peninsula and the Bonavista Peninsula were severely damaged.
February 16-19, 1962 Three inch diameter glaze ice occurred near Gander causing the failure of approximately one mile of transmission line.
January 24, 1964 Five inch diameter glaze ice deposited on conductors in the Conception Bay area with up to 8 inches deposited on structures.
January 2, 1965 One and a half inch diameter glaze ice occurred in the Gander area as a result of a 38 hour storm which affected the whole island in varying degrees.
January 6, 1965 Up to 15 inch diameter glaze ice occurred in the La Scie area on the Northeast Coast.
January 12, 1966 Rime ice of approximately one inch thickness occurred on many hilly (500' elevation areas near St. John's. One to three inches was reported at elevations near 1000 ft.
January 20, 1966 Six inch diameter glaze ice occurred in the Trinity and Conception Bay areas. Winds of 30-40 mph accompanied this storm.
January 1967 Five to six (inch) diameter rime ice occurred on Transmission Lines near Buchans. The conductor from one of the Power Commissions (sic) newly constructed 230 KV transmission lines (TL 205, Ice Zone), not energized up to that time, came to within six feet of the ground but returned to normal heights after the rime melted.
February 27-28, 1970 Five to six inch diameter glaze ice



with icicles occurred on Transmission Lines in the Sunnyside area as a result of freezing precipitation. Over a million dollars damage resulted to transmission lines in this area. This storm caused the largest economic loss in recent times. February 14, 1971 Four to five inches diameter glaze ice occurred in Western Newfoundland, in the Humber Valley and in 2-3 miles wide bands across the North West Coast. Extended outages, caused by differential stretching of the all aluminum conductors, occurred on Bowater Power Co.'s two double circuit 69 KV lines between Deer Lake and Corner Brook. This was the first time in the 40 year life of these lines that an outage of this nature had occurred. Two conductors on a long span on the N & LPC's TL 205 west of Grand Lake and outside the 205 Heavy Ice Zone came down."

The same paper included an extensive discussion of the February 1970 storm and the resulting damage.

It is interesting to note that all of the damaging storms listed occurred in January and February. The freezing precipitation period in Newfoundland extends from November through May with February and March having the greatest frequency of occurrence. Subsequent to this list, another icing storm occurred in the Sunnyside area. This occurred on 27 and 28 December 1972.

A few more details are available regarding the storms listed:

February 27, 1958 - four-inch diameter glaze in St. John's area. A deep low-pressure center with occluded frontal system moved northeastward across southeast of the island on 26 February. Between 1:00 a.m. on 27 February and 4:00 p.m. on 1 March, 46 hours of freezing precipitation were reported with an average wind speed of 23 mph. An additional 12 hours of light rain with a temperature of 33°F fell during the period. This could well have been freezing rain somewhere in the area. Subsequent to this period, 10 hours of freezing precipitation occurred on 2 March and 27 hours on the 4th and 5th of that month.

February 10-11, 1962 - three-quarter inch glaze in St. Lawrence area. A fast moving storm system moved rapidly up the east coast of the United States and over the Avalon Peninsula. Strong winds aloft resulted in a great deal of overrunning. St. John's reported 28 hours of liquid precipitation with temperatures between 29-33°F. At Argentia, 25 hours were reported with temperatures between 32-35°F. Temperatures warmed rapidly at the end of the storm.

February 16-19, 1962 - three-inch diameter glaze near Gander. Strong onshore flow from the north-northwest resulted in 30 hours of freezing drizzle at Gander on 15-16 February. Wind speeds during the period averaged 21 mph with probable gusts to 50 mph. This was followed by 16 hours of snow on 18-19 February with an average of 33 mph winds and gusts to 55 mph.

January 24, 1964 - five-inch diameter glaze in Conception Bay area. Once again, a deep low-pressure center moved northward east of the island. Freezing precipitation started at St. John's-Torbay at 8:00 p.m. on the 22nd and was nearly continuous through 7:00 p.m. on the 24th. Temperatures remained between 30° and 32°F and wind speeds averaged 20 mph with gusts to 40 mph during the period.

January 2, 1965 and January 6, 1965 - one and one-half inch diameter glaze in Gander area and up to 15-inch diameter in the La Scie area. Actually icing both at Gander and at La Scie some 80 to 90 miles to the northwest probably started on 31 December 1964. Between 7:00 p.m. New Year's Eve and 7:00 p.m. on 5 January, Gander reported 81 hours of liquid precipitation within a temperature range of 30 to 33°F. Winds for the 81-hour period averaged only 12 mph, but reached 30 mph on the hourly reports and undoubtedly gusted above 40 mph at times.

January 12, 1966 - one- to three-inch rime ice near St. John's. Deep low-pressure center with accompanying frontal systems moved from the southwest to northeast across the western portion of the island. Strong southerly winds and low clouds swept the island, causing the icing with very cold air from the north following the system preventing early melting. Icing was probably widespread on higher terrain in the eastern half of the island.

January 20, 1966 - six-inch diameter glaze in Trinity Bay and Conception Bay areas. A very deep low-pressure center located southeast of the Avalon Peninsula on 18 January moved slowly to the northeast. Strong north-northeast winds brought copious amounts of moisture-laden air to the northeast coastal areas over a three-day period. St. John's-Torbay reported 52 hours of mixed precipitation in three days with the temperature holding between 30° and 33°F. The average wind speed for the period was near 25 mph. Gander reported 64 hours in four days.

Gust ?

January 1967 - five- to six-inch diameter rime near Buchans. No date given, however most likely period appears to be 4-6 January 1967 when a low center with an occluded system moved over western Newfoundland from the south. An extended period of low ceilings and moderate winds resulted. No observations from Buchans since 1964 were available; however, Deer Lake, Stephenville, and Gander all reported low ceilings and surface temperatures near freezing. Gander had 25 hours below 300 ft during the period and 40 hours below 1000 ft. The higher terrain near Buchans would likely have been in the clouds for an extended period.

