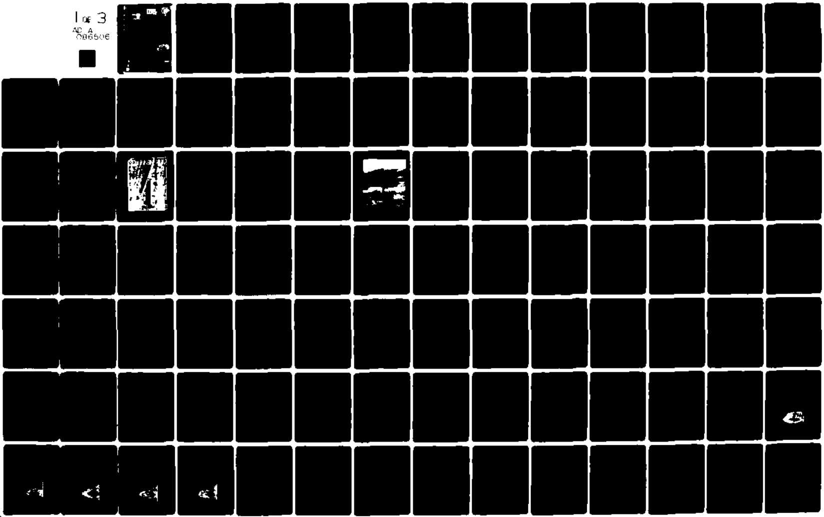
AD-A086 506 IIT RESEARCH INST CHICAGO IL F/G 10/2
NAVY-NEW HAMPSHIRE WIND ENERGY PROGRAM.(U)
NOV 79 S A BORTZ, R A BUDENHOLZER N00014-79-C-6503
UNCLASSIFIED IITRI-M6052 NL

1 of 3
AD A
086506



REPORT DOCUMENTATION PAGE	READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER / 2. GOVT ACCESSION NO. AD-A086 506	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) (6) NAVY-NEW HAMPSHIRE WIND ENERGY PROGRAM	5. TYPE OF REPORT & PERIOD COVERED IITRI Final Report June 4 - October 31, 1979
	6. PERFORMING ORG. REPORT NUMBER No. M6052
7. AUTHOR(s) (10) S.A. Bortz, R.A. Budenholzer, R.D. Carlson, I. Fieldhouse, J. Kornfeld, ~~R.S. Norman~~, R.W. Porter, W. Rosenkranz	8. CONTRACT OR GRANT NUMBER(s) (15) N00014-79-C-6503
9. PERFORMING ORGANIZATION NAME AND ADDRESS (11) Nov 79	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Scientific Officer Director, Navy Energy & Natural Resources R&D Office Navy Material Command Washington, D.C. 20360	12. REPORT DATE November 1979
	13. NUMBER OF PAGES
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) IIT Research Institute 10 West 35th Street Chicago, Illinois 60616	15. SECURITY CLASS. (of this report) UNCLASSIFIED
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE N/A

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

(12) 351

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

Same (9) Final rept. 4 Jun-31 Oct 79

18. SUPPLEMENTARY NOTES

None (14) IITRI-M6052

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Windpower	Portsmouth Shipyard
Energy prices	Windpower financing
Electricity Costs	Wind analysis
New Hampshire	Wing resource

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This program investigated the potential of the Mt. Washington, New Hampshire area for generating electric power from wind energy as an alternative to fossil fuels. The U.S. Naval Shipyard at Portsmouth, New Hampshire is among those facilities which could benefit initially from successful wind generated power.

IIT Research Institute (IITRI) specialists performed the following tasks:

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE
S/N 0102-LF-014-6601

1[illegible]350

20. ABSTRACT (Cont'd)

(1) Evaluation of New Hampshire's wind energy resources for potential electric power generation using meteorological, topographical, biological and other available information,

(2) Assessment of the environmental, social, technical, and other possible barriers to the development of wind energy resources, AND

(3) Economic evaluation of installing one or more wind turbine-generators to supply power either directly to the Shipyard or to lines of the Public Service Company of New Hampshire which supplies the Shipyard.

IITRI researchers gathered available wind speed statistics for Mt. Washington and a number of other locations in New Hampshire to determine suitability for electric power generation. These data, together with additional wind speed measurements IITRI obtained experimentally on seven mountaintop sites over a two week period, provided sufficient data to develop two independent computerized methods for correlating wind speed for those peaks. These methods permit both evaluation of wind speed characteristics for any desired mountaintop in New Hampshire not blocked by other peaks, and also determination of the annual average wind use for both the MOD-2 and Darrieus wind turbine-generators when located on these peaks. Fifty-nine potential mountaintop sites were selected for study. Since peaks below 2,000 feet have low average wind speeds and peaks above 4,000 feet have severe icing and wind gust problems, seven sites having altitudes near 3,000 feet and located near transmission lines were selected for economic analysis.

Before carrying out the economic analysis, power generation characteristics of the latest wind turbine-generator models were carefully studied to determine their suitability for the sites. The two models chosen for comparison were the 2.5 MW(e) MOD-2 wind generator and the 0.5 MW(e) Darrieus machine. Wind utilization factors for these models were computed on a seasonal basis with annual values determined for each of the models using wind speed power curves for the unit. Wind speeds were adjusted for altitude and computations carried out using Weibull and Rayleigh wind frequency distributions. The Weibull distribution was selected for the economic analysis.

Three alternate ownership options were investigated: public (tax exampt), utility (taxable), and private (taxable). In utility ownership, the levelized cost of producing electricity by wind power, as compared with the levelized cost of producing it by alternate means, was evaluated in $/kWh(e). For public or private ownership, the levelized cost of production using wind power was compared to the amount for which the electricity produced could be sold to the utility under the New Hampshire Limited Energy Producers Act. The rate of return on investment was also determined for both utility and private ownership.

Since in all cases studied the savings in cost of producing electricity is sufficient to make the installation of a wind turbine-generator highly attractive, wind power appears to be beneficial to New Hampshire and would certainly improve the economic and energy environment in the State, regardless of ownership. The Portsmouth Navy Yard would share in this benefit along with all others in the State. IITRI recommends further studies be undertaken to identify the best sites in terms of local conditions (such as topography and relation to transmission lines) and to fully assess the economic benefit to be gained by wisely exploiting the wind energy resources of New Hampshire.

12

IITRI Final Report No. M6052
(formerly IITRI No. D6169)

"NAVY-NEW HAMPSHIRE WIND ENERGY PROGRAM"

for

United States Navy
Headquarters, Naval Material Command
Washington, D.C. 20360

Contract No. N00014-79-C-6503

November 1979

Prepared by:

S.A. Bortz
R.A. Budenholzer
R.D. Carlson
I. Fieldhouse
J. Kornfeld
R.S. Norman
R.W. Porter
W. Rosenkranz

EXECUTIVE SUMMARY

This program investigated the potential of the Mt. Washington, New Hampshire area for generating electric power from wind energy as an alternative to fossil fuels. The U.S. Naval Shipyard at Portsmouth, New Hampshire is among those facilities which would benefit initially from successful wind generated power.

IIT Research Institute (IITRI) specialists performed the following tasks:

- Evaluation of New Hampshire's wind energy resources for potential electric power generation using meteorological, topographical, biological and other available information.
- Assessment of the environmental, social, technical, and other possible barriers to the development of wind energy resources.
- Economic evaluation of installing one or more wind turbine-generators to supply power either directly to the Shipyard or to lines of the Public Service Company of New Hampshire which supplies the Shipyard.

IITRI researchers gathered available wind speed statistics for Mt. Washington and a number of other locations in New Hampshire to determine suitability for electric power generation. These data, together with additional wind speed measurements IITRI obtained experimentally on seven mountaintop sites over a two week period, provided sufficient data to develop two independent computerized methods for correlating wind speed for those peaks. These methods permit both evaluation of wind speed characteristics for any desired mountaintop in New Hampshire not blocked by other peaks, and also determination of the annual average wind use for both the MOD-2 and Darrieus wind turbine-generators when located on these peaks.

Using detailed maps of the State obtained from the Highway Department, Forestry Service and the Public Service Company of New Hampshire, 59 potential mountaintop sites were selected for study. Since peaks below 2,000 feet have low average wind speeds and peaks above 4,000 feet have severe icing and wind gust problems, seven sites having altitudes near 3,000 feet and located near transmission lines were selected for economic analysis. These sites were North Moat Mountain, Mt. Crescent, Mt. Randolph, Bald Cap, Mt. Wolf, Mt. Kearsarge and Mt. Croydon. In addition, the local, social, and environmental factors (such as electromagnetic interference, access, habitation) were reviewed in detail.

Before carrying out the economic analysis, power generation characteristics of the latest wind turbine-generator models were carefully studied to determine their suitability for the sites. The two models chosen for comparison were the 2.5 MW(e) MOD-2 wind generator and the 0.5 MW(e) Darrieus machine. Wind utilization factors for these models were computed on a seasonal basis with annual values determined for each of the models using wind speed power curves for the unit. Wind speeds were adjusted for altitude and computations carried out using Weibull and Rayleigh wind frequency distributions. The Weibull distribution was selected for the economic analysis.

A critical factor in the economic analysis was the definition of to whom the economic benefit or penalty accrues. Under present conditions, a remote site can be justified only on the basis of using existing utility transmission lines, owing to the high construction cost per mile for a new line. Present lines may be used under the terms of the New Hampshire Limited Energy Producers Act wherein power from the wind generator could be sold to the utility at $0.04 - 0.045/kWh(e), and the Navy could repurchase it at the Shipyard site under the current rate structure.

Operation of the wind turbine-generator under these conditions would actually be independent of any purchase. Yet, the State's economy would accrue a great deal of advantage if the power produced could displace that which would otherwise be generated from fuel oil.

As a consequence, three alternate ownership options were investigated: public (tax exempt), utility (taxable), and private (taxable). In utility ownership, the levelized cost of producing electricity by wind power, as compared with the levelized cost of producing it by alternate means, was evaluated in \$/kWh(e). For public or private ownership, the levelized cost of production using wind power was compared to the amount for which the electricity produced could be sold to the utility under the New Hampshire Limited Energy Producers Act. The rate of return on investment was also determined for both utility and private ownership.

Assuming credit for capacity can be claimed, Mt. Wolf is the most economically attractive of the seven selected sites for all three types of ownership. This is followed in order of attractiveness by: Crescent, North Moat, Randolph, Bald Cap, Kearsarge, and Croydon mountains. In addition, the MOD-2 machine is economically superior for all sites because of its higher annual utilization factor.

In assessing the priority of sites, there was little difference between the first five sites and any one of them could be selected over the others with only slight change in economic results. Therefore, final site selection should consider such factors as easy access, nearness to transmission lines, non-ruggedness of terrain, and avoidance of electromagnetic (TV, etc.) interference. These factors do not appear to cause serious problems for wind power in New Hampshire.

Since in all cases the savings in cost of producing electricity is sufficient to make the installation of a wind turbine-generator highly attractive, wind power appears to be beneficial to New Hampshire and would certainly improve the economic and energy environment in the State, regardless of ownership. The Portsmouth Navy Yard would share in this benefit along with all others in the State. IITRI recommends further studies be undertaken to identify the best sites in terms of local conditions (such as topography and relation to transmission lines) and to fully assess the economic benefit to be gained by wisely exploiting the wind energy resources of New Hampshire.

TABLE OF CONTENTS

TABLE OF CONTENTS
(Cont'd)

SECTION PAGE

TABLE OF CONTENTS
(Cont'd)

LIST OF FIGURES

LIST OF FIGURES (Cont'd)

LIST OF FIGURES (Cont'd)

LIST OF FIGURES (Cont'd)

LIST OF FIGURES (Cont'd)

LIST OF FIGURES (Cont'd)

LIST OF FIGURES (Cont'd)

LIST OF FIGURES (Cont'd)

LIST OF TABLES

LIST OF TABLES (Cont'd)

NEW HAMPSHIRE WIND ENERGY STUDY

1.0 INTRODUCTION

On June 4, 1979 IIT Research Institute (IITRI) entered into a contract with the Director, Navy Energy and Natural Resources R&D Office of the Naval Material Command, to investigate the potential of using wind energy in the Mount Washington area to supply power to the power companies of New Hampshire who in turn would sell energy as needed to the Portsmouth Naval Shipyard. A draft of a final report was required to be submitted to the Navy Energy Natural Resources Office by September 17, 1979.

The objective of this program is to undertake a four task assignment to investigate the feasibility of employing wind power in the Mt. Washington Area of the State of New Hampshire as a possible energy source to the New Hampshire power grid.

Task 1. Resource Assessment: A detailed wind energy resource assessment will be developed using available meterological data as well as topographic, and biological indications of wind energy.

Task 2. Institutional and Technical Considerations: In this task, barriers to the development of the wind energy resource in the Mt. Washington area for application to the Portsmouth Shipyard will be identified and documented. These barriers will include environmental, social, technical and other issues that may preclude development of the resource for the stated application.

Task 3. User Requirements: Based upon the electrical needs of the Portsmouth Shipyard provided by the Navy, the potential of the Mt. Washington area wind energy resource to satisfy a portion of these needs will be assessed using input from tasks 1 and 2.

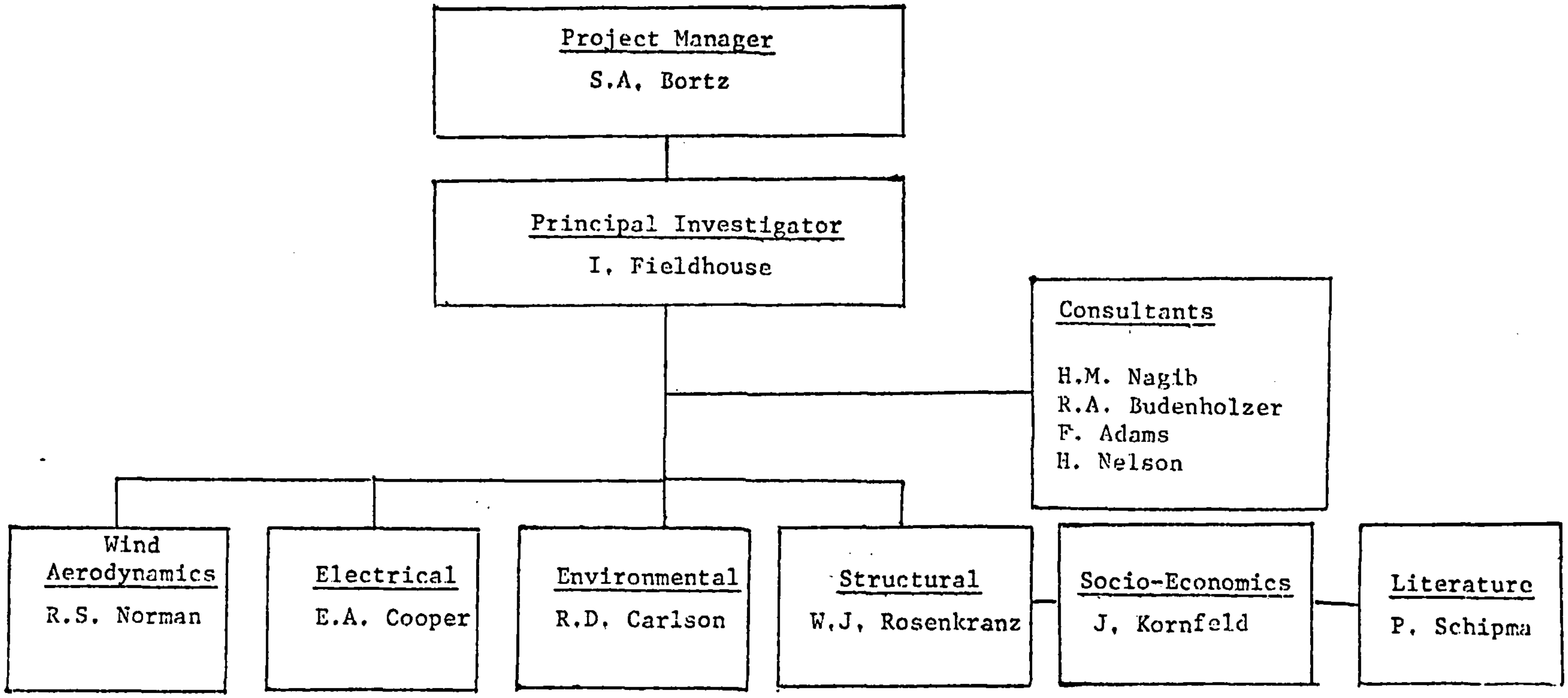
Task 4. Liaison with the Department of Energy Wind Energy Program: During pursuit of tasks 1 and 2 close liaison will be maintained with, and input will be sought from, Department of Energy organizations and contractors active in the wind energy area. It is particularly important to take input from the ongoing Department of Energy National Wind Characterization Program and the Wind Energy Generator and Power Conditioning Development Programs.

Based on the task requirements, IITRI assembled the team shown in Figure 1.1. This team was further supplemented by suggestions from Dr. Carl Aspliden of the Department of Energy Wind Office Headquarters. Dr. Ross B. Corotis of Northwestern University, Evanston, Illinois was added to the team to do wind characterization studies and Dr. Robert Porter of Illinois Institute of Technology was added to perform the related economic analysis. In addition information and cooperation was obtained from the Governor's Council on Energy from the State of New Hampshire; wind data from the New Hampshire State Forestry Service; icing information from the State Clinotologist, Dr. G. Pregent; and data on power generation and the power grid system from the Public Service Company of New Hampshire. These sources also recommended others which were able to provide considerable data regarding availability of wind energy in the State of New Hampshire.

Using this information as our data base, siting studies were made which indicated that there was potential for a wind energy system in New Hampshire. The analysis showed very high correlation for wind energy between the Mount Washington summit and low level sites for time of day and season of the year. Based on this work, it was decided to obtain specific data from seven sites in the Mt. Washington area and use this input to determine potential wind turbine generator sites. This work indicated that sixty potential sites at approximately the 3000 foot level would produce average 20 mph winds all year round. This is adequate for operation of most wind energy systems. From this information, seven sites appear to be promising with regard to siting close to the New Hampshire Public Service Company

Figure 1-1

PROJECT ORGANIZATION CHART



power grid system. It appears to us that this work is important in that it provides a mechanism for using past information as a data base for site modeling and selection which will greatly reduce the amount of additional new data required for this purpose. The limitation for this type of analysis is that local wind characteristics for a 10 year period from a nearby site must be available as a data base for the analysis.

A review of both the MOD-2 and Darrieus machines was made for potential use in the Mt. Washington area. This information was obtained from visits to Sandia Laboratory in New Mexico (Darrieus) and NASA/Lewis in Cleveland, Ohio (MOD-2). Socioeconomic as well as legal considerations were taken into account with regard to placement of units at the potential sites. The personnel at the Energy Law Institute, Franklin Pierce Law Center in New Hampshire, were very helpful in providing needed information.

Costs of electric energy production generated with present facilities at the Portsmouth Naval Shipyard and also costs of power generated by the Shipyard were formulated. These may be compared to estimated wind generator production costs of electric energy fed into the Public Service Company of New Hampshire lines from various potential wind energy sites. Based on the data and analysis provided in this study, it is our opinion that wind energy conversion systems can be usefully developed in New Hampshire and could provide power for the State as well as supplement the power needs of the Portsmouth-New Hampshire Shipyard. This would also result in significant savings in fuel oil consumption.

2.0 WIND ENERGY CONVERSION SYSTEMS

There are two wind machine designs currently under development and production in the United States: the horizontal axis and the vertical axis concepts. Substantially greater technical efforts have been devoted to the horizontal axis machines.

2.1 Horizontal Axis Wind Turbines

In 1973, the Federal government designated the NASA-Lewis Research Center as the responsible agency for large, horizontal axis wind turbines. The first large system (designated MOD-0) became operational at a NASA site in Sandusky, Ohio in 1975. This machine has been used as a research facility by NASA to study performance parameters, machinical design and in-service problems. The MOD-0 unit is a 2-bladed design with 125-foot rotor diameter rated at 100 kW(e). Using the operating experience of the MOD-0 unit, the Department of Energy sponsored construction of three MOD-0A units [200 kW(e)] with planned installation of a fourth unit in 1980.(1)

Location of 200 kW(e) Units	Installation Date
Clayton, N.M.	Nov. 1977
Culebra, Puerto Rico	July 1978
Block Island, Rhode Island	May 1979
Kaena Pt., Oahu, Hawaii	1980 (planned)

The MOD-0A units are similar to the MOD-0 unit except for a larger generator and a larger gearbox yielding a total capacity of 200 kW(e).

In July 1979, a MOD-1 unit was put into operation at Boone, North Carolina. The MOD-1 project was begun in 1974 with the following design parameters:(2)

Rated Power: 2000 kW(e)
Rotor: 2-bladed, 200-ft diameter
Control: Full open pitch control

Rotational Speed: 35 RPM (constant)
Prime Contractor: General Electric Co.

The largest horizontal axis machine now under development in the United States is the MOD-2 project. Initiated in 1976 by DOE with the Boeing Engineering and Construction Company, this unit is designed to produce 2500 kW(e) of electricity at economical rates. The MOD-2 has a 200 ft. tower with a 2-bladed, 300 ft. diameter rotor operating at 17.5 RPM. With respect to electricity costs, Fig. 2.1 shows a comparison of costs for the three designs: MOD-OA, MOD-1, and MOD-2. As can be seen, the reduction of electricity costs with increasing machine size is dramatic. The improved technology for MOD-2 units reduces the cost to about \$0.04/kWh(e) at a mean wind speed of 18 mph for the 100th machine.(3) NASA-Lewis has recently issued a request to industry to submit proposals for a MOD-3 concept. The primary objective for this future concept is to provide electricity at \$0.02-\$0.03/kWh(e).

MOD-2 Design

Since the MOD-2 design is the only large horizontal axis wind energy conversion system (WECS) in the final design stage which provides economical electricity, the details of this unit are presented here. An artist's concept of an installed MOD-2 unit is presented in Fig. 2.2. The MOD-2 is rated at 2.5 Mw(e) capacity with the following operational parameters as a function of wind speed:

	Wind Speed, mph	
	at hub height (200 ft.)	at 30 ft.
Rated power	27.7	19.9
Cut in	14	8.7
Cut out	45	35.4

At wind speeds above the cut in speed, the MOD-2 will be delivering power. At 30 ft. height wind speeds of 19.9 to 35.4 mph, the MOD-2 unit will deliver the rated power of 2.5 Mw(e). No power is produced at wind speeds over 35.4 mph (30 ft. height).

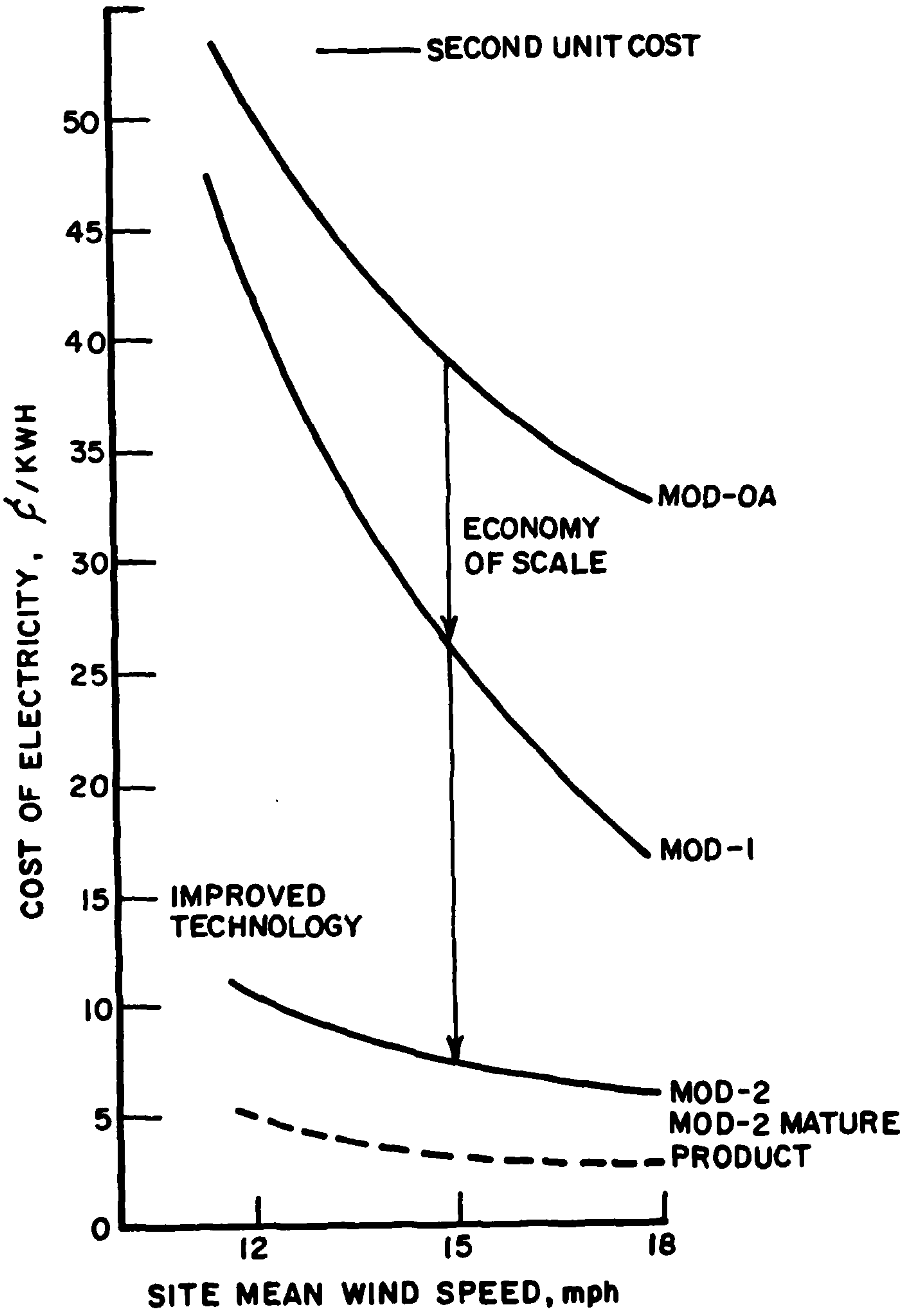


Figure 2.1 Cost of Electricity for Large Horizontal Axis WECS[3]

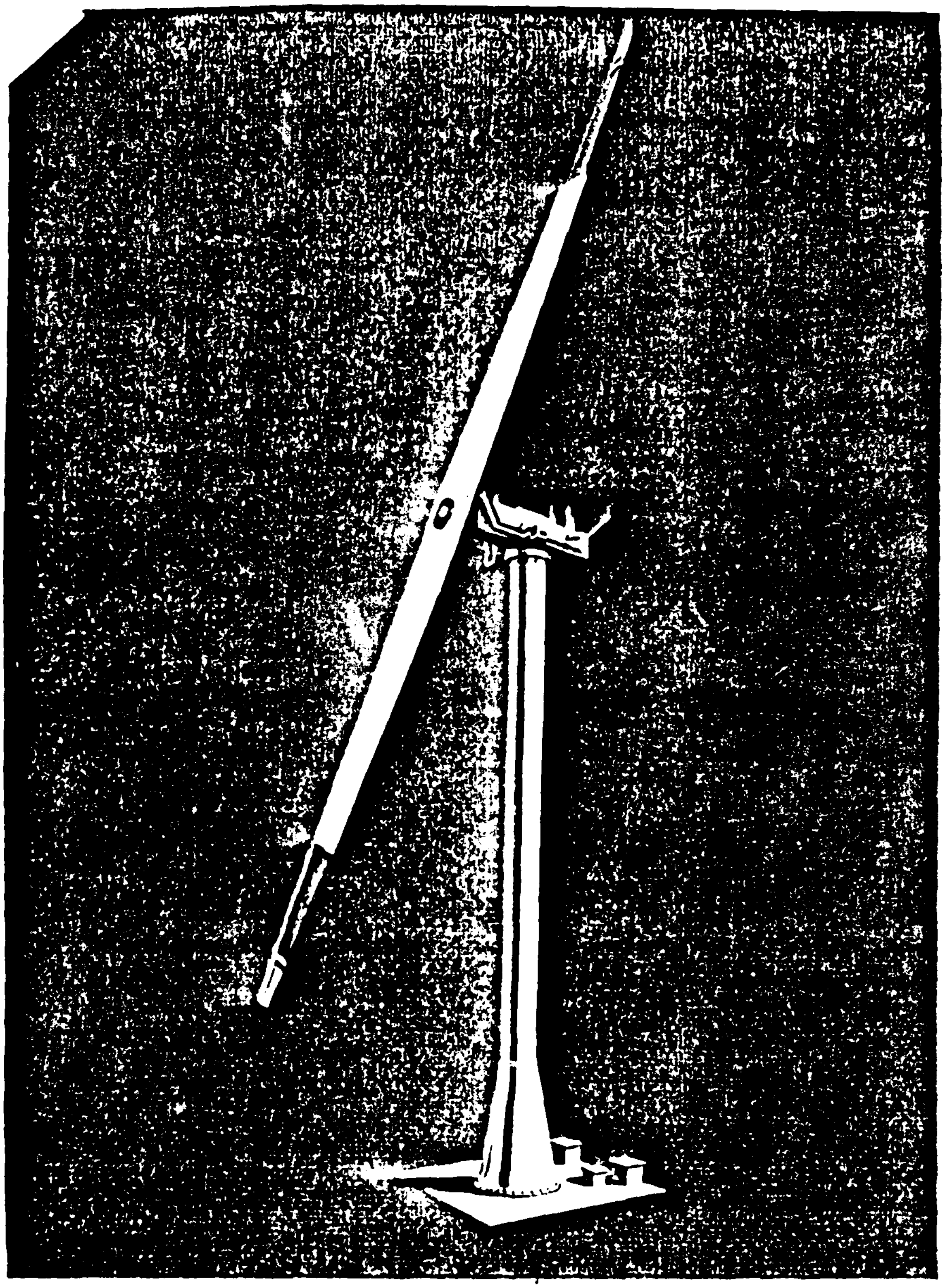


Figure 2.2 MOD-2 Artist Conception

Exhibit II-1

The overall MOD-2 geometry is shown in Fig. 2.3.(4) Distinguishing features are:

- upwind, 2-bladed rotor with 300 ft. diameter
- outer 45 ft. of each blade is controllable
- cylindrical steel tower
- teetering hub for rotor

The blade area constitutes 3% of the rotor disc area, and the rotor rpm is 17.5. A three-stage, planetary gear box is used to step up the rotor rpm to 1800 rpm for compatibility with a 4160 volt, 2500 kW(e) synchronous generator. The gearbox is an advanced Swedish design with very low overall weight. The power coefficient (Cp, fraction of total wind energy captured) for the rotor is 0.4 or greater for a hub height speed range of 18-25 mph. The coefficient peaks at 0.415 at 20 mph.

Under severe storm conditions, the MOD-2 is designed to survive winds up to 120 mph. Should ice form on the blades, the unit would be automatically stopped until icing conditions abated.

With respect to machine costs, the second and third units are expected to cost $4 million each with projected electricity costs of about $0.08/kWh(e). The first three MOD-2 units are planned for installation at one site (to be selected) in 1980. For future production plans, at a rate of 8 units per month, the 100th machine would cost approximately $2 million and operate at a projected electricity cost of about $0.04/kWh(e).

2.2 Vertical Axis Wind Turbines

In 1925, G.J.M. Darrieus patented the concept of a vertical axis wind turbine. Today, the Darrieus design has evolved to a fixed-pitch design with 2 or 3 curved blades attached at both ends to a rotating, vertical tower. The blade shape approximates a freely turning rope where the major stresses are expected to be purely tension. In 1974, the Department of Energy designated

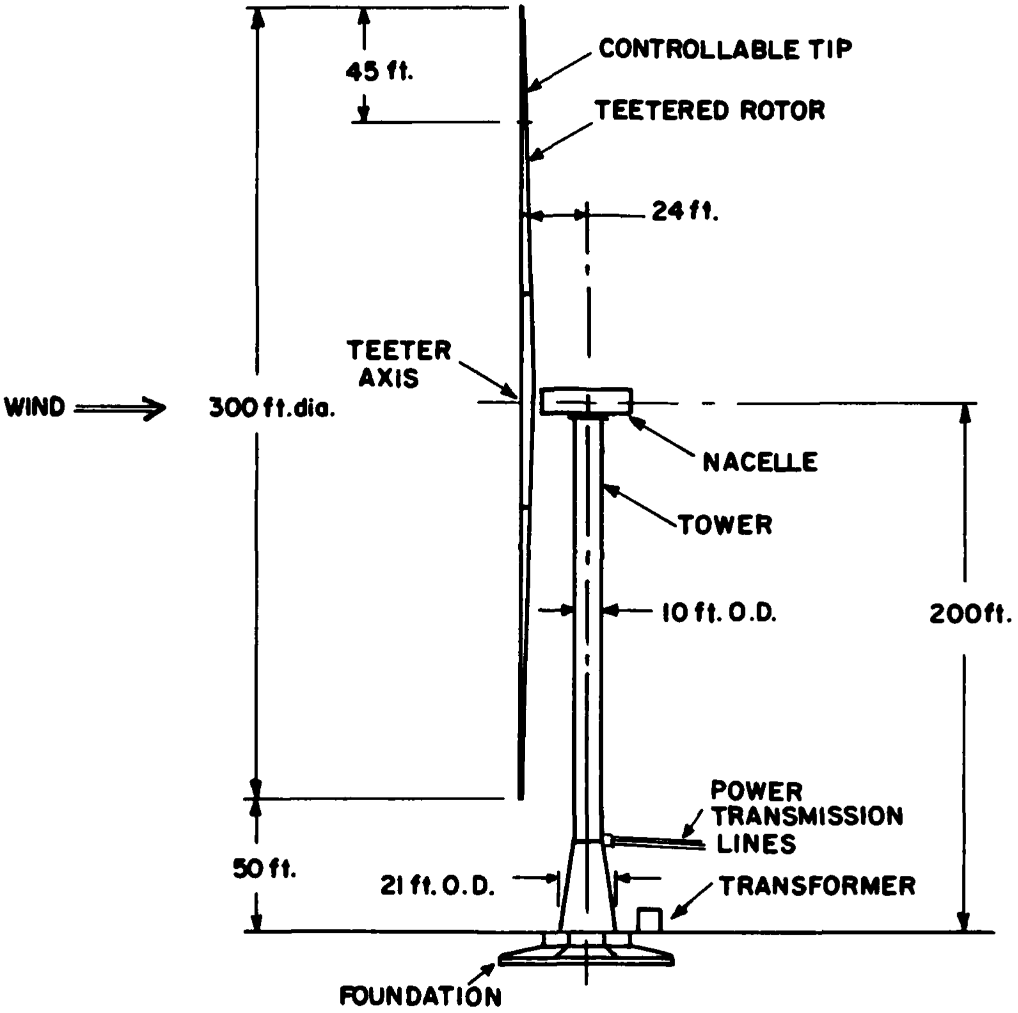


Figure 2.3 Geometry of MOD-2 Horizontal Axis WECS (Ref. 4)

Sandia Laboratories as the center for Federally-supported vertical axis systems. Since that time, Sandia has developed the Darrieus concept (sometimes called the "eggbeater" design) into efficient, power generation systems. The largest unit currently operating at the Sandia facility in Albuquerque, N. Mexico is shown in Fig. 2.4. The 17 meter high rotor is shown with two extruded aluminum blades. This unit has been operated with several two and three-blade configurations up to 60 kW(e) power output. While Sandia has operated small, research units (5 and 17 meter sizes), the National Research Council of Canada has operated a 200 kW Darrieus design on Magdalen Island in Canada. Interestingly, the Magdalen Island unit failed under unusual circumstances. A maintenance team left the machine unattended overnight without the brake system engaged. The machine self-started under varying wind conditions, accelerated to twice the normal rpm rating, and ultimately failed structurally after several hours operation at very high speed. Significantly, the blades did not disintegrate or fail catastrophically. One of the guy wires failed so that the vertical tower fell over. This occurence indicates that under runaway conditions the Darrieus machines will fail in a noncatastrophic manner while the MOD-2 unit blades would fly apart catastrophically and could cause damage because of flying parts. The Magdalen Island unit is being replaced, and the Canadian effort is being directed toward multimegawatt Darrieus machines.

The Alcoa Company has made a firm committment to the design and construction of large, Darrieus machines.(5) Alcoa has been a supplier of blades for the 17 meter unit at Sandia. Currently Alcoa is prepared to manufacture and install Darrieus machines from 8 to 500 kW(e) capacities. As with the horizontal axis machines, the investment and electricity costs per kilowatt hour decrease substantially as size increases. The largest machine currently (1979) available for production is shown in Fig. 2.5. This unit is 123 ft. high and 82 ft. in diameter. It has a generator

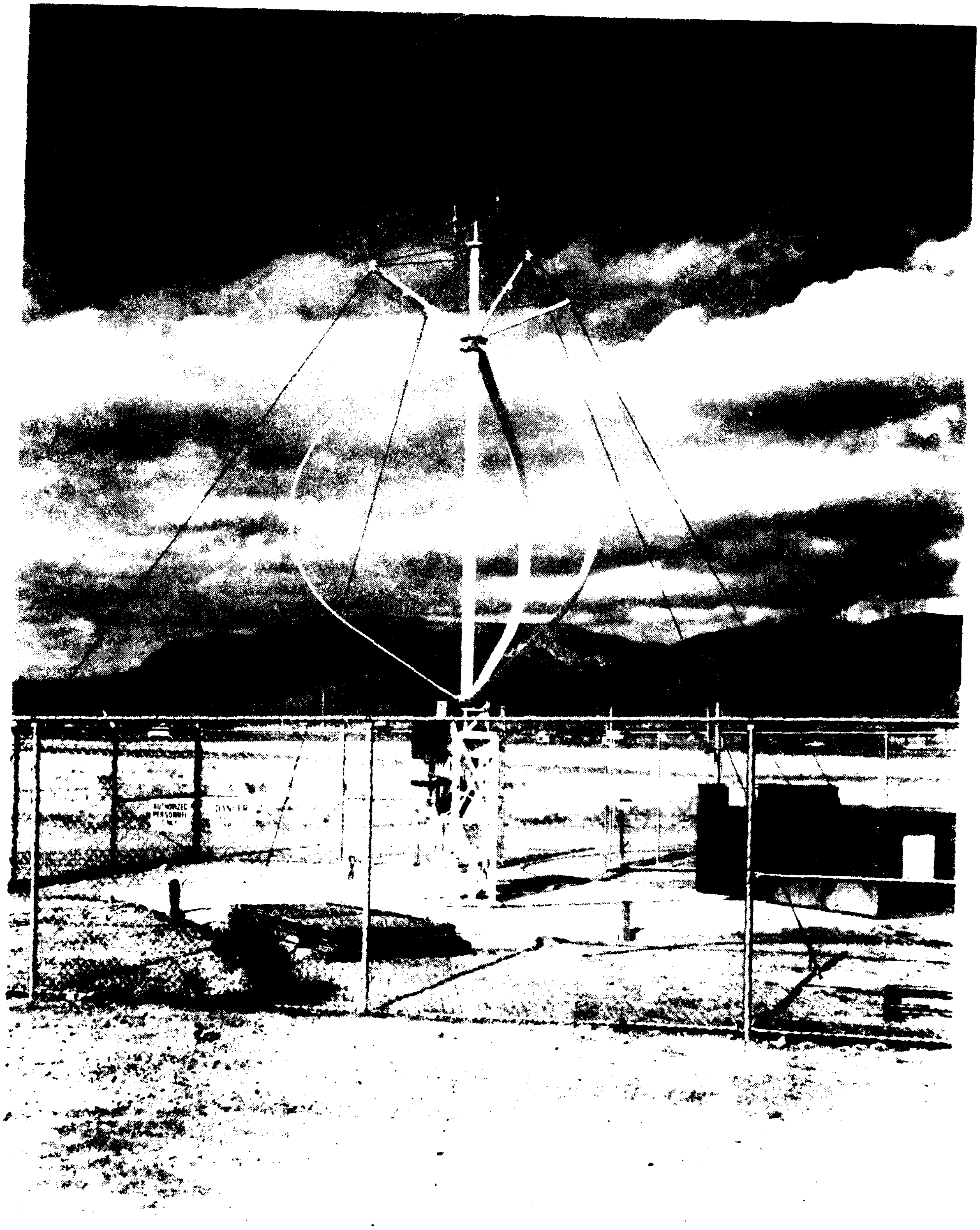


Figure 2.4 Darrieus Vertical Axis Wind Turbine

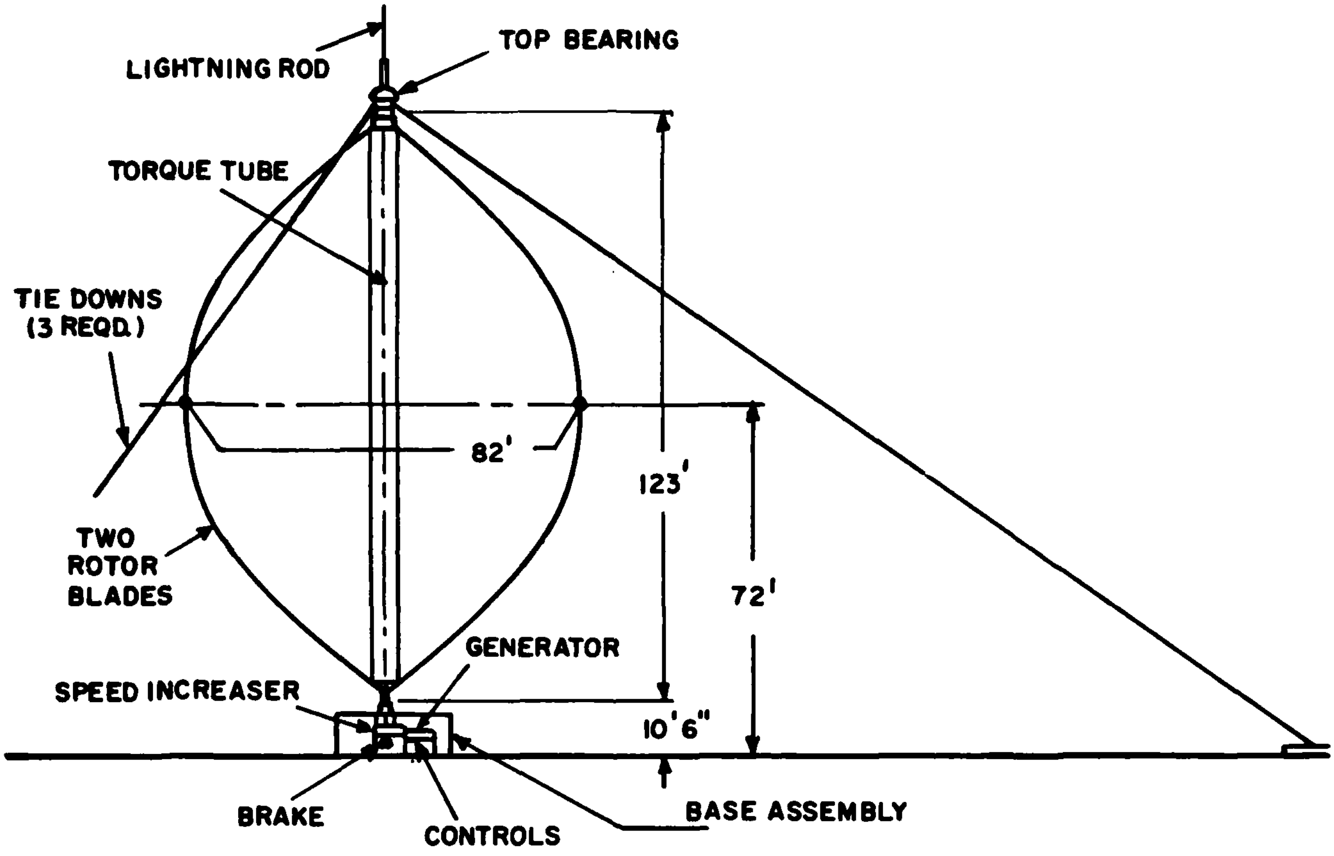


Figure 2.5 Alcoa Design for 500 kW Vertical Axis WECS(5)

capacity of 500 kW(e) which is reached with a reference wind speed of 35 mph at 30 ft. height. The nominal rotor speed of 41 rpm is stepped to the full load speed of 1825 rpm with a speed increaser located near ground level at the base of the torque tube.

The power coefficient for the 2-bladed Alcoa design has been measured on the 17 meter unit at Sandia to be 0.42-0.45. Therefore, the aerodynamic efficiency of the 500 kW(e) Alcoa design is expected to be approximately equal to the MOD-2 design. With respect to costs, Alcoa has established an installed cost (first quarter 1979 dollars) of $190,000 for the 500 kW(e) unit and estimated the typical electricity costs at $0.02-$0.04/kWh(e). Two of these units will be installed during the first half of 1980.(6)

Proponents of the Darrieus concept list the following advantages:

- No power control is required since wind is accepted from all directions.
- No pitch control is required since the concept is self-regulating at a constant rpm.
- Machinery components are at ground level.
- No tower shadow effect.

The planning for megawatt or multimegawatt machines has begun at Alcoa. The limiting factor for larger machines is the blade extrusion technology which is now limited to 29 inch chord blades. The megawatt machines will require blade chords of 3 ft. to nearly 10 ft. This blade technology is not expected before 1983.

3.0 SITE CHARACTERISTICS

In order to adequately place a wind energy system, a considerable amount of study must be devoted to the wind characteristics and topography in the area. This will include wind direction, average speed, type of terrain (rolling or flat and heights of potential sites), continuity of wind velocity, and effect of changing seasons.

3.1 Wind Characteristics

Long term wind characteristics are required for potential WECS sites. At least 2 years of data should be presented, for a given site, along with information from a nearby weather station for at least 10 years. Since the available wind power varies as the cube of the average wind speed, one mph variation in average speed can produce significant changes in the long term output of any WECS. For example, if a proposed site actually had an average wind speed of 13 mph rather than the expected 14 mph, the available power would be reduced by 20%. For lower averages, the variations are more dramatic. An actual speed of 9 mph instead of a predicted 10 mph produces a drop of 27% in available power. Therefore, accurate long term characteistics are extremely important.

3.1.1 Required Parameters

The average, annual wind speed at a site is used only for gross selection processes. In order to predict the annual power output from a given WECS system, much more information is required. Most wind information is referred to a standard elevation of 30 ft. above ground. For large WECS installations, the local speed versus height distribution would be desirable--especially the hub height values for horizontal axis WECS. For one or more elevations, the following information is required.

- Mean wind speed
  Method of calculation should be included.

- Wind speed frequency in percent
  For specific speed increments, the percent of observations in each increment as well as a cummulative total is required.

- Wind direction frequency in percent
  Here, the percent of observations at each wind direction is required.

- Wind speed and direction joint frequency in percent
  Here, a cross-tabulation of fraction of observations versus speed and direction is required.