February 14, 1971 - four- to five-inch diameter glaze in Humber Valley. A surface low with a complex frontal system developed in southeastern United States and moved rapidly up the eastern seaboard, over New Brunswick, and across western Newfoundland. Deer Lake reported 16 hours of freezing rain with an average wind speed near 15 mph. This would be expected to result in approximately 1.7 inches radial ice. At more exposed locations, the winds would have been stronger. A 20-mph average should have given approximately 2.4 inches radial ice. Surface temperatures at Deer Lake during the period ranged from 25 to 29°F. The surrounding ridges may have been in air above the freezing level and received only rain. Cold air was trapped in the valley. Daniels Harbour reported nine hours of freezing rain and a total of 15 hours of liquid precipitation with the temperature between 26° and 33°F. The temperature continued to rise at the end of the period.

December 27-28, 1972 - ice storm in isthmus area. A double low center deepening east and southeast of Nova Scotia was nearly stationary the morning of the 27th. The system drifted slowly northeastward until it was just south of the Avalon Peninsula by the morning of the 28th. The center then moved up the east coast of the Peninsula. We had no hourly reports available for 1972, but freezing precipitation probably changed to snow about noon on the 28th. Winds should have been near 40 knots.

50 mph!!

XI. LOADING PROBABILITIES BY LINE SEGMENT

The ice and wind loadings in the form of 10-, 25-, 50-, and 75-year return period values are listed in Tables XIV through XVII. The corresponding graphs for maximum wind speeds, glaze icing, rime icing, and wet snow are shown in Figs. 29 through 32. These segment values are based on the station values modified for altitude and exposure. Computations of ice and snow accumulations are based on a 2.0-inch diameter conductor with the exception of the Gull Lake to Churchill Falls segment which was computed for a 1.5-inch conductor. Ice and snow loadings are computed for accompanying winds being perpendicular to the conductor. In theory, accumulations are a function of the angle of the wind; however, there has been very little actual measurement of the effect of wind angle on ice accretion. Combined wind speed and ice loading values are also shown in Tables XIV through XVII.

Table XIV

10-YEAR RETURN PERIOD VALUES

Seg. No.		Maximum Winds: Wind Dir.	Maximum Winds: Wind Speed (mph)	Maximum Winds: Max. Gusts (mph)	Maximum Ice Loads: Glaze Rad. in.	Maximum Ice Loads: Glaze lb/ft	Maximum Ice Loads: Rime Rad. in.	Maximum Ice Loads: Rime lb/ft (0.9)	Maximum Ice Loads: Wet Snow Rad. in.	Maximum Ice Loads: Wet Snow lb/ft (0.5)	Combined Wind and Ice Loads: Wind Speed (mph)	Combined Wind and Ice Loads: Glaze Rad. in.	Combined Wind and Ice Loads: Glaze lb/ft (0.9)	Combined Wind and Ice Loads: Rime Rad. in.	Combined Wind and Ice Loads: Rime lb/ft (0.5)
1	Holyrood to Whitbourne (<500 ft)	W	75	100	2.9	17.4	3.8	15.0	0.8	1.5	62	2.2	11.3	2.4	7.2
2	Whitbourne to 10 miles west of Clarenville (<500 ft)	W	80	105	3.5	23.6	4.3	18.4	0.8	1.5	66	2.8	16.5	2.8	9.1
3	10 miles west of Clarenville to Grand Falls (≤800 ft)	WSW	70	95	2.4	12.9	3.1	10.8	1.2	2.6	58	1.7	7.7	1.7	4.3
4	(800-1200 ft elevations west of Gander Lake)	WSW	80	105	2.7	15.5	3.5	13.1	1.4	3.2	66	2.0	9.8	2.1	5.9
5	Grand Falls to Buchans (400 ft to 900 ft)	WSW	62	87	2.7	15.5	1.1	2.3	0.8	1.5	51	2.0	9.8	0.7	1.3
6	Buchans to Kitty's Brook (900 ft to 1200 ft)	NNW	78	103	2.7	15.5	1.1	2.3	0.9	1.8	64	2.0	9.8	0.7	1.3
7	Kitty's Brook to north end of Humber Valley 49°35'N (≤500 ft)	SW	53	75	2.2	11.3	0.7	1.3	1.2	2.6	44	1.4	5.8	0.7	1.3
8	North end of Humber Valley to top of ridge of Long Range Mountains on north side of Main River ~49°50'N (300 ft to 1200 ft)	NNW	62	87	2.2	11.3	1.7	4.3	1.4	3.2	51	1.4	5.8	1.0	2.0
9	Along ridge to 51°N (1200 ft to 1800 ft)	NNW	80	105	3.5	23.6	7.3	46.2	1.7	4.3	66	2.8	16.5	5.8	30.8
10	Along west Coastal Plain (≤500 ft)	SW	68	93	2.7	15.5	2.1	5.9	0.9	1.8	56	2.0	9.8	1.3	2.9
11	51°N to Strait of Belle Isle (≤500 ft)	NNE	75	100	2.9	17.4	3.8	15.0	2.2	6.3	62	2.2	11.3	2.4	7.2
12	Strait of Belle Isle to 30 miles inland from coast near corner of Quebec (<500 ft)	NNW	68	93	2.7	15.5	2.1	5.9	2.2	6.3	56	2.0	9.8	1.3	2.9
13	Same area (500-1500 ft)	NNW	75	100	2.9	17.4	4.8	22.2	3.1	10.8	62	2.2	11.3	3.4	12.5

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Table XIV (cont.)