These are the basic parameters which are required for WECS siting. For even greater accuracy, hourly wind speed statistics should be compiled so that hourly wind power (proportional to U^3) could be calculated. Statistics are also summarized by season of the year and month as well as annual data. Finally, the persistence of winds of discrete speed ranges can also be computed so that the expected duration of speed increments can be recorded. In summary, comprehensive wind statistics are required to accurately characterize a given WECS site.

3.1.2 Evaluation of Wind Environment in New Hampshire

In order to select appropriate sites for large WECS installations, the wind environment of the State of New Hampshire had to be evaluated. It was well known that Mt. Washington had extremely high wind conditions at the summit. Peak winds on Mt. Washington often are over 100 mph. On April 12, 1934, a sudden storm on Mt. Washington produced a peak gust of 231 mph.(7) The area surrounding Mt. Washington is called the White Mountain region of New Hampshire - located in the northern part of the state. The lower part of New Hampshire is designated as the

Eastern New England Upland region while the Coastal region is called the Coastal Lowlands. Since these three regions have quite different topology and weather conditions, it is important to obtain wind data for each region. The basic question to be resolved is:

- Do the three regions of New Hampshire have similar wind patterns or are they completely independent?

3.1.2.1 U.S. Weather Bureau Data for Lower New Hampshire

The first step in resolving the question of wind patterns and in obtaining long term wind data was to evaluate past U.S. Weather Bureau data for New Hampshire. The following seven cities are listed as having some wind data available through the U.S. Weather Bureau:

City	Location	Weather Bureau I.D. No.	Period of Record
Berlin	-	94770	6/50-9/60
Concord	Municipal Airport	14745	1/60-12/70
Durham	-	94714	12/39-12/42
Keene	Dillant-Hopkins Airport	94721	9/62-8/67
Lebanon	FAA	94765	1/59-12/64
Manchester	Grenier AFB	14710	4/38-9/57
Portsmouth	Pease AFB	04743	4/56-12/70

To evaluate the statistical wind data available at these sites, IITRI requested that Dr. Ross B. Corotis act as a consultant on the project. Dr. Corotis agreed to this arrangement and to utilize several computer programs, which he had developed, to analyze the available data.(8,9) Consequently, the IITRI techniques for evaluating and reducing the wind information reflect Dr. Corotis' methods.

IITRI requested magnetic tape data from the National Climatic Center (NCC) in Asheville, N. Carolina for all of the above seven sites. For three of the listed sites, no data were available on tape. IITRI received magnetic tape data from NCC for the following sites and time periods:

City	Period of Record	No of Years
Concord	1/1/48 - 12/31/64	17
West Lebanon	1/1/49 - 12/31/58	10
Lebanon	1/1/59 - 12/31/64	6
Manchester	4/1/51 - 3/31/67	16
Portsmouth	4/1/56 - 12/31/74	18.7

The definition of two sites in Lebanon, N.H. occurred when the Federal Aviation Administration operated the site after Jan. 1, 1959. Therefore, two sets of data were evaluated for Lebanon, N.H.

The taped data was delivered to Dr. Corotis where the following information was derived using the Northwestern University Computer Center:

- Average wind speed, variance, standard deviation and skewness as a function of month, season and year.
- Average wind power (velocity cubed), variance, and standard deviation as a function of month, season and year.
- Histrogram of wind direction as a function of season.
- Cross tabulation of wind speed and direction as a function of season.
- Persistence of wind run for several speed ranges.
- Autocorrelation function for different seasons.
- Crosscorrelation function for city pairs for specific time periods.

Distributions of wind speed as a function of the total number of observations for four seasons are presented for the Concord site in Figs. 3.1 through 3.4. The average wind speed for the 17 year period ranged from 2.3 m/sec in summer to 3.4 m/sec in winter. Average available wind power in watts/m^2 is also shown for each season. Similar plots for the other four sites are shown in Figs. 3.5 through 3.20. The monthly average wind speeds are shown in Figs. 3.21 through 3.25 for the respective cities. Fig. 3.26 shows a comparison of all 5 cities. The average annual wind speed and available power are summarized here:

City	Average Annual Wind Speed, m/sec	Average Annual Wind Power, watts/m^2
Concord	2.9	50
W. Lebanon	2.3	41
Lebanon	2.1	35
Manchester	2.2	39
Portsmouth	3.4	67

It is clear that none of these sites is favorable for location of a large WECS.

The most important data to be derived from the NCC tapes for this study are the crosscorrelation results. The general crosscorrelation function can be written as:

$$R_{xy}(\tau) = E[X(t) \cdot Y(t+\tau)]$$

where X(t) and Y(t) are independent functions of time t, and τ is a time log parameter. Then, if X(t) and Y(t) are the wind statistics at sites X and Y, the crosscorrelation between these two sites would give a comparison of how the sites may or may not relate to each other. If the crosscorrelation is zero or very small, there is no similarity of statistics between the two sites. If the correlation coefficient is 1.0, then each site is experiencing the same phenomenon. Correlation coefficients above 0.5 indicate that each site is behaving similarly. Note that data for exactly

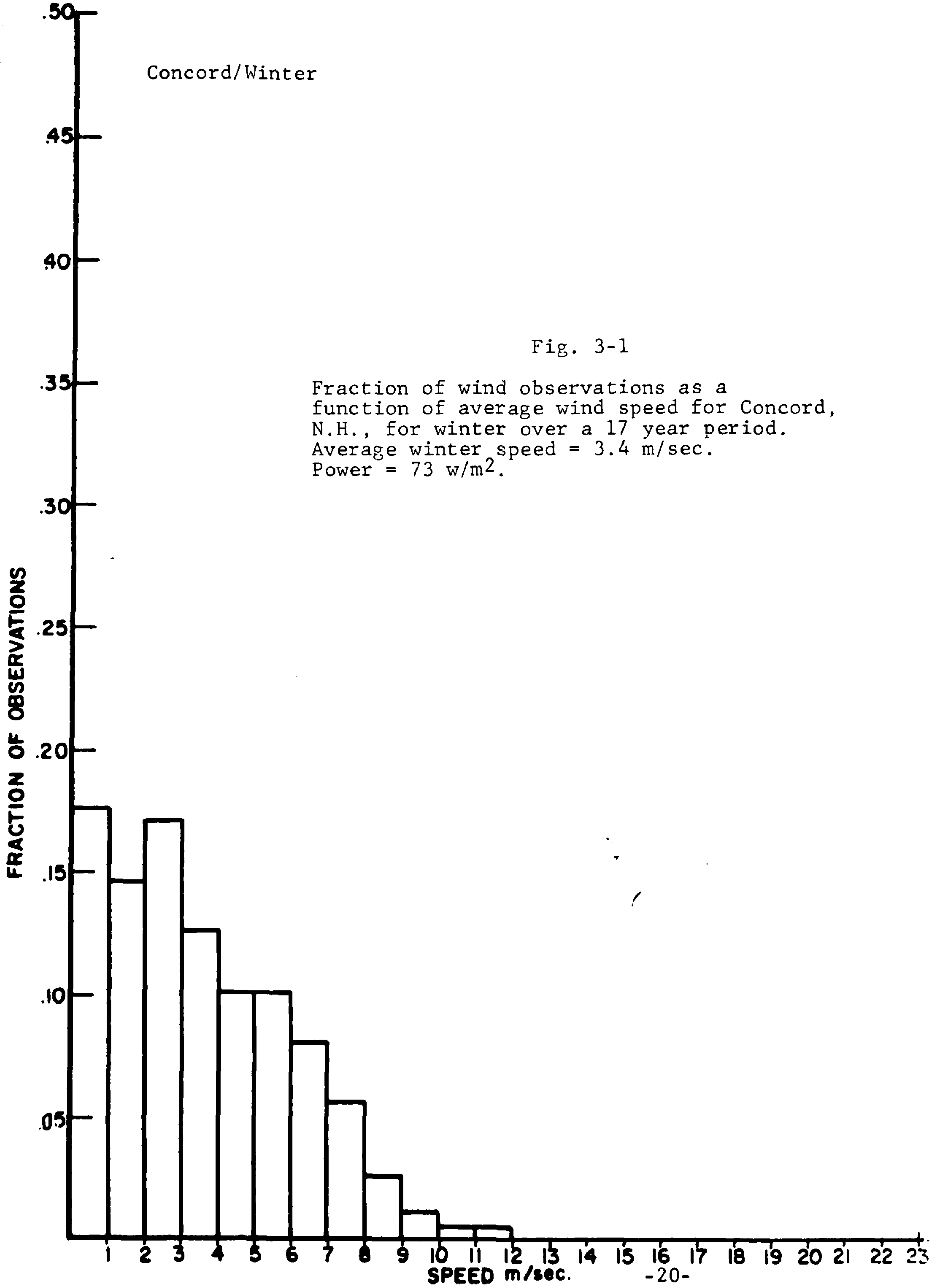


Fig. 3-1

Fraction of wind observations as a function of average wind speed for Concord, N.H., for winter over a 17 year period. Average winter speed = 3.4 m/sec. Power = 73 w/m^2.

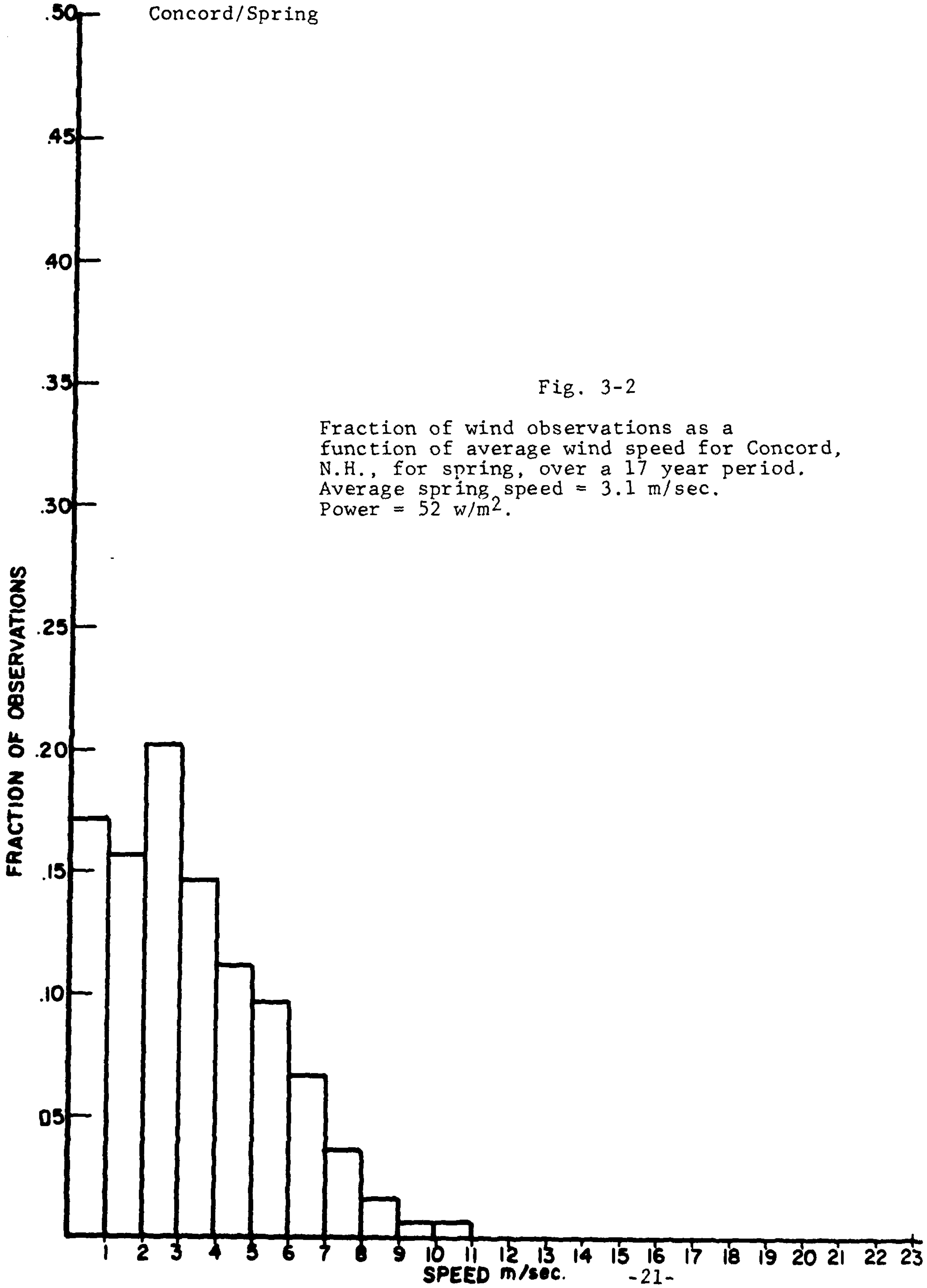


Fig. 3-2

Fraction of wind observations as a function of average wind speed for Concord, N.H., for spring, over a 17 year period. Average spring speed = 3.1 m/sec. Power = 52 w/m^2.

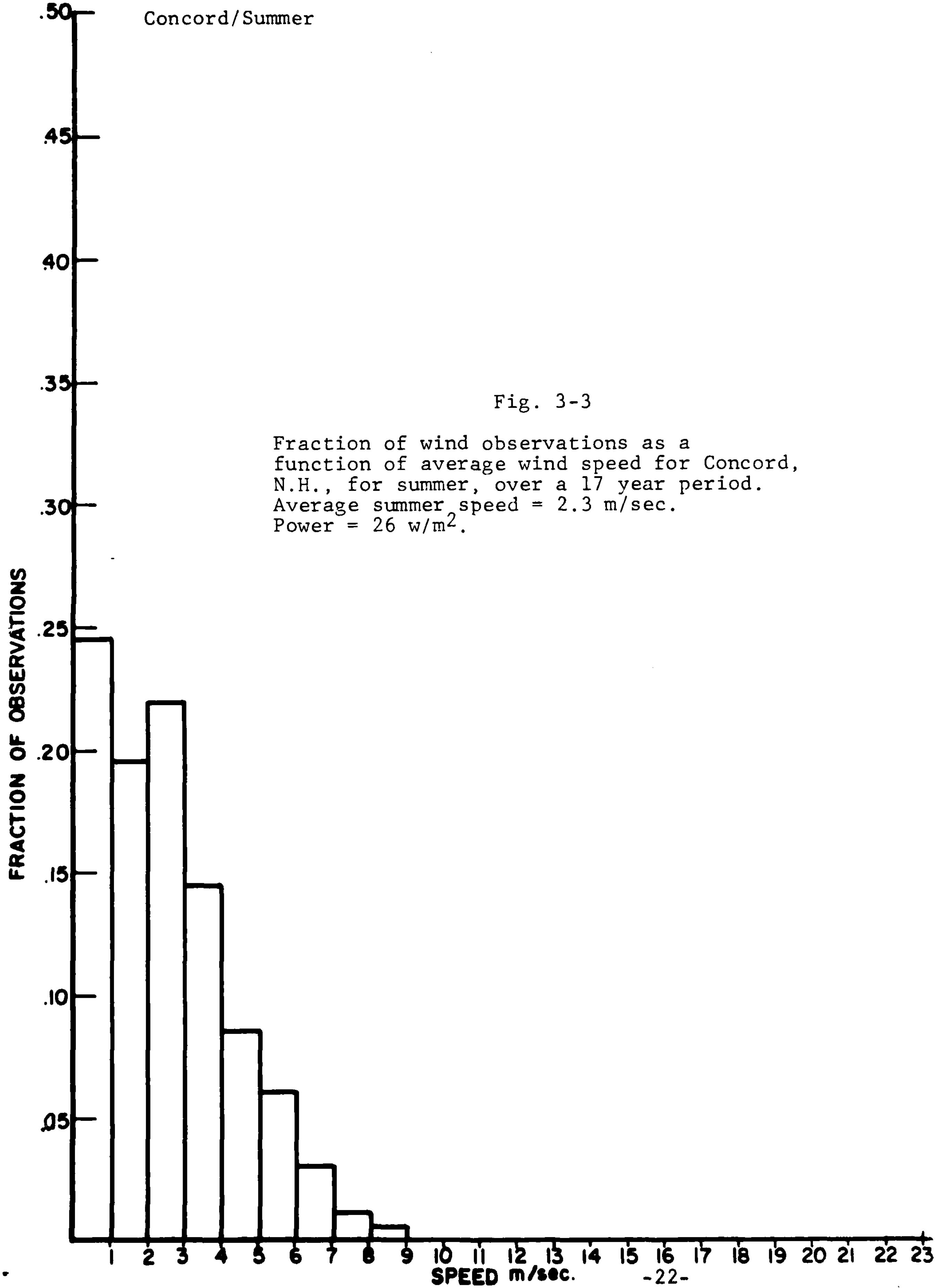


Fig. 3-3

Fraction of wind observations as a function of average wind speed for Concord, N.H., for summer, over a 17 year period. Average summer speed = 2.3 m/sec. Power = 26 w/m^2.

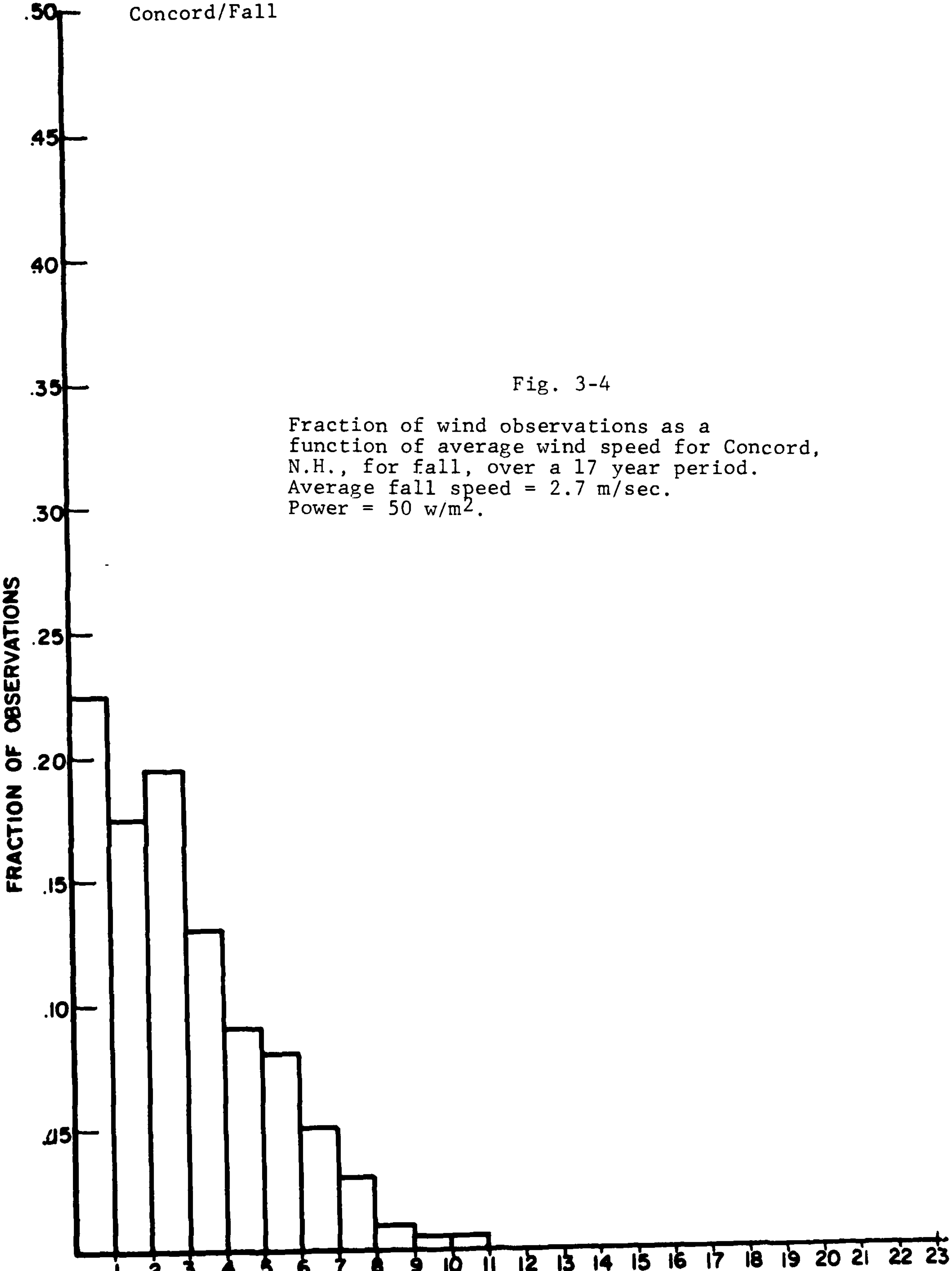


Fig. 3-4

Fraction of wind observations as a function of average wind speed for Concord, N.H., for fall, over a 17 year period. Average fall speed = 2.7 m/sec. Power = 50 w/m^2.

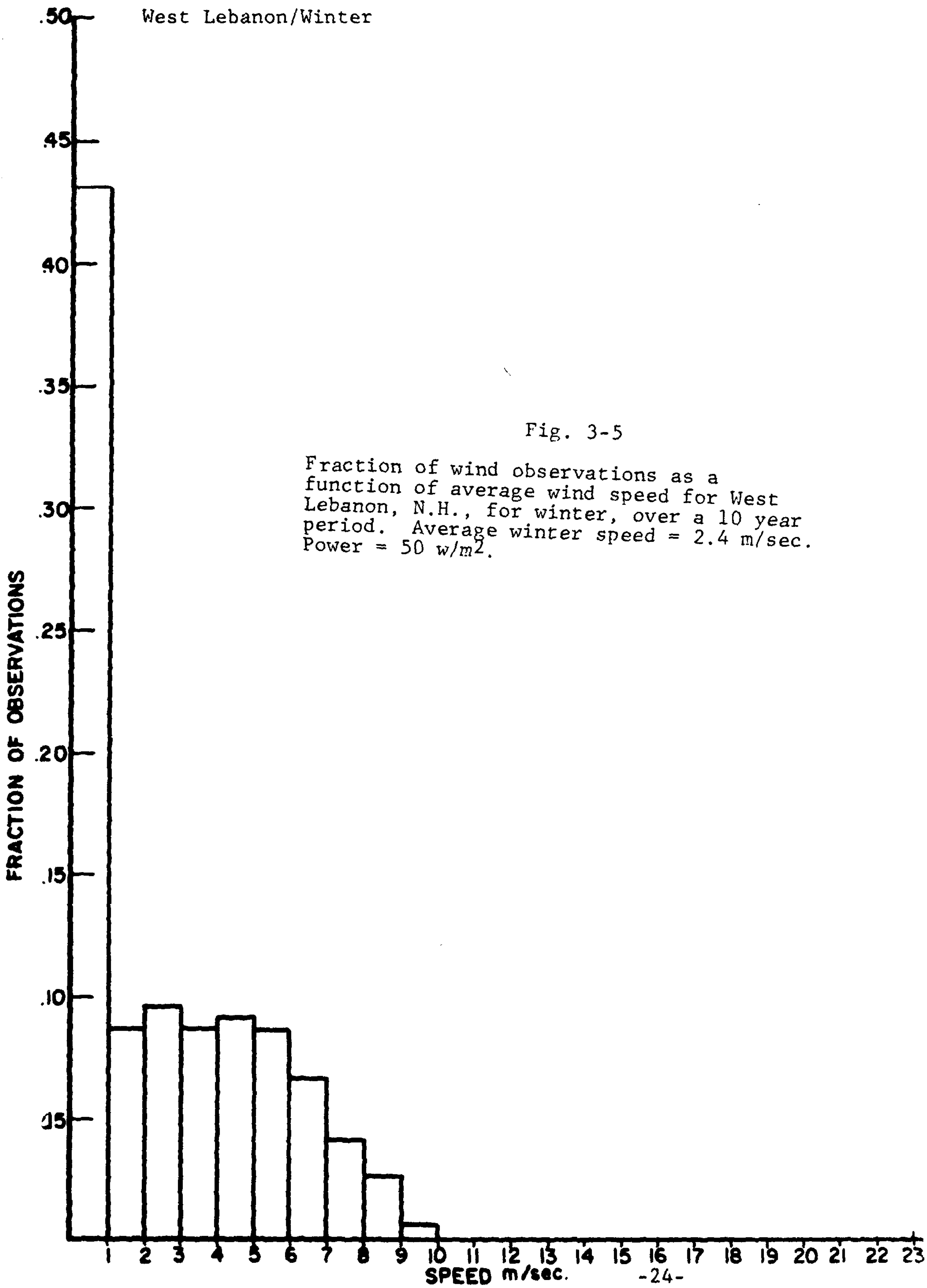


Fig. 3-5

Fraction of wind observations as a function of average wind speed for West Lebanon, N.H., for winter, over a 10 year period. Average winter speed = 2.4 m/sec. Power = 50 w/m2.

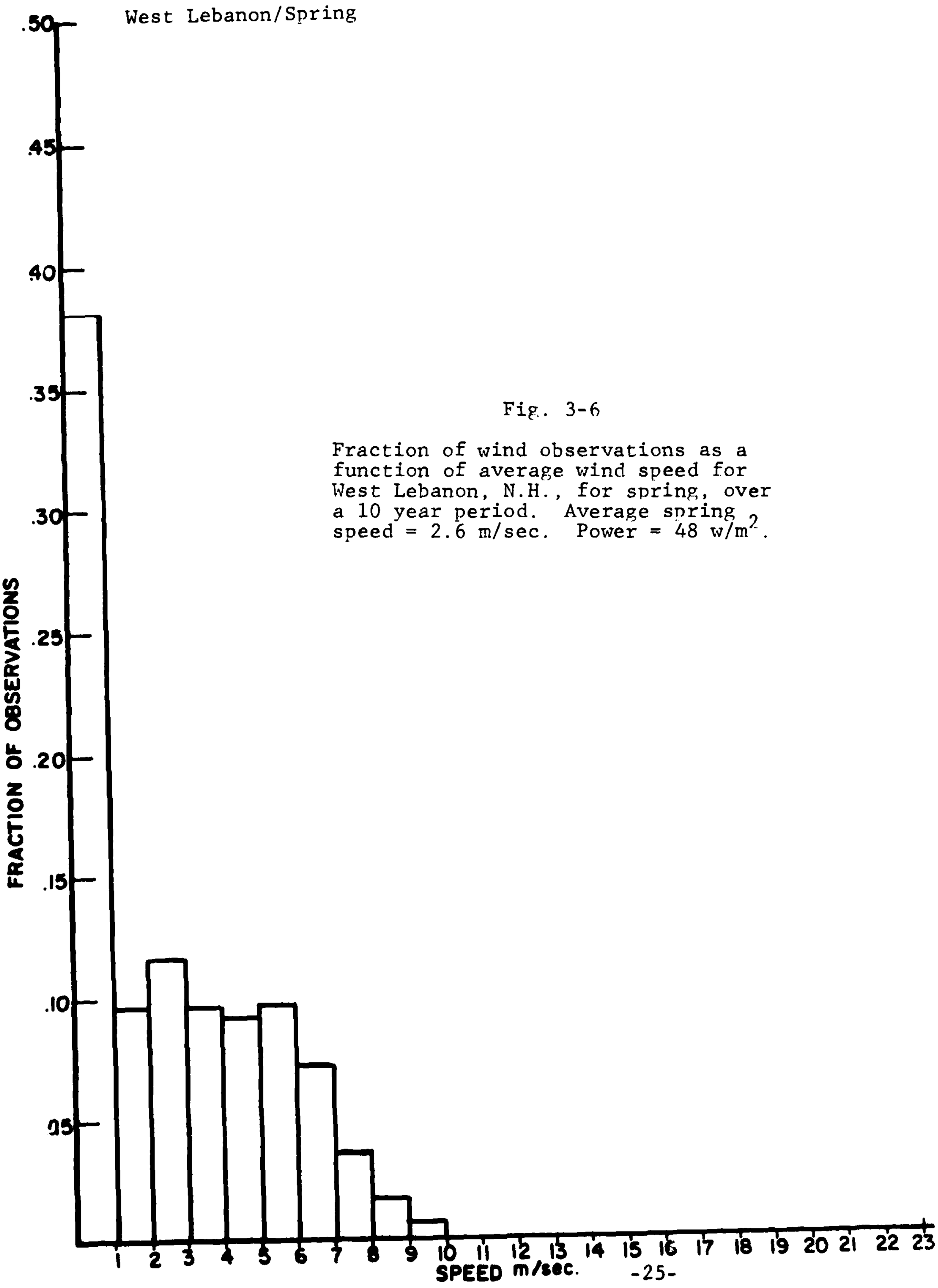


Fig. 3-6

Fraction of wind observations as a function of average wind speed for West Lebanon, N.H., for spring, over a 10 year period. Average spring speed = 2.6 m/sec. Power = 48 w/m^2.

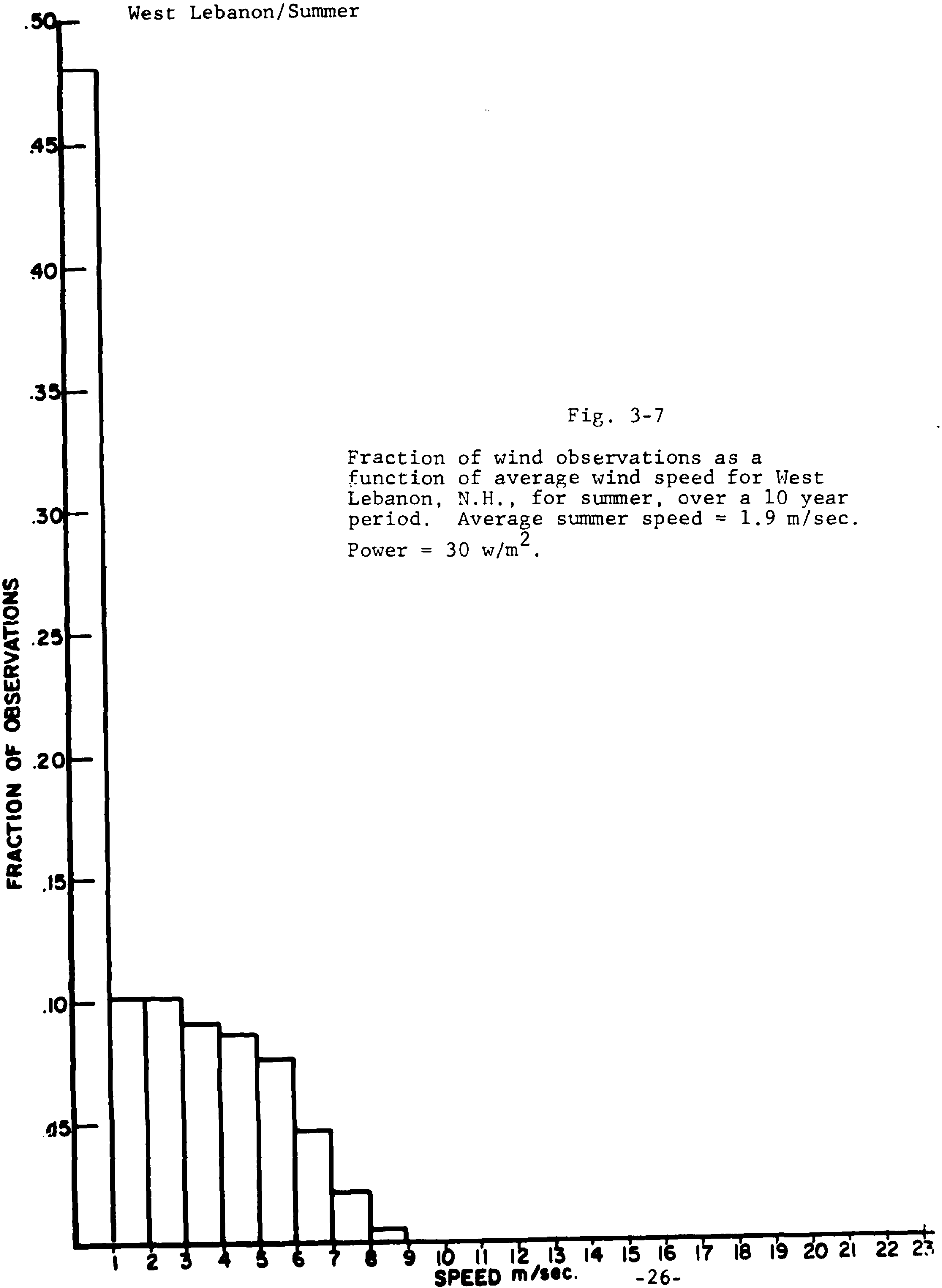


Fig. 3-7

Fraction of wind observations as a function of average wind speed for West Lebanon, N.H., for summer, over a 10 year period. Average summer speed = 1.9 m/sec. Power = 30 w/m^2.

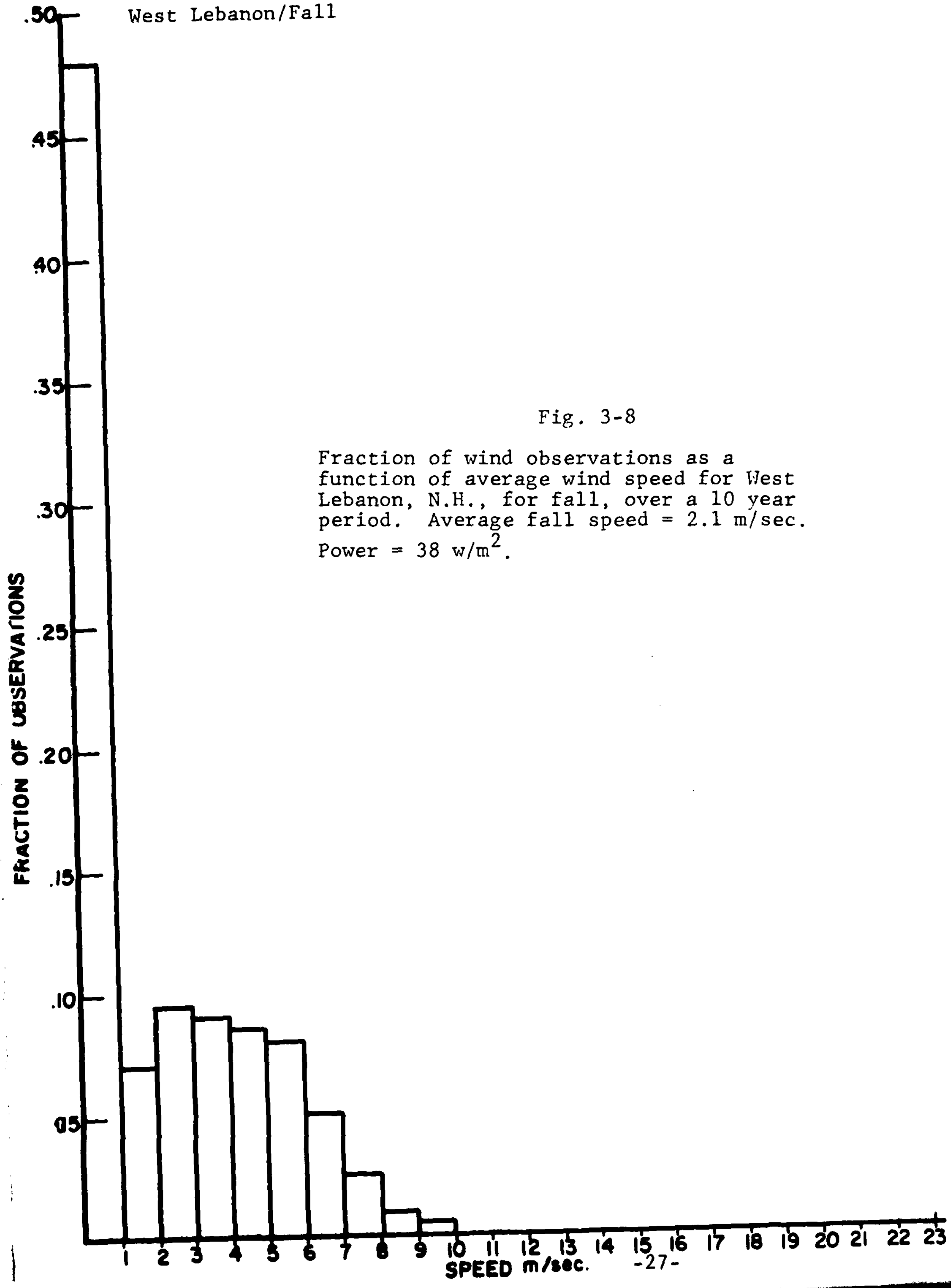


Fig. 3-8

Fraction of wind observations as a function of average wind speed for West Lebanon, N.H., for fall, over a 10 year period. Average fall speed = 2.1 m/sec. Power = 38 w/m^2.

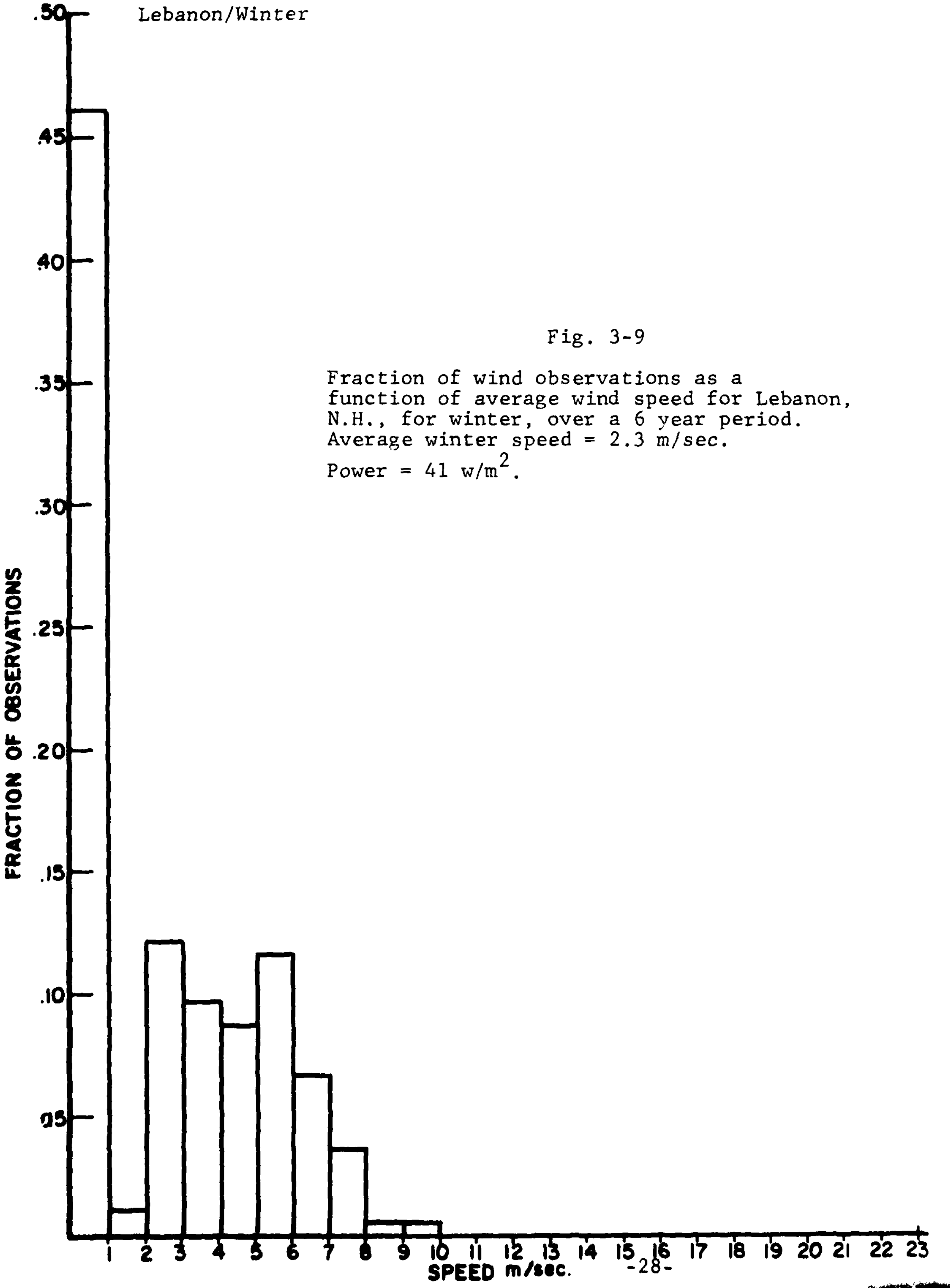


Fig. 3-9

Fraction of wind observations as a function of average wind speed for Lebanon, N.H., for winter, over a 6 year period. Average winter speed = 2.3 m/sec.

Power = 41 w/m^2.

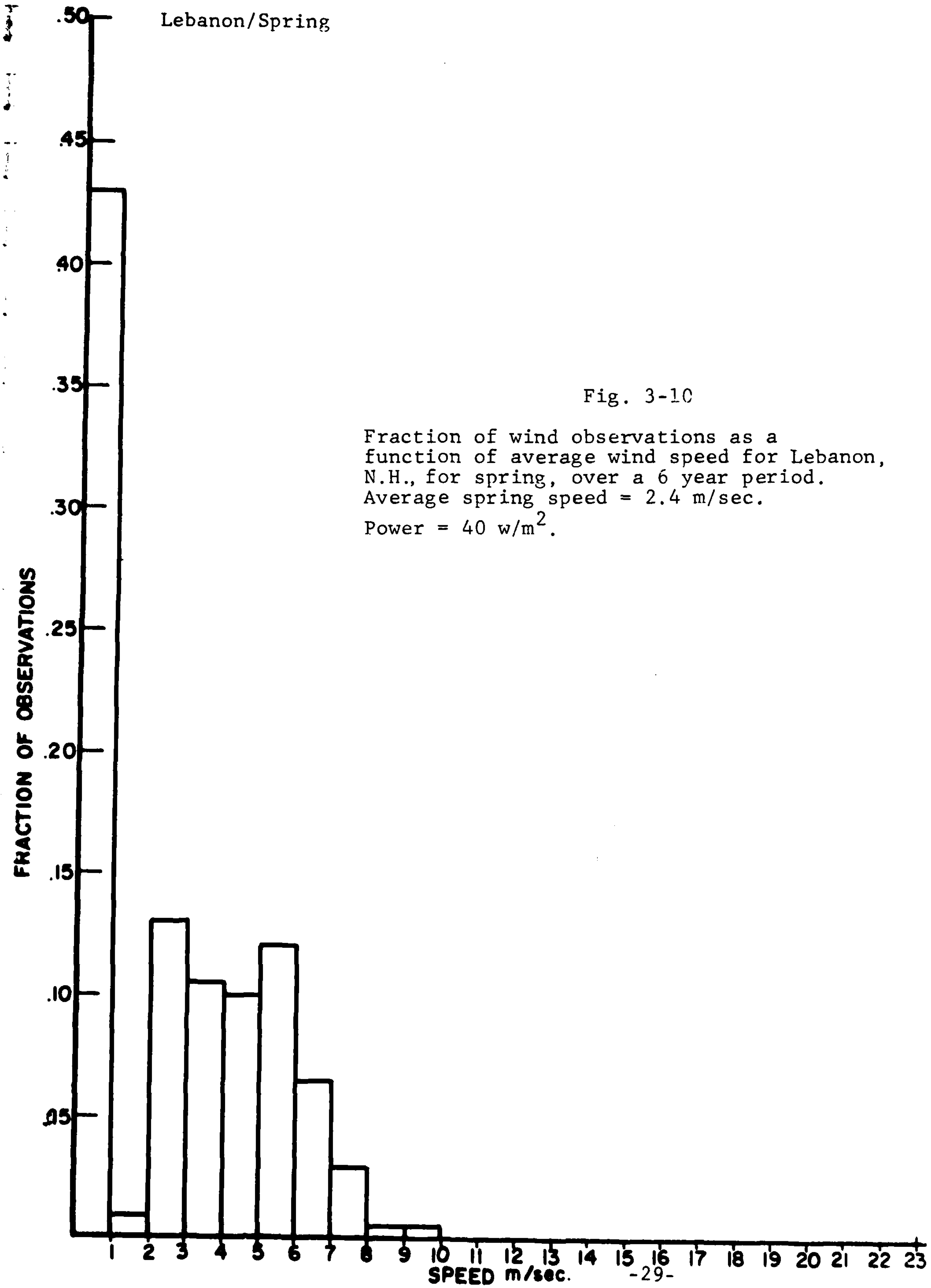


Fig. 3-10

Fraction of wind observations as a function of average wind speed for Lebanon, N.H., for spring, over a 6 year period. Average spring speed = 2.4 m/sec.

Power = 40 w/m^2.

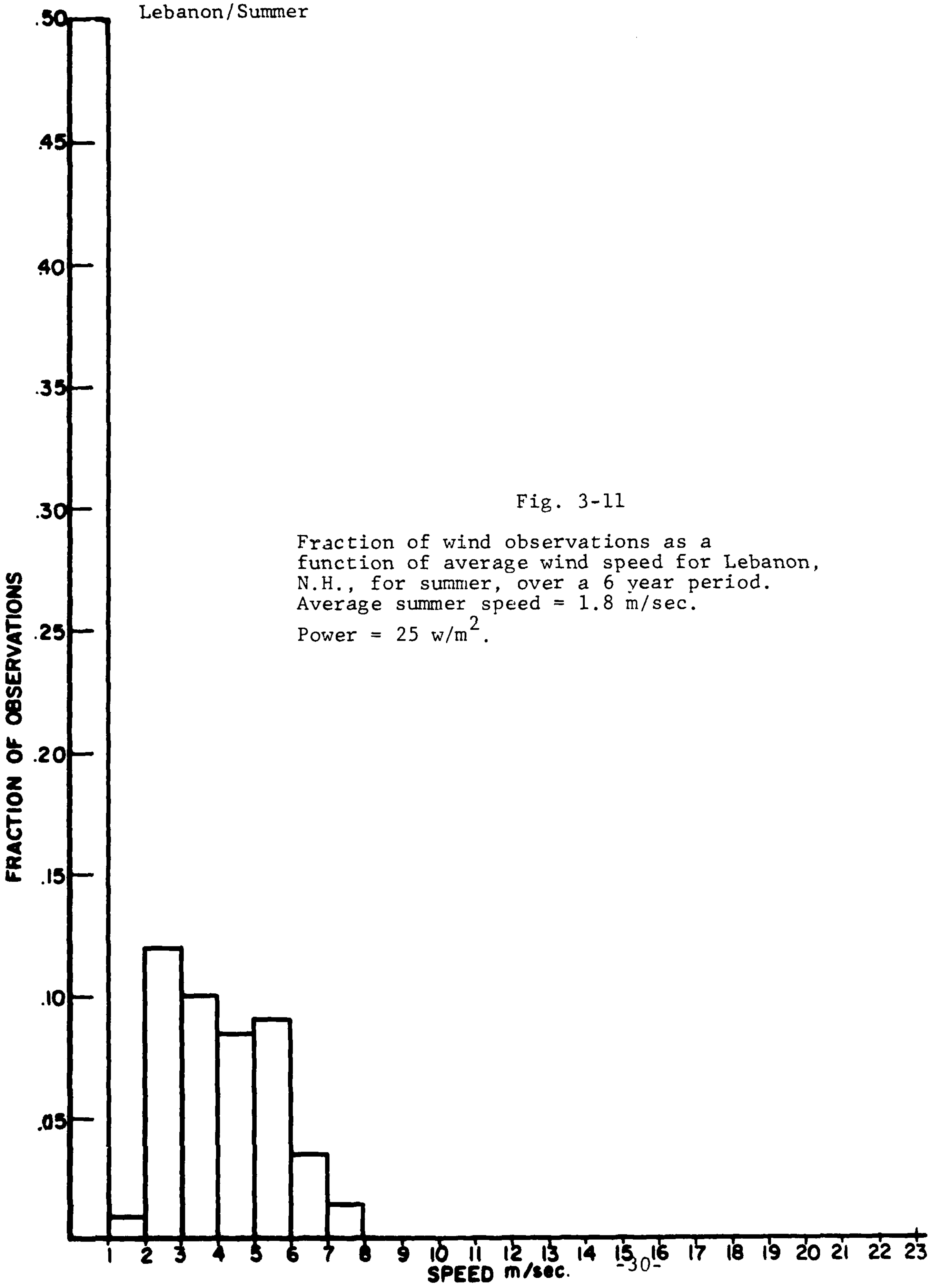


Fig. 3-11

Fraction of wind observations as a function of average wind speed for Lebanon, N.H., for summer, over a 6 year period. Average summer speed = 1.8 m/sec. Power = 25 w/m^2.

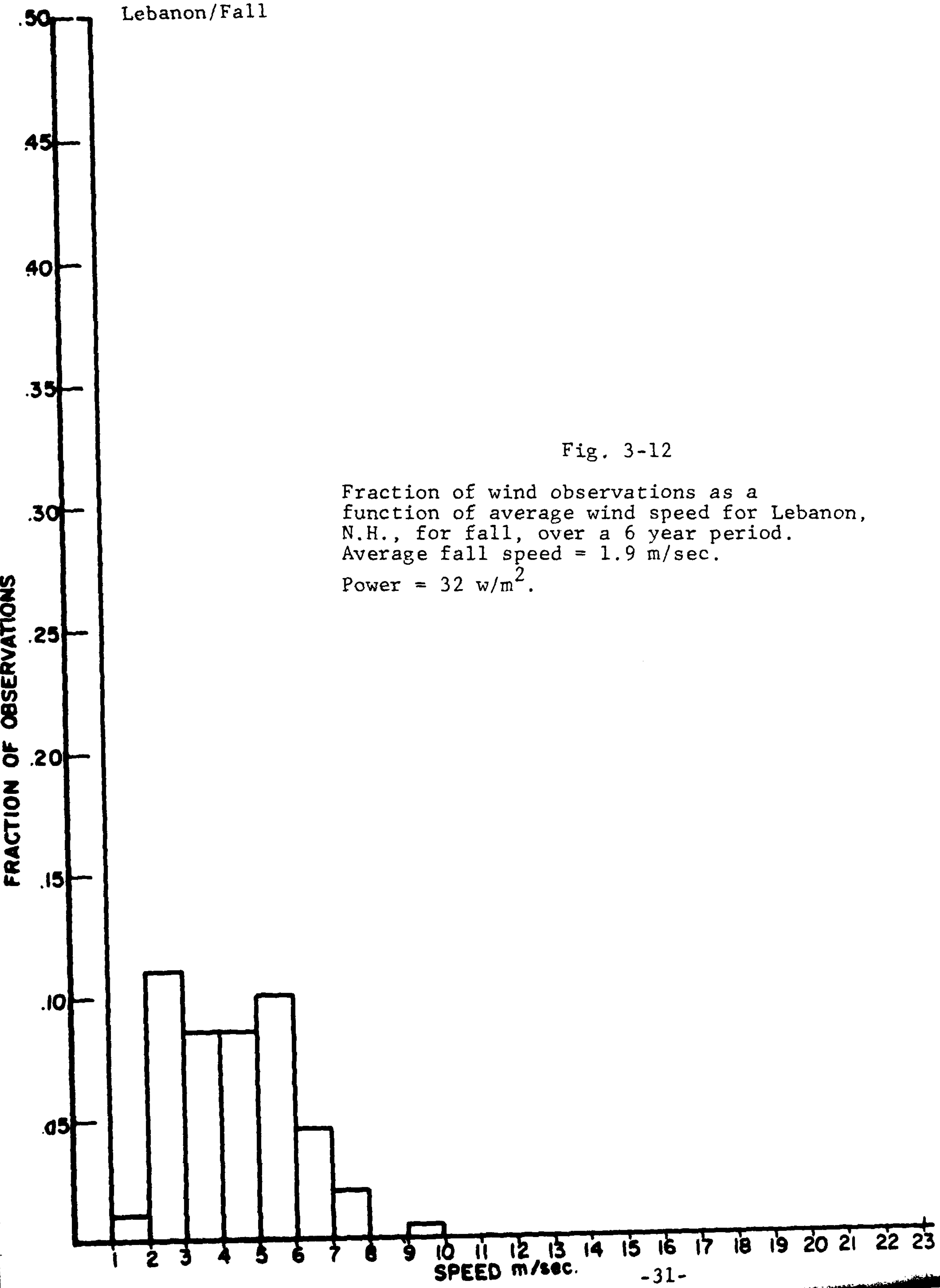


Fig. 3-12

Fraction of wind observations as a function of average wind speed for Lebanon, N.H., for fall, over a 6 year period. Average fall speed = 1.9 m/sec.

Power = 32 w/m^2.

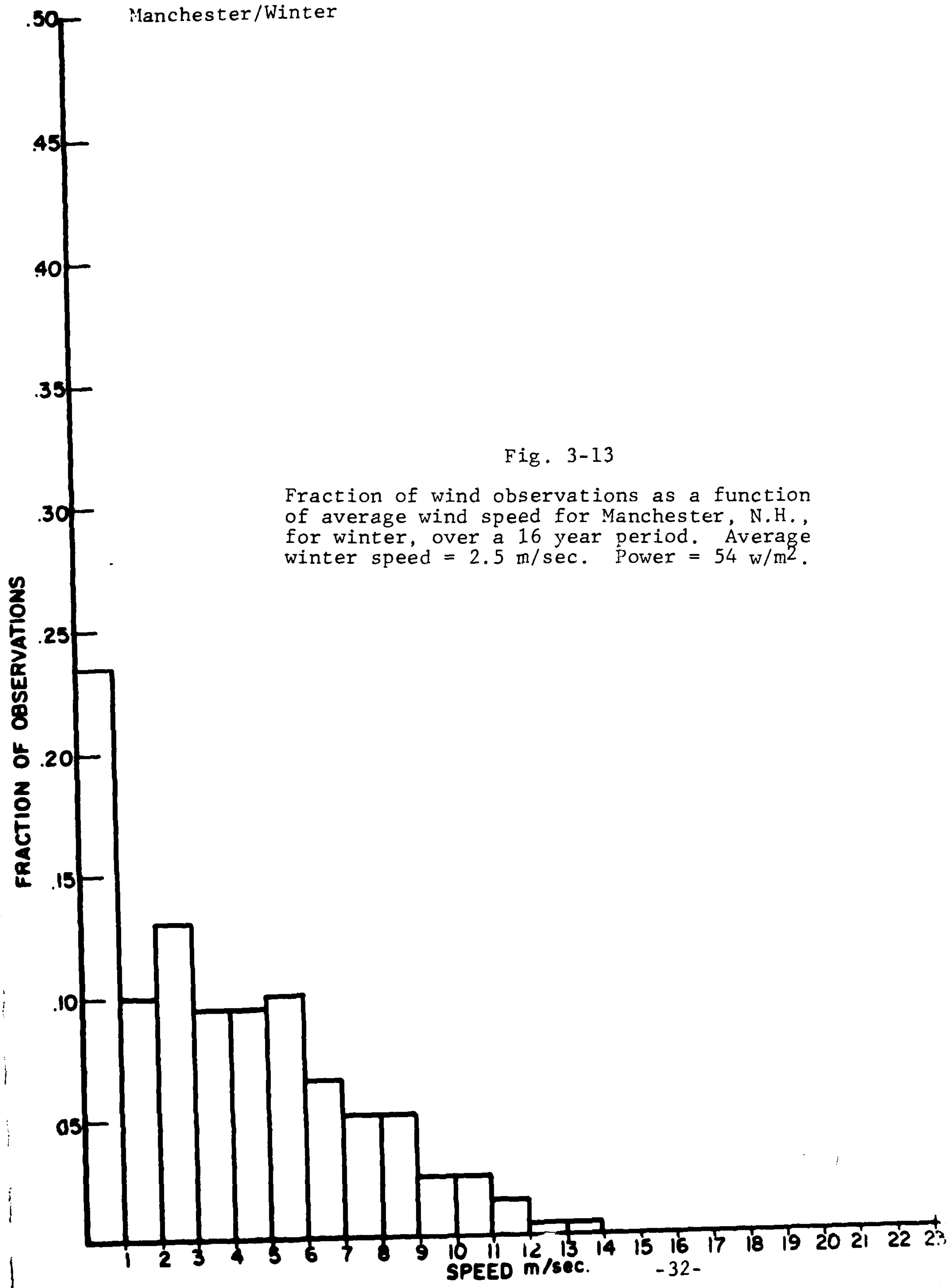


Fig. 3-13

Fraction of wind observations as a function of average wind speed for Manchester, N.H., for winter, over a 16 year period. Average winter speed = 2.5 m/sec. Power = 54 w/m^2.

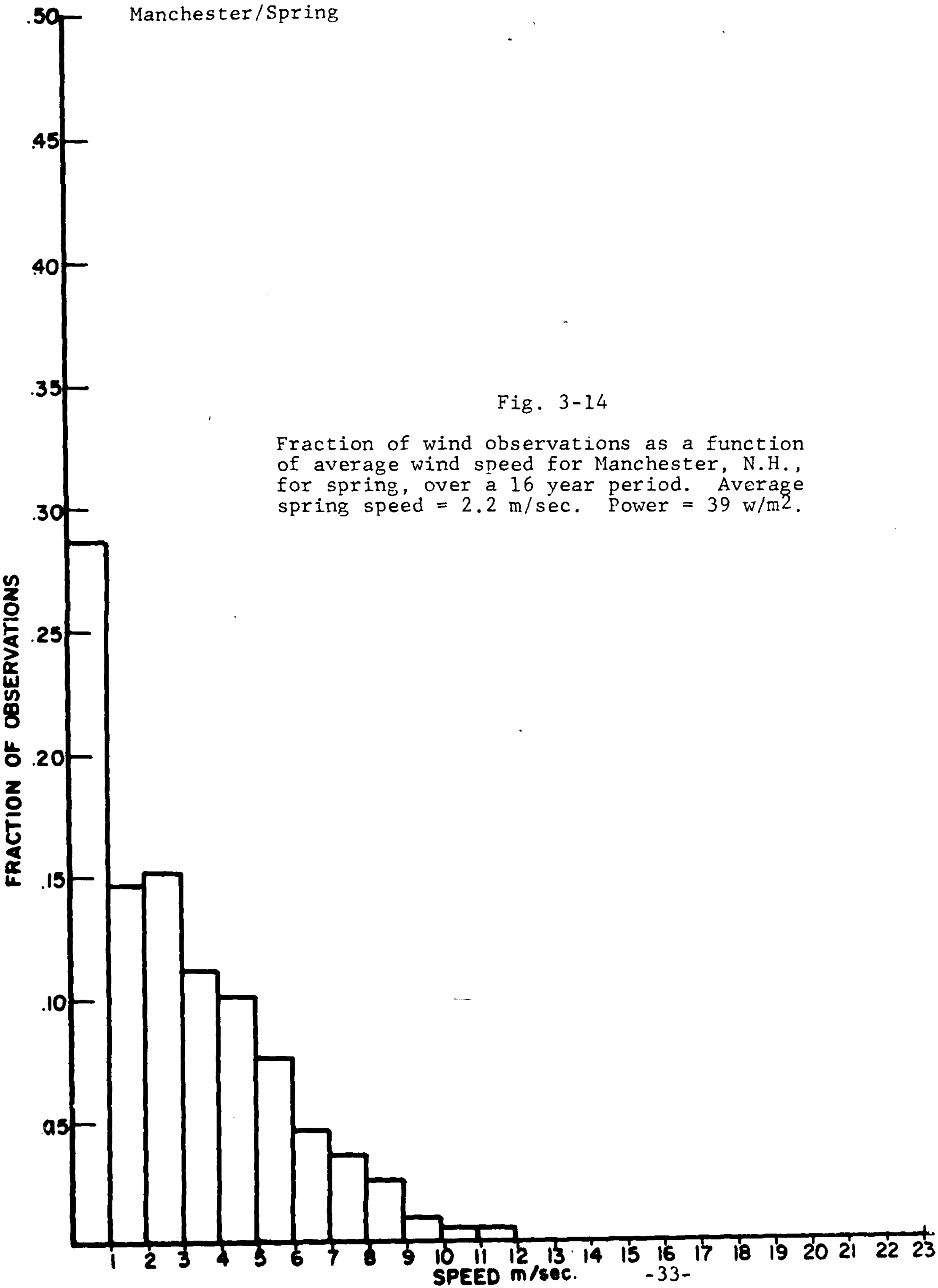


Fig. 3-14

Fraction of wind observations as a function of average wind speed for Manchester, N.H., for spring, over a 16 year period. Average spring speed = 2.2 m/sec. Power = 39 w/m^2.

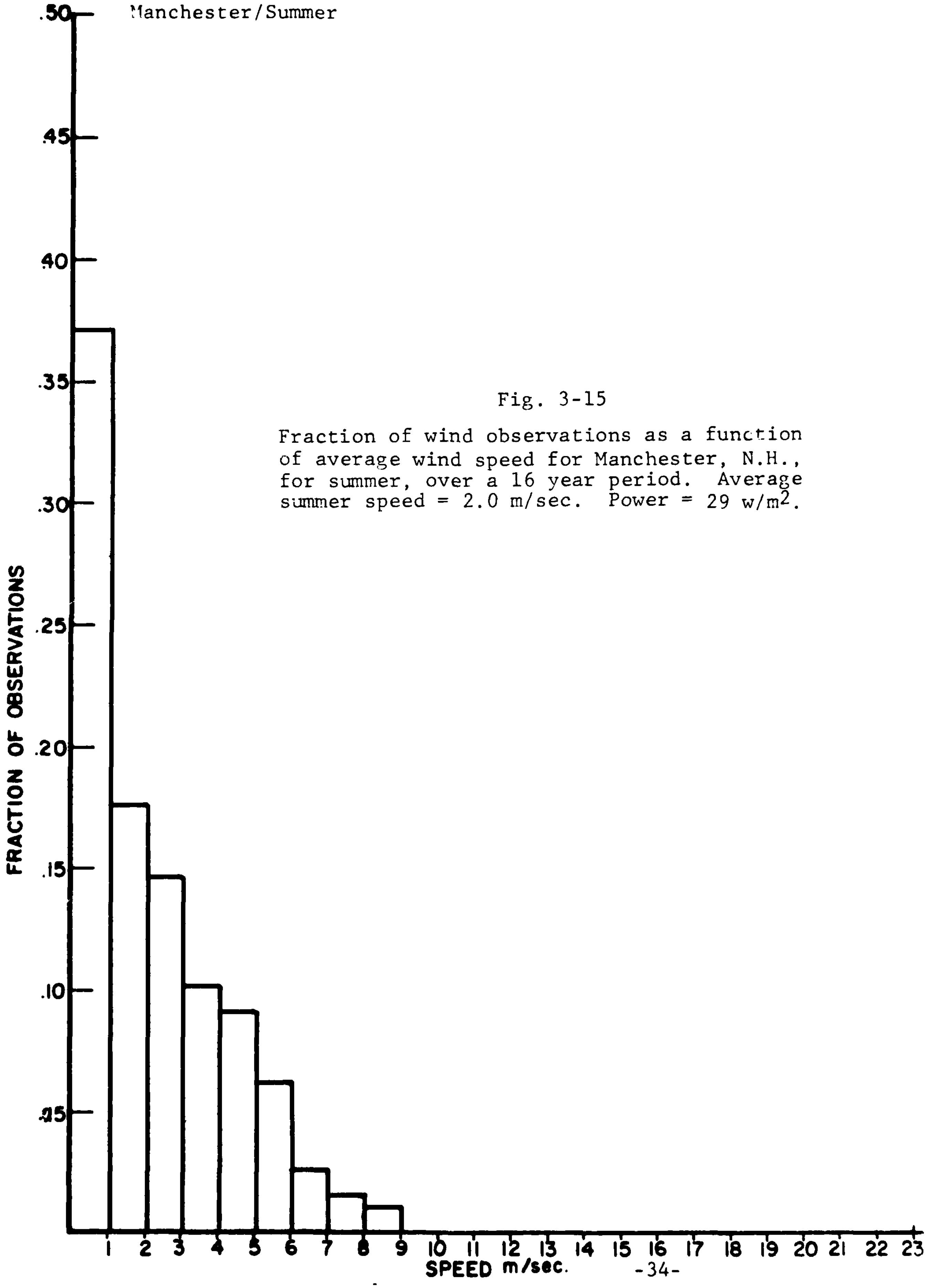


Fig. 3-15

Fraction of wind observations as a function of average wind speed for Manchester, N.H., for summer, over a 16 year period. Average summer speed = 2.0 m/sec. Power = 29 w/m^2.

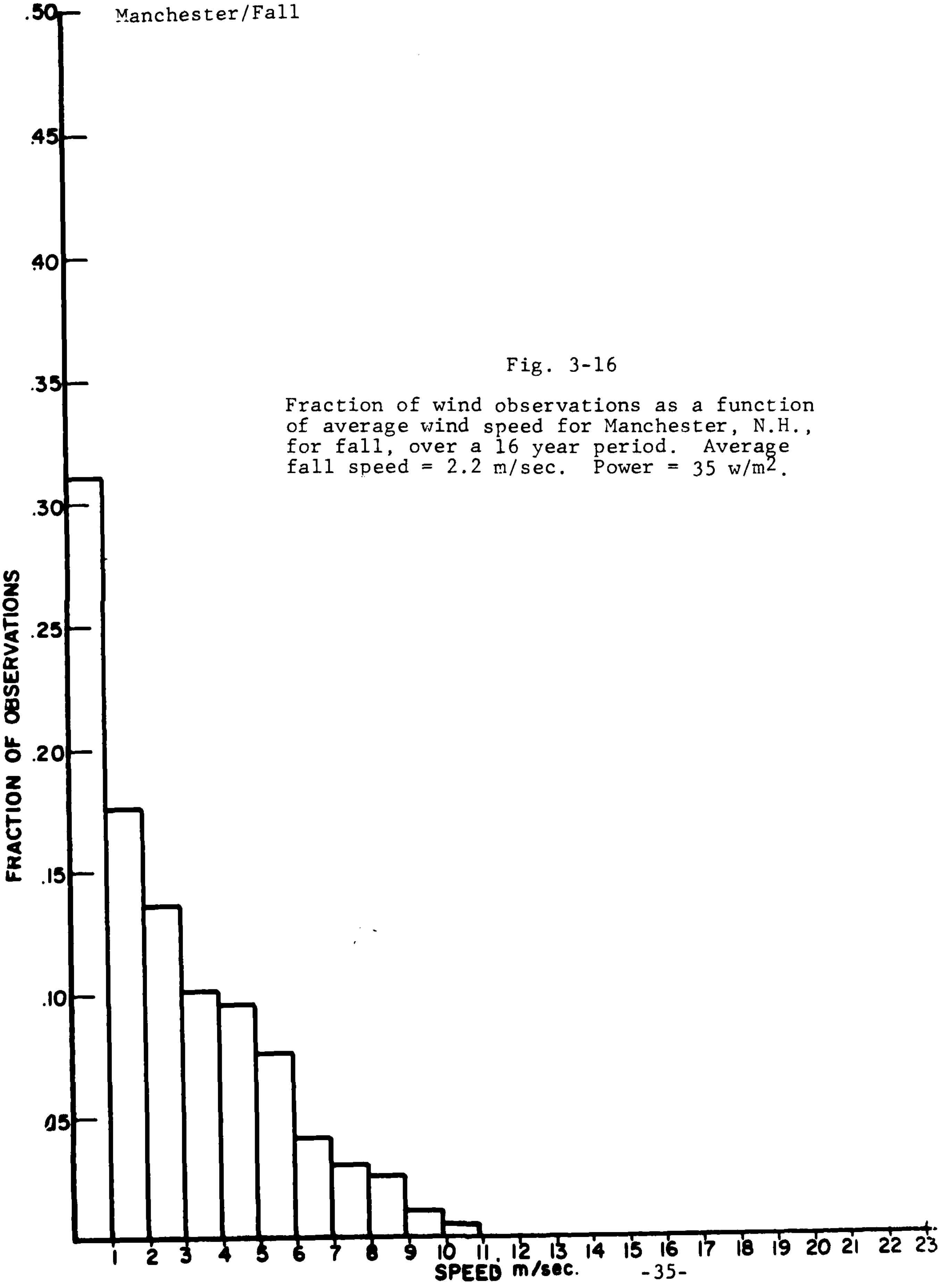


Fig. 3-16

Fraction of wind observations as a function of average wind speed for Manchester, N.H., for fall, over a 16 year period. Average fall speed = 2.2 m/sec. Power = 35 w/m^2.

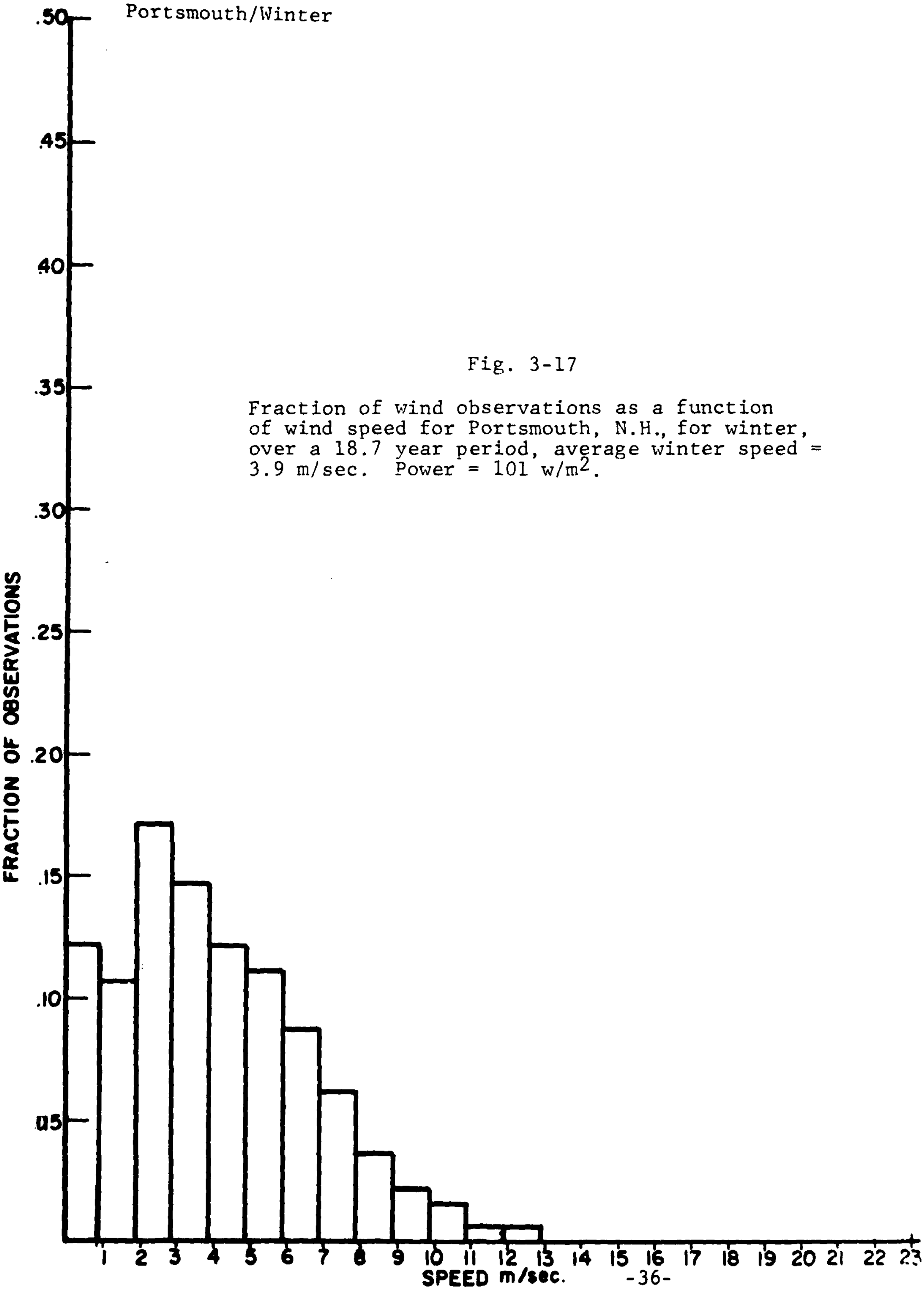


Fig. 3-17

Fraction of wind observations as a function of wind speed for Portsmouth, N.H., for winter, over a 18.7 year period, average winter speed = 3.9 m/sec. Power = 101 w/m^2.

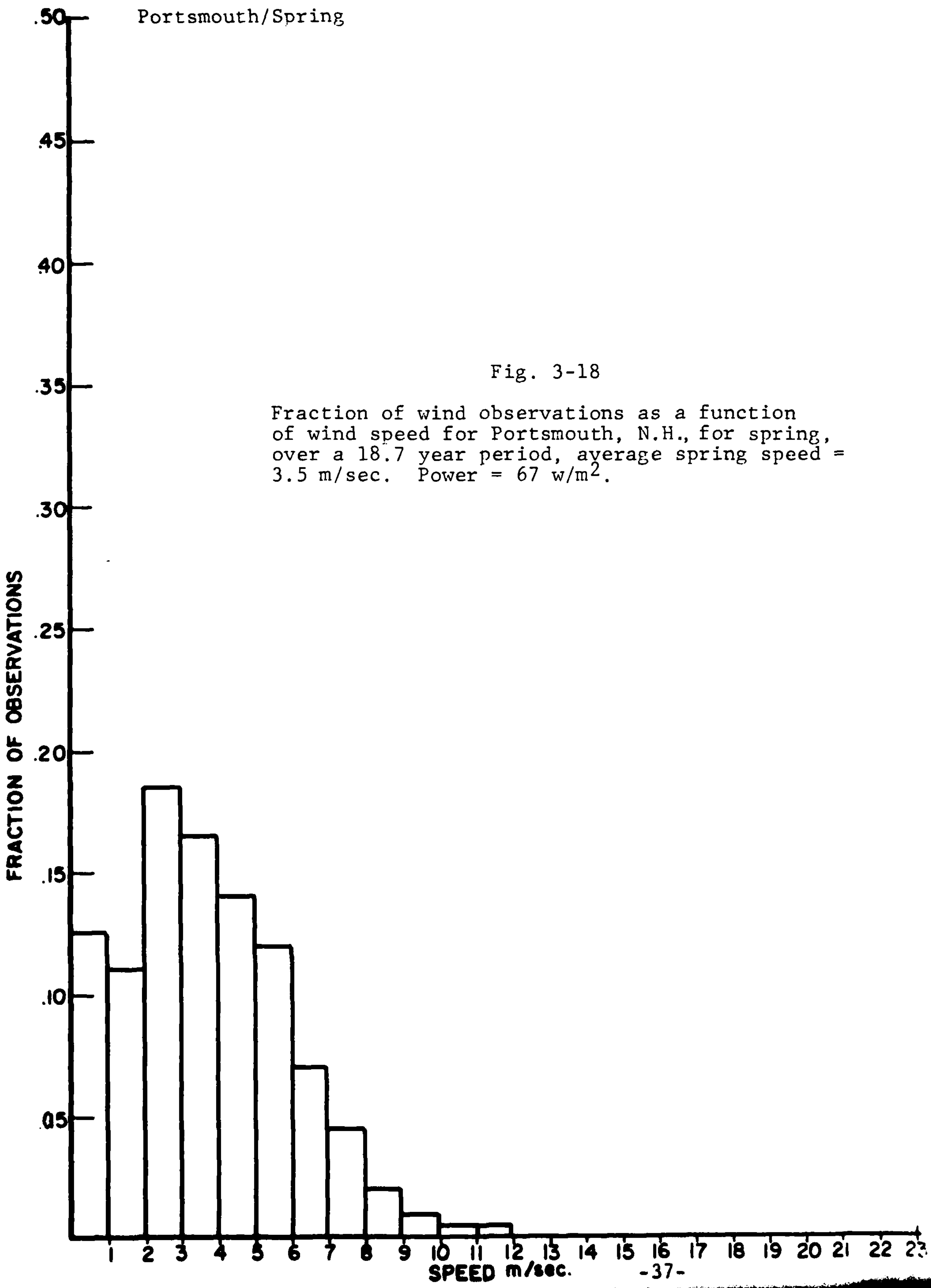


Fig. 3-18

Fraction of wind observations as a function of wind speed for Portsmouth, N.H., for spring, over a 18.7 year period, average spring speed = 3.5 m/sec. Power = 67 w/m^2.

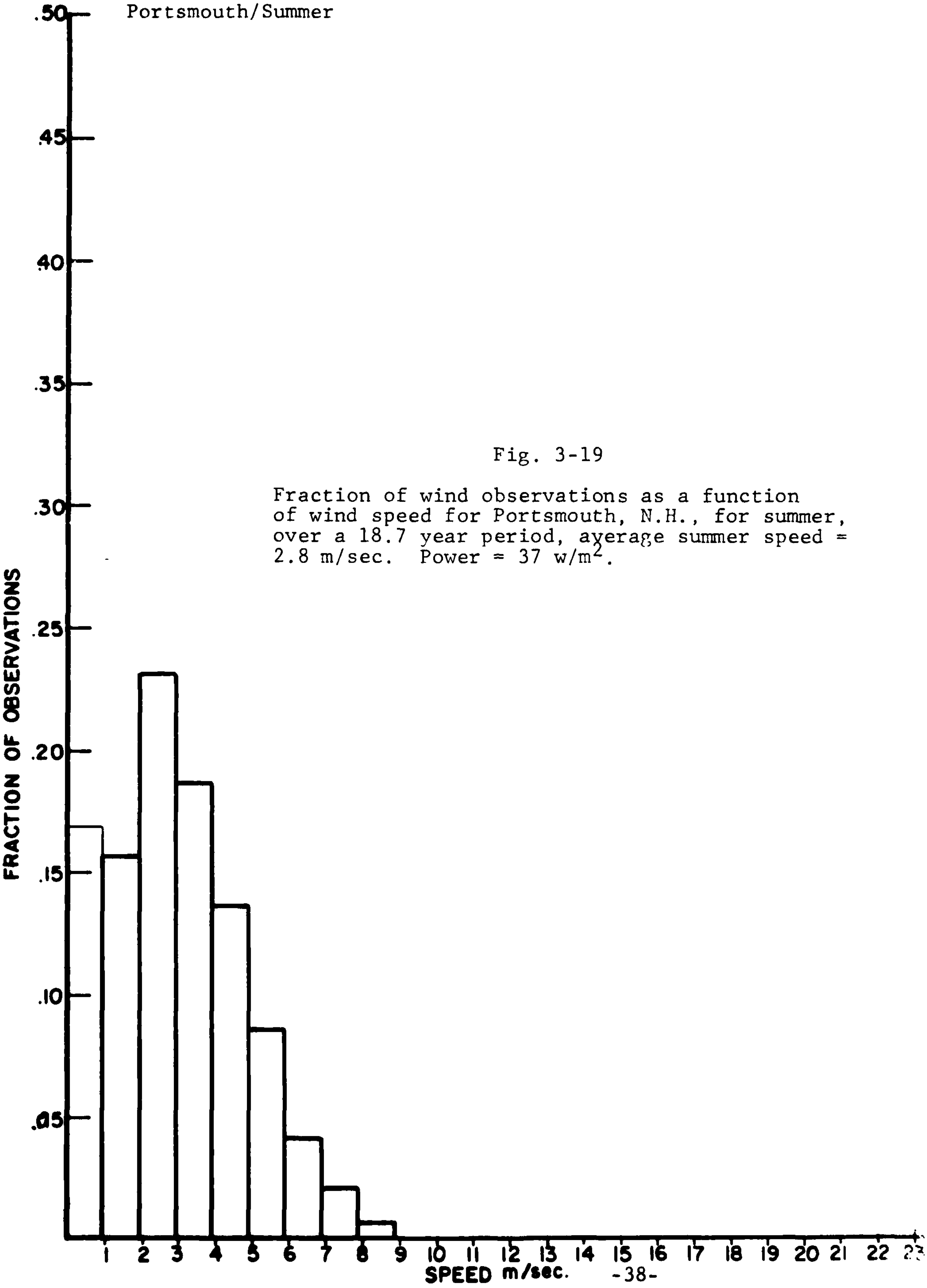


Fig. 3-19

Fraction of wind observations as a function of wind speed for Portsmouth, N.H., for summer, over a 18.7 year period, average summer speed = 2.8 m/sec. Power = 37 w/m^2.

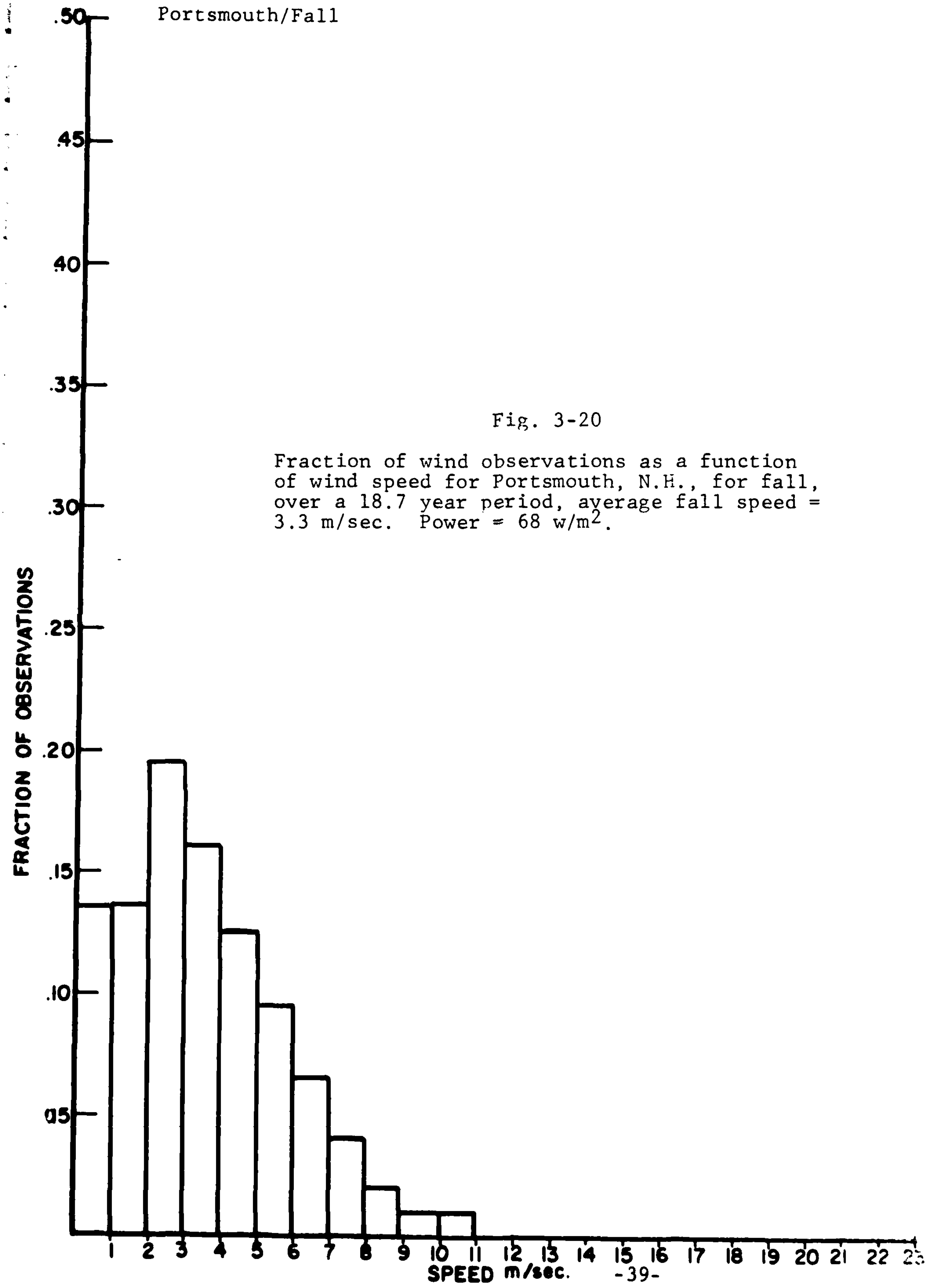


Fig. 3-20

Fraction of wind observations as a function of wind speed for Portsmouth, N.H., for fall, over a 18.7 year period, average fall speed = 3.3 m/sec. Power = 68 w/m^2.

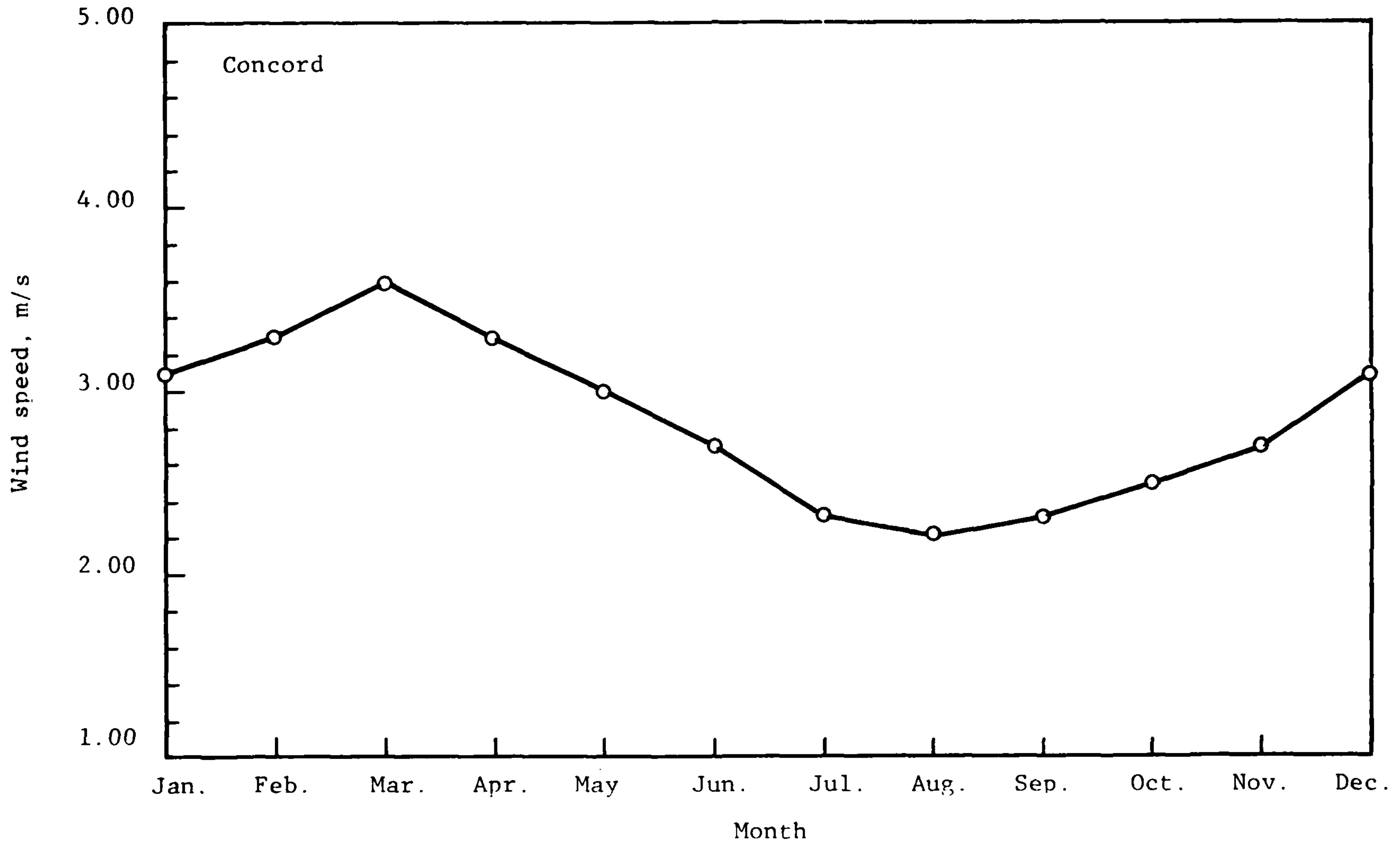


Fig. 3-21

Average monthly wind speed for Concord, N.H., over a 17 year period. Average annual speed = 2.9 m/sec. Power = 50 w/m2.

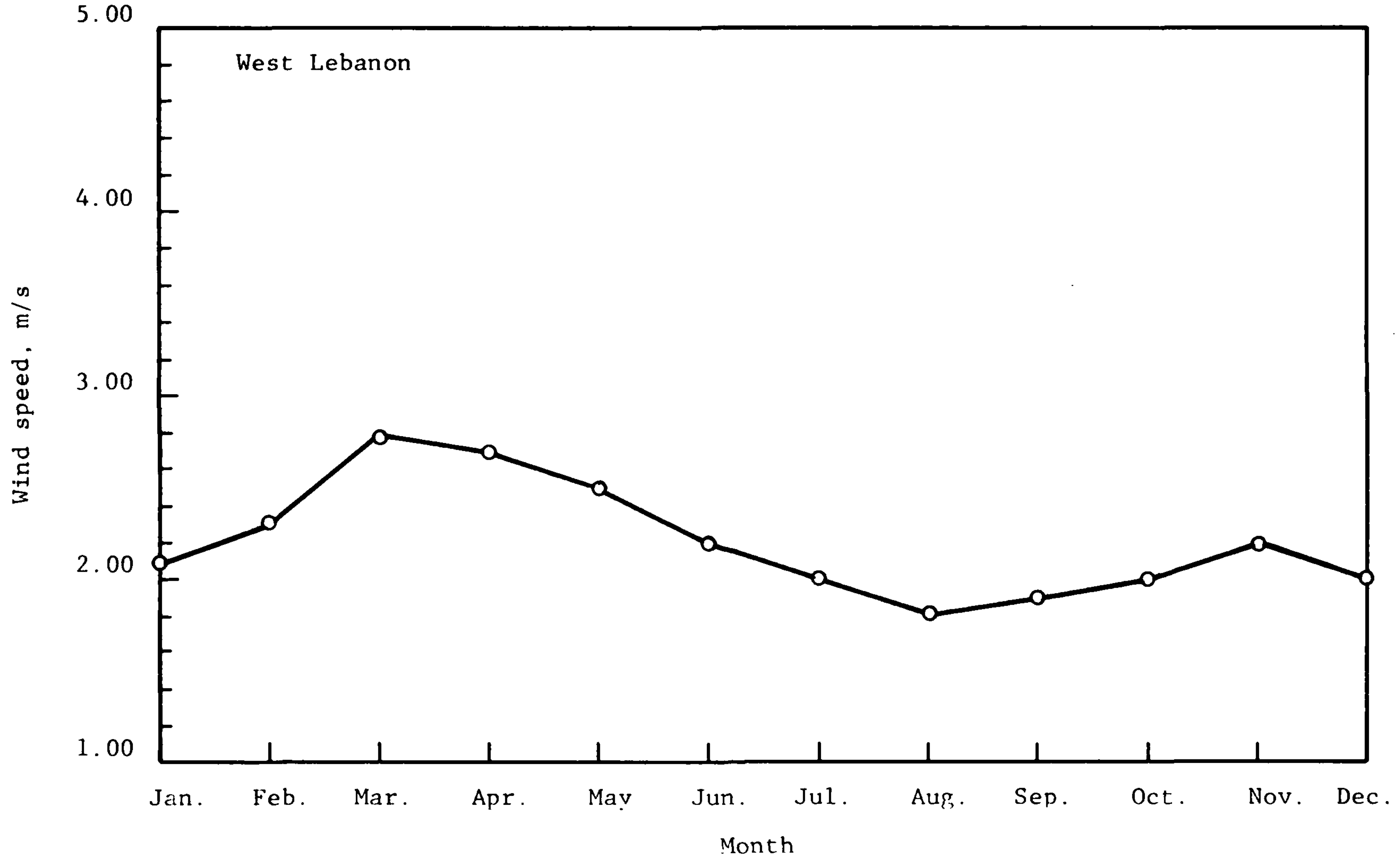


Fig. 3-22

Average monthly wind speed for West Lebanon, N.H., over a 10 year period. Average annual speed = 2.3 m/sec. Power = 41 w/m^2.

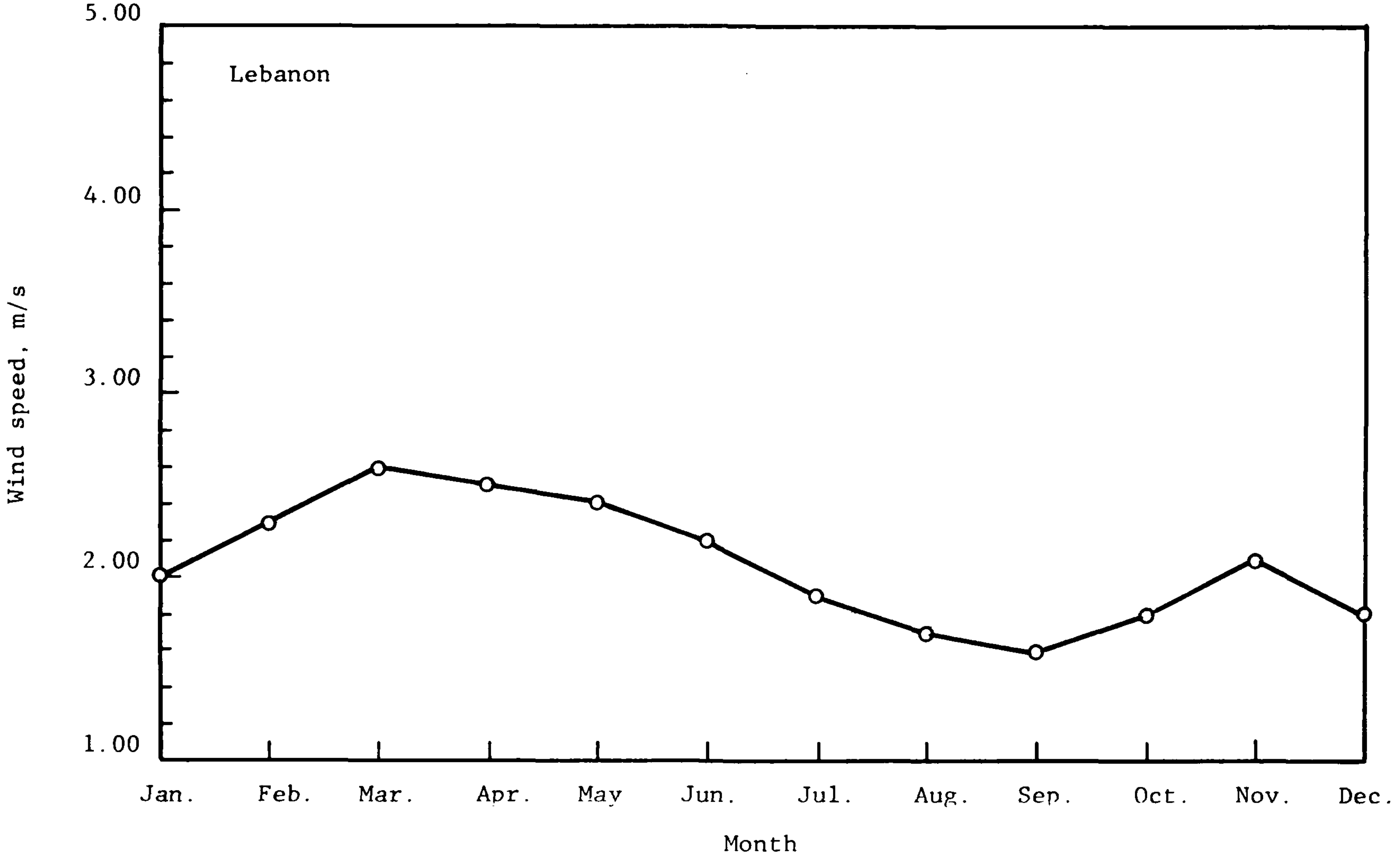


Fig. 3-23

Average monthly wind speed for Lebanon, N.H., over a 6 year period. Average annual speed = 2.1 m/sec. Power = 35 w/m2.