Seg. No.		Maximum Winds			Maximum Ice Loads						Combined Wind and Ice Loads				
		Wind	Wind	Max.	Glaze		Rime		Wet Snow		Wind	Glaze		Rime	
		Dir.	Speed (mph)	Gusts (mph)	Rad. in.	lb/ft	Rad. in.	lb/ft (0.9)	Rad. in.	lb/ft (0.5)	Speed (mph)	Rad. in.	lb/ft (0.9)	Rad. in.	lb/ft (0.5)
14	30 miles inland to 58°40'W (1000 ft to 1400 ft)	NNW	58	81	1.3	5.3	1.7	4.3	1.4	3.2	48	0.6	1.9	1.0	2.0
15	58°40'W to 60°05'W (≥1500 ft)	NNW	58	81	1.5	6.4	3.1	10.8	1.7	4.3	48	0.8	2.7	1.7	4.3
16	60°05'W to 60°30'W (≤1300 ft and protected from north)	W	50	72	0.6	1.9	1.1	2.3	1.2	2.6	42	0.5	1.5	0.7	1.3
17	60°30'W to Gull Lake Valley (≥1400 ft)	NW	60	83	1.3	5.3	3.1	10.8	1.4	3.2	50	0.6	1.9	1.7	4.3
18	60°30'W to Muskrat Falls (≤1200 ft)	NNW	60	83	1.8	8.4	3.5	13.1	1.4	3.2	50	1.1	4.2	2.1	5.9
19	Gull Lake to Goose Bay along river (≤500 ft)	NE	53	75	1.5	6.4	0.7	1.3	1.2	2.6	44	0.8	2.7	0.7	1.3
20	Grand Falls to north end of Humber Valley (Alternate Route)	NNE	80	105	2.7	15.5	3.5	13.1	1.7	4.3	66	2.0	9.8	2.1	5.9
21	North end Humber Valley to south end Deer Lake (≤500 ft)	SW	53	75	2.2	11.3	0.7	1.3	1.2	2.6	44	1.4	5.8	0.7	1.3
22	South end Deer Lake to Stephenville (500-1300 ft)	SW	60	83	2.2	11.3	2.1	5.9	0.9	1.8	50	1.4	5.8	1.3	2.9
23	Gull Lake to Churchill Falls (500-1600 ft)	NNW	60	83	0.6	1.5	2.1	5.1	0.8	1.3	50	0.5	1.2	1.3	2.5

Table XV

25-YEAR RETURN PERIOD VALUES

Seg. No.		Maximum Winds			Maximum Ice Loads						Combined Wind and Ice Loads				
		Wind Dir.	Wind Speed (mph)	Max. Gusts (mph)	Glaze Rad. in.	Glaze lb/ft	Rime Rad. in.	Rime lb/ft (0.9)	Wet Snow Rad. in.	Wet Snow lb/ft (0.5)	Wind Speed (mph)	Glaze Rad. in.	Glaze lb/ft (0.9)	Rime Rad. in.	Rime lb/ft (0.5)
1	Holyrood to Whitbourne (<500 ft)	W	85	115	3.4	22.5	5.0	23.8	1.0	2.0	70	2.5	13.8	3.0	10.2
2	Whitbourne to 10 miles west of Clarenville (<500 ft)	W	90	122	4.0	29.4	5.5	28.1	1.0	2.0	74	3.1	19.4	3.5	13.1
3	10 miles west of Clarenville to Grand Falls (≤800 ft)	WSW	80	105	2.9	17.4	4.0	16.3	1.5	3.6	66	2.1	10.5	2.0	5.4
4	(800-1200 ft elevations west of Gander Lake)	WSW	90	122	3.2	20.4	4.4	19.2	1.8	4.7	74	2.3	12.1	2.4	7.2
5	Grand Falls to Buchans (400 ft to 900 ft)	WSW	70	95	3.2	20.4	1.4	3.2	1.0	2.0	58	2.3	12.1	0.8	1.5
6	Buchans to Kitty's Brook (900 ft to 1200 ft)	NNW	85	110	3.2	20.4	1.4	3.2	1.3	2.9	70	2.3	12.1	0.8	1.5
7	Kitty's Brook to north end of Humber Valley 49°35'N (≤500 ft)	SW	60	83	2.5	13.8	1.0	2.0	1.5	3.6	49	1.5	6.4	0.8	1.5
8	North end of Humber Valley to top of ridge of Long Range Mountains on north side of Main River ~49°50'N. (300 ft to 1200 ft)	NNW	70	95	2.5	13.8	2.0	5.4	1.8	4.7	58	1.5	6.4	1.1	2.3
9	Along ridge to 51°N (1200 ft to 1800 ft)	NNW	90	122	4.0	29.4	8.5	60.8	2.0	5.4	74	3.1	19.4	6.4	36.6
10	Along west Coastal Plain (≤500 ft)	SW	75	100	3.2	20.4	2.8	9.1	1.3	2.9	62	2.3	12.1	1.5	3.6
11	51°N to Strait of Belle Isle (≤500 ft)	NNE	85	115	3.4	22.5	5.0	23.8	2.5	7.7	70	2.5	13.8	3.0	10.2
12	Strait of Belle Isle to 30 miles inland from coast near corner of Quebec (<500 ft)	NNW	75	100	3.2	20.4	2.8	9.1	2.5	7.7	62	2.3	12.1	1.5	3.6
13	Same area (500-1500 ft)	NNW	85	115	3.4	22.5	6.0	32.7	3.5	13.1	70	2.5	13.8	4.0	16.3

Table XV (cont.)

Seg. No.		Maximum Winds: Wind Dir.	Wind Speed (mph)	Max. Gusts (mph)	Maximum Ice Loads: Glaze Rad. in.	Glaze lb/ft	Rime Rad. in.	Rime lb/ft (0.9)	Wet Snow Rad. in.	Wet Snow lb/ft (0.5)	Combined Wind and Ice Loads: Wind Speed (mph)	Glaze Rad. in.	Glaze lb/ft (0.9)	Rime Rad. in.	Rime lb/ft (0.5)
14	30 miles inland to 58°40'W (1000 ft to 1400 ft)	NNW	65	87	1.7	7.7	2.0	5.4	1.8	4.7	54	0.7	2.3	1.1	2.3
15	58°40'W to 60°05'W (≥1500 ft)	NNW	65	87	1.9	9.1	3.8	15.0	2.0	5.4	54	0.9	3.2	1.8	4.7
16	60°05'W to 60°30'W (≤1300 ft and protected from north)	W	55	78	1.0	3.7	1.4	3.2	1.5	3.6	46	0.5	1.5	0.8	1.5
17	60°30'W to Gull Lake Valley (≥1400 ft)	NW	65	87	1.7	7.7	4.0	16.3	1.8	4.7	54	0.7	2.3	2.0	5.4
18	60°30'W to Muskrat Falls (≤1200 ft)	NNW	65	87	2.2	11.3	4.4	19.2	1.8	4.7	54	1.3	5.3	2.4	7.2
19	Gull Lake to Goose Bay along river (≤500 ft)	NE	60	83	1.9	9.1	1.0	2.0	1.5	3.6	50	0.9	3.2	0.8	1.5
20	Grand Falls to north end of Humber Valley (Alternate Route)	NNE	90	122	3.2	20.4	4.4	19.2	2.0	5.4	74	2.3	12.1	2.4	7.2
21	North end Humber Valley to south end Deer Lake (≤500 ft)	SW	60	83	2.5	13.8	1.0	2.0	1.5	3.6	49	1.5	6.4	0.8	1.5
22	South end Deer Lake to Stephenville (500-1300 ft)	SW	65	87	2.5	13.8	2.8	9.1	1.3	2.9	54	1.5	6.4	1.5	3.6
23	Gull Lake to Churchill Falls (500-1600 ft)	NNW	65	87	1.0	3.1	2.8	8.2	1.0	1.7	54	0.5	1.2	1.5	3.1