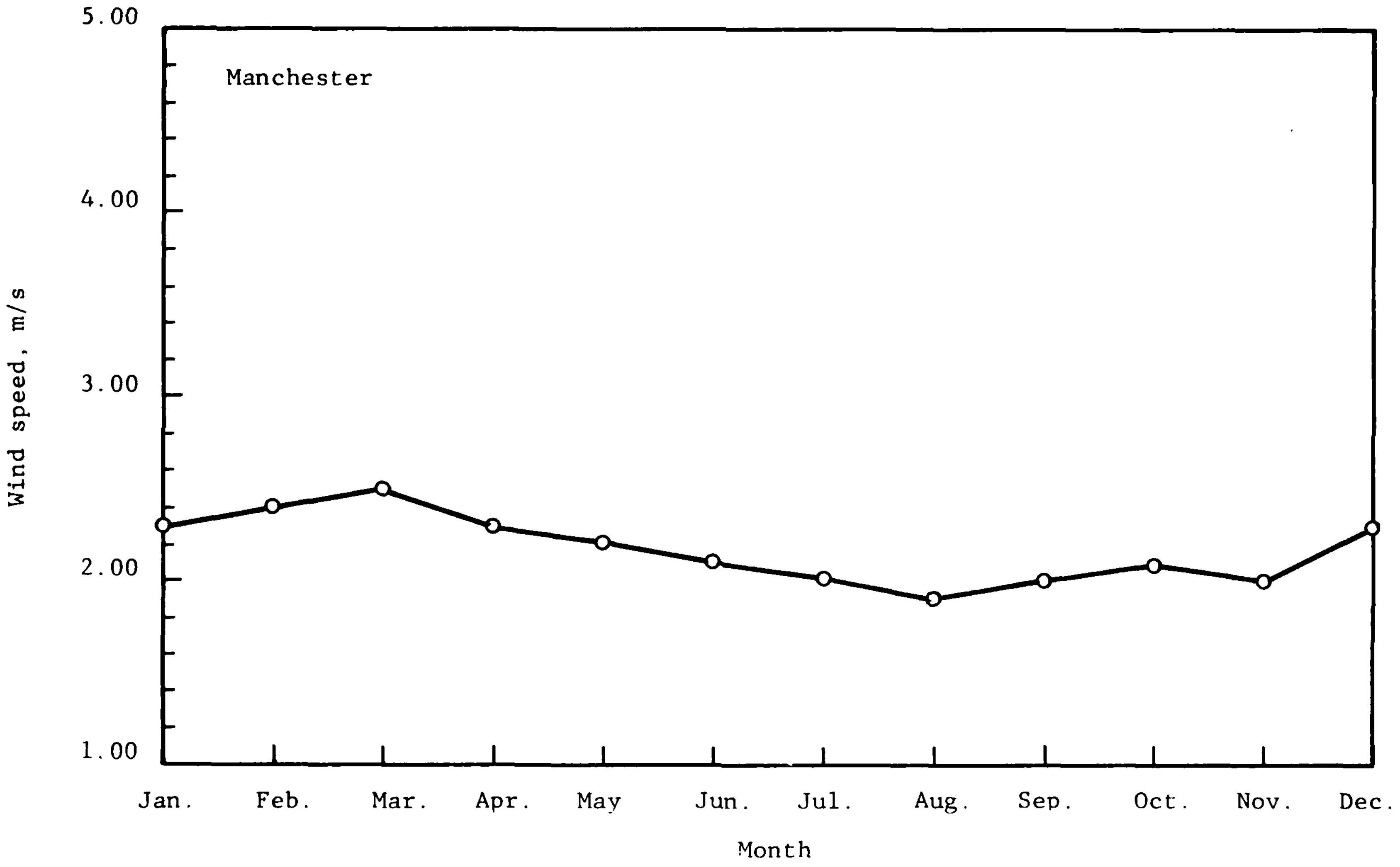


Fig. 3-24

Average monthly wind speed for Manchester, N.H., over a 16 year period. Average annual speed = 2.2 m/sec. Power = 39 w/m^2.

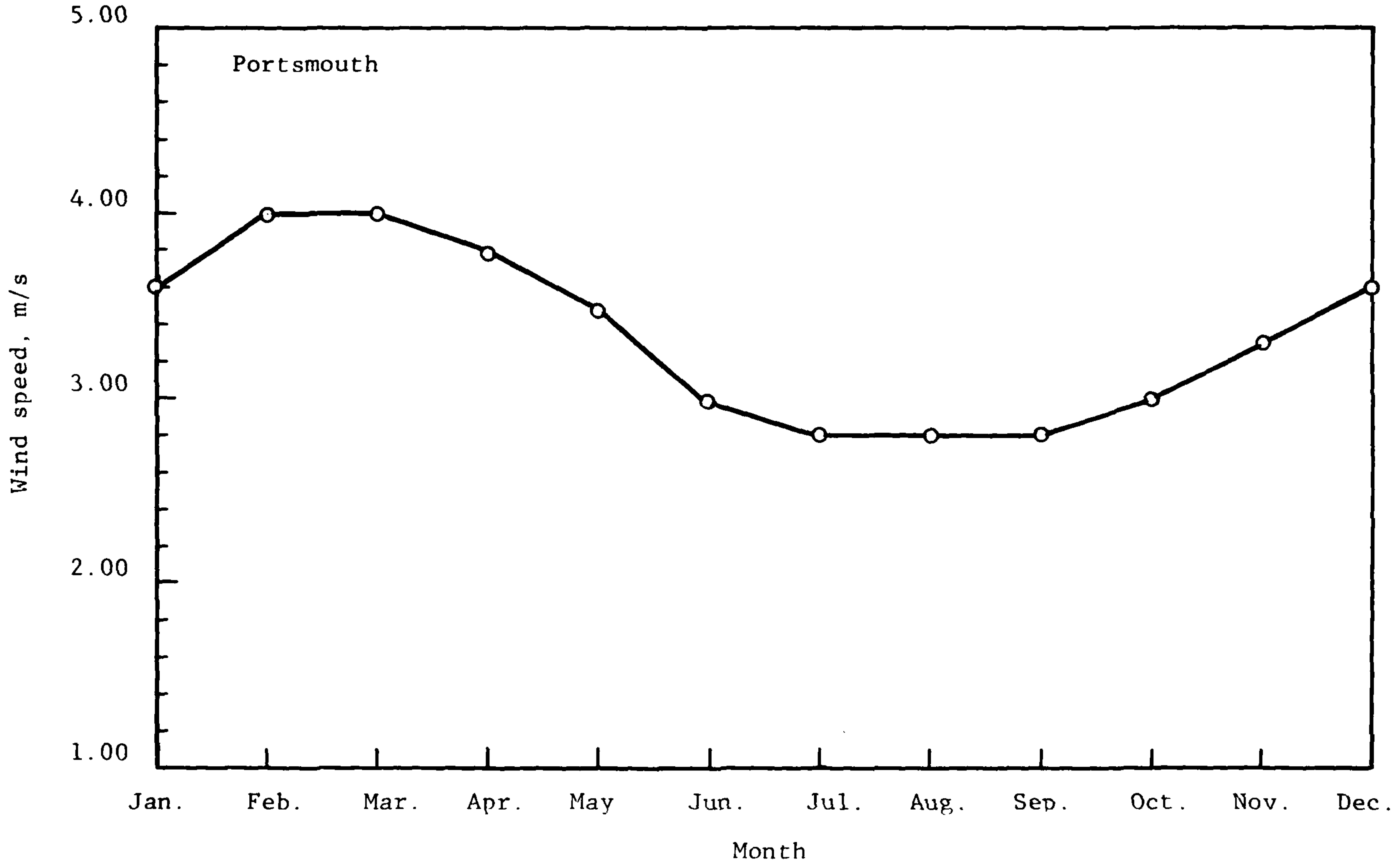


Fig. 3-25

Average monthly wind speed for Portsmouth, N.H., over a 18.7 year period. Average annual speed = 3.4 m/sec. Power = 67 w/m^2.

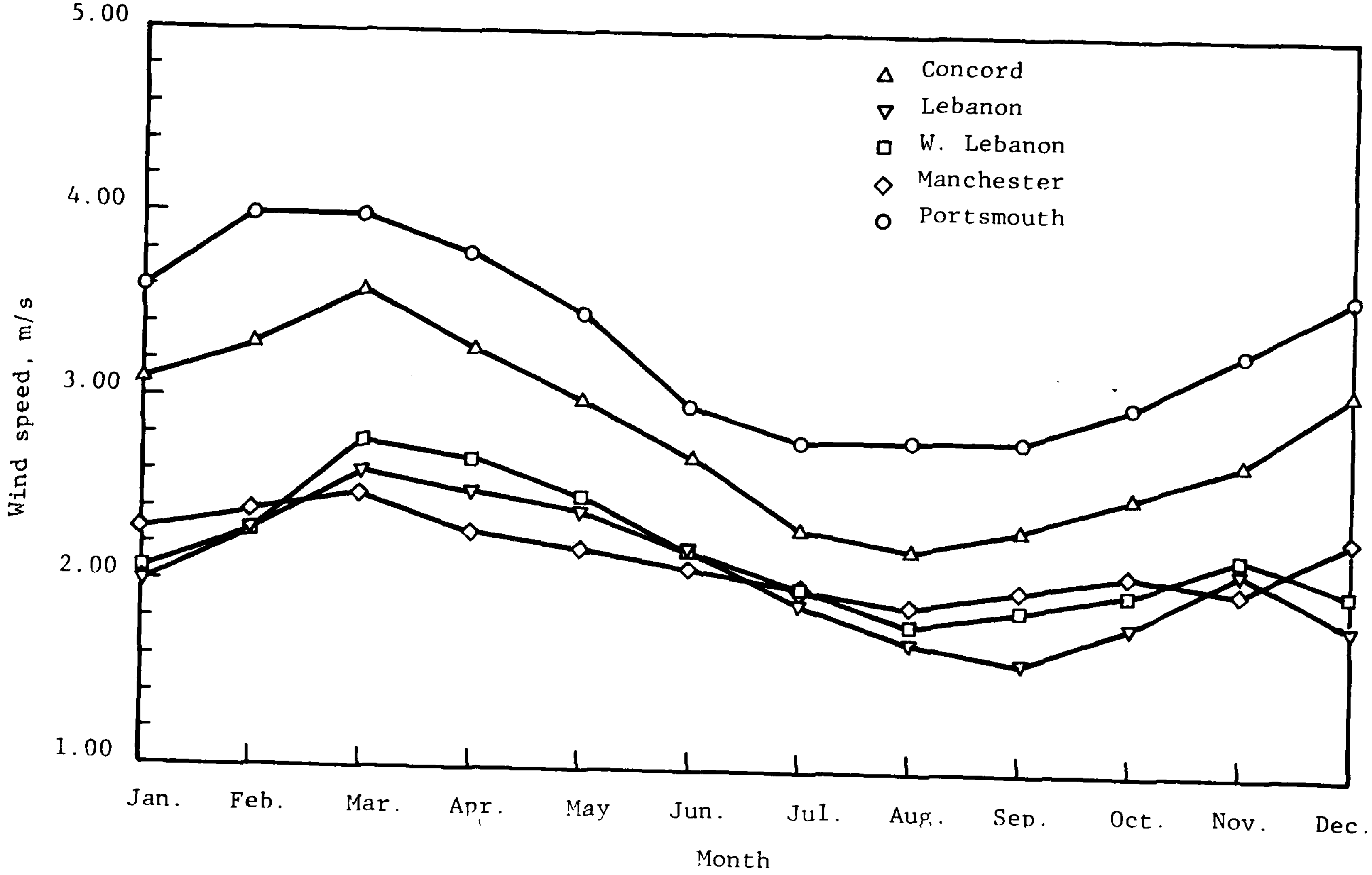


Fig. 3-26

Comparison of monthly wind averages for five New Hampshire Sites.

the same calendar time period must be used to obtain cross-correlation information. The Corotis programs are written to obtain crosscorrelation data for pairs of wind sites. In Figs. 3.27 through 3.34 correlation coefficient (Rho) is plotted as a function of log time in hours for the following city pairs:

Concord-Lebanon
Concord-Portsmouth
Concord-Manchester
Lebanon-Portsmouth

These pairings were possible because NCC data were given at the same time for these sites. Significantly, all of the cross-correlation coefficients for velocity are at least 0.5 at zero log time. Even the distant points of Lebanon and Portsmouth have coefficients of 0.5. Therefore, a strong trend of data indicates that when it is windy at one point in lower New Hampshire, it is windy at most other sites in the lower part of the state even at the coastal sites. The next step in evaluating overall state wind potential would be to compare sites in the White Mountains with the rest of the state.

3.1.2.2 Mt. Washington Long Term Data

The Mt. Washington Observatory has recorded weather data for many years at the summit location. Hourly wind data have been reported to NCC on Surface Weather Observation forms which NCC has converted to daily and monthly average Local Climatological Data (LCD's). Widger(10) has summarized Mt. Washington data for the period of 1948-1975. The average wind speed as a function of calendar month is shown in Fig. 3.35. The figures for one year (1970) are shown as an indication of the variation from the long term average.

In order to evaluate Mt. Washington with respect to the other lower New Hampshire cities, IITRI requested copies of the daily Surface Weather Observation forms from NCC for a two-year

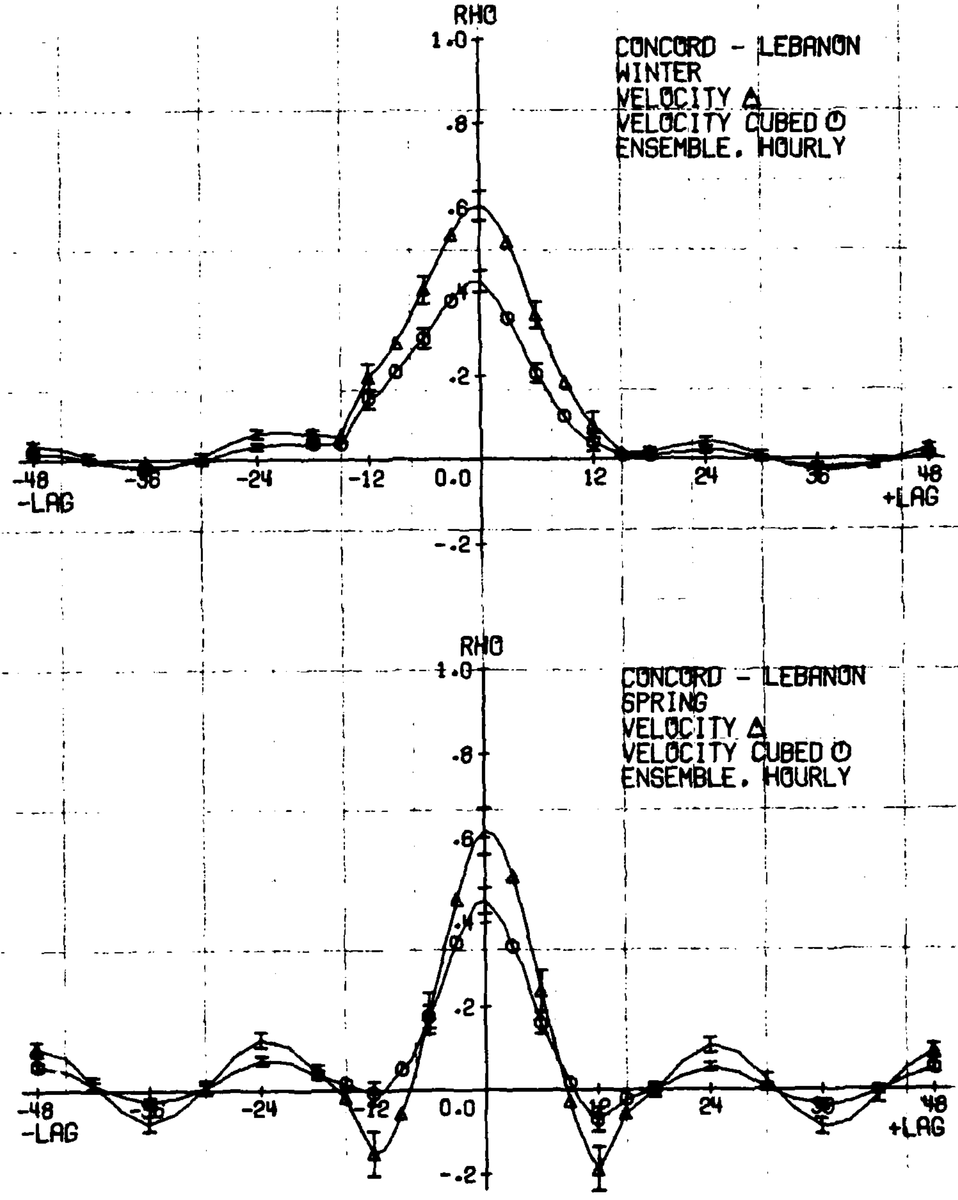


Fig. 3-27

Crosscorrelation of wind velocity data for Concord-Lebanon, sites for winter and spring.

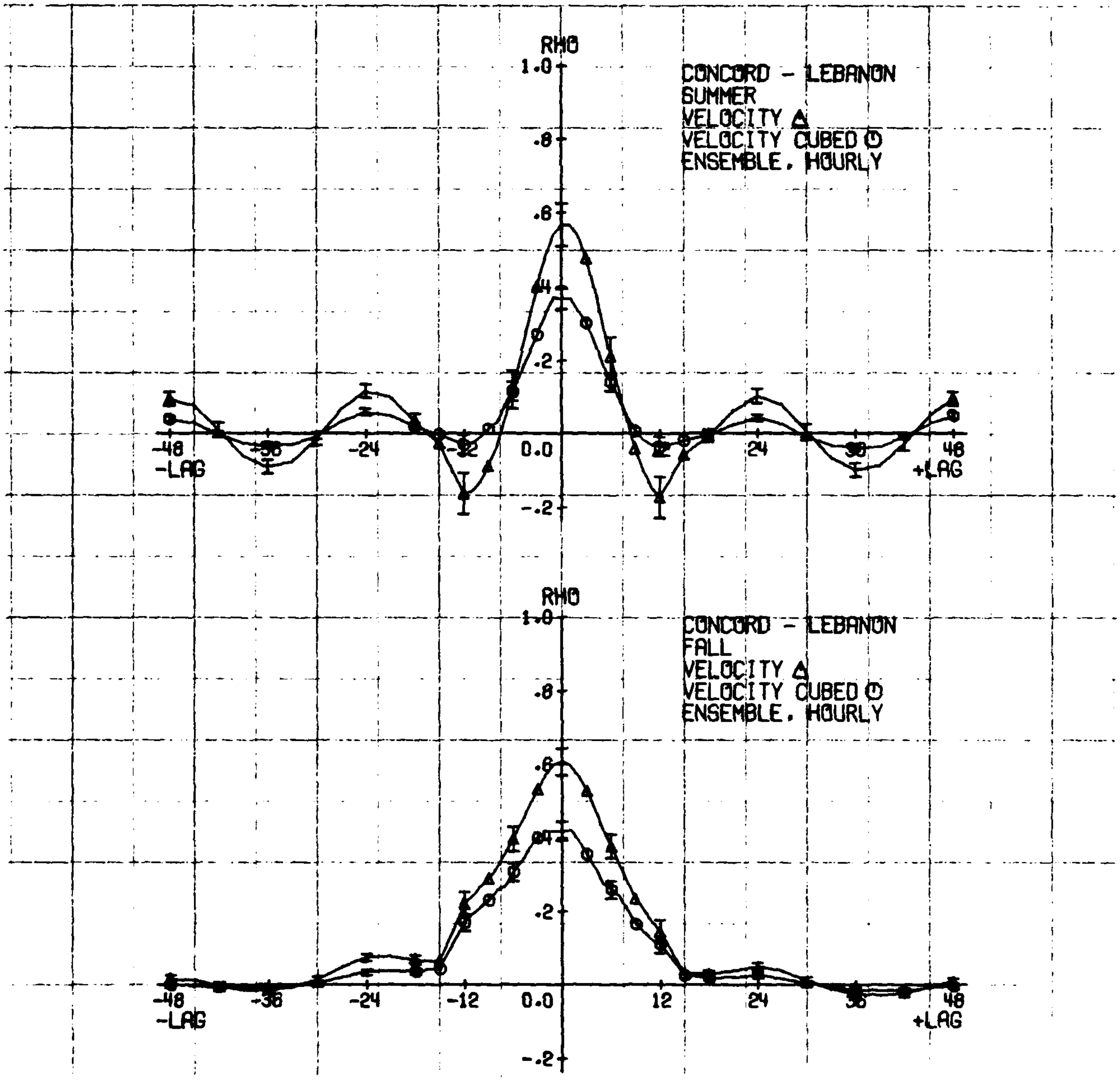


Fig. 3-28

Crosscorrelation of wind velocity data for Concord-Lebanon, sites for summer and fall.

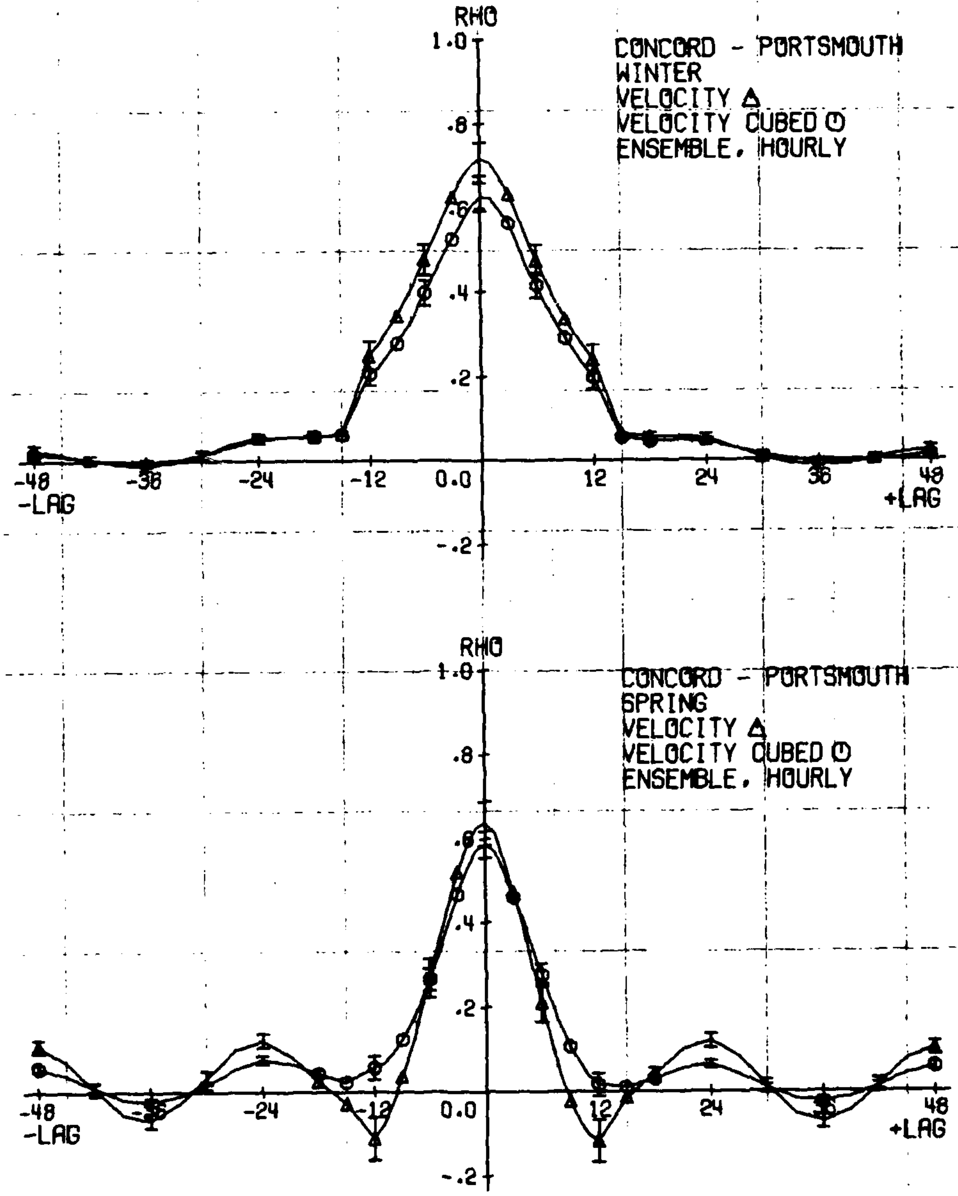


Fig. 3-29

Crosscorrelation of wind velocity data for Concord-Portsmouth, sites for winter and spring.

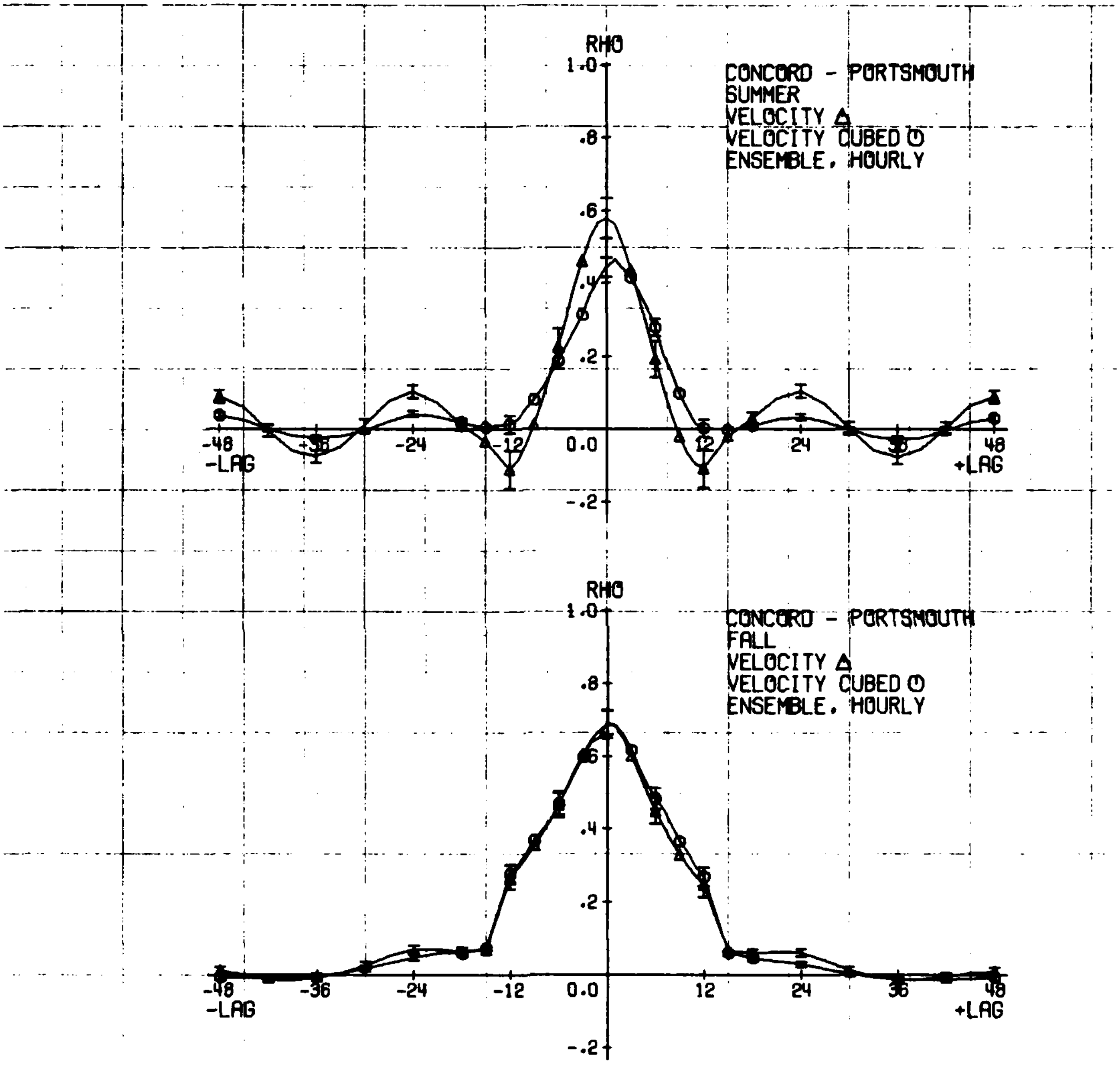


Fig. 3-30

Crosscorrelation of wind velocity data for Concord-Portsmouth, sites for summer and fall.

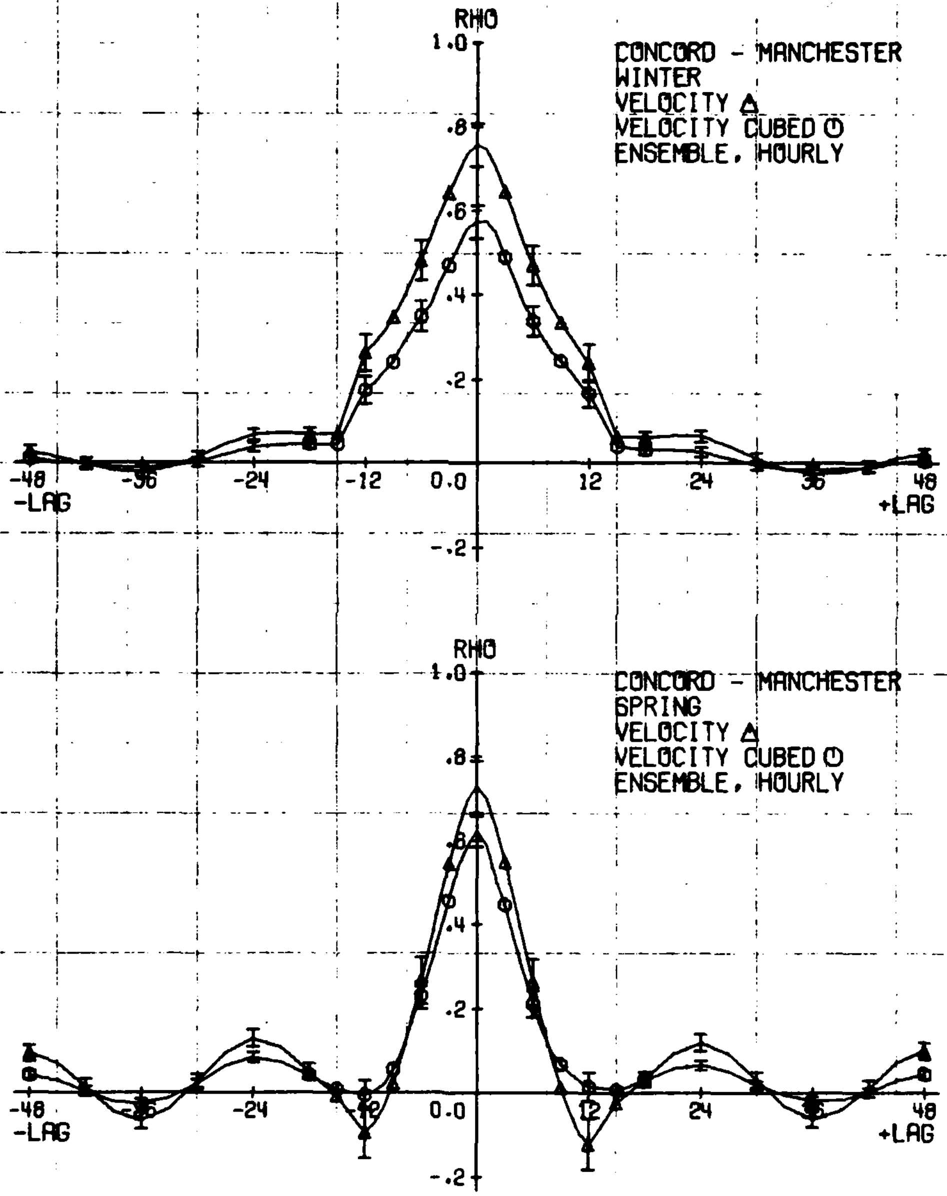


Fig. 3-31

Crosscorrelation of wind velocity data for Concord-Manchester, sites for winter and spring.

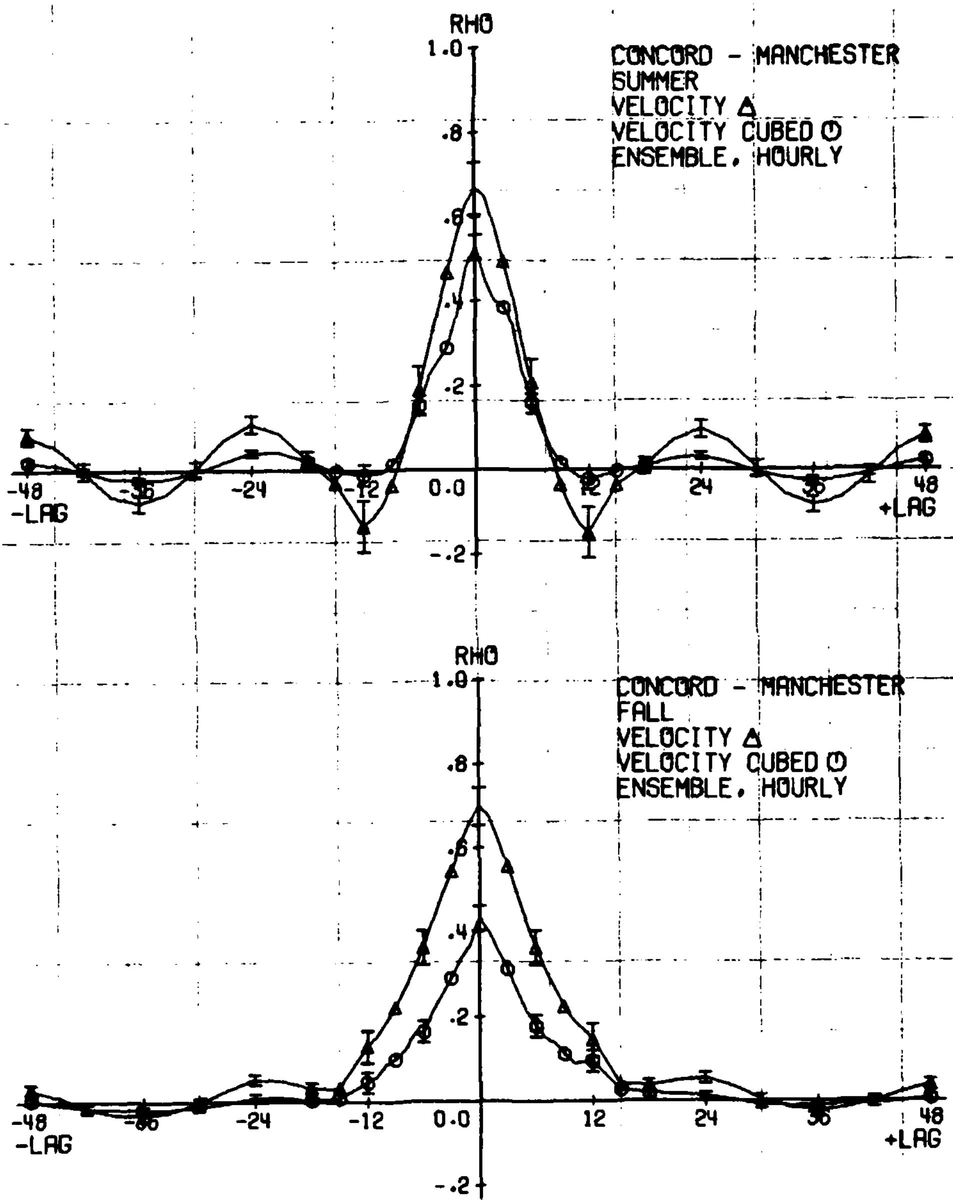


Fig. 3-32

Crosscorrelation of wind velocity data for Concord-Manchester, sites for summer and fall.

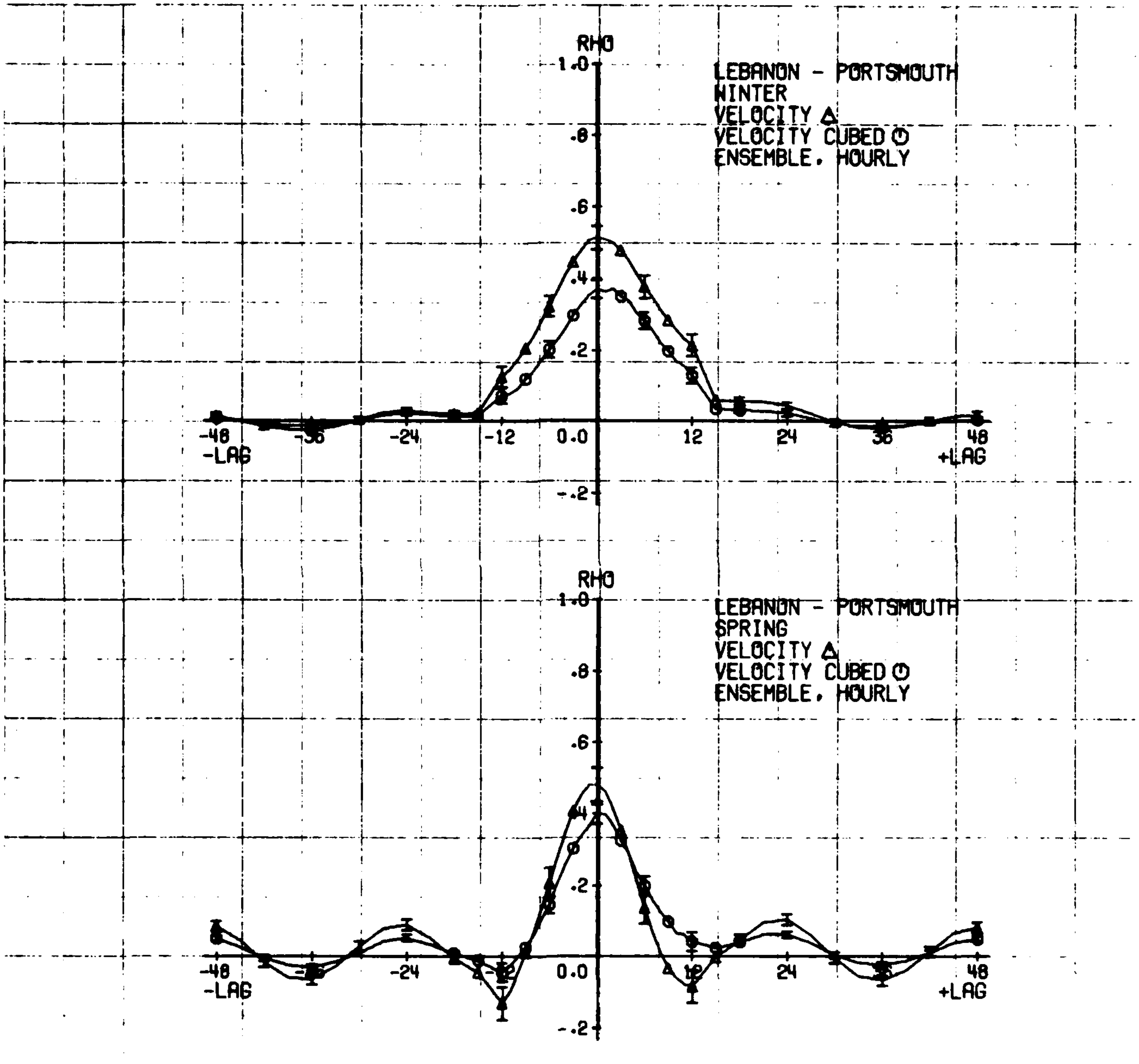


Fig. 3-33

Crosscorrelation of wind velocity data for Lebanon-Portsmouth, sites for winter and spring.

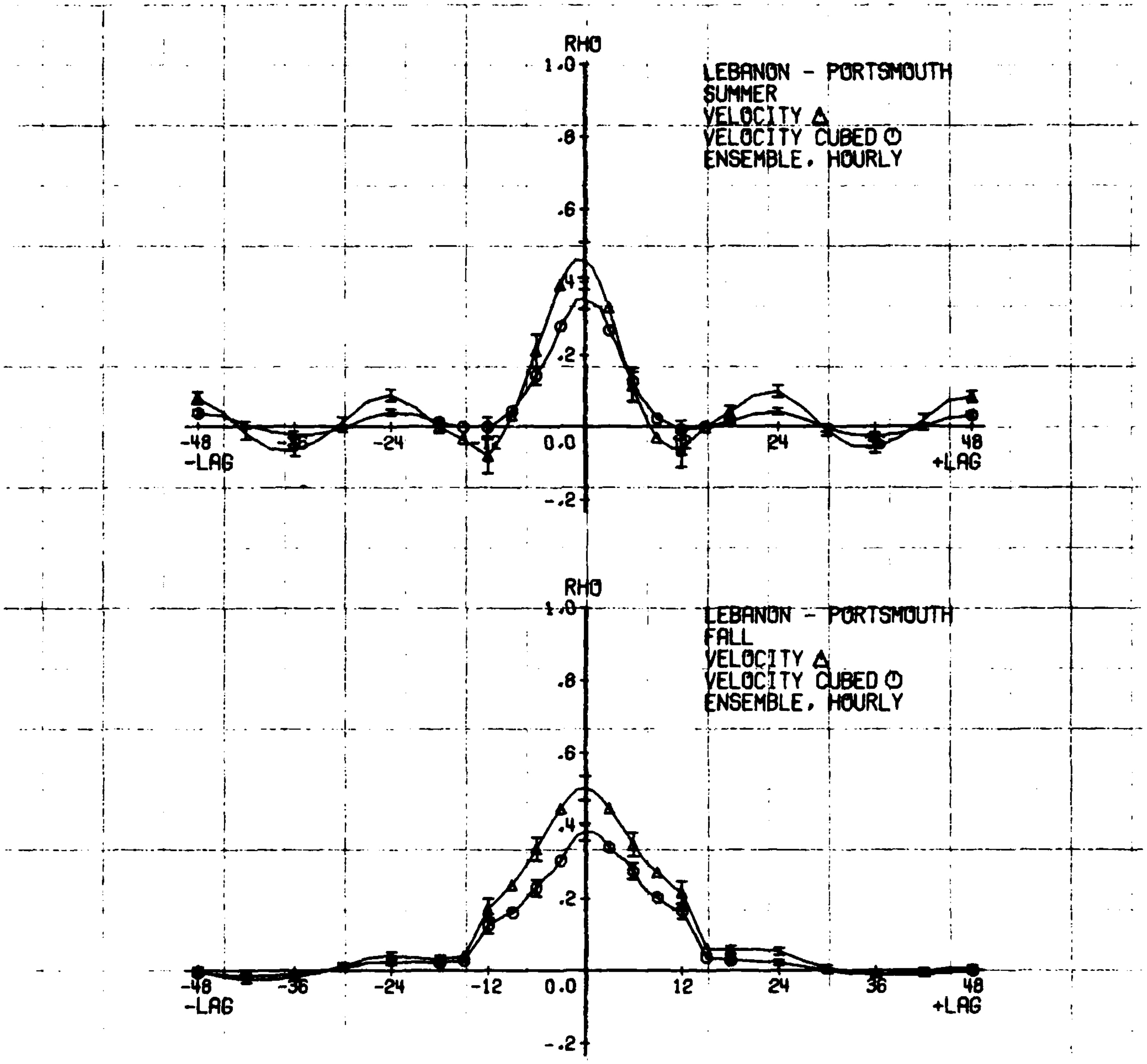


Fig. 3-34

Crosscorrelation of wind velocity data for Lebanon-Portsmouth, sites for summer and fall.