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Table XVI

50-YEAR RETURN PERIOD VALUES

Seg. No.		Maximum Winds			Maximum Ice Loads						Combined Wind and Ice Loads				
		Wind Dir.	Wind Speed (mph)	Max. Gusts (mph)	Glaze Rad. in.	Glaze lb/ft	Rime Rad. in.	Rime lb/ft (0.9)	Wet Snow Rad. in.	Wet Snow lb/ft (0.5)	Wind Speed (mph)	Glaze Rad. in.	Glaze lb/ft (0.9)	Rime Rad. in.	Rime lb/ft (0.5)
1	Holyrood to Whitbourne (<500 ft)	W	93	124	3.8	27.0	5.7	29.9	1.2	2.6	76	2.8	16.5	3.4	12.5
2	Whitbourne to 10 miles west of Clarenville, (<500 ft)	W	98	132	4.4	34.5	6.2	34.6	1.2	2.6	80	3.4	22.5	3.9	15.7
3	10 miles west of Clarenville to Grand Falls (≤800 ft)	WSW	88	119	3.3	21.4	4.7	21.4	1.8	4.7	72	2.3	12.1	2.4	7.2
4	(800-1200 ft elevations west of Gander Lake)	WSW	98	132	3.6	24.7	5.1	24.6	2.0	5.4	80	2.6	14.7	2.8	9.1
5	Grand Falls to Buchans (400 ft to 900 ft)	WSW	76	101	3.6	24.7	1.6	3.9	1.2	2.6	62	2.6	14.7	1.0	2.0
6	Buchans to Kitty's Brook (900 ft to 1200 ft)	NNW	90	115	3.6	24.7	1.6	3.9	1.5	3.6	74	2.6	14.7	1.0	2.0
7	Kitty's Brook to north end of Humber Valley 49°35'N (≤500 ft)	SW	65	87	3.1	19.4	1.2	2.6	1.8	4.7	54	2.0	9.8	1.0	2.0
8	North end of Humber Valley to top of ridge of Long Range Mountains on north side of Main River ~49°50'N (300 ft to 1200 ft)	NNW	76	101	3.1	19.4	2.2	6.3	2.0	5.4	62	2.0	9.8	1.2	2.6
9	Along ridge to 51°N (1200 ft to 1800 ft)	NNW	98	132	4.4	34.5	9.5	74.4	2.3	6.7	80	3.4	22.5	6.8	40.7
10	Along west Coastal Plain (≤500 ft)	SW	80	105	3.6	24.7	3.2	11.3	1.5	3.6	66	2.6	14.7	1.8	4.7
11	51°N to Strait of Belle Isle (≤500 ft)	NNE	93	124	3.8	27.0	5.7	29.9	2.7	8.6	76	2.8	16.5	3.4	12.5
12	Strait of Belle Isle to 30 miles inland from coast near corner of Quebec (<500 ft)	NNW	80	105	3.6	24.7	3.2	11.3	2.7	8.6	66	2.6	14.7	1.8	4.7
13	Same area (500-1500 ft)	NNW	93	124	3.8	27.0	6.7	39.7	3.8	15.0	76	2.8	16.5	4.4	19.2

Table XVI (cont.)

Seg. No.		Maximum Winds: Wind Dir.	Wind Speed (mph)	Max. Gusts (mph)	Maximum Ice Loads: Glaze Rad. in.	lb/ft	Rime Rad. in.	lb/ft (0.9)	Wet Snow Rad. in.	lb/ft (0.5)	Combined Wind and Ice Loads: Wind Speed (mph)	Glaze Rad. in.	lb/ft (0.9)	Rime Rad. in.	lb/ft (0.5)
14	30 miles inland to 58°40'W (1000 ft to 1400 ft)	NNW	70	90	2.1	10.5	2.2	6.3	2.0	5.4	58	1.0	3.7	1.2	2.6
15	58°40'W to 60°05'W (≥1500 ft)	NNW	70	90	2.3	12.1	4.3	18.4	2.3	6.7	58	1.2	4.7	2.0	5.4
16	60°05'W to 60°30'W (≤1300 ft and protected from north)	W	59	82	1.4	5.8	1.6	3.9	1.8	4.7	49	0.5	1.5	1.0	2.0
17	60°30'W to Gull Lake Valley (≥1400 ft)	NW	69	89	2.1	10.5	4.7	21.4	2.0	5.4	57	1.0	3.7	2.4	7.2
18	60°30'W to Muskrat Falls (≤1200 ft)	NNW	69	89	2.6	14.7	5.1	24.6	2.0	5.4	57	1.5	6.4	2.8	9.1
19	Gull Lake to Goose Bay along river (≤500 ft)	NE	64	86	2.3	12.1	1.2	2.6	1.8	4.7	53	1.2	4.7	1.0	2.0
20	Grand Falls to north end of Humber Valley (Alternate Route)	NNE	98	132	3.6	24.7	5.1	24.6	2.3	6.7	80	2.6	14.7	2.8	9.1
21	North end Humber Valley to south end Deer Lake (≤500 ft)	SW	65	87	3.1	19.4	1.2	2.6	1.8	4.7	54	2.0	9.8	1.0	2.0
22	South end Deer Lake to Stephenville (500-1300 ft)	SW	69	89	3.1	19.4	3.2	11.3	1.5	3.6	57	2.0	9.8	1.8	4.7
23	Gull Lake to Churchill Falls (500-1600 ft)	NNW	69	89	1.4	5.0	3.2	10.2	1.2	2.2	57	0.5	1.2	1.8	4.0