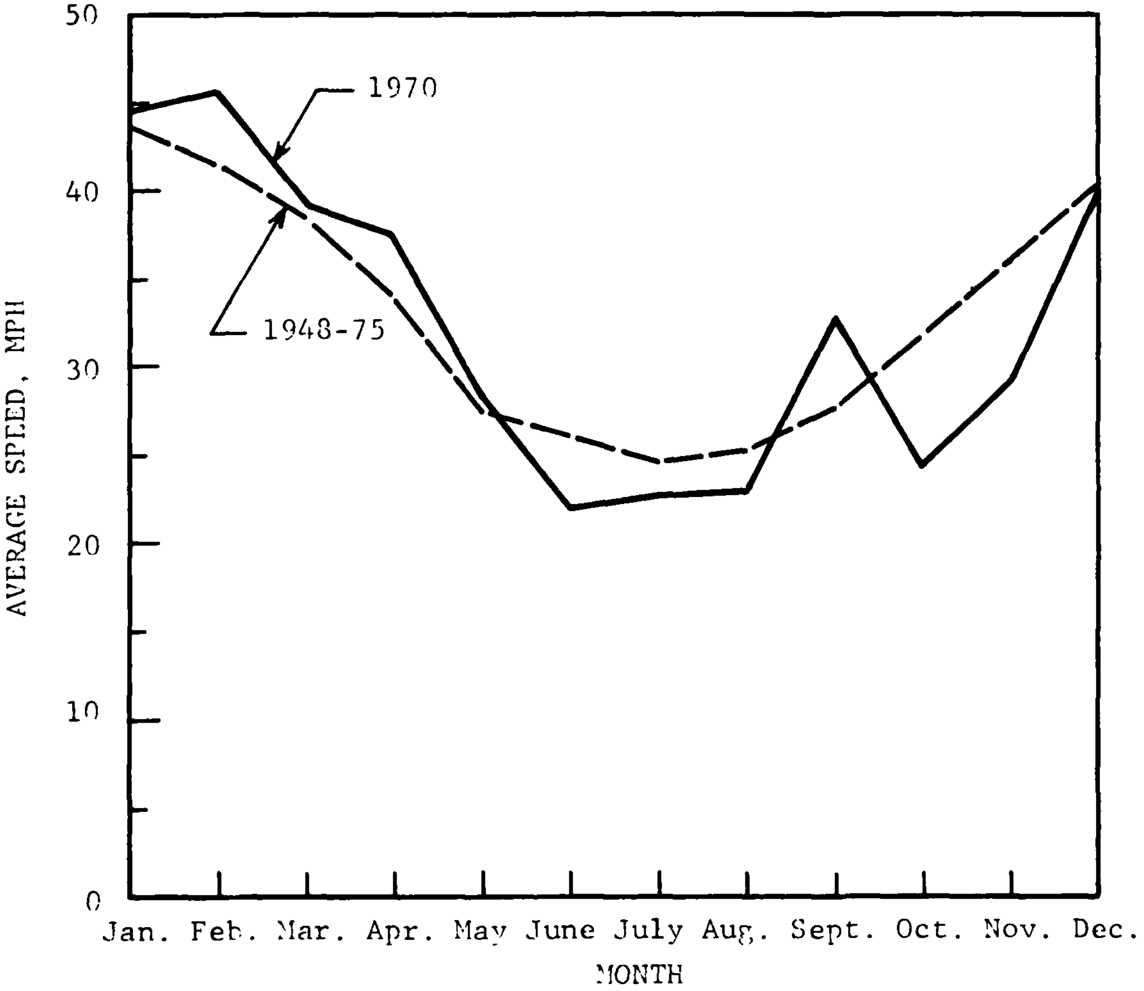


Fig. 3-35

Average monthly wind speed at Mt. Washington, N.H. for 1948 - 1975.
Annual average = 33.1 mph.

period (1977-78). The hourly wind speed and direction information on these forms was then punched on cards and reduced using the Corotis programs at Northwestern University. The seasonal distributions of wind speeds are shown in Figs. 3.36 through 3.39. The annual average wind speed was 15.34 m/sec (34.2 mph) for the two year period. The average annual wind power available at Mt. Washington for 1977 and 1978 was 4460 watts/m^2. In tabular form, the averages for 1977 and 1978 at Mt. Washington were:

Condition	Wind Speed, mph	Available Wind Power watts/m^2
Annual average	34.2	4460
Winter	42.6	7260
Spring	31.2	3530
Summer	29.7	2680
Fall	33.5	4380

Note that the 1977-78 annual average of 34.1 mph was slightly above the 1948-75 average of 33.1 mph. Also, the available wind power calculations were based on hourly data for the two year period.

The wind direction data were also tabulated for Mt. Washington for 1977 and 1978. In order to present wind speed-direction information concisely, the graphical plotting capabilities of the Fluid Mechanics Laboratory at IIT were utilized. Under the direction of Dr. Hassan M. Nagib, the direction-speed data were input so that a special contour plotting routine could be applied. The seasonal and annual averages for these contour plots are shown in Figs. 3.40 through 3.44.

Since Mt. Washington has very severe wind gusts (often over 100 mph) and severe icing conditions in the winter, the survivability of a large WECS system would be questionable. The MOD-2 is designed to survive 125 mph winds. Alcoa Darrieus concepts are designed for steady winds up to 100 mph with a 1.2 gust factor (to 120 mph). Neither MOD-2 or Darrieus concepts will guarantee

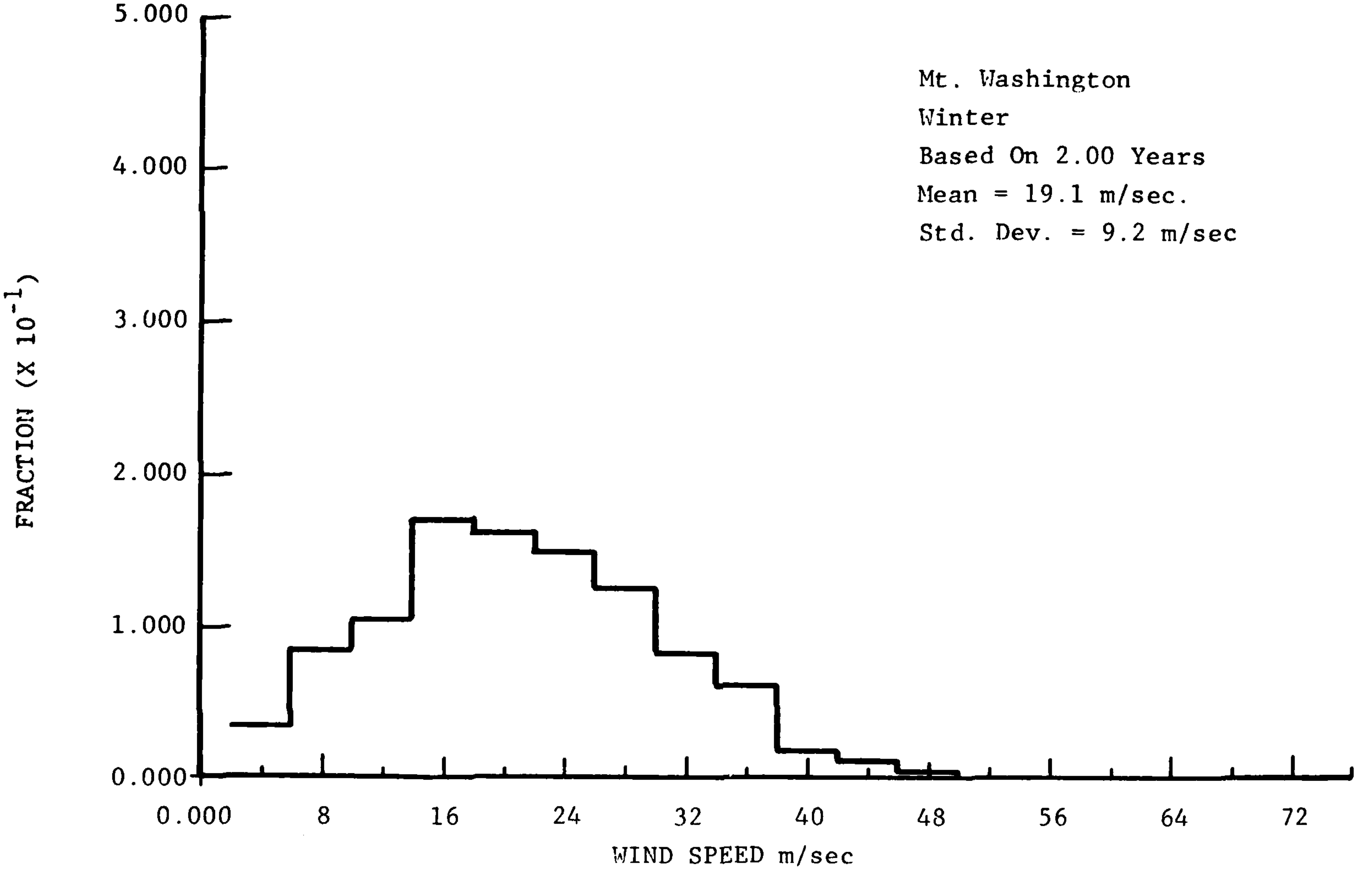


Figure 3.36 Fraction of Observations as a Function of Wind Speed for Mt. Washington for Winter, 1977 and 1978

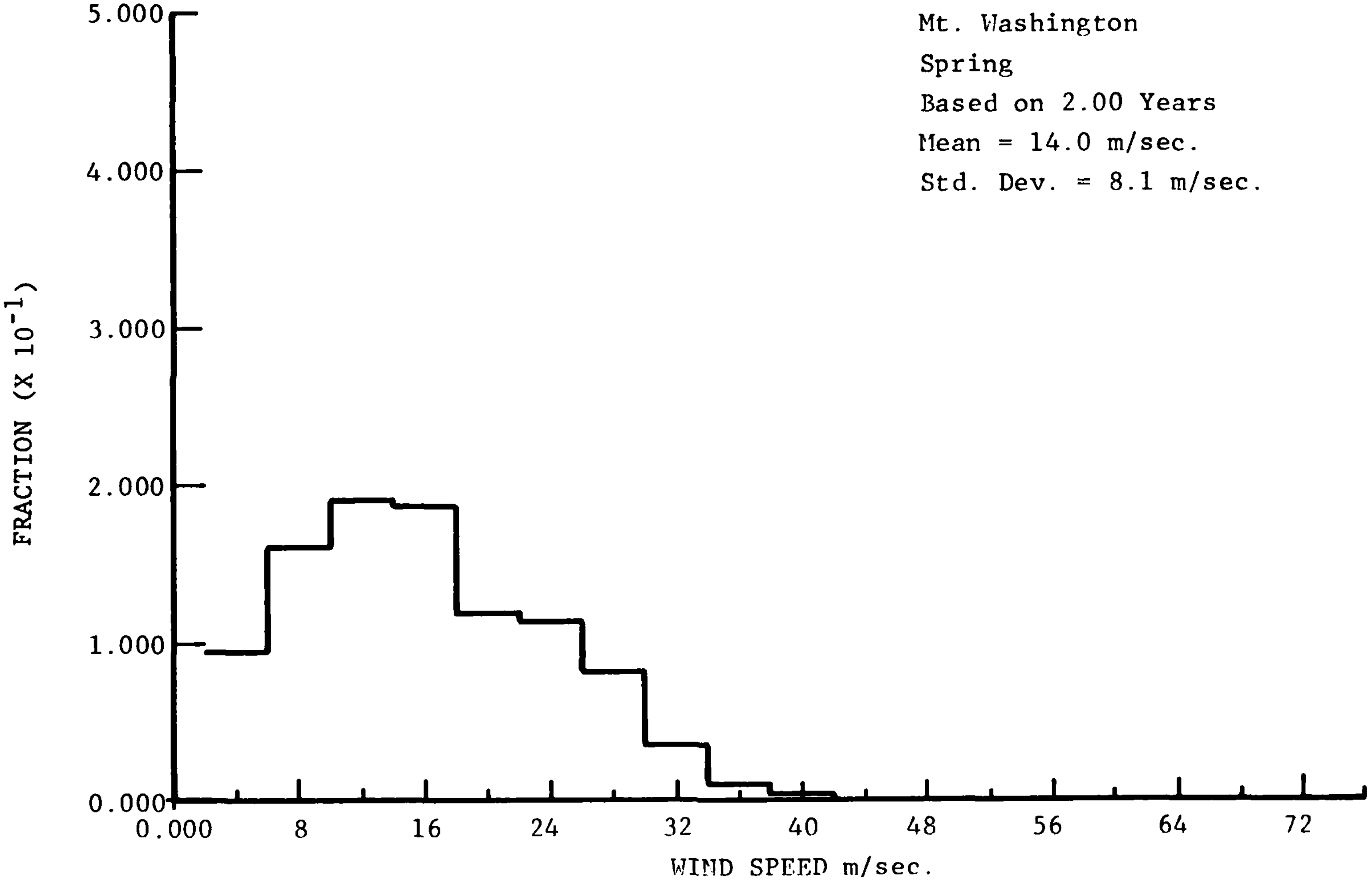


Figure 3.37 Fraction of Observations as a Function of Wind Speed for Mt. Washington for Spring, 1977 and 1978

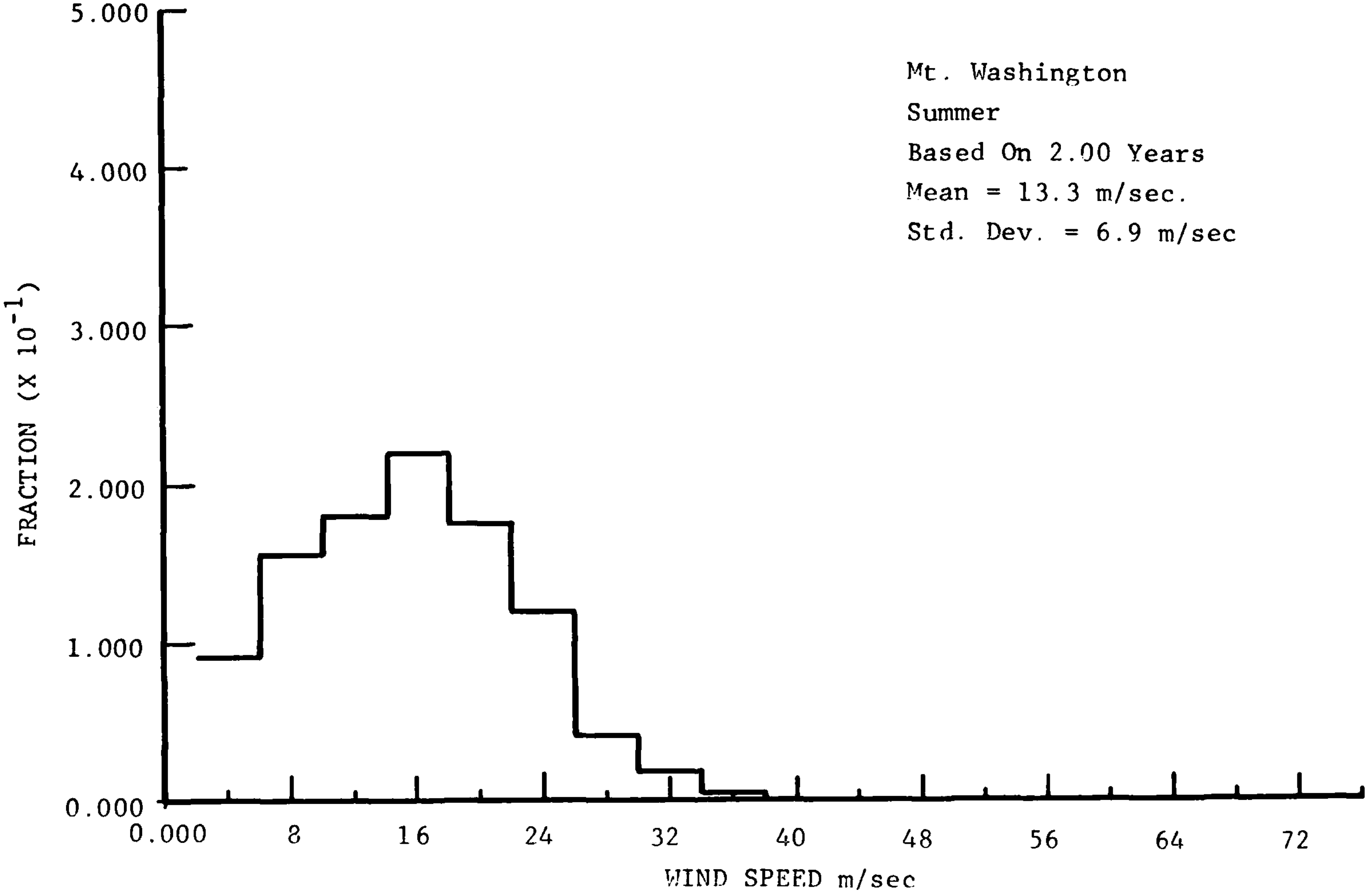


Figure 3.38 Fraction of Observations as a Function of Wind Speed for Mt. Washington for Summer, 1977 and 1978

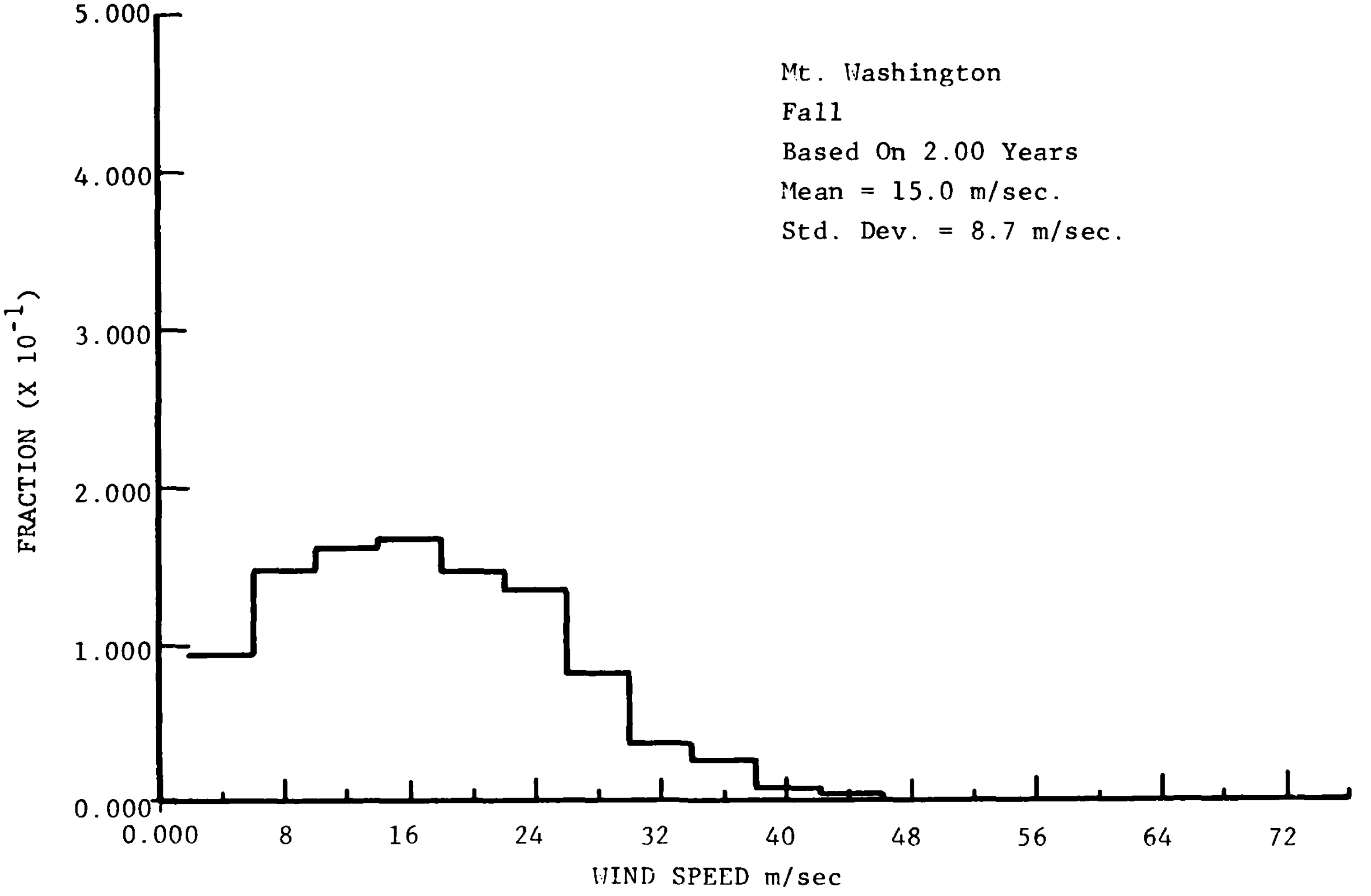


Figure 3.39 Fraction of Observations as a Function of Wind Speed for Mt. Washington for Fall, 1977 and 1978.

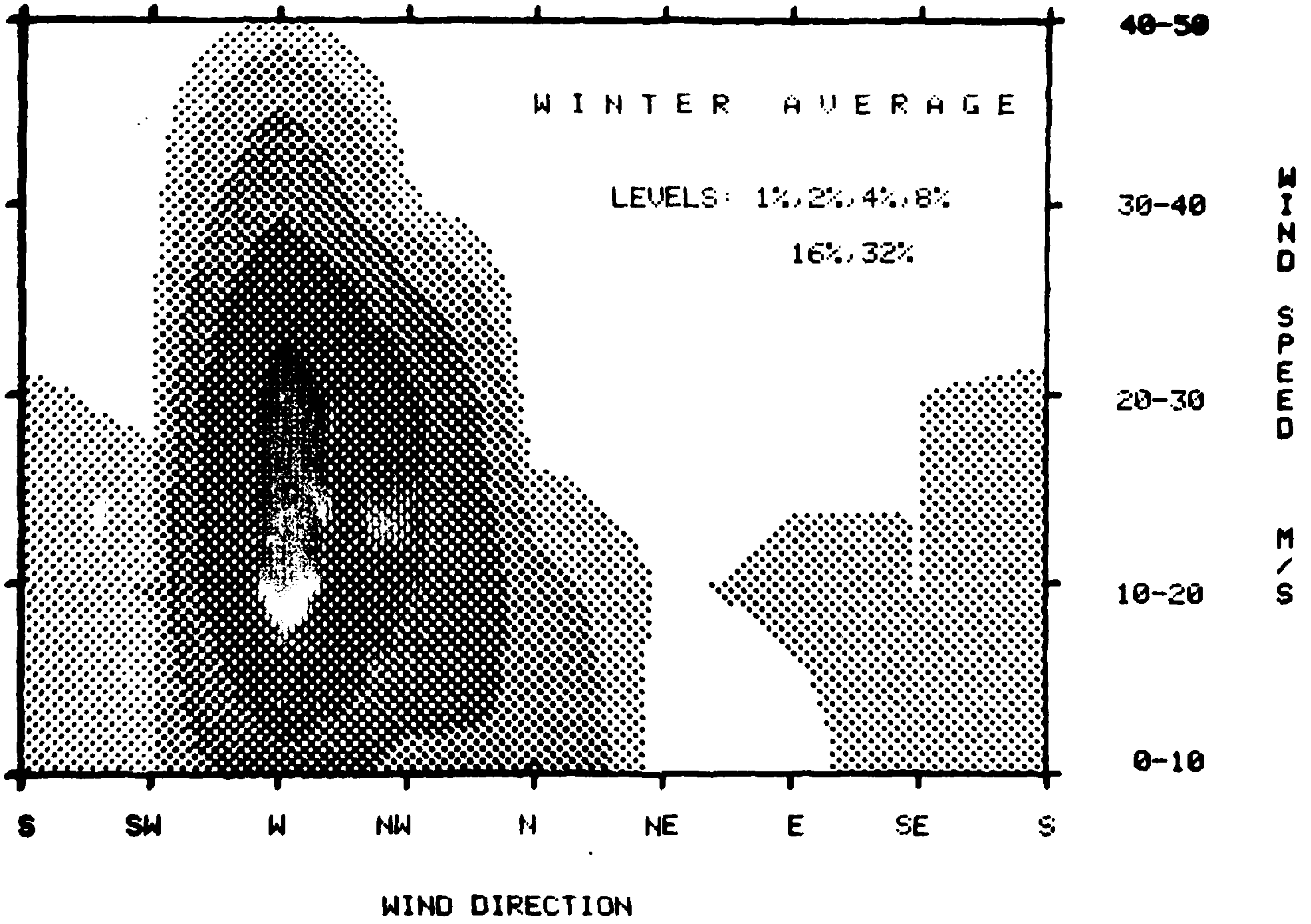


Figure 3.40 Seasonal Wind Speed and Direction Contours for Mt. Washington Averaged for 1977 and 1978

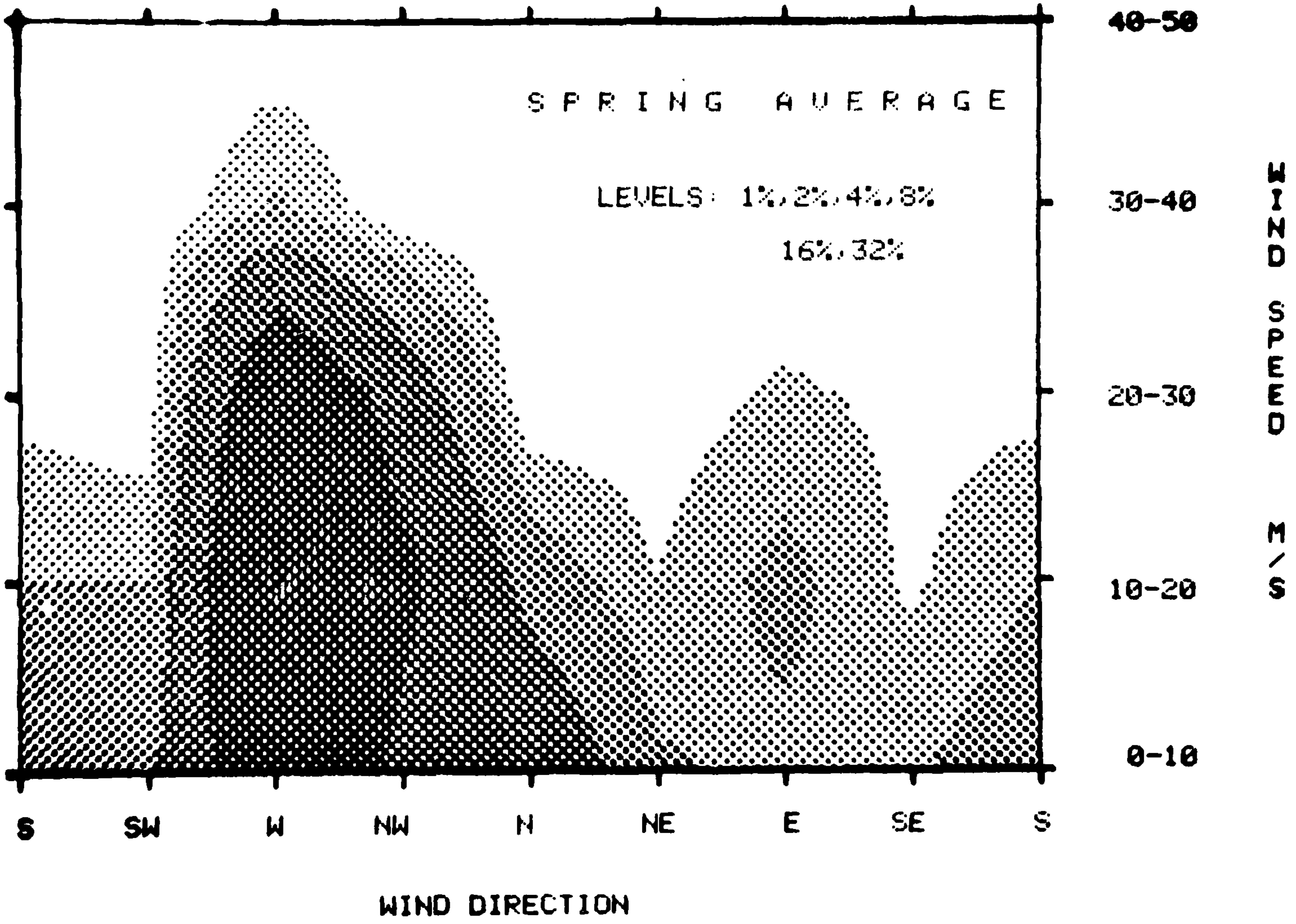


Figure 3.41 Seasonal Wind Speed and Direction Contours for Mt. Washington Averaged for 1977 and 1978

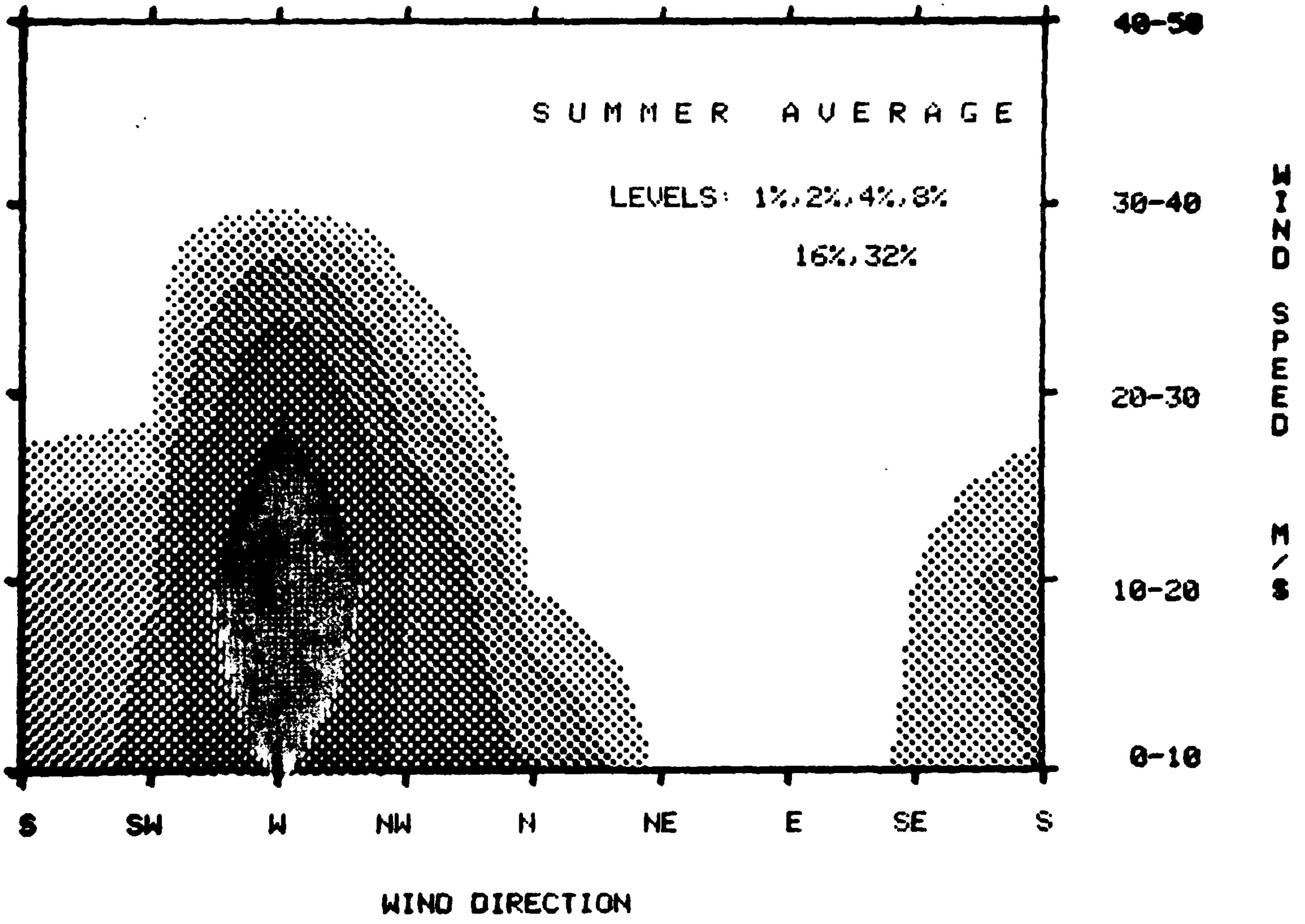


Figure 3.42 Seasonal Wind Speed and Direction Contours for Mt. Washington Averaged for 1977 and 1978

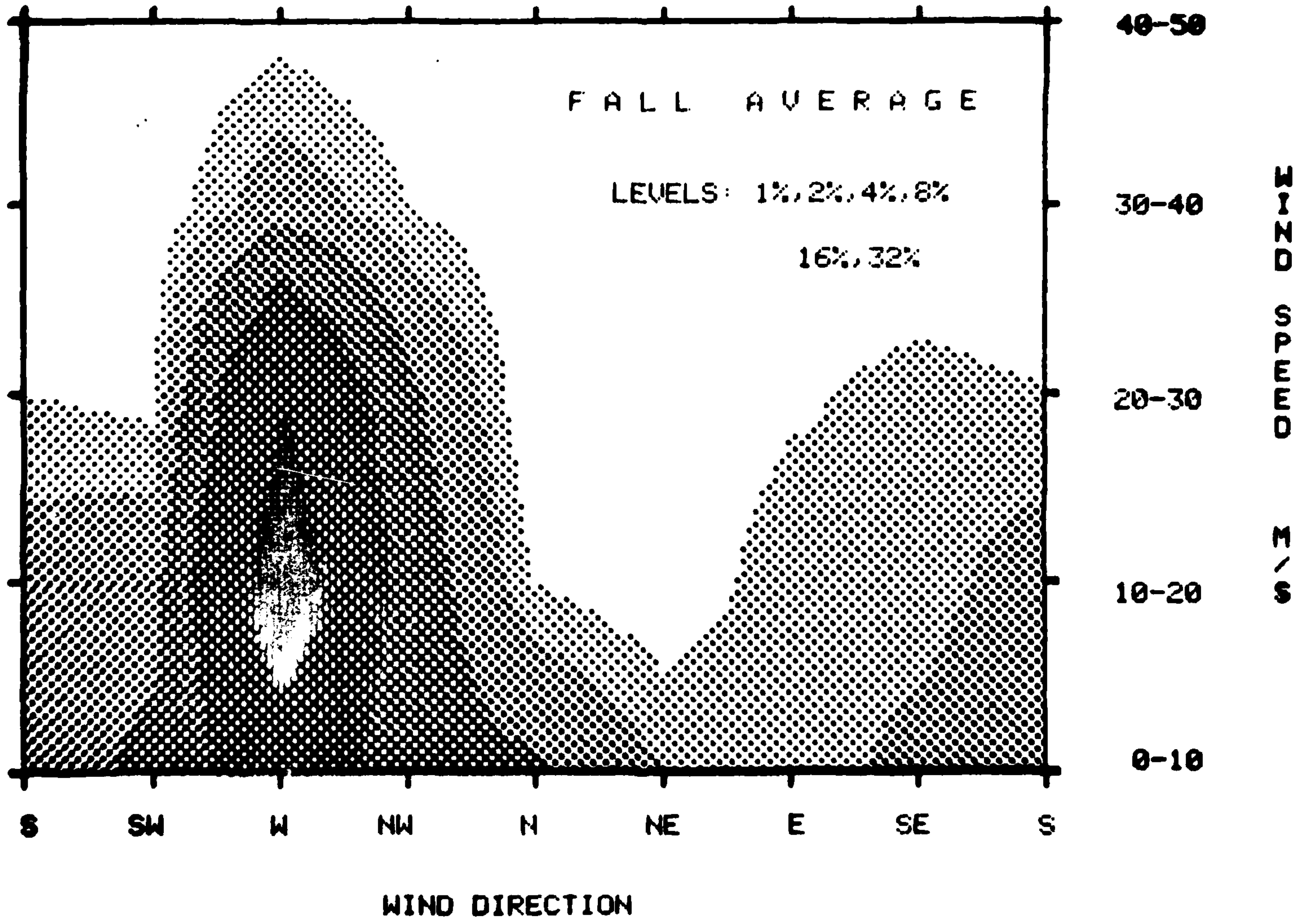


Figure 3.43 Seasonal Wind Speed and Direction Contours for Mt. Washington Averaged for 1977 and 1978

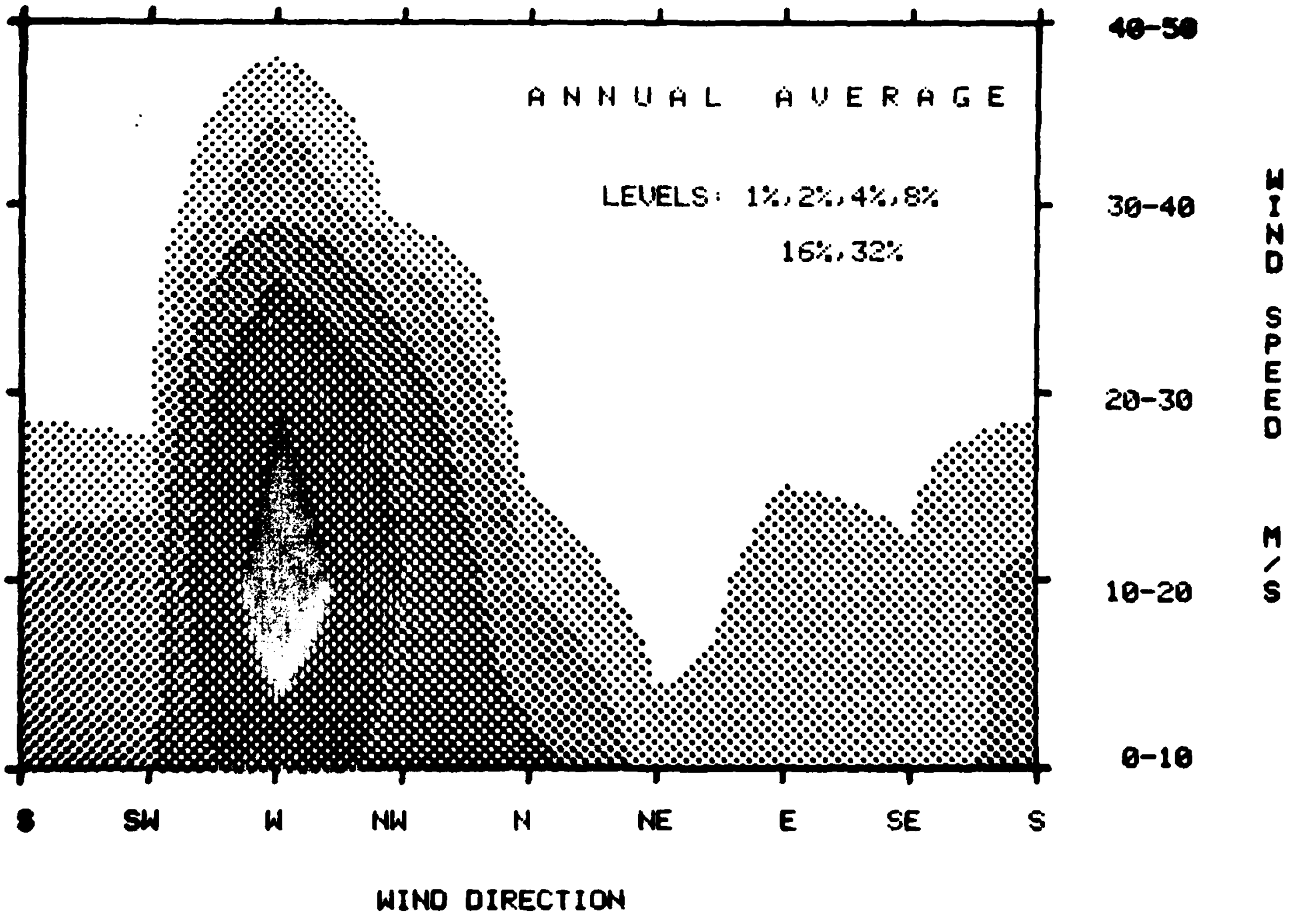


Figure 3.44 Annual Average for Two Years of Data

operation under severe icing conditions. Since the hazards at Mt. Washington are so severe, it would not be advisable to site a large unit there until operating experience shows that a WECS would survive and operate regularly. Therefore, other sites in the White Mountains were surveyed for high wind speeds.

3.1.2.3 1978 Fire Tower Data

The State of New Hampshire operates several Forest Fire Service lookout stations atop mountains which surround the National Forest of the White Mountains. Some wind measurements had been made at several of these sites during part of the year in 1978. These data were copied and sent to IITRI by personnel from the State of New Hampshire. Five of the sites were selected as having the highest wind speeds. These sites were:

Station	Town	County	Ground Elevation, ft.	Tower Height, ft.
Prospect	Lancaster	Coos	2065	60
Green	Effingham	Caroll	1907	68
Milan	Milan	Coos	1737	55
Hyland	Westmoreland	Cheshire	1510	64
Federal	Milford	Hillsborough	677	52

The wind speed data for these sites was recorded once per day for the spring through fall period of 1978. These data were summarized and plotted as a function of season and the results are shown in Figs. 3.45 through 3.49. For comparison purposes, these five sites are shown together in Fig. 3.50.

Annual averages have not been computed for these sites since winter measurements were not made. However, the general trends indicate that none of these sites will yield annual winds speeds above 10 mph.

In evaluating these 1978 measurement and other short term data at lower elevation sites, IITRI determined that none of these

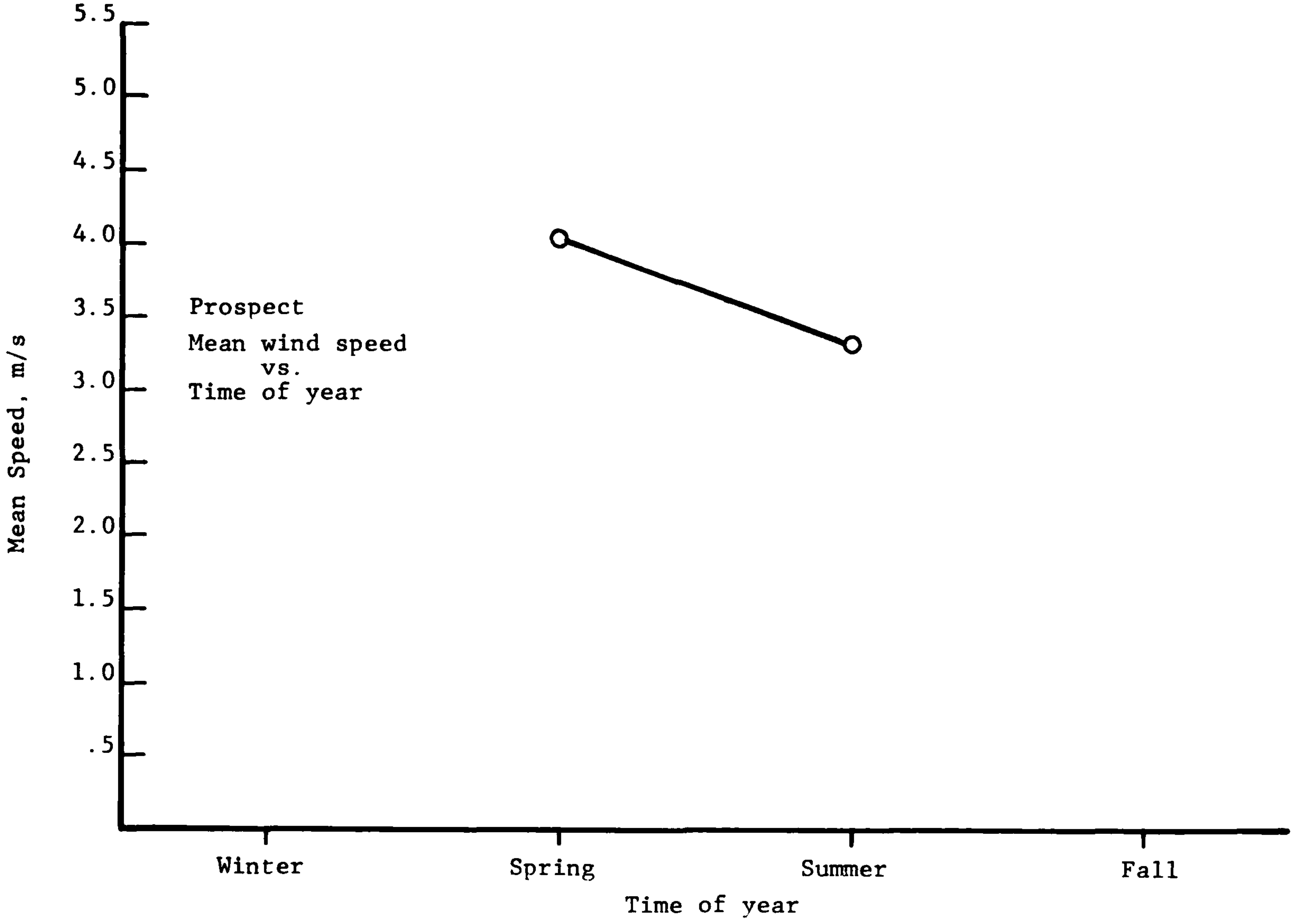


Figure 3.45 Fire Tower Daily Data for Spring & Summer 1978, Prospect Mountain Station