Table XVII

75-YEAR RETURN PERIOD VALUES

Seg. No.		Maximum Winds			Maximum Ice Loads						Combined Wind and Ice Loads				
		Wind Dir.	Wind Speed (mph)	Max. Gusts (mph)	Glaze Rad. in.	Glaze lb/ft	Rime Rad. in.	Rime lb/ft (0.9)	Wet Snow Rad. in.	Wet Snow lb/ft (0.5)	Wind Speed (mph)	Glaze Rad. in.	Glaze lb/ft (0.9)	Rime Rad. in.	Rime lb/ft (0.5)
1	Holyrood to Whitbourne (<500 ft)	W	97	131	3.9	28.2	6.3	35.6	1.3	2.9	79	2.9	17.4	3.7	14.4
2	Whitbourne to 10 miles west of Clarenville, (<500 ft)	W	102	135	4.5	35.8	6.8	40.7	1.3	2.9	84	3.4	22.5	4.3	18.4
3	10 miles west of Clarenville to Grand Falls (≤800 ft)	WSW	92	125	3.4	22.5	5.1	24.6	2.0	5.4	75	2.2	11.3	2.6	8.1
4	(800-1200 ft elevations west of Gander Lake)	WSW	102	135	3.7	25.8	5.5	28.1	2.2	6.3	84	2.7	15.5	2.9	9.7
5	Grand Falls to Buchans (400 ft to 900 ft)	WSW	80	105	3.7	25.8	1.8	4.7	1.3	2.9	66	2.7	15.5	1.3	2.9
6	Buchans to Kitty's Brook (900 ft to 1200 ft)	NNW	93	126	3.7	25.8	1.8	4.7	1.7	4.3	76	2.7	15.5	1.3	2.9
7	Kitty's Brook to north end of Humber Valley 49°35'N (≤500 ft)	SW	68	88	3.2	20.4	1.4	3.2	2.0	5.4	56	2.1	16.5	1.2	2.6
8	North end of Humber Valley to top of ridge of Long Range Mountains on north side of Main River ~49°50'N (300 ft to 1200 ft)	NNW	80	105	3.2	20.4	2.4	7.2	2.2	6.3	66	2.1	10.5	1.4	3.2
9	Along ridge to 51°N (1200 ft to 1800 ft)	NNW	102	135	4.5	35.8	10.0	81.7	2.4	7.2	84	3.4	22.5	7.5	48.5
10	Along west Coastal Plain (≤500 ft)	SW	83	108	3.7	25.8	3.5	13.1	1.7	4.3	68	2.7	15.5	2.0	5.4
11	51°N to Strait of Belle Isle (≤500 ft)	NNE	97	131	3.9	28.2	6.3	35.6	2.9	9.7	79	2.9	17.4	3.7	14.4
12	Strait of Belle Isle to 30 miles inland from coast near corner of Quebec (<500 ft)	NNW	83	108	3.7	25.8	3.5	13.1	2.9	9.7	68	2.7	15.5	2.0	5.4
13	Same area (500-1500 ft)	NNW	97	131	3.9	28.2	7.3	46.2	4.0	16.3	79	2.9	17.4	4.6	20.7

Table XVII (cont.)

Seg. No.		Maximum Winds: Wind Dir.	Maximum Winds: Wind Speed (mph)	Maximum Winds: Max. Gusts (mph)	Maximum Ice Loads: Glaze Rad. in.	Maximum Ice Loads: Glaze lb/ft	Maximum Ice Loads: Rime Rad. in.	Maximum Ice Loads: Rime lb/ft (0.9)	Maximum Ice Loads: Wet Snow Rad. in.	Maximum Ice Loads: Wet Snow lb/ft (0.5)	Combined Wind and Ice Loads: Wind Speed (mph)	Combined Wind and Ice Loads: Glaze Rad. in.	Combined Wind and Ice Loads: Glaze lb/ft (0.9)	Combined Wind and Ice Loads: Rime Rad. in.	Combined Wind and Ice Loads: Rime lb/ft (0.5)
14	30 miles inland to 58°40'W (1000 ft to 1400 ft)	NNW	73	92	2.2	11.3	2.4	7.2	2.2	6.3	60	1.1	4.2	1.4	3.2
15	58°40'W to 60°05'W (≥1500 ft)	NNW	73	92	2.4	12.9	4.6	20.7	2.4	7.2	60	1.3	5.3	2.3	6.7
16	60°05'W to 60°30'W (≤1300 ft and protected from north)	W	62	85	1.5	6.4	1.8	4.7	2.0	5.4	51	0.5	1.5	1.3	2.9
17	60°30'W to Gull Lake Valley (≥1400 ft)	NW	72	91	2.2	11.3	5.1	24.6	2.2	6.3	59	1.1	4.2	2.6	8.1
18	60°30'W to Muskrat Falls (≤1200 ft)	NNW	72	91	2.7	15.5	5.5	28.1	2.2	6.3	59	1.6	7.1	2.9	9.7
19	Gull Lake to Goose Bay along river (≤500 ft)	NE	67	88	2.4	12.9	1.4	3.2	2.0	5.4	55	1.3	5.3	1.2	2.6
20	Grand Falls to north end of Humber Valley (Alternate Route)	NNE	102	135	3.7	25.8	5.5	28.1	2.4	7.2	84	2.7	15.5	2.9	9.7
21	North end Humber Valley to south end Deer Lake (≤500 ft)	SW	68	88	3.2	20.4	1.4	3.2	2.0	5.4	56	2.1	10.5	1.2	2.6
22	South end Deer Lake to Stephenville (500-1300 ft)	SW	72	91	3.2	20.4	3.5	13.1	1.7	4.3	59	2.1	10.5	2.0	5.4
23	Gull Lake to Churchill Falls (500-1600 ft)	NNW	72	91	1.5	5.5	3.5	11.9	1.3	2.5	59	0.5	1.2	2.0	4.8