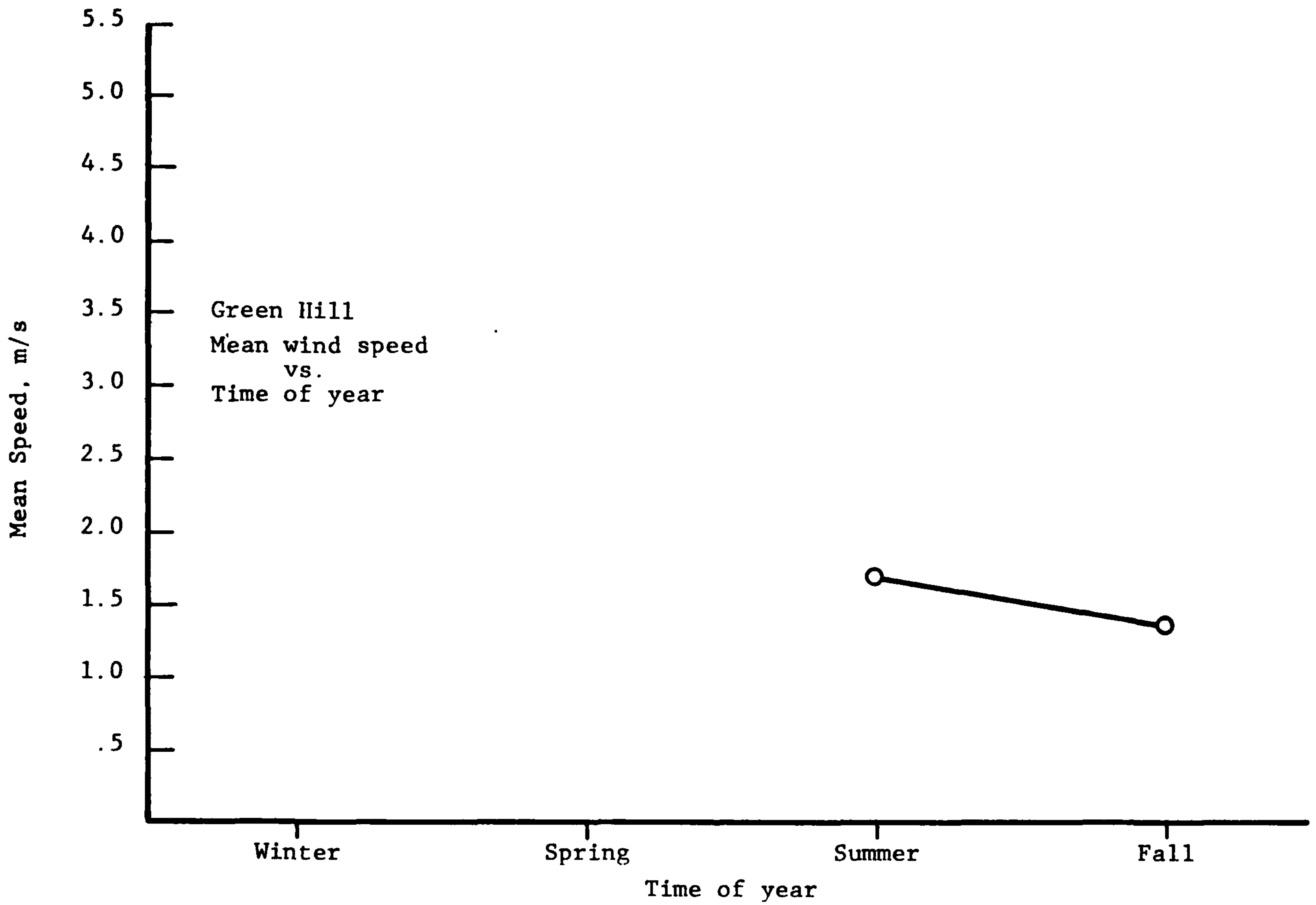


Figure 3.46 Fire Tower Daily Data for Summer & Fall 1978, Green Hill Station

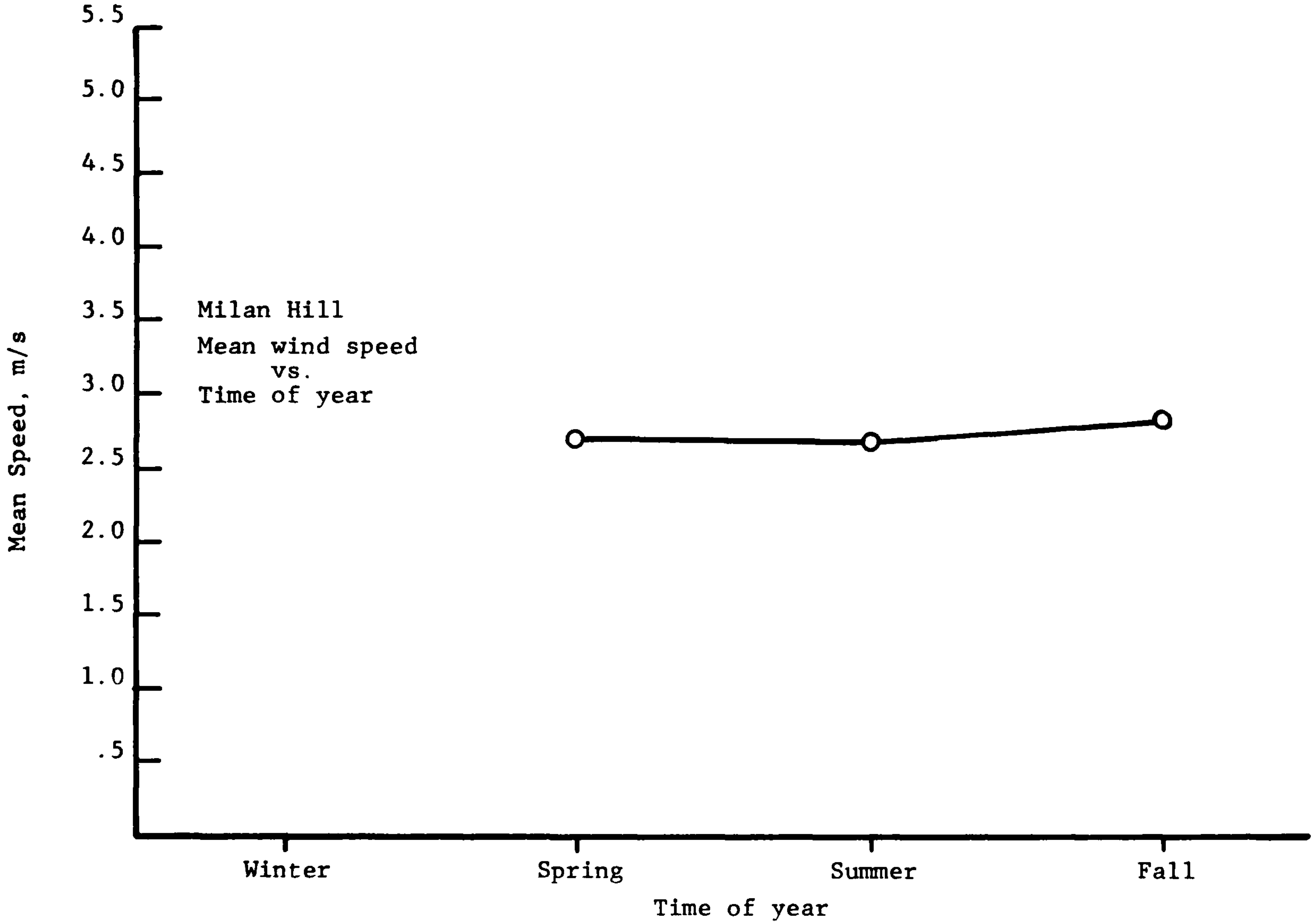


Figure 3.47 Fire Tower Daily Data for Spring, Summer, and Fall, 1978, Milan Hill Station

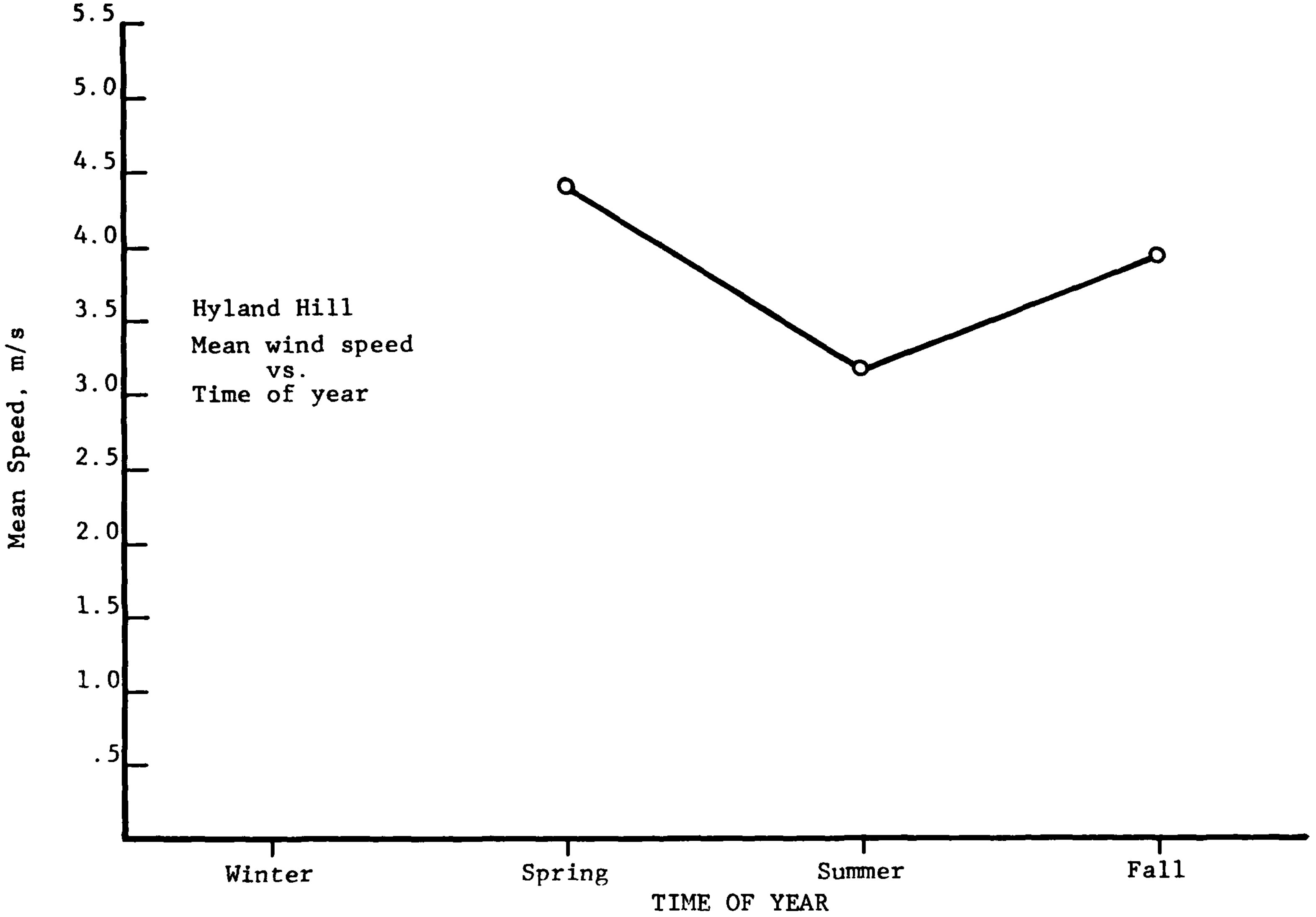


Figure 3.48 Fire Tower Daily Data for Spring, Summer, and Fall, 1978, Hyland Hill Station

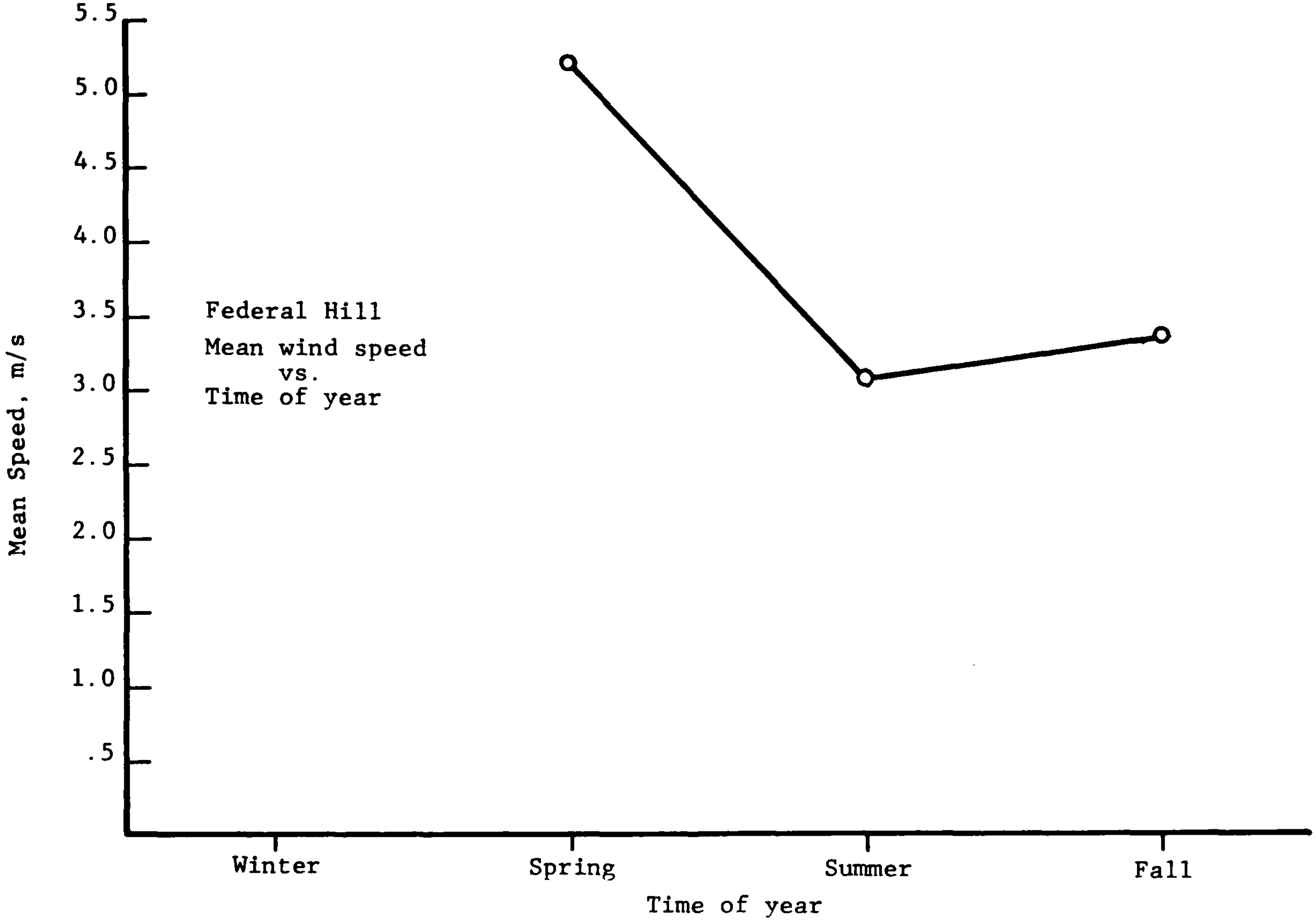


Figure 3.49 Fire Tower Daily Data for Spring, Summer, and Fall, 1978, Federal Hill Station

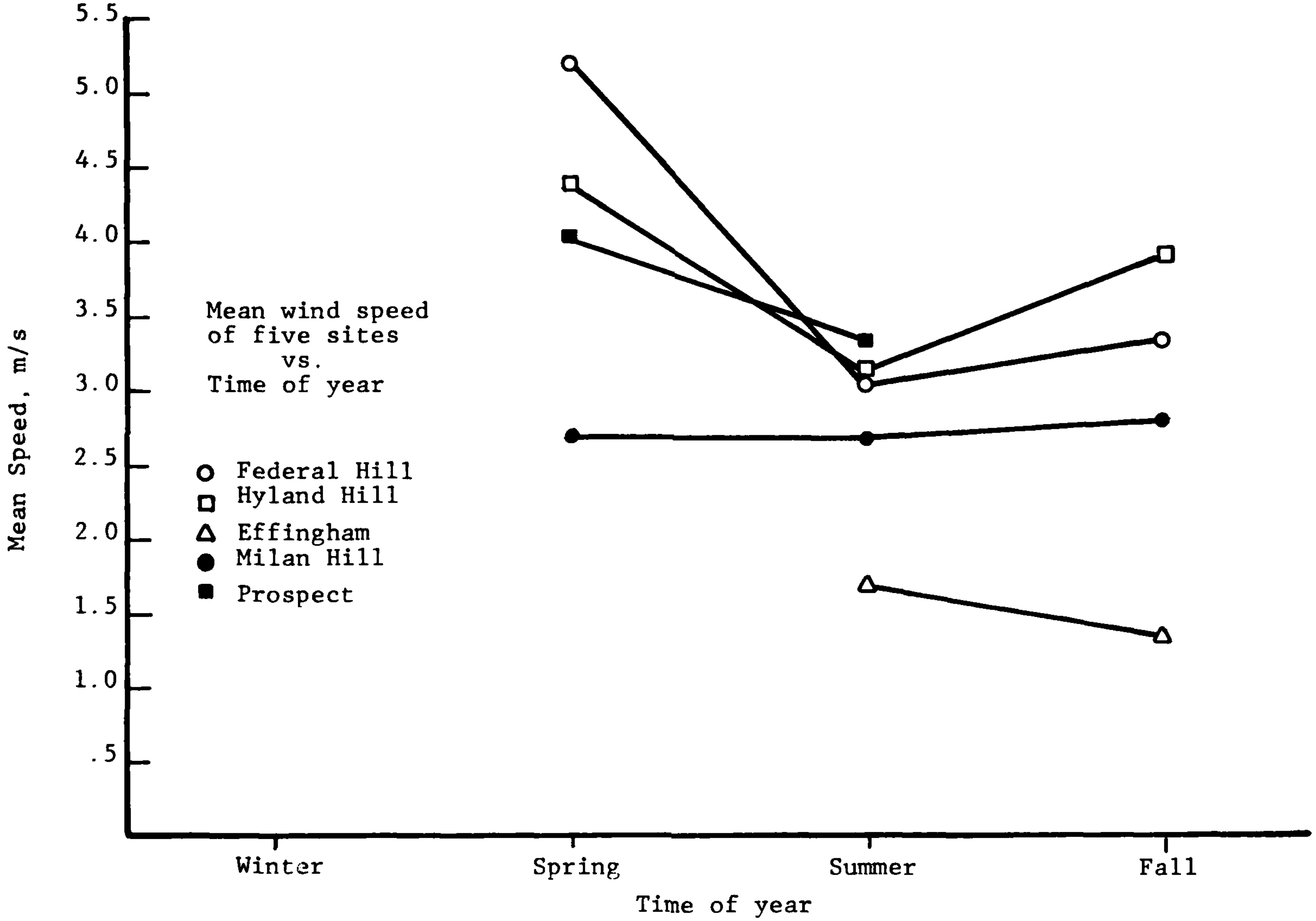


Figure 3.50 Comparison of 1978 Daily Data For Five Fire Tower Sites

sites had good potential for a WECS location. The only alternative for obtaining some actual wind data was to make short term measurements at higher mountain locations during the summer of 1979. Corotis(11) describes a technique for predicting annual wind speeds for sites using short term data compared with a reference location where long term information is known. After discusstions with Dr. Corotis, IITRI decided to pursue the following actions during August 1979:

- Select several medium height mountains where existing fire lookout towers were manned by state personnel.
- Install wind measuring equipment at towers where none existed.
- Schedule state personnel to make short term readings of the instruments for a two week period in August 1979.
- Obtain similar wind data from Mt. Washington for exactly the same time periods.
- Estimate the annual wind speed at these sites using the Corotis techniques.

Some of the basic questions to be answered by this procedure were:

Are the wind patterns on isolated peaks in or around the White Mountains similar to the Mt. Washington wind patterns? When it is windy on Mt. Washington, is it windy on other isolated peaks? Do the White Mountains wind statistics correlate as well as the lower elevation sites?

3.1.3 Short Term Measurements, August 1979

Instrumentation was chosen for these measurements based on the following criteria:

- Instantaneous measurements would be made so that cross-correlations between sites could be accomplished.
- Instruments had to be installed easily and operate on battery power.
- Simplicity was important because untrained personnel would operate and read the instruments.
- Instruments had to be inexpensive since they were expendable.

The wind speed and direction sensors made by Weather Measure Corp. (P.O. Box 41257, Sacramento, CA) were selected for the installations. Separate meters were read for wind speed and direction. The speed indicator was self-powered while the direction indicator required a 9 volt battery. Six WSZ00-SD sensors with W221 indicators were purchased and prepared for installation on pipe masts above the roofs of existing fire towers (6-9 ft. above the roof). Specific towers were selected for:

- varying mountain heights,
- locations surrounding the White Mountains,
- unobstructed peaks.

In Fig. 3.51, the locations of the seven selected sites are shown. The corresponding station information is:

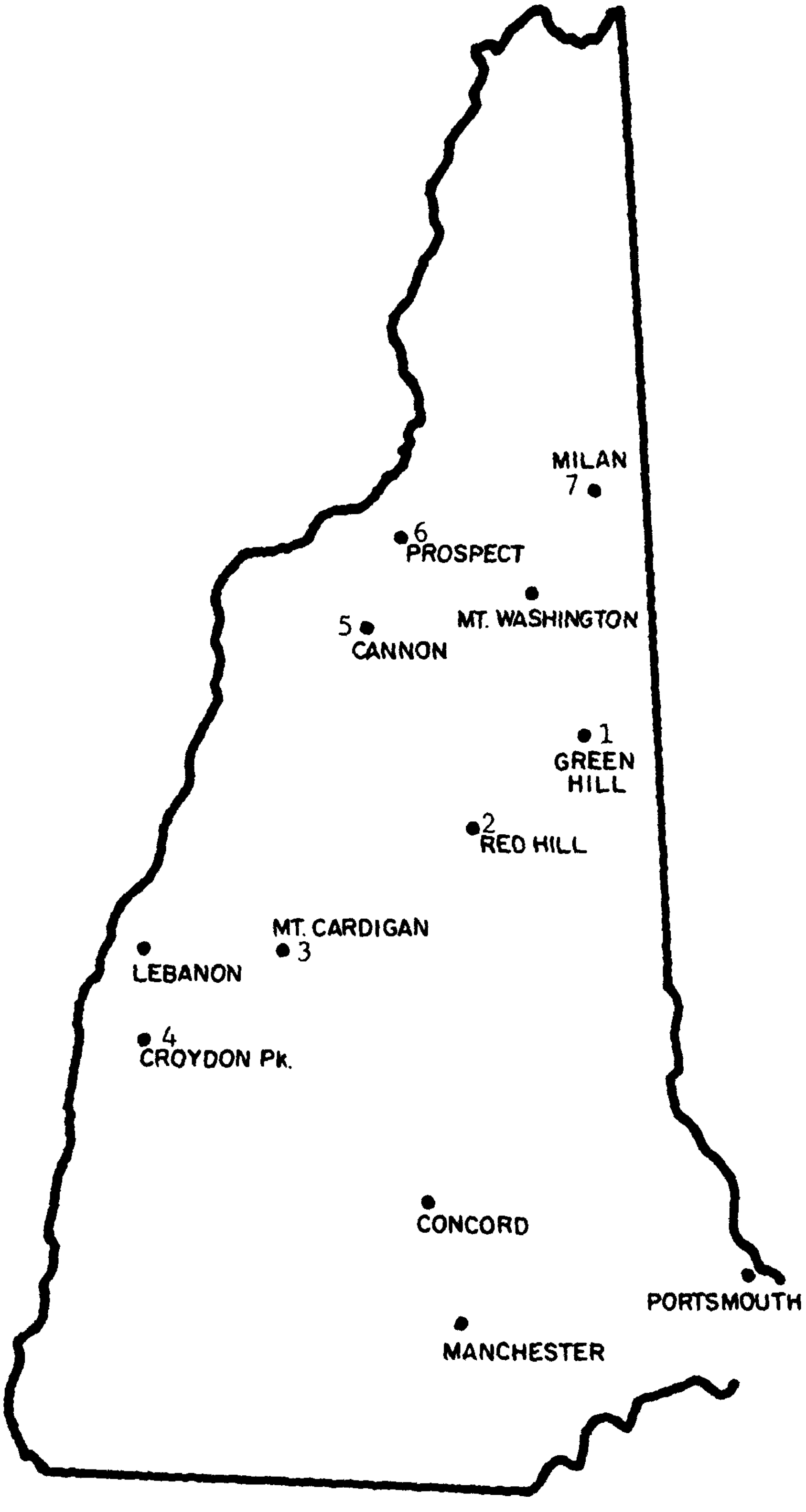


Figure 3-51 Location of Seven Sites for August 1979 Experiment

AD-A086 506   IIT RESEARCH INST CHICAGO IL   F/G 10/2
NAVY-NEW HAMPSHIRE WIND ENERGY PROGRAM.(U)
NOV 79 S A BORTZ, R A BUDENHOLZER   N00014-79-C-6503
UNCLASSIFIED   IITRI-M6052   NL

2 OF 3
AD A
086506

Station	Town	County	Ground Elevation, ft.	Tower Height, ft.	Existing Instrumentation
Cannon	Franconia	Grafton	4080	30	no
Cardigan	Orange	Grafton	3121	32	no
Croydon	Croydon	Sullivan	2780	34	no
Prospect	Lancaster	Coos	2065	60	yes
Red Hill	Sandwich	Carroll	2029	38	no
Green Mt.	Effingham	Carroll	1907	68	no
Milan	Milan	Coos	1737	55	yes

Since two of the towers had operating instruments, IITRI personnel installed five sets of instruments on the other five towers during the August 2-4, 1979 period after checking the manufacturer's calibration setting for wind speed. Wind direction was set with a compass.

Fire tower personnel were instructed to read wind speed and direction at 10 a.m., 1 p.m. and 4 p.m. for the 14 days of August 6 through 19, 1979. One of the major risks was that the instrument readings were not precise at speeds below 5 mph. Therefore, if averages were below 5 mph, considerable error would result. In order to obtain a one-minute average, personnel wrote down speed readings every 10 seconds for one minute and averaged the result. Finally, at the end of the two week period, the Mt. Washington values for the same times were obtained. The raw data are presented in graphical form in Figs. 3.52 through 3.65. These plots are divided into the four higher and four lower elevations as a function of hour for speed and direction. The daily 24-hour average at Mt. Washington is shown in Fig. 3.66.

The following general trends can be observed:

- The wind speed at the higher elevations tends to follow Mt. Washington.
- The daily average wind speeds are similar to the hourly data.

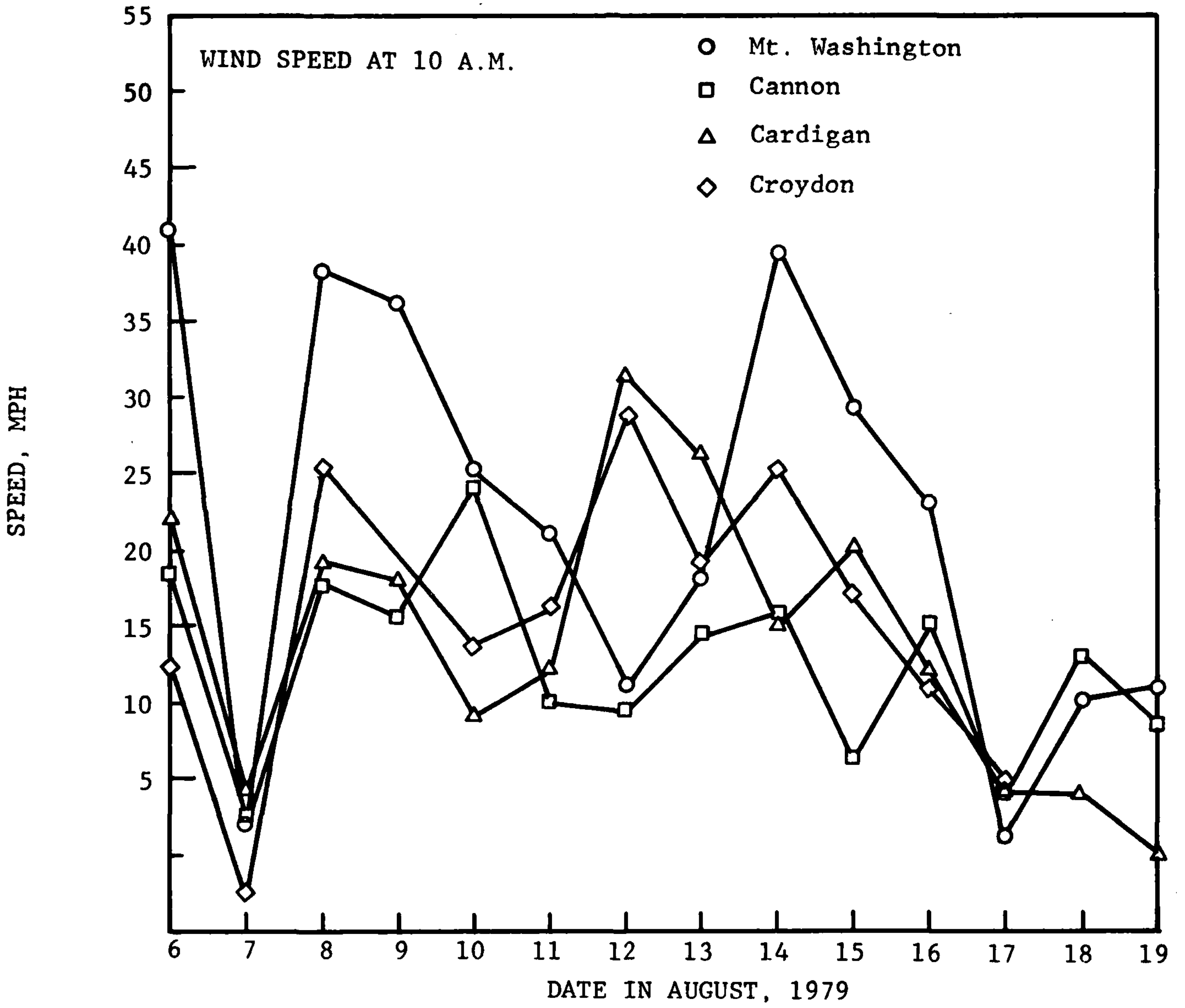


Figure 3.52 Comparison of Wind Speeds At Four Higher Elevation Sites During Aug. 6-19, 1979, 10 A.M. Readings

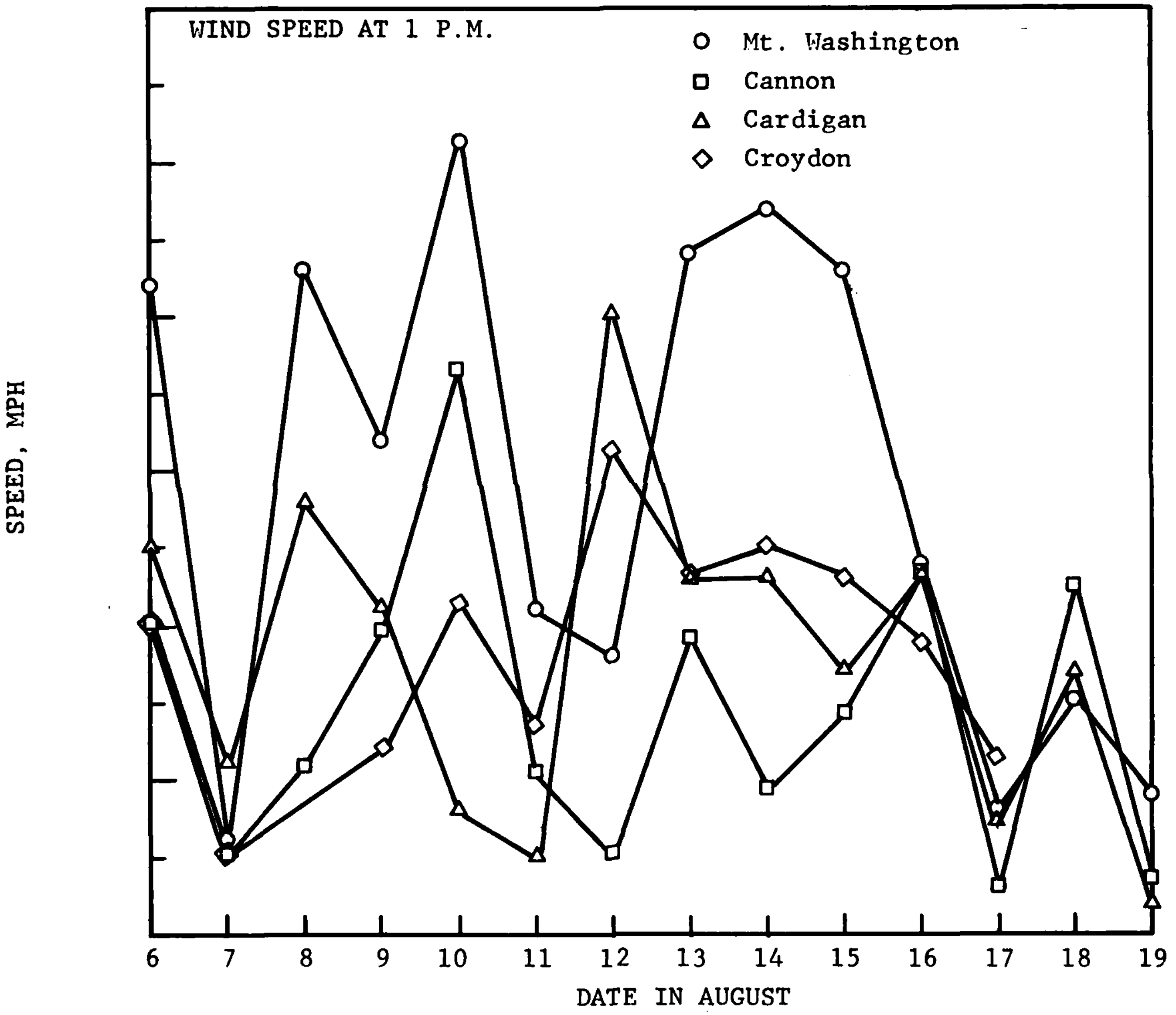


Figure 3.53. Comparison of Wind Speeds at Four Higher Elevation Sites During Aug. 6-19, 1979, 1 P.M. Readings

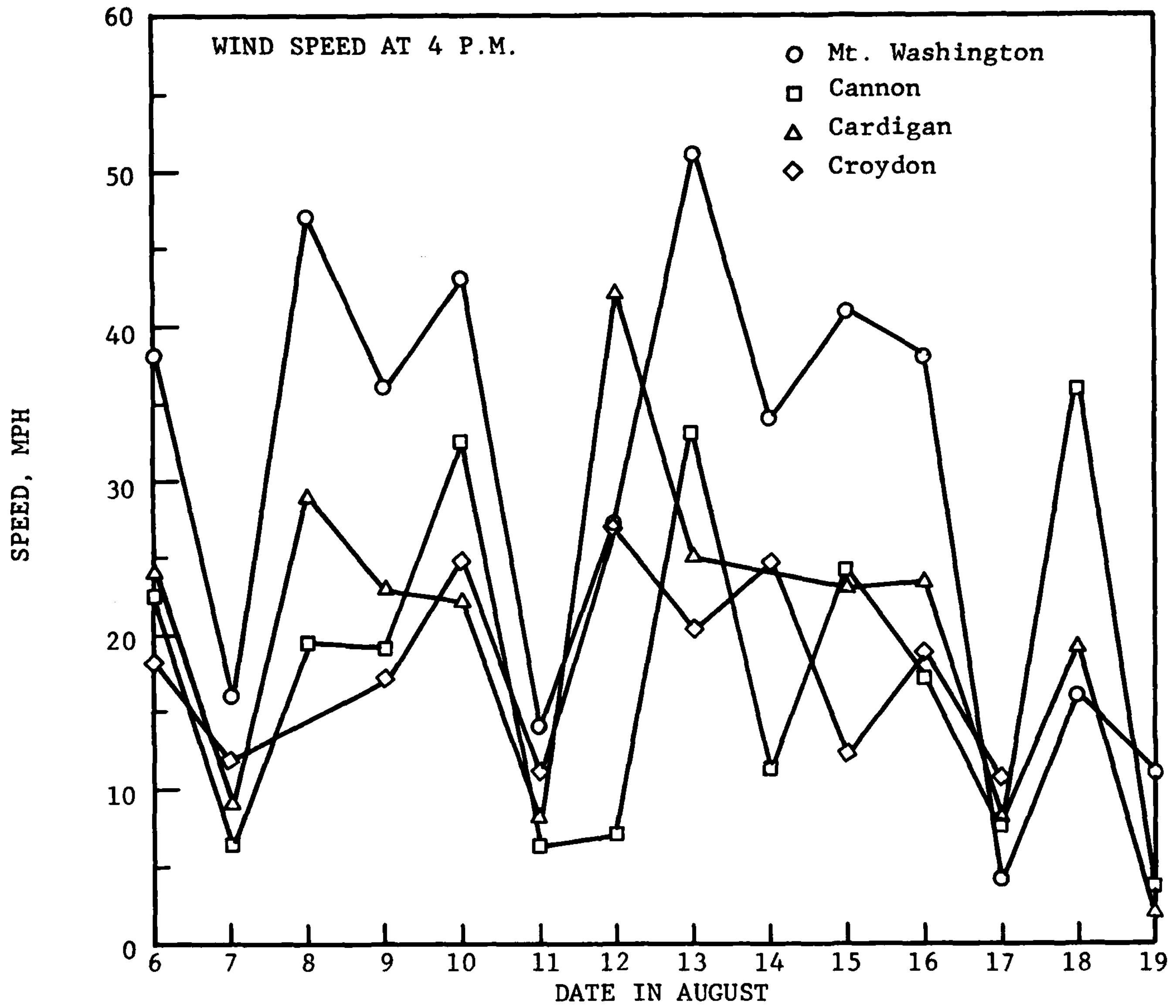


Figure 3.54 Comparison of Wind Speeds at Four Higher Elevation Sites During Aug. 6-19, 1979, 4 P.M. Readings

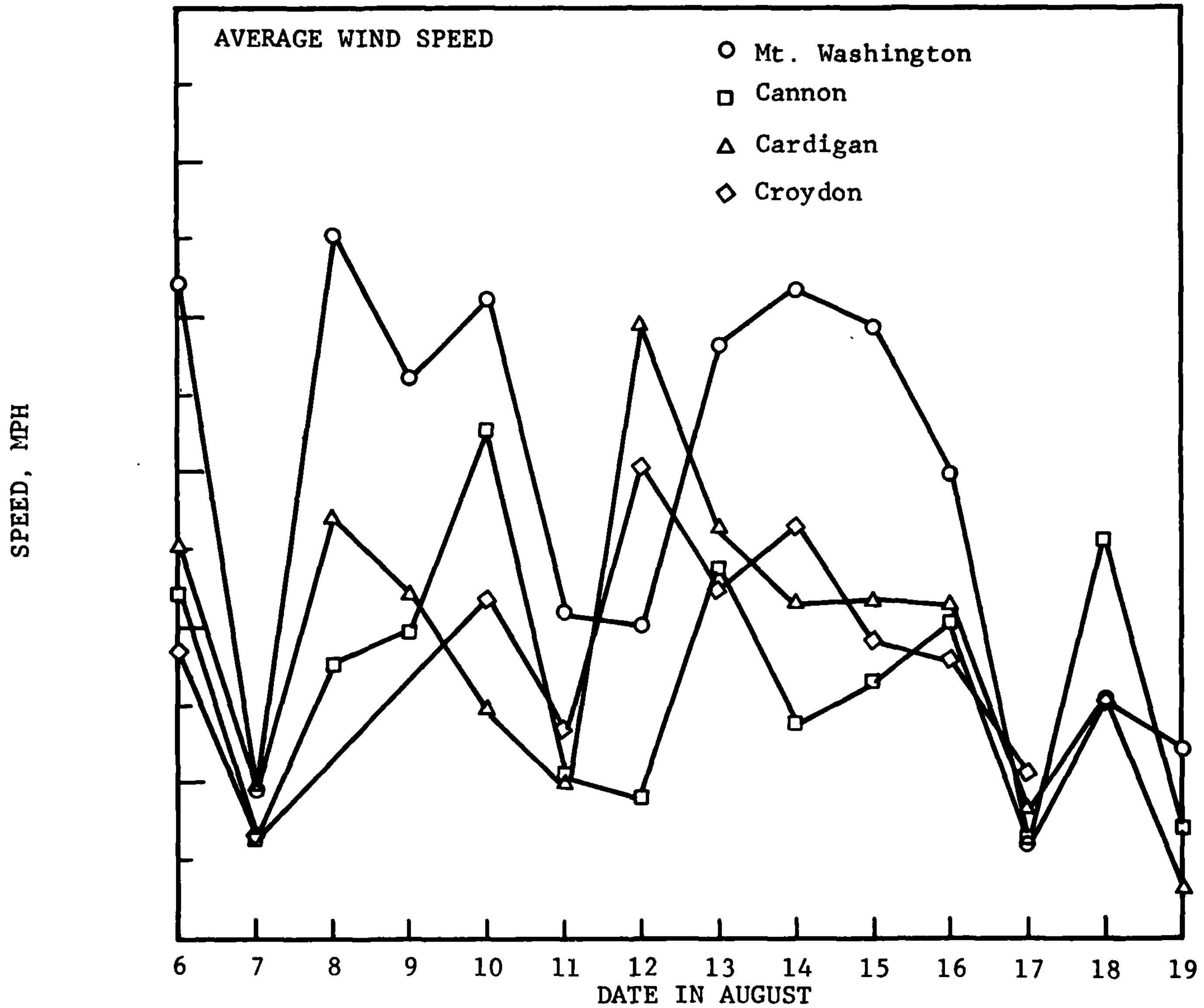


Figure 3.55 Comparison of Wind Speeds at Four Higher Elevation Sites During Aug. 6-19, 1979, Daily Average of Three Readings

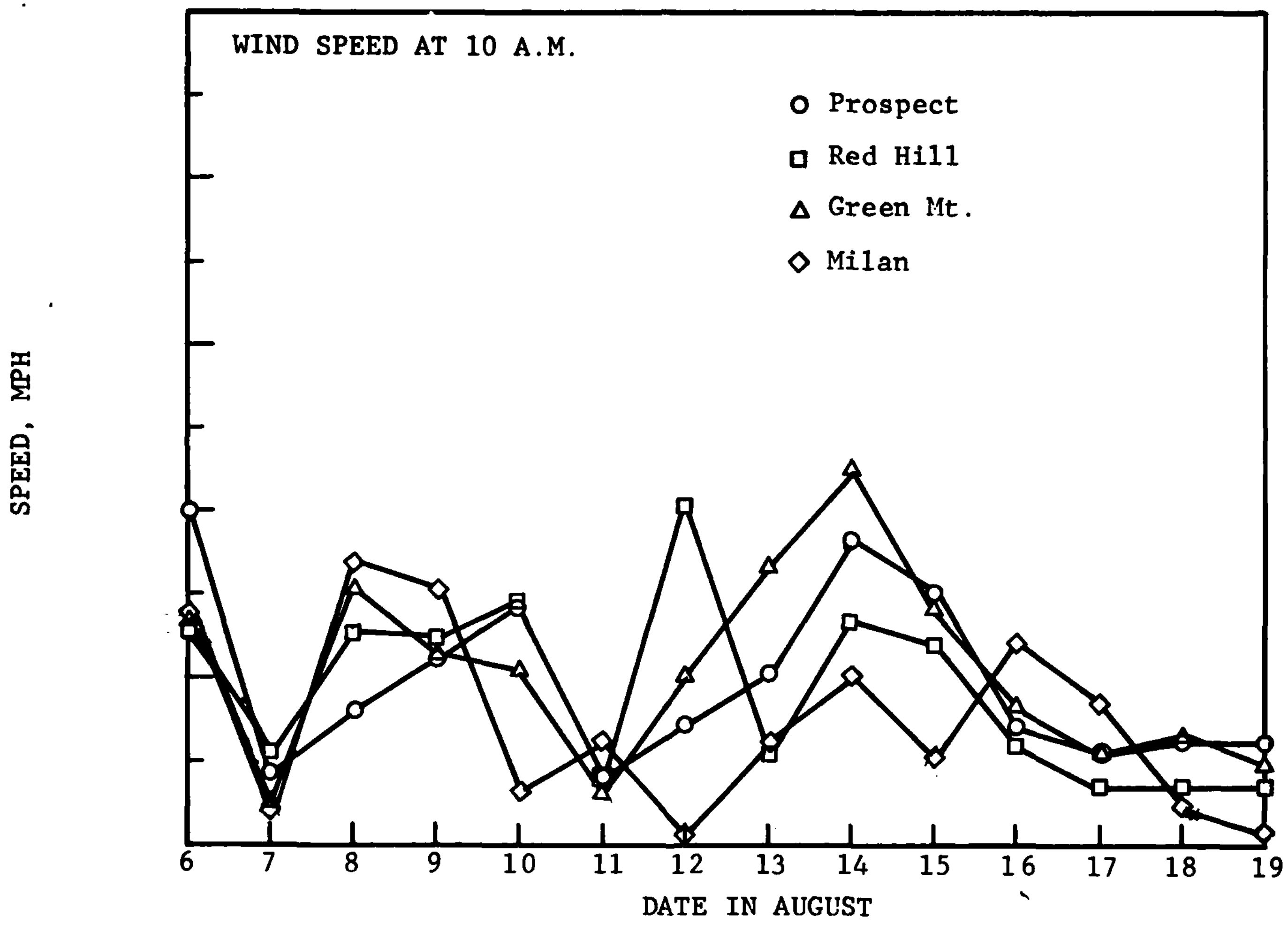


Figure 3.56 Comparison of Wind Speeds At Four Lower Elevation Sites During Aug. 6-19, 1979, 10 A.M. Readings

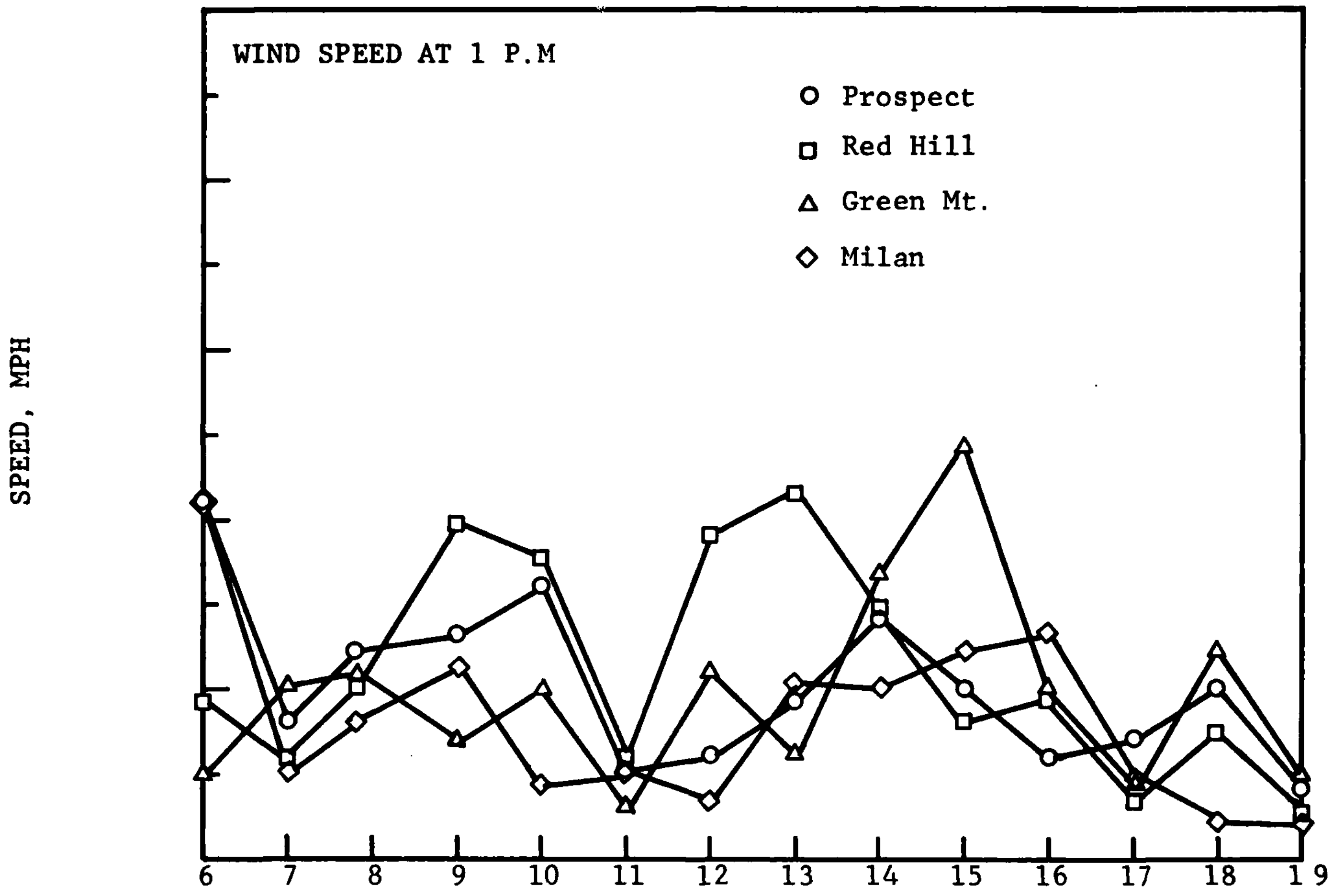


Figure 3.57 Comparison of Wind Speeds At Four Lower Elevation Sites During Aug. 6-19, 1979, 1 P.M. Readings