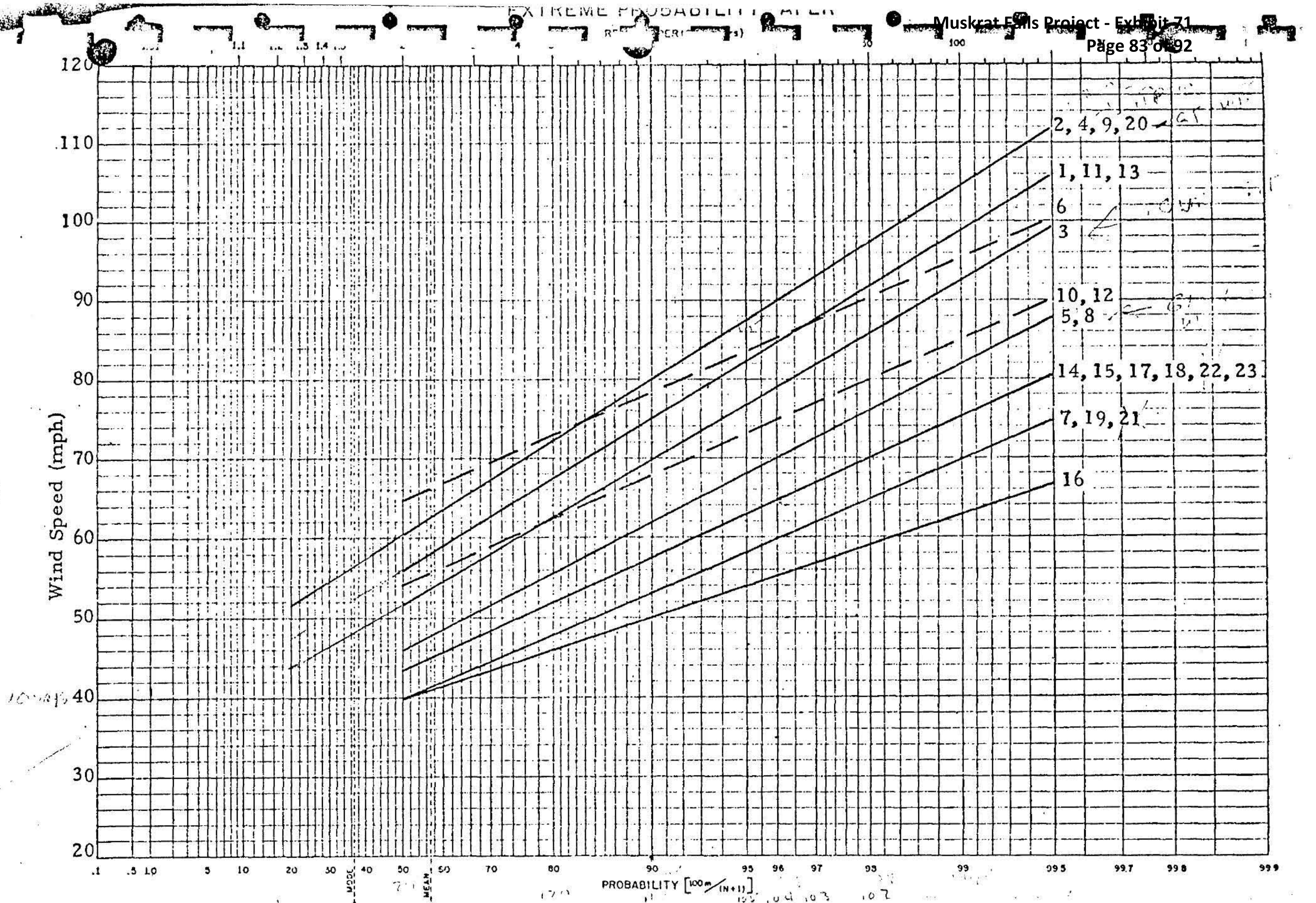

Fig. 29. MAXIMUM WIND SPEED PROBABILITIES BY LINE SEGMENT

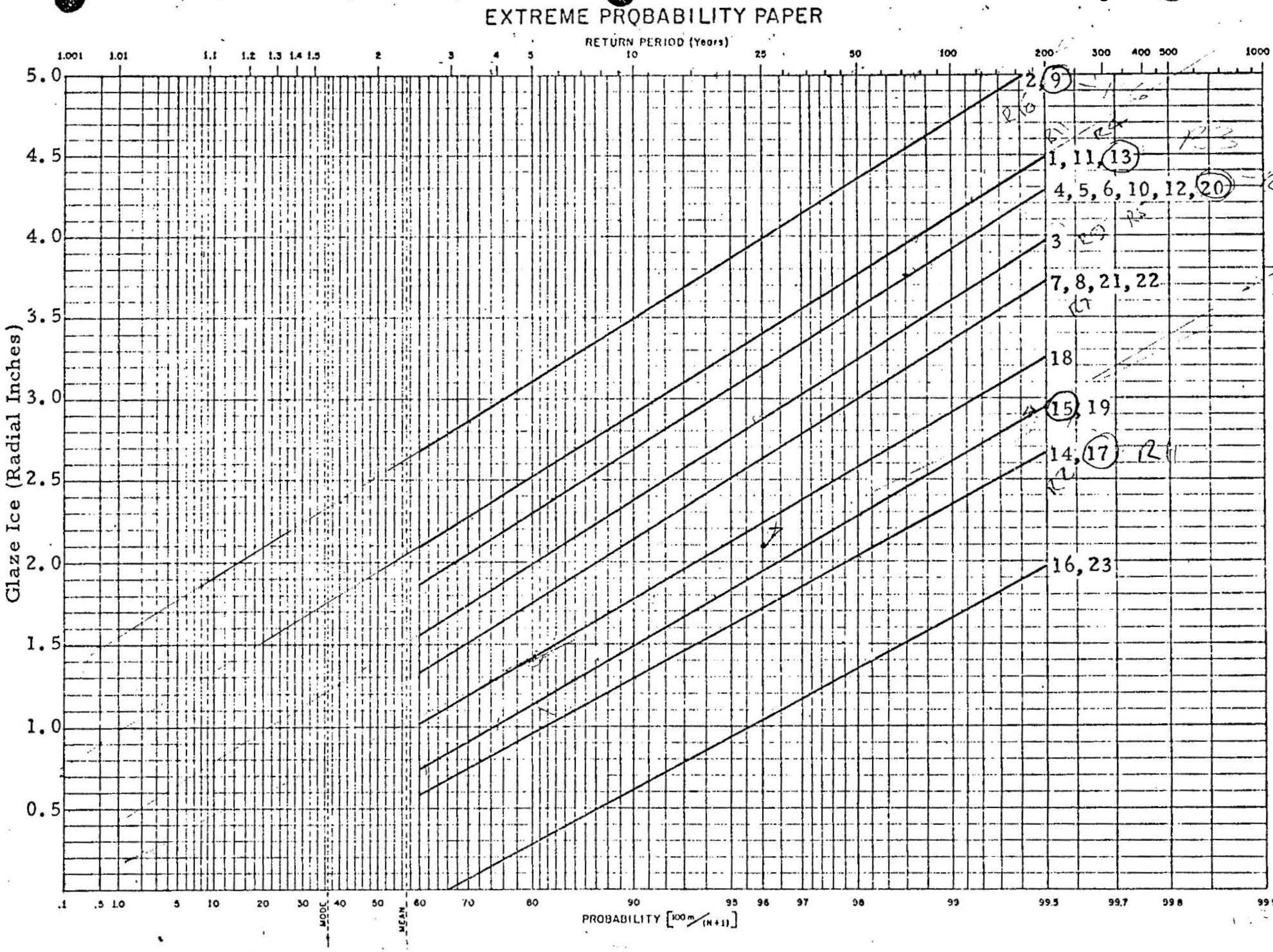

Fig. 30. MAXIMUM GLAZE ICING PROBABILITIES BY LINE SEGMENT

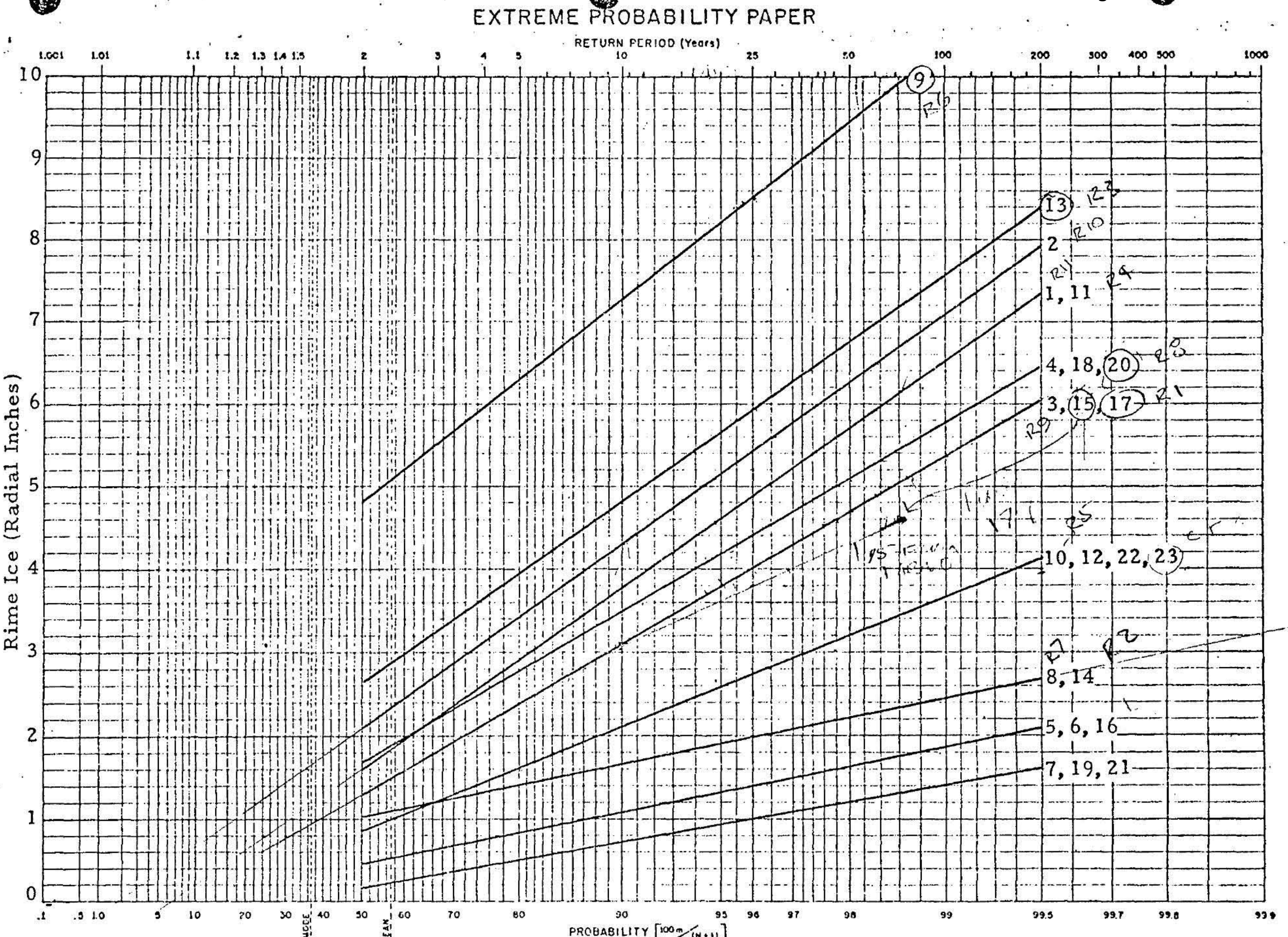

Fig. 31. MAXIMUM RIME ICING PROBABILITIES BY LINE SEGMENT

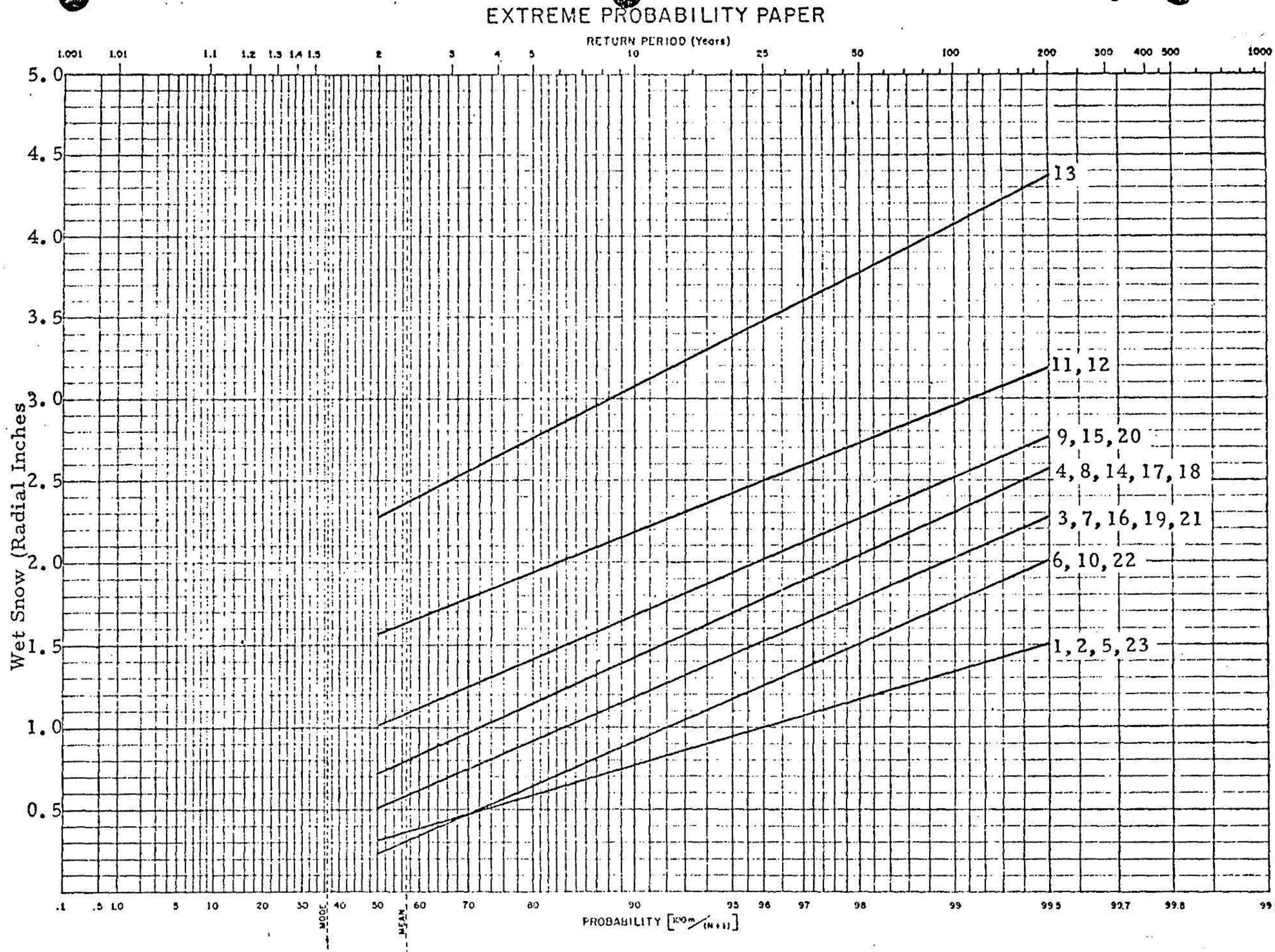

Fig. 32. MAXIMUM WET SNOW PROBABILITIES BY LINE SEGMENT

XII. CONCLUSIONS AND RECOMMENDATIONS

The principal conclusions of the study are the following:

- Significant amounts of glaze ice from freezing precipitation can be expected to occur throughout Newfoundland and the coastal areas of Labrador. The heaviest accumulations will occur in eastern Newfoundland, along the high terrain of the northwest peninsula, and near the Strait of Belle Isle. Near the isthmus to the Avalon Peninsula and along the ridge of the Long Range Mountains, 25-year return period values of four radial inches of glaze ice are likely.

- The same areas are vulnerable to heavy accumulations of rime icing. Extremely large amounts of rime or mixed icing are expected to occur along the ridge of the Long Range Mountains. Extreme values of 8.5 radial inches of rime are expected in a 25-year return period in that area.

- Both types of ice will sometimes stay on the conductors for several days.

- Wet snow occurs throughout the area and heavy accumulations sticking to the conductors will occur near the Strait of Belle Isle; however, loadings will not be great enough to be the limiting design values.