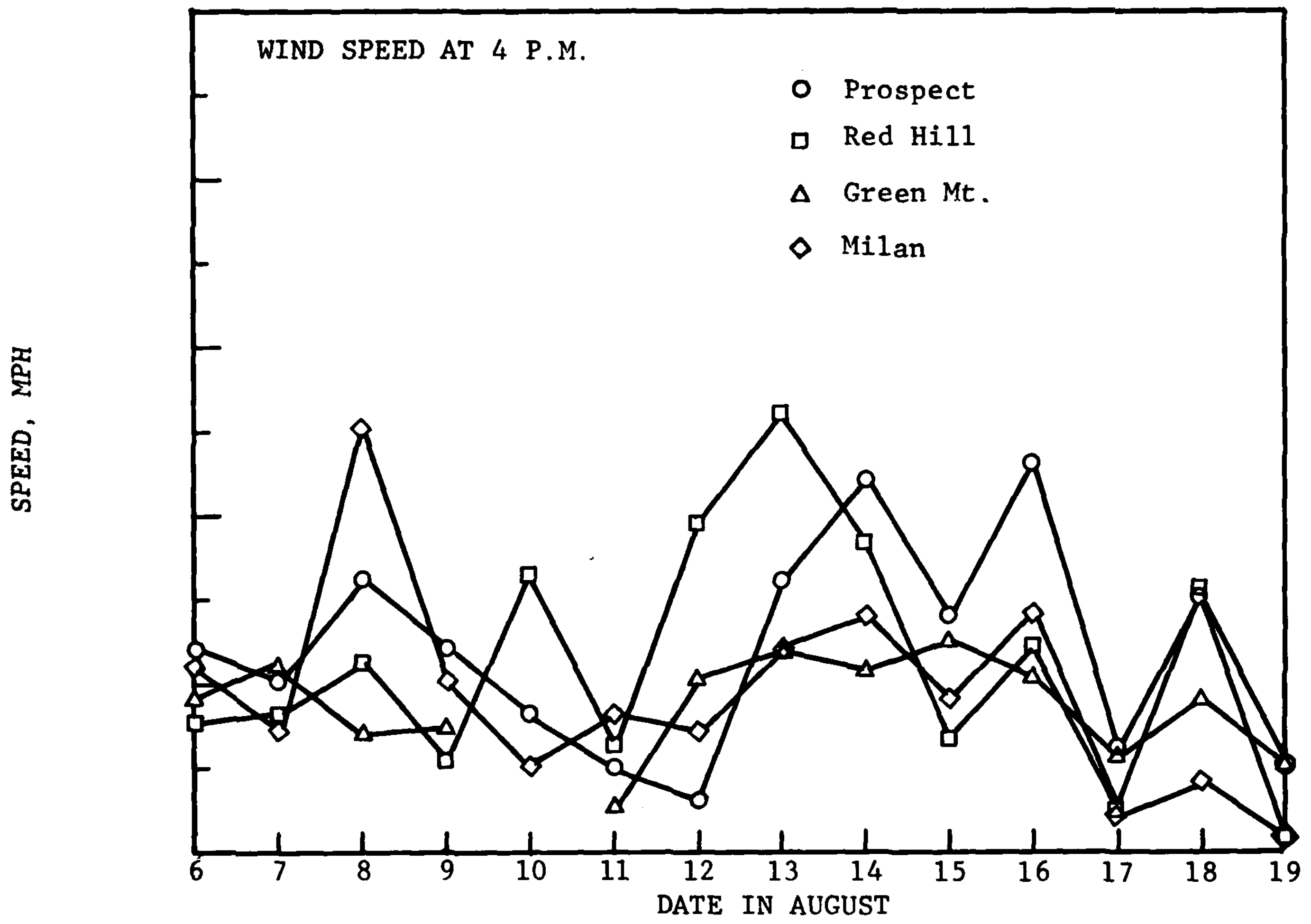


Figure 3.58 Comparison of Wind Speeds At Four Lower Elevation Sites During Aug. 6-19, 1979, 4 P.M. Readings

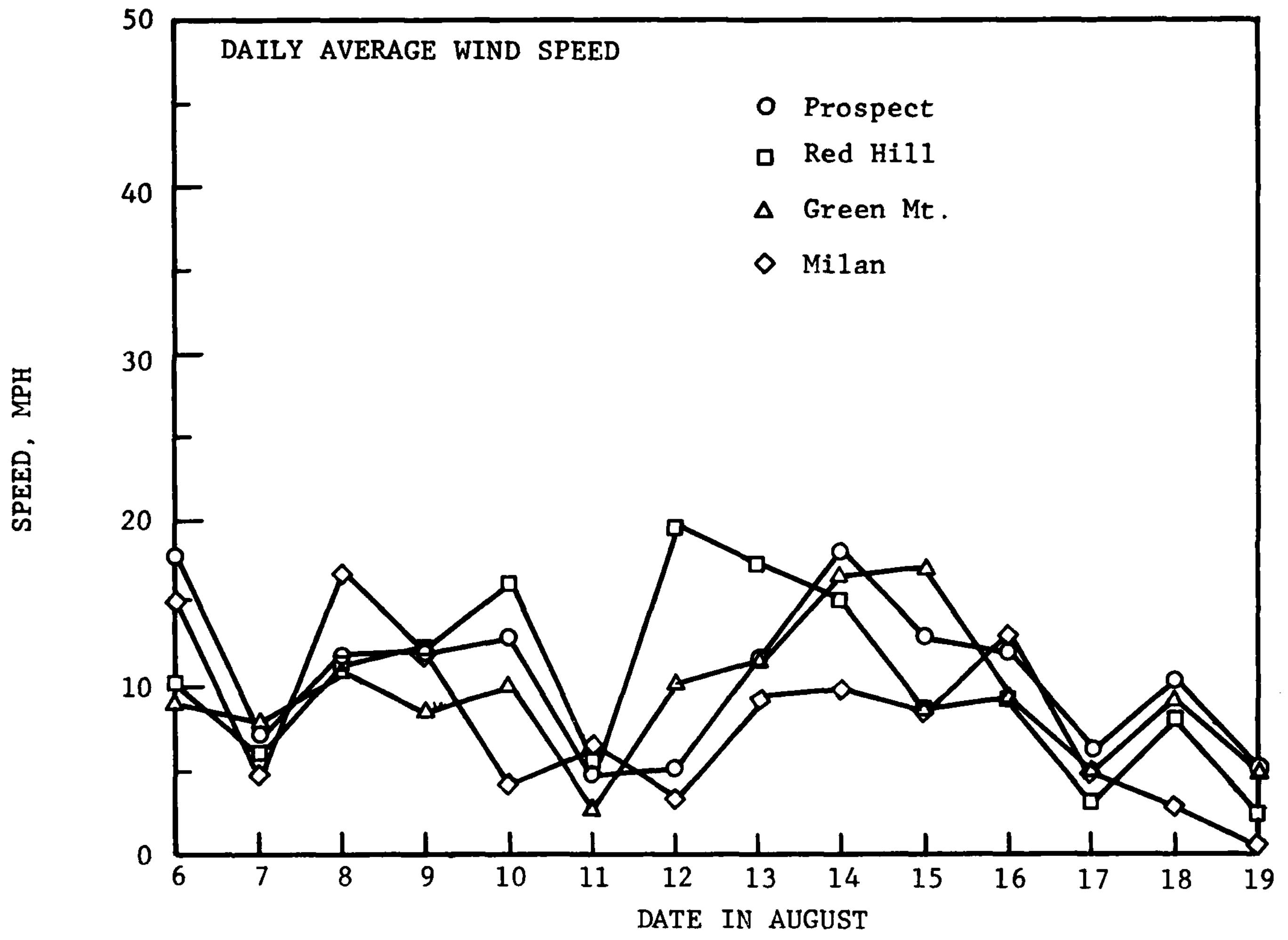


Figure 3.59 Comparison of Wind Speeds At Four Lower Elevation Sites During Aug. 6-19, 1979, Daily Average of Three Readings

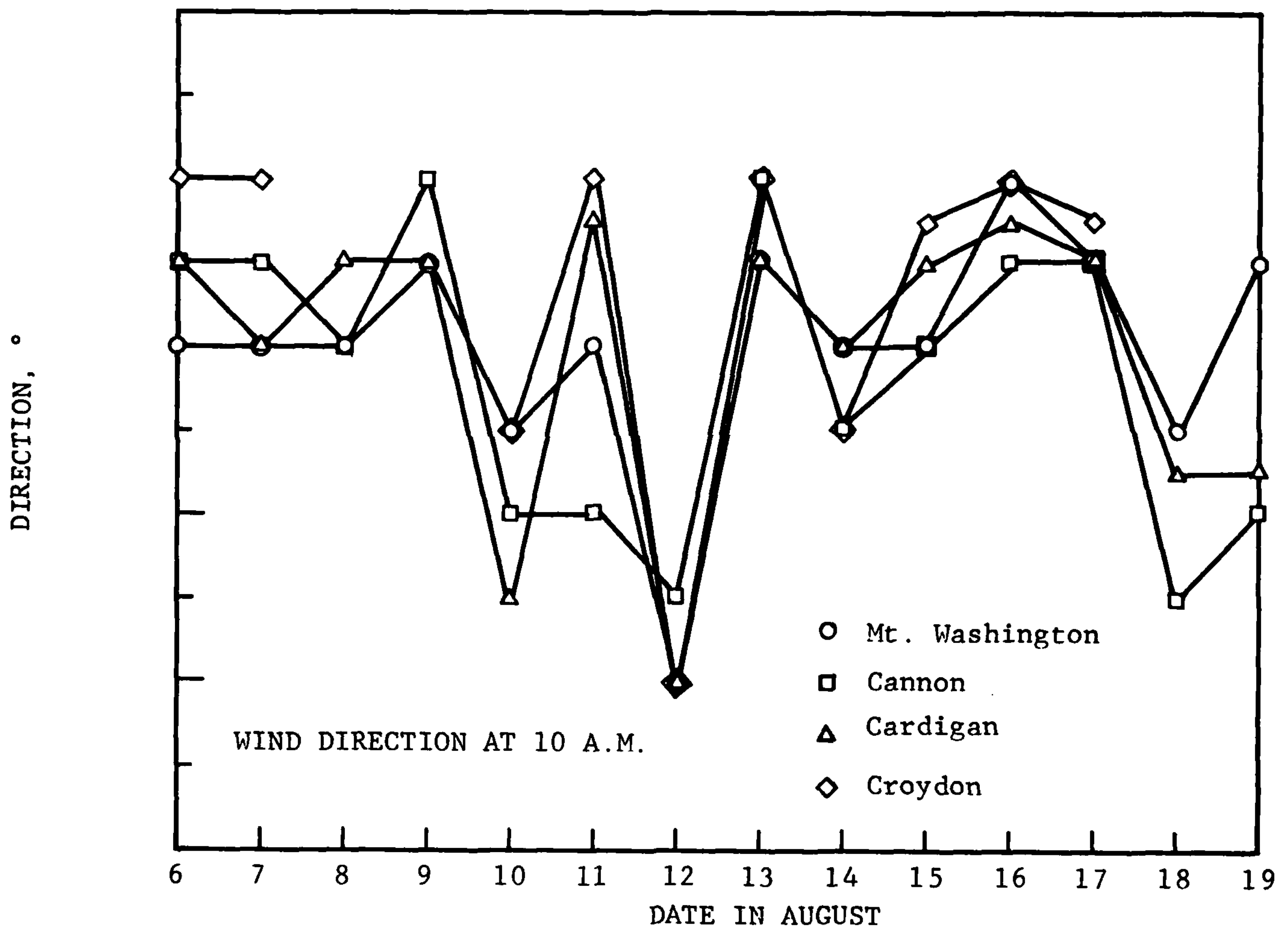


Figure 3.60 Comparison of Wind Direction At Four Higher Elevation Sites During Aug. 6-19, 1979, 10 A.M. Readings

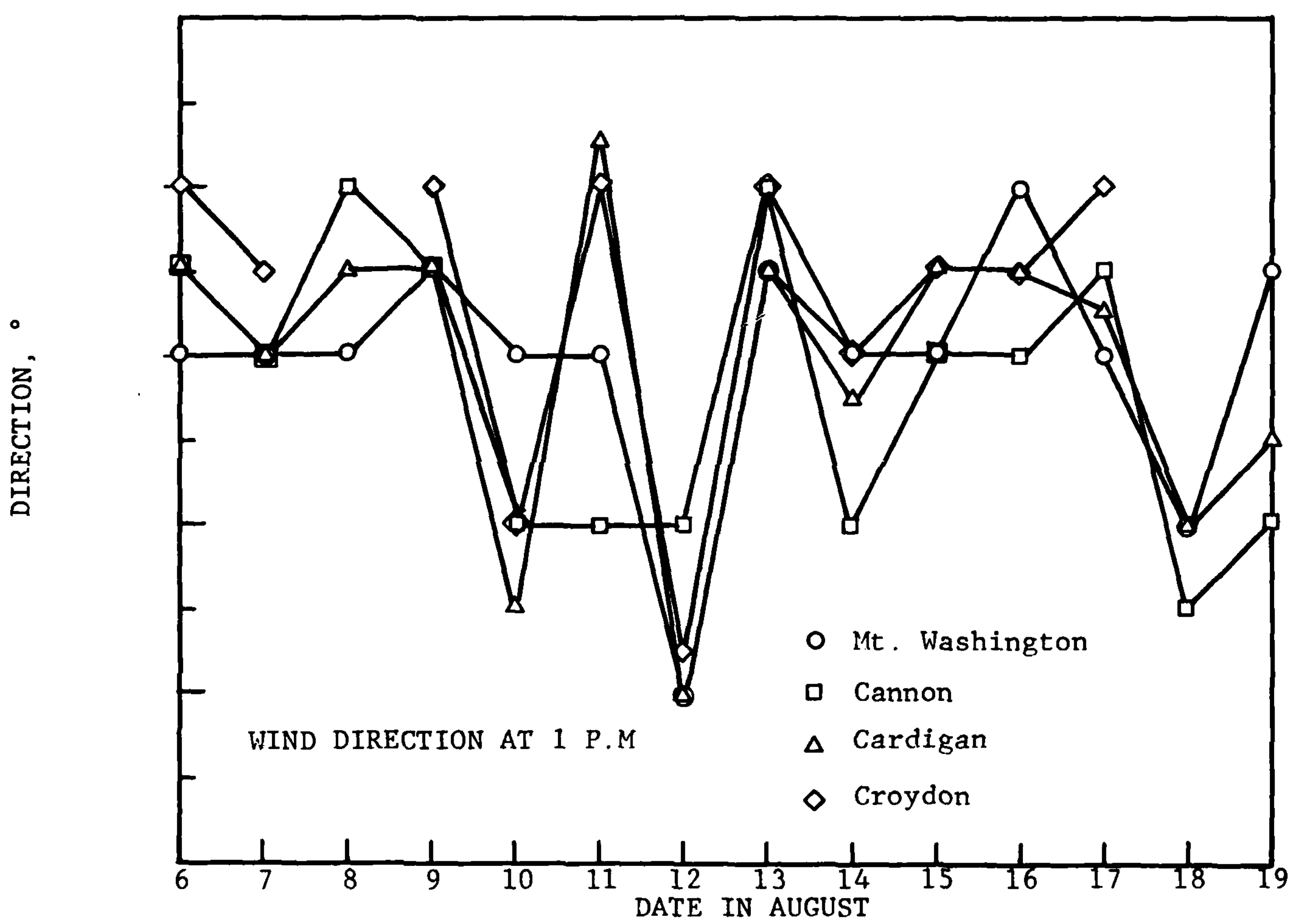


Figure 3.61 Comparison of Wind Direction at Four Higher Elevation Sites During Aug. 6-19, 1979, 1 P.M. Readings

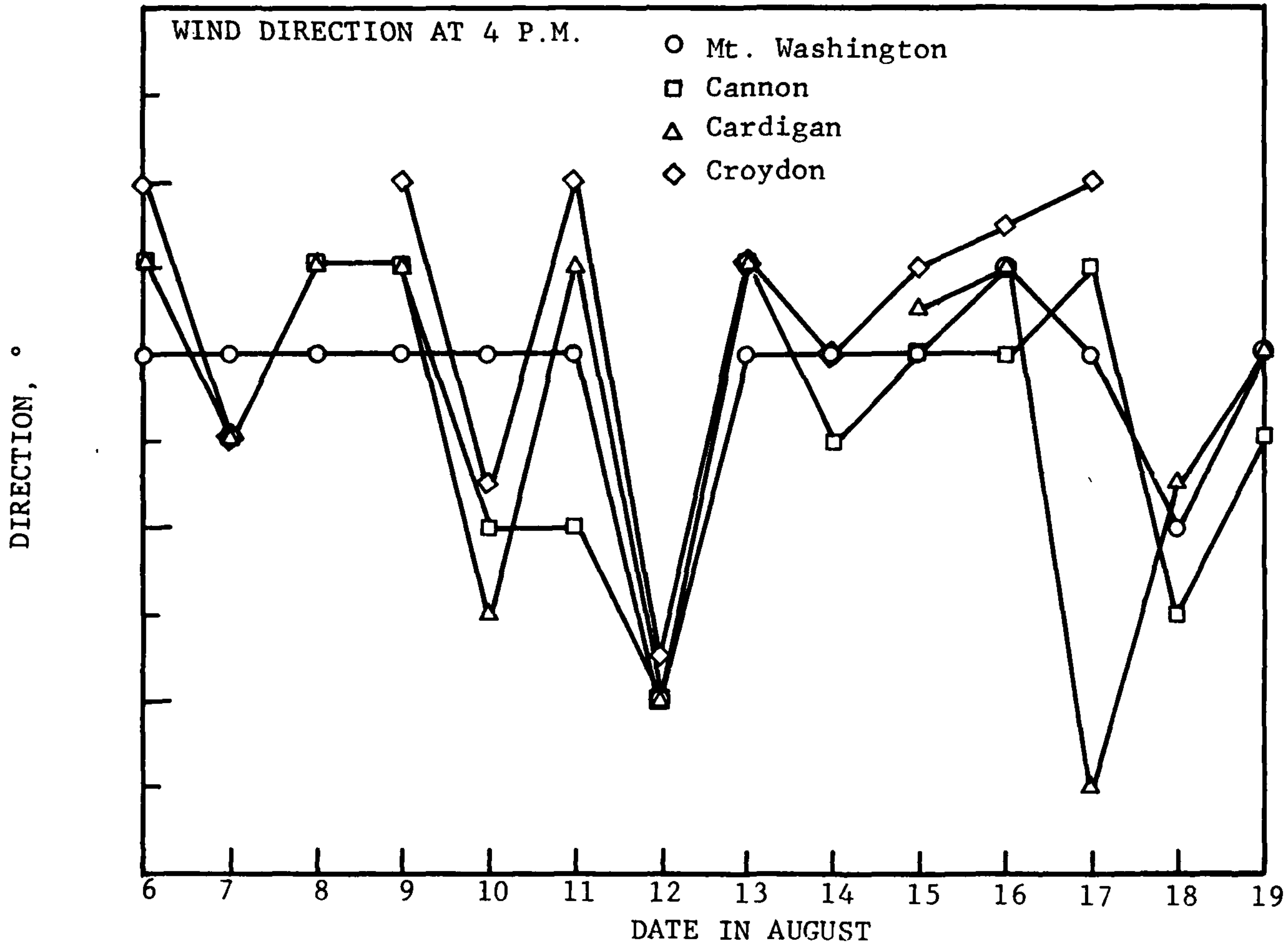


Figure 3.62 Comparison of Wind Direction at Four Higher Elevation Sites During Aug. 6-19, 1979 4 P.M. Readings

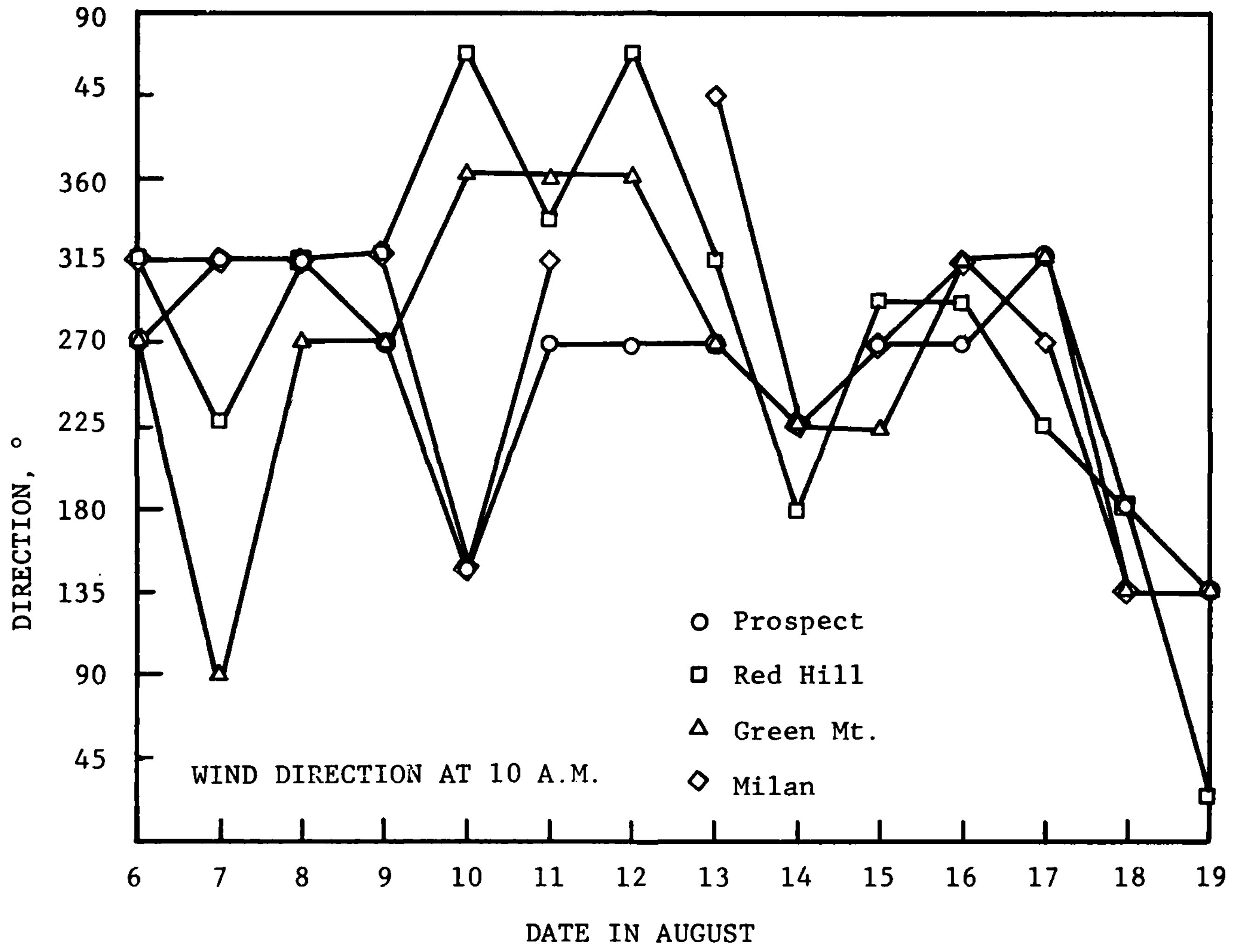


Figure 3.63 Comparison of Wind Direction at Four Lower Elevation Sites During August 6-19, 1979. 10 A.M. Readings

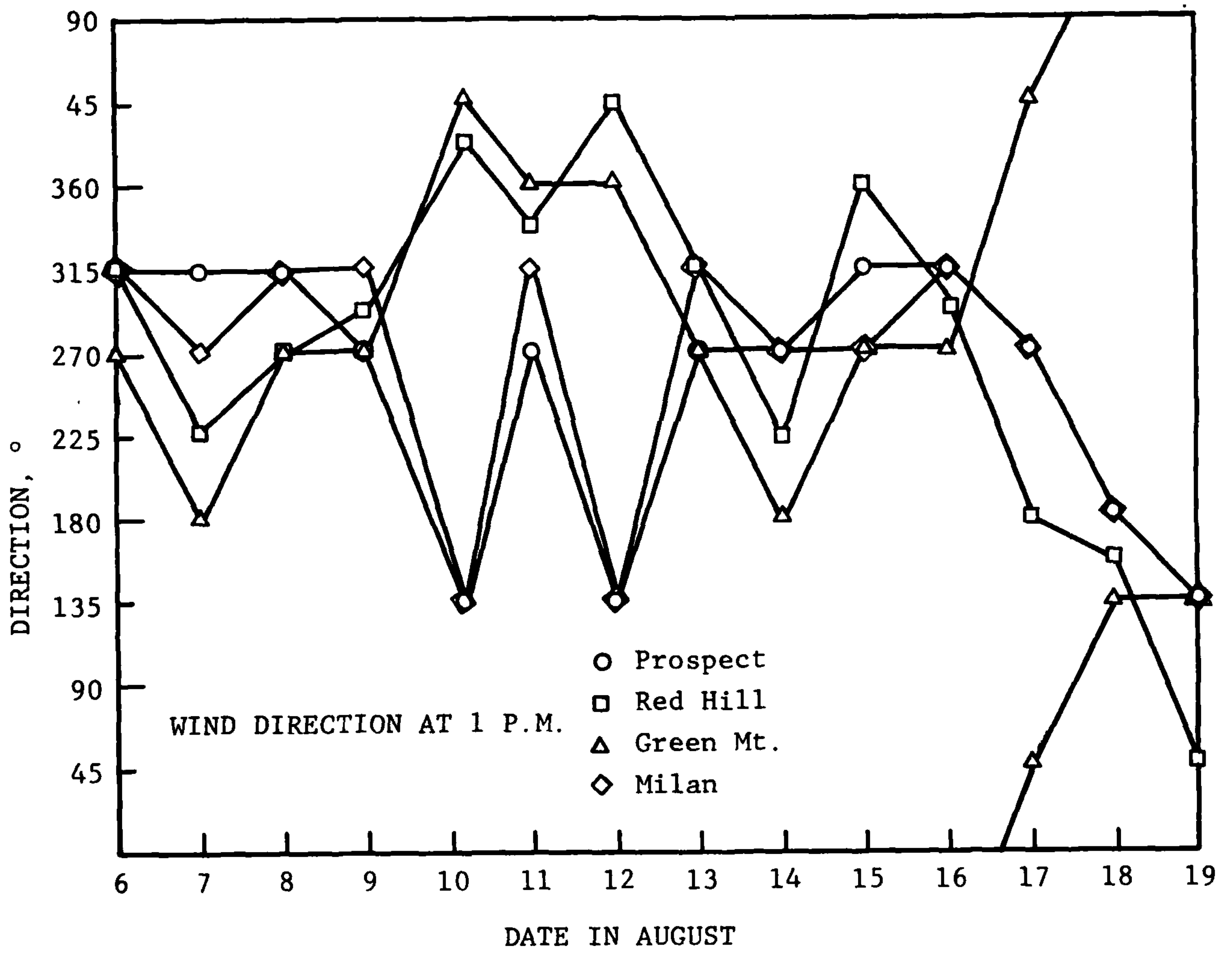


Figure 3.64 Comparison of Wind Direction at Four Lower Elevation Sites During August 6-19, 1979. 1 P.M. Readings

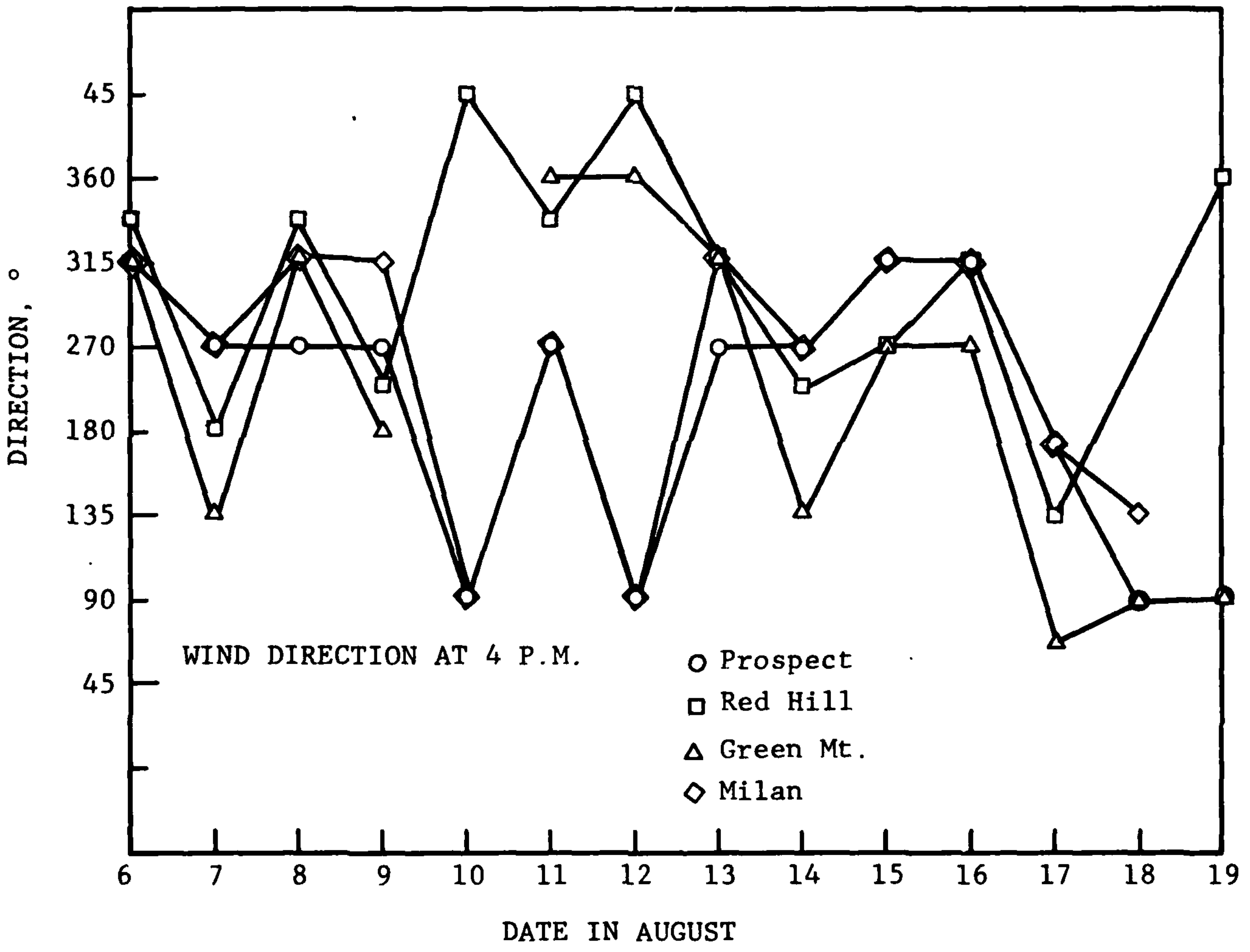


Figure 3.65 Comparison of Wind Direction at Four Lower Elevation Sites During August 6-19, 1979. 4 P.M. Readings

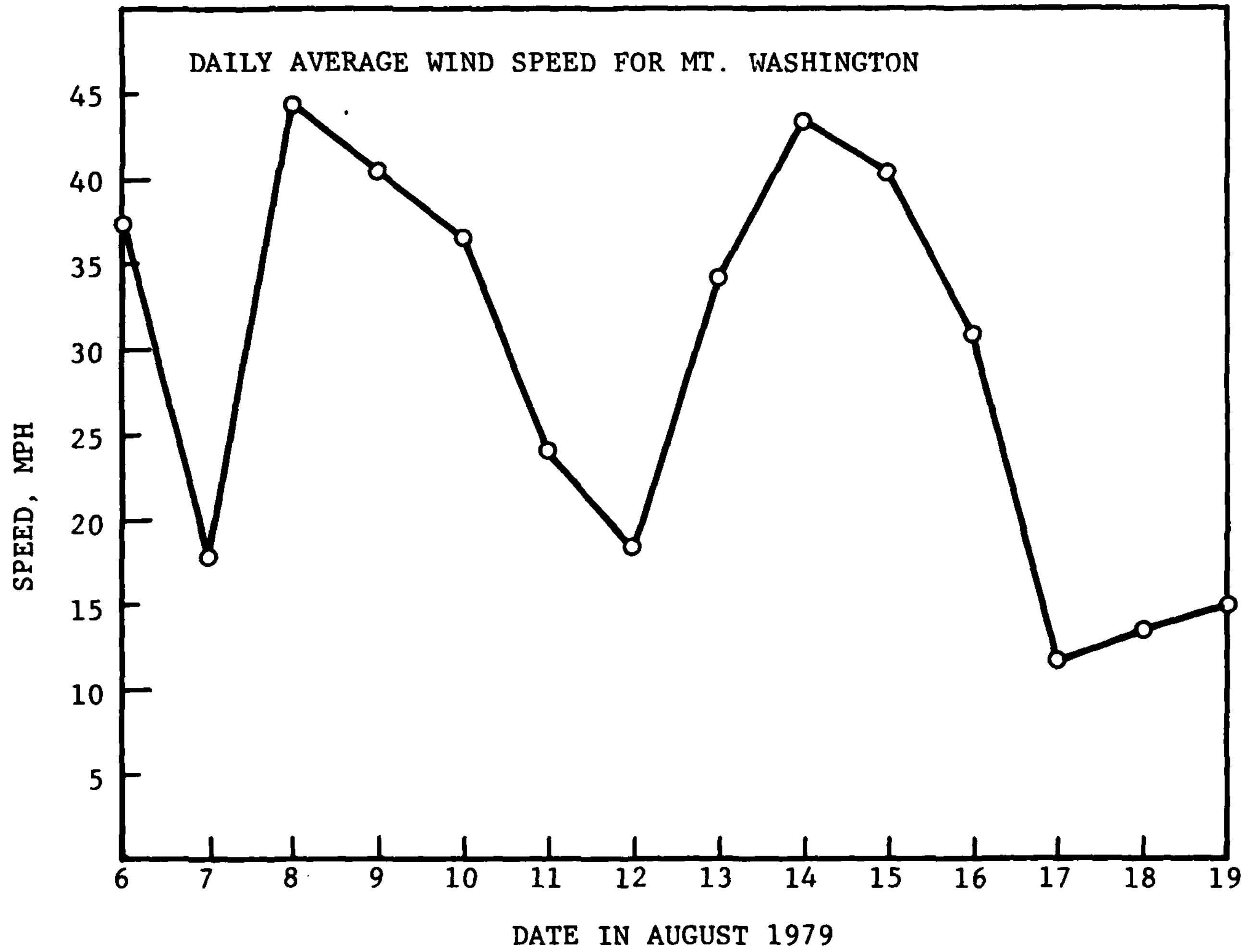


Figure 3.66 Daily Wind Speed Average (for 24 hourly readings) for Mt. Washington for August 6-19, 1979

- The wind direction at the higher sites tends to follow the Mt. Washington direction.
- The wind speeds at Cardigan and Croydon were higher than Mt. Washington on August 12 when the wind was from the east.
- Most wind speeds were well over 5 mph.

The data appeared to be significantly accurate so that the Corotis' statistical methods were applied to the 42 wind speed readings for each site. (NOTE the Croydon instrument failed on August 8 and was replaced.) A compilation of these calculations is shown in Tables 3.1 and 3.2. The average speed for the two week period showed the expected trend of decreasing level with decreasing elevation. Note that the Cannon site appeared to be lower than expected. One possible reason for this is that Cannon is not an isolated mountain peak. There are several surrounding peaks which are considerably higher. Therefore, Cannon may be shielded and thus not behave as an isolated peak.

The Mt. Washington behavior during the two week period compared to the long term average (1948-1975) is:

Average Speed for August 6-19, 1979 = 12.7 m/sec or 28.3 mph
Average Speed for August for 1948-1975 = 11.4 m/sec or 25.4 mph.

Therefore, the observed period was windier than normal. Comments from the site observers correlated with these Mt. Washington numbers. The cross-correlation of wind speed data between Mt. Washington and all the other sites (Table 3.2) is quite high--ranging from 0.61 to 0.82. These cross-correlations strengthen the concept that it is windy at every mountain peak in the White Mountains when it is windy at Mt. Washington.

The Corotis method(11) may be used to estimate the long term average velocity at a particular site compared to a reference site:

TABLE 3-1

WIND SPEED FOR HEIGHT LOCATIONS IN NEW HAMPSHIRE FOR PERIOD OF AUGUST 6-19, 1979

Site	Annual Elevation, ft	Average Speed, m/sec			Daily Average m/sec	Standard Deviation, m/sec
		10 a.m.	1 p.m.	4 p.m.		
Mt. Washington	6262	12.0	12.9	13.3	12.7	6.4
Cannon	4080	7.8	6.5	7.8	7.4	4.0
Cardigan	3121	8.5	8.0	8.8	8.4	4.4
Croydon	2780	9.1	8.4	7.8	8.7	3.4
Prospect	2065	4.3	4.5	5.3	4.7	2.4
Red Hill	2029	4.1	5.0	5.0	4.7	2.8
Green Mt.	1907	4.5	4.3	3.8	4.2	2.2
Milan	1737	3.2	3.4	4.1	3.5	2.5

TABLE 3-2

CROSS-CORRELATION OF WIND SPEED BETWEEN MT. WASHINGTON AND OTHER SITES FOR AUGUST 6-19, 1979 DATA

Mt. Washington

Cross Correlation	Cannon	Cardigan	Croydon	Prospect	Red Hill	Green	Milan
10 a.m.	0.68	0.48	0.53	0.76	0.54	0.73	0.73
1 p.m.	0.36	0.34	0.58	0.71	0.58	0.36	0.47
4 p.m.	0.47	0.67	0.60	0.55	0.55	0.58	0.70
All Readings	0.58	0.49	0.53	0.66	0.56	0.51	0.63
Daily Average	0.65	0.70	0.81	0.82	0.61	0.67	0.72

$$E\left[V_a\right] = E\left[V_a/V_b\right] - R_{ab}\,(V_b - E\left[V_b\right])\,\frac{S_a}{S_b}$$

where

$E\left[V_a\right]$ is the long term average wind velocity at a proposed site

$E\left[V_a/V_b\right]$ is the average velocity observed at the proposed site

V_b is the average wind observed at the reference site during the same period

$E\left[V_b\right]$ is the historical long term average at the reference site

S_a and S_b are the standard deviations at the two sites for the measured period

R_{ab} is the cross-correlation for the two sites for the measured period.

The August 6-19, 1979 period can be used as the measuring period and the long term data at Mt. Washington for the reference. Using the data for Cannon as an example:

$$\begin{array}{l}\text{Pred. An. Avg.}\\ \text{Speed at Cannon}\end{array} = \begin{array}{l}\text{Obs. Avg. At}\\ \text{Cannon During}\\ \text{Aug. 6-19, 1979}\end{array} - \rho \left[\begin{array}{l}\text{Mt. Wash. Aug.}\\ \text{6-19, 1979 Avg.}\end{array} - \begin{array}{l}\text{Mt. Wash}\\ \text{An. Avg.}\end{array}\right]$$

(Standard Deviation Ratio)

$$\text{Cannon Annual} = 7.4 - 0.65\,[12.7 - 14.8]\,\frac{3.95}{6.4}$$

$$= 7.4 + 0.8$$

$$= 8.2 \text{ m/sec} = 18.3 \text{ mph.}$$

The results are tabulated for the other sites in Table 3.3 and shown graphically in Figure 3-67. For these calculations, the 1/1 slope on the log-log presentation is reasonable for the lower

TABLE 3-3

ESTIMATED ANNUAL AVERAGE WIND SPEED AT SEVEN SITES BASED ON COROTIS METHOD (REF. W2)

Site	Elevation, ft	Estimated Annual Average m/sec	(mph)	$\frac{U\ \text{Site}}{U\ \text{Mt. Wash.}}$	$\frac{H\ \text{Site}}{H\ \text{Mt. Wash.}}$
Mt. Washington	6262	14.8	(33.1)	1.00	1.00
Cannon	4080	8.2	(18.3)	0.55	0.65
Cardigan	3121	9.5	(21.2)	0.64	0.50
Croydon	2780	9.6	(21.4)	0.65	0.44
Prospect	2065	5.4	(12)	0.36	0.33
Red Hill	2029	5.2	(11.7)	0.35	0.32
Green Mt.	1907	4.7	(10.5)	0.32	0.30
Milan	1737	4.1	(9.2)	0.28	0.28

elevation sites. However, the three higher elevations (Cannon, Cardigan and Croydon) deviate somewhat from this trend. Since the Corotis technique did not utilize wind direction in the statistical analysis of the short term data, some additional information could be obtained by including wind direction in the analysis. Dr. H.M. Nagib of IIT utilized the August 1979 data and long term Mt. Washington information to include this and other effects to improve the correlation of data.

3.1.4 A Novel Technique for Prediction of Wind Conditions at Various New Hampshire Sites From Mount Washington Observations

After wind anemometers and vanes were installed on several forest fire observation towers, data were collected three times a day for a period of two weeks. The elevation of the seven sites at which the wind direction and speed data were obtained, as well as their locations, have been identified in the previous sections. Similar data from the Mount Washington observatory were also recorded during the same time period.

The objective of this section of the report was to develop a reliable method for predicting the long range wind statistics at these sites based on their short time correlation with the Mount Washington observations. Since these sites represent the wide range of elevations encountered in the middle and the northern part of the state, such a prediction technique would lead to a method for estimating the wind characteristics at various locations in this region. This would in turn lead to a method for predicting the available wind power at several candidate locations in the state of New Hampshire and for estimating the electrical power that could be generated by a wind machine installed at each site.

A novel method based on conditioned statistical technique was developed by Nagib and Drubka of IIT in order to achieve this goal. The method is described and the results are summarized at the end of this section. In particular, this method was developed after the results of the previous section were obtained and carefully evaluated. The specific needs of this program and the paucity of the data necessitated the development of a sophisticated new approach to enhance the reliability of the results, and thereby increase the accuracy and the confidence level of the predictions. While the conventional technique may be very useful in many other cases, the present approach was specifically designed for the stated objectives.

As represented by Figs. 3.67 and 3.68, such conventional methods lead to results with low reliability when applied to the present data. When all the data recorded for each site (42 samples) are averaged to obtain a mean wind speed ($\overline{U}$) and their standard deviation (u') is calculated, one finds that the ratio $u'/\overline{U}$ is often larger than 0.5. For some sites this ratio is even higher, almost reaching a value of 1.0. When the results are summarized in a graphical form using log-log scales as shown in Fig. 3.68, one observes at least two trends of the averaged data. Even ignoring the large standard deviations for each site, the data may be represented by the equation:

$$U_{\text{site}}/U_{\text{Mt. Wash.}} = (\text{Site Elev./Mt. Wash. Elev.})^{\eta}$$

where $0.3 < \eta < 0.8$

Such correlations are not satisfactory and can only be used in conjunction with a high risk in any predictions of long range wind statistics of the various sites.

As described in the previous section, when a conventional technique based on the Weibull distribution is used to predict the long range statistics from the limited number of samples available, one finds a similar bifurcation in the trend of the data as shown in Fig. 3.67. For a detailed description of this technique and its application to other wind power predictions the reader is referred to the publications of Corotis discussed in the previous sections. The results of

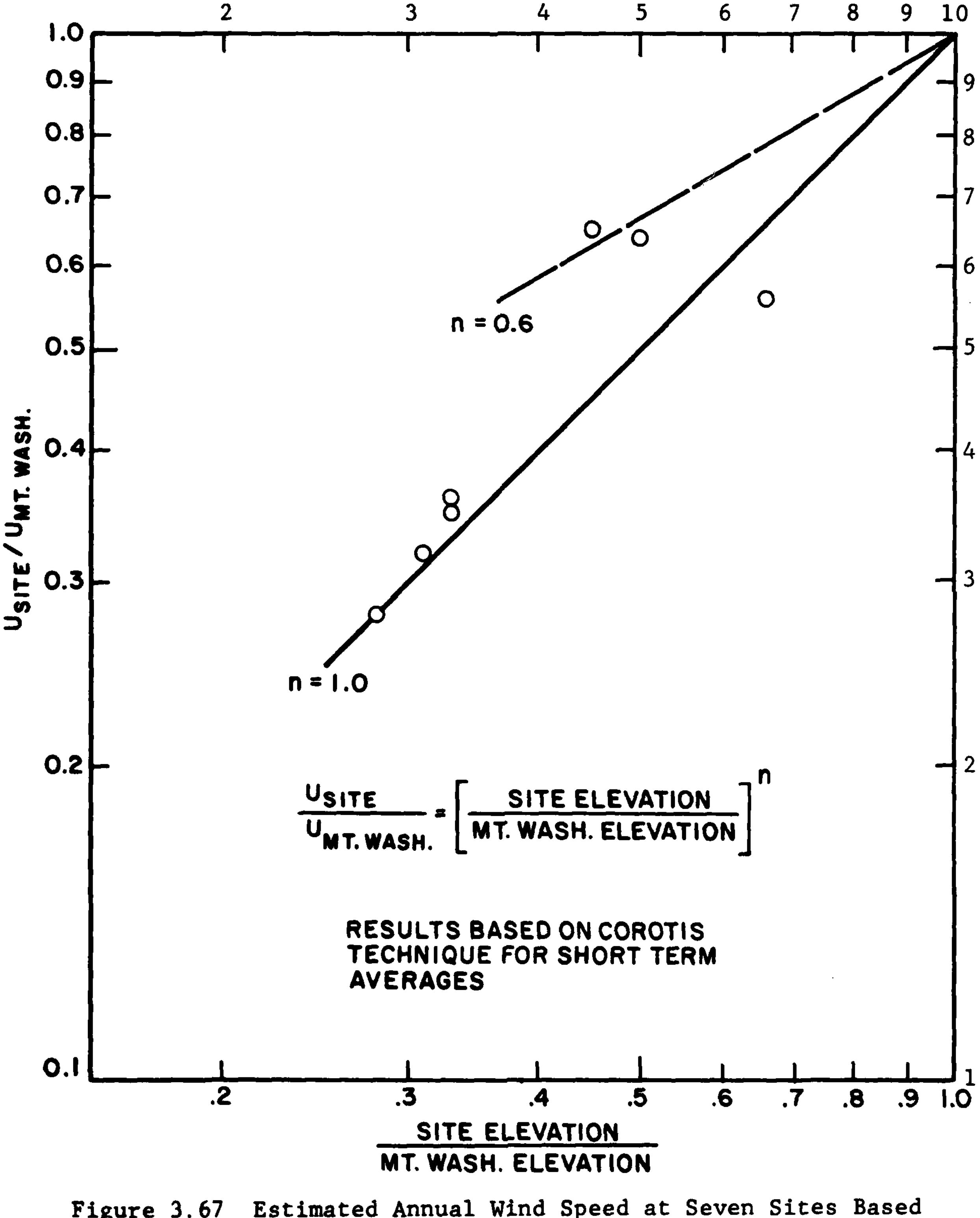


Figure 3.67 Estimated Annual Wind Speed at Seven Sites Based on August 6-19, 1979 Data

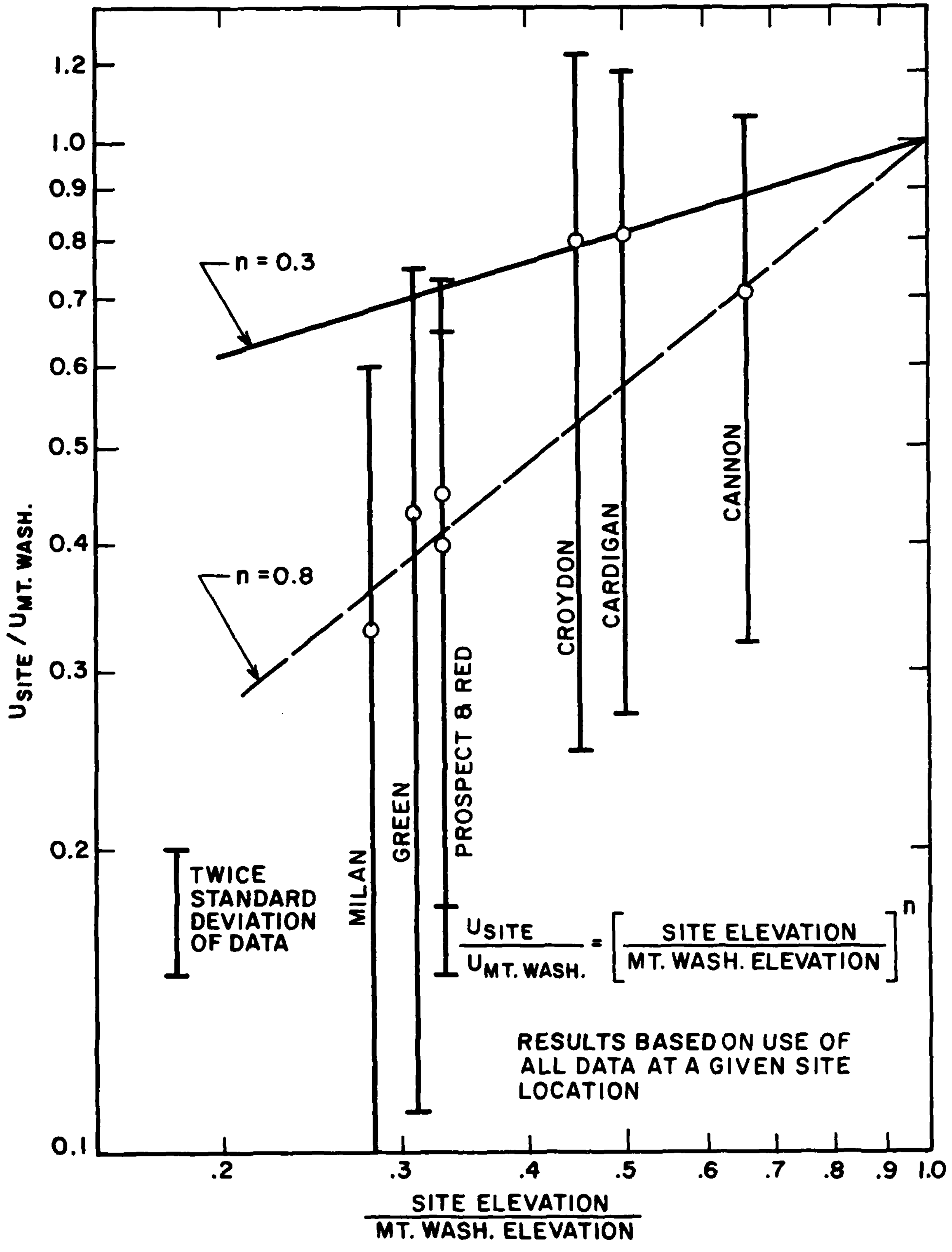


Figure 3.68. Presentation of All August 1979 Data Without Conditioning or Referencing.