- Wind gust speeds exceeding 100 mph must be expected over most of Newfoundland and the coastal area of Labrador. Extreme gust values exceeding 120 mph in a 25-year return period will occur over some of the most exposed terrain.

- High wind speeds will occur both during and following icing storms.

- The extent of line affected in any one icing storm will depend on the location and orientation of the storm system with regards to the line. Heavy ice loadings may occur over extensive areas - perhaps as much as 60 miles of line; however, extreme value loadings will be local phenomena limited to a few miles of line and usually to a few spans.

- The proposed route traverses three essentially independent weather regimes. From an end-to-end reliability viewpoint, this means that in any given 50-year period a "fifty-year storm" may hit each of the three regions. A transmission line designed to the 50-year extreme values in each segment will thus have a non-failure expectancy overall of only 17 years.

- Much of these proposed transmission line routes are through areas completely devoid of any recorded weather data. Long stretches of route have been included in the line segments for loading estimation. Local variations within the segments will be large.

If the planning for construction of these proposed lines is to go forward, two general areas of concern should be investigated more fully. First, in the area of wind or ice loadings, on-site measurements should be made to validate the estimated relationships between the established reporting stations and the remote areas. A program of remote instrumentation for measurement of winds and icing in the most critical areas is needed. The extreme conditions expected and the inaccessibility of the sites will make such an undertaking very difficult and expensive, but a fantastic amount of effort and expenditure is at stake. It is likely that new methods of measurement and readout will have to be developed to cope with the expected icing.

Second, in the area of salt contamination, more detailed information is needed. The nature of sea-salt contamination is mainly locality specific, and as such presents a problem that should be dealt with on a local basis. This would entail sampling during varying types of meteorological conditions along the coastline of interest to determine the amount of salt produced in the locality, as well as sampling at various inland points to determine the degree of salt intrusion. A theoretical model of salt transport does exist, but has not been completely verified in the field. Upon verification of such a model, measurements of salt production on a daily basis could be combined with the transport model to estimate the sea-salt flux in regions near a coastline. Laboratory studies of deposition efficiencies would complement such a program and yield a relatively accurate method of monitoring sea-salt contamination on local powerlines.

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