Fig. 3.67 may be represented in the form of a correlation

$$U_{site}/U_{Mt.Wash.} = [\text{Site Elev./Mt. Wash. Elev.}]^{\eta}$$

where $0.6 < \eta < 1.0$

Such correlation ignores the standard deviation of the short term data which is comparable to that shown in Fig. 3.68. This is only a slight improvement over the simple averaging of all the short term data carried out in Fig. 3.68. We considered neither of these approaches to be completely satisfactory, which led us to the development of the present novel technique.

In order for the relation between the limited samples of data from each site and the simultaneous records at Mount Washington to be representative of long range statistics, the weather conditions have to be reasonably homogeneous over the distance between the site and the Mount Washington Observatory. Even if the wind speed is as high as 50 m/s it would require 1000 sec. (approx. 20 min) for a parcel of air to travel the average distance of 50 km between the two points of observation. However, spacial cross-correlations between various sites in New Hampshire, e.g., Lebanon and Concord, that were discussed in earlier sections indicated correlation as high as 0.6 at zero time delay. Some long time correlation values of 0.4 were even obtained over larger distances (approx. 100 km) in New Hampshire. This indicates that during an appreciable amount of the time the wind patterns are correlated over the sites in question and Mount Washington. The goal of our approach was to purify the limited data samples available and to select the ones significant for our long range predictions.

First, given the variation in the atmospheric stability conditions with the time of day it was decided to break up the data for each site into three groups corresponding to the three times of the day they were recorded. Next, if the sample wind speed at the site is to be related to the wind at Mount Washington at the same time (i.e., both in a homogeneous wind condition), the difference between the wind direction at the site and at Mount Washington should follow a most probable pattern. This difference in wind direction is defined as

$\Delta\theta$ = Wind direction at the site in degrees from north -- Wind direction at Mount Washington in degrees from north.

and is calculated for each of the 42 times the samples were recorded. The distribution of the number of samples for each of the values of $\Delta\theta$ in 45° increments is given in Fig. 3.69 for the three times 10 a.m., 1 p.m. and 4 p.m. at the Cardigan site. For example, one notes that the bulk of the samples falls in the range $-45° < \Delta\theta < 45°$ for the 10 a.m. and the 1 p.m. samples. For the 4 p.m. time the bulk of the data is in the range $0 < \Delta\theta < 90°$ indicating the differences in the stability conditions for the late afternoon winds.

One can think of the diagrams of Fig. 3.69 as probability density distributions indicating the most probable differences in wind direction between Cardigan and Mount Washington. One can then include only the results from the most probable conditions in any correlation between the two sites. Samples outside the most probable conditions may be ignored assuming that they resulted from nonhomogeneous conditions over the sites. The data of Fig. 3.69 are replotted in a polar plot in Fig. 3.70, to give the reader a better physical feeling for the results. The similar plots for the sites at Cannon, Croydon, Green, Milan, Prospect and Red Hill are presented in Figs. 3.71, 3.72, 3.73, 3.74, 3.75 and 3.76, respectively. While many of the sites indicate no difference in the mean wind direction between the site and Mount Washington, some sites give $\overline{\Delta\theta} = +45°$, e.g., Croydon, and some give $\overline{\Delta\theta} = -45°$, e.g., Green. Some of these differences may represent local terrain conditions. Such trends are indicative of the importance of the present approach.

When Fig. 3.68 is replotted using only data from the most probable values of $\Delta\theta$ one obtains Fig. 3.77. Even though, for

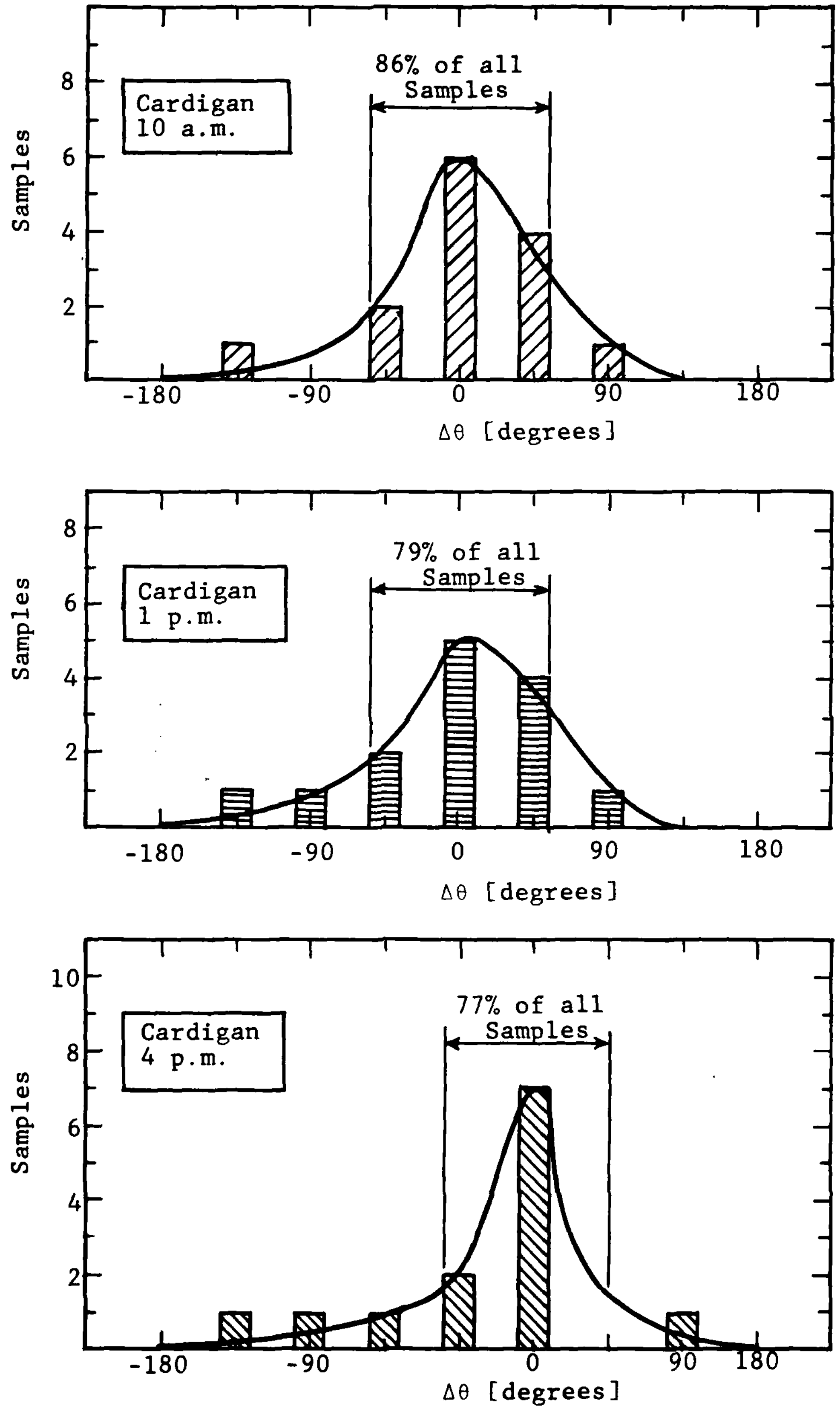


Figure 3.69. Wind Direction Distribution at Cardigan. August 6-19, 1979 Data.

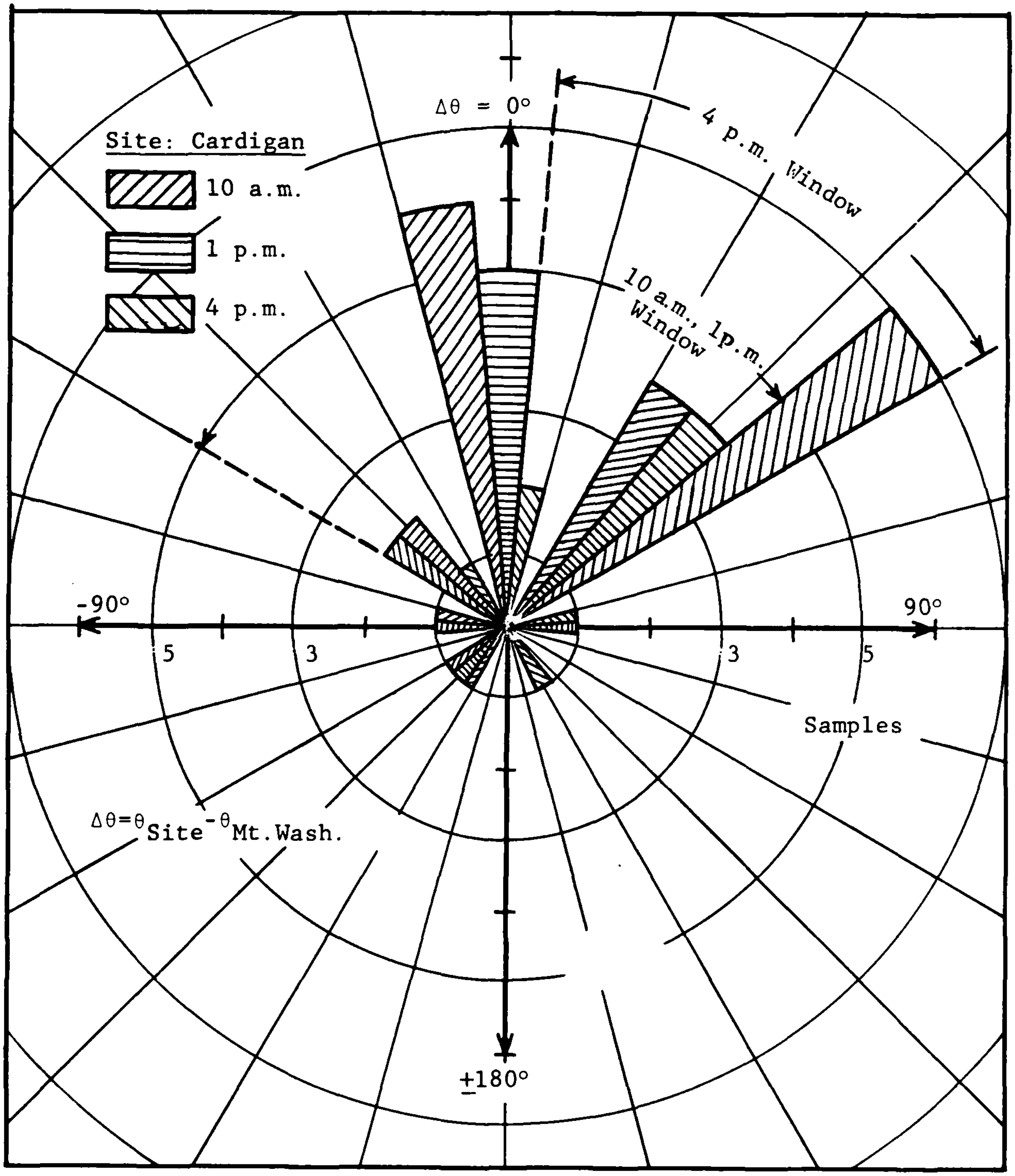


Figure 3.70. Polar Presentation of Wind Direction Data at Cardigan. August 6-19, 1979 Data.

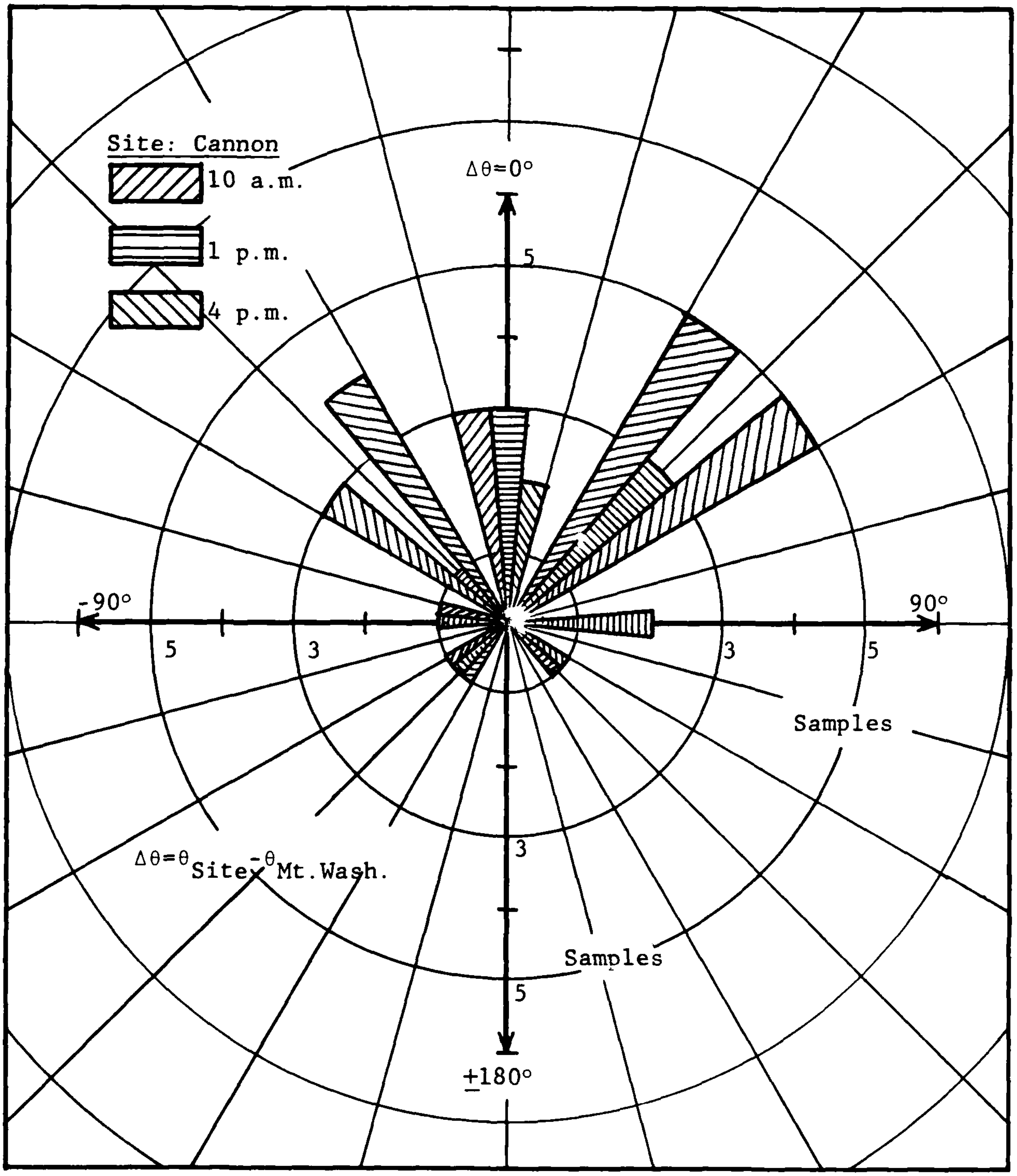


Figure 3.71. Polar Presentation of Wind Direction Data at Cannon. August 6-19, 1979 Data.

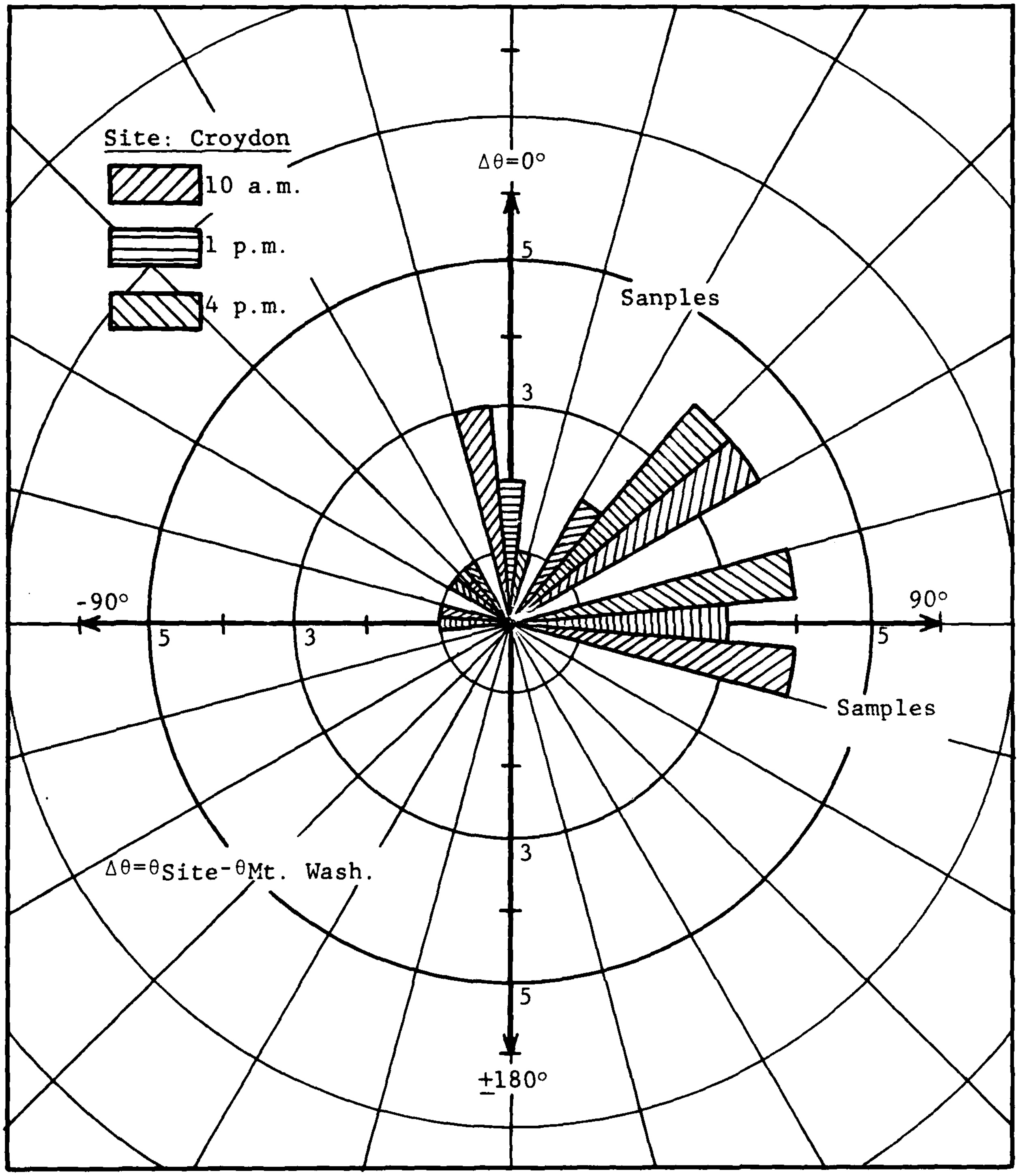


Figure 3.72. Polar Presentation of Wind Direction Data at Croydon. August 6-19, 1979 Data.

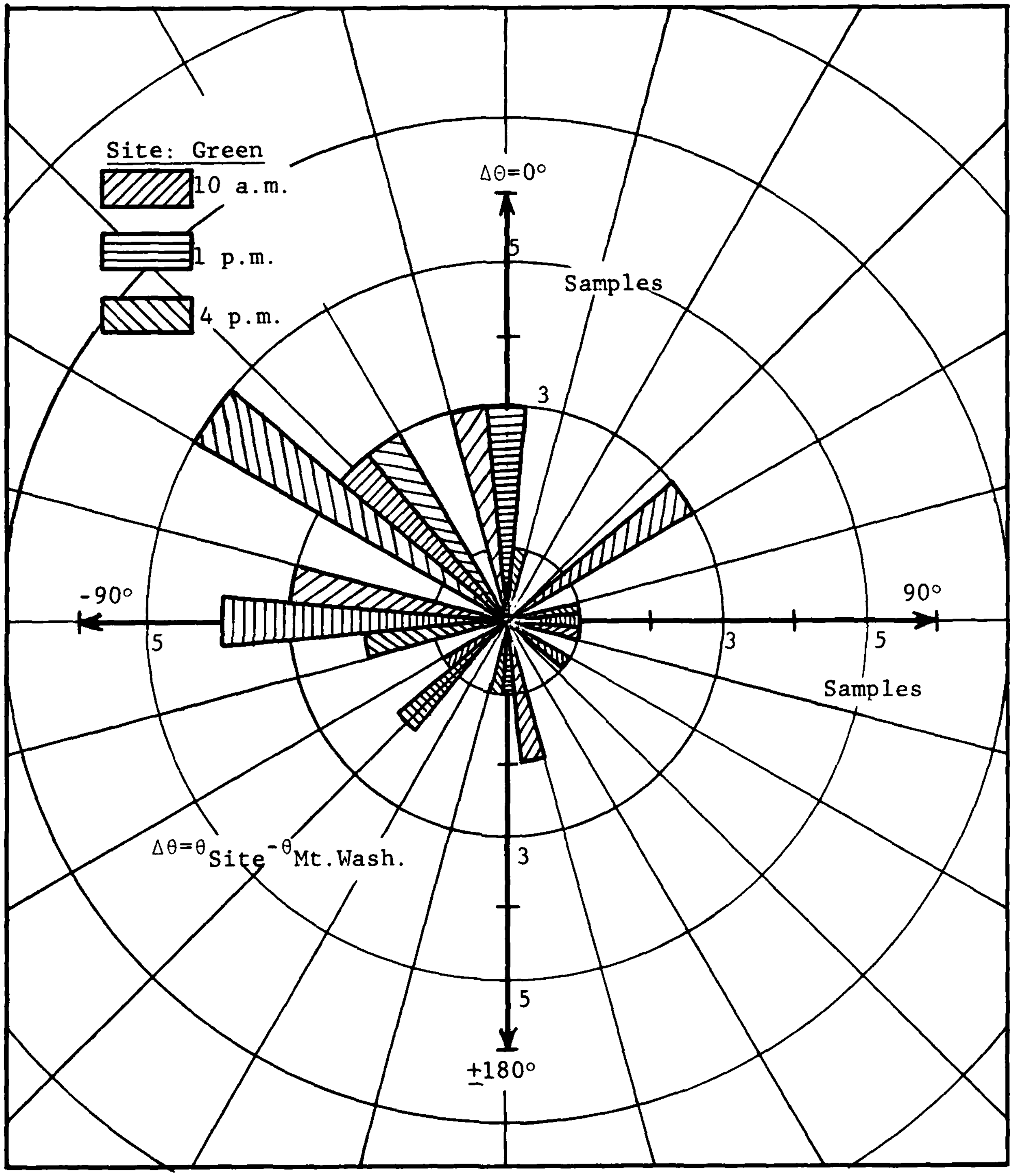


Figure 3.73. Polar Presentation of Wind Direction Data at Green Hill. August 6-19, 1979 Data.

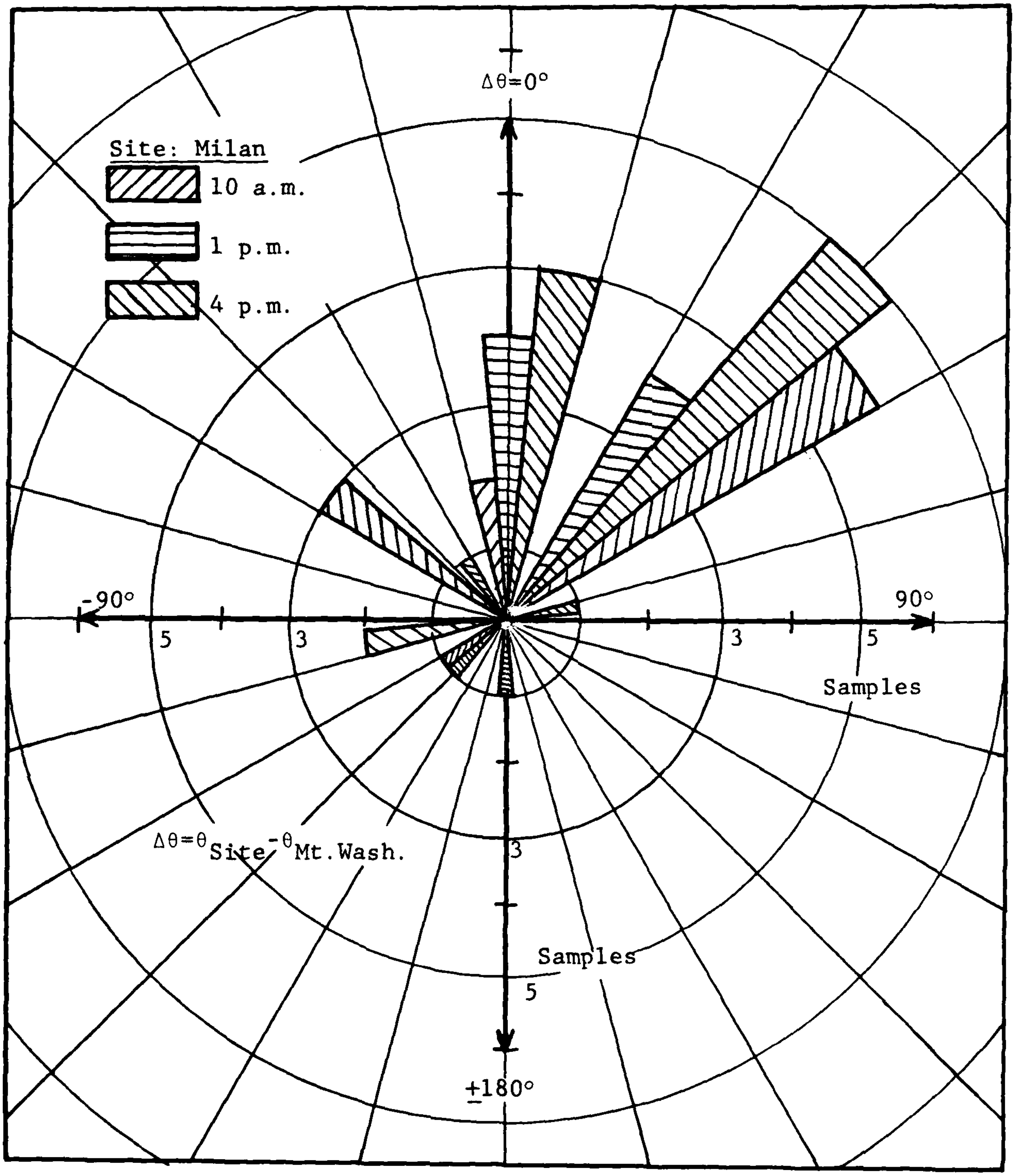


Figure 3.74. Polar Presentation of Wind Direction Data at Milan. August 6-19, 1979 Data.

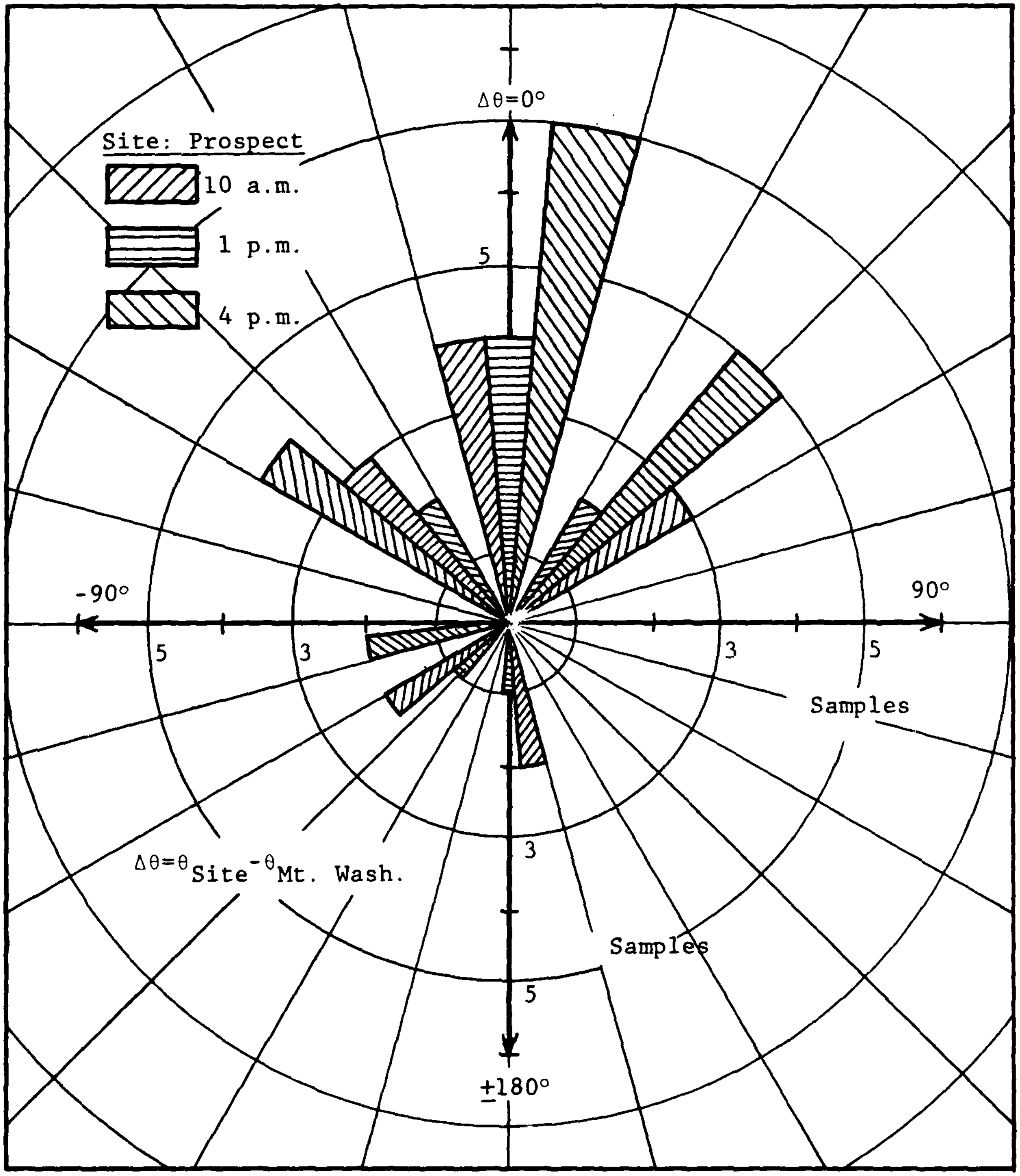


Figure 3.75. Polar Presentation of Wind Direction Data at Prospect. August 6-19, 1979 Data.

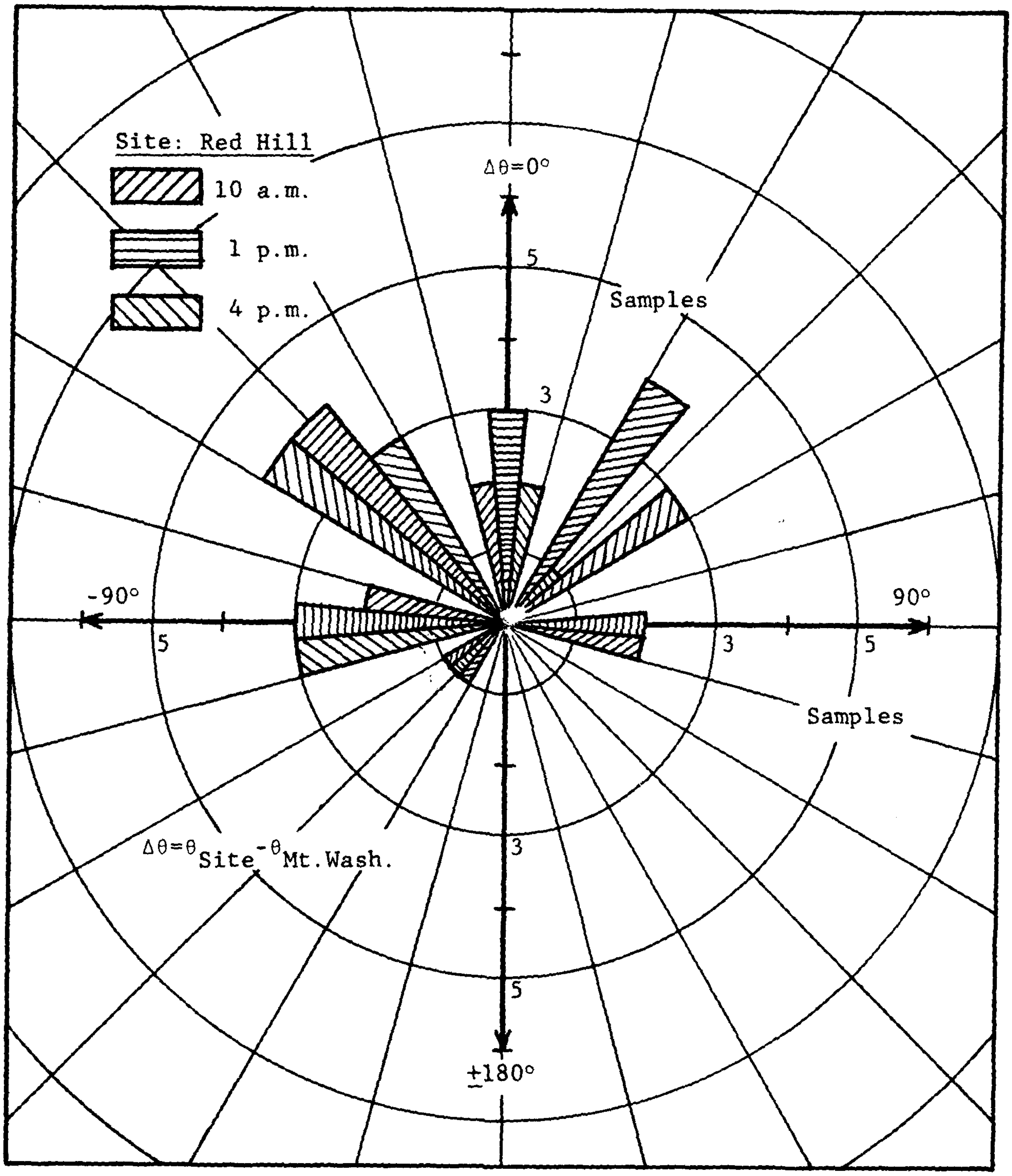


Figure 3.76. Polar Presentation of Wind Direction Data at Red Hill. August 6-19, 1979 Data.

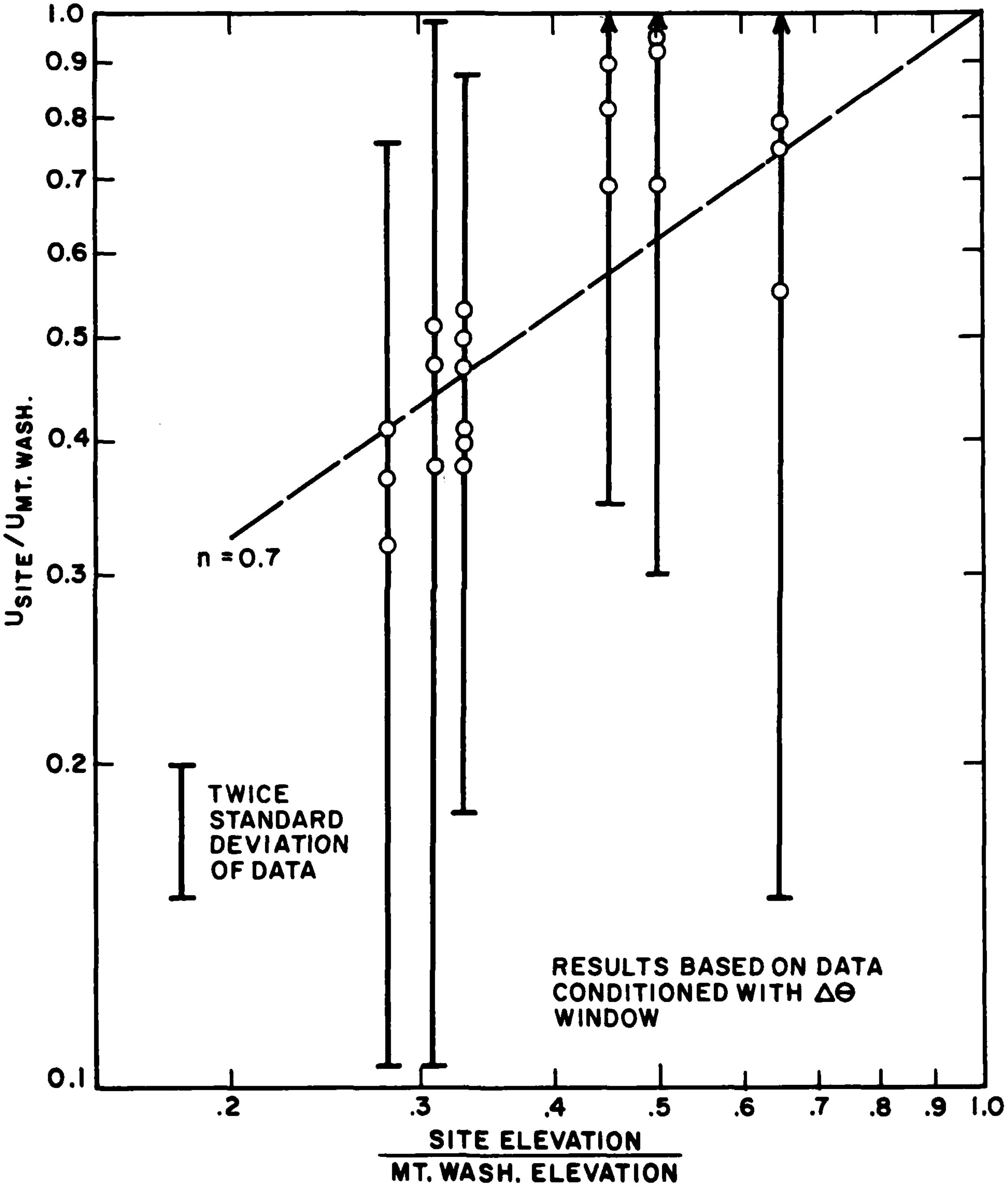


Figure 3.77. Presentation of August 19, 1979 Data Conditioned with Δθ Window.

some sites we have used more than one range of most probable $\Delta\theta$'s in Fig. 3.77, the resulting correlation of the data is somewhat improved over that of Figs. 3.67 and 3.68.

Another important parameter that one can use to condition the data in an attempt to purify it is the wind speed at the reference site of Mount Washington. High wind speeds are more likely to be homogeneous over the 50 km distances in question. Using 10 m/s as a threshold for this method of conditioning the data, the samples are replotted in Fig. 3.78 using only the samples corresponding to wind speeds larger than 10 m/s at Mount Washington. The correlation obtained from this approach is very similar to that achieved in Fig. 3.67, and is also not satisfactory.

Finally, when both criteria of high wind speeds and most probable $\Delta\theta$'s are used to condition the data, the samples can be represented by Fig. 3.79. Here, we find that there is only one general trend of the data and that even including the standard deviation of all samples one can correlate the data by the relation

$$U_{\text{site}}/U_{\text{Mt.Wash.}} = [\text{Site Elev./Mt. Wash. Elev.}]^{\eta}$$

where $\eta = 1.0 \pm 0.25$

The only slight deviation from this correlation is observed at Cannon where many surrounding mountains may have a strong effect on sheltering the observation site. This would lead to the observed lower value at Site Elev./Mt. Wash. Elev. = 0.66.

It is very important to point out that since the data were purified systematically and objectively and since the resulting correlation includes the entire remaining samples plus and minus their standard deviation the confidence level in the resulting correlation is as high as one should expect from even long range data. The fact that we were able to achieve this with short term data speaks for the strength of the novel approach of Nagib and Drubka.

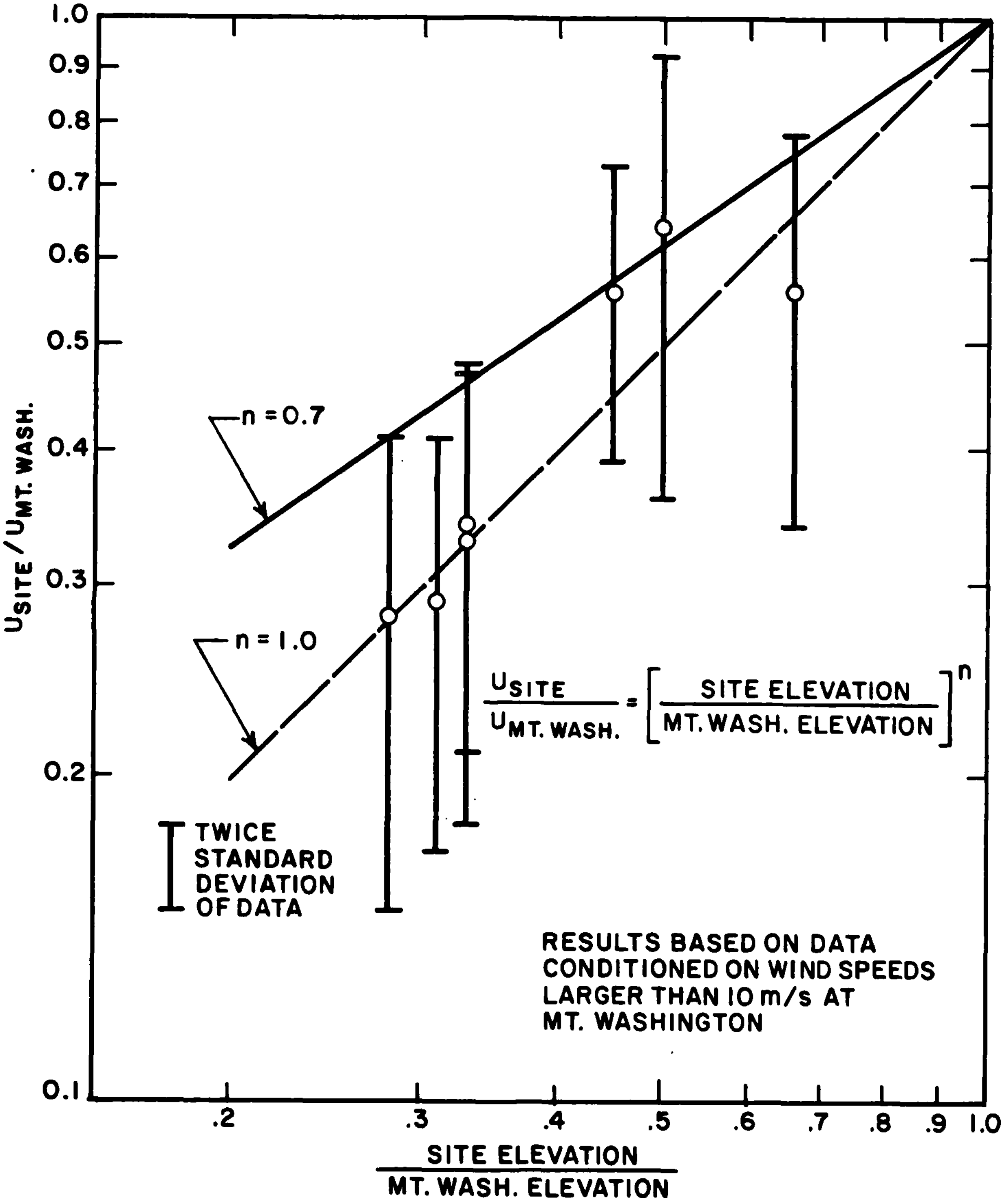


Figure 3.78. Presentation of August 1979 Data Conditioned on Wind Speeds Larger Than 10 m/sec at Mount Washington.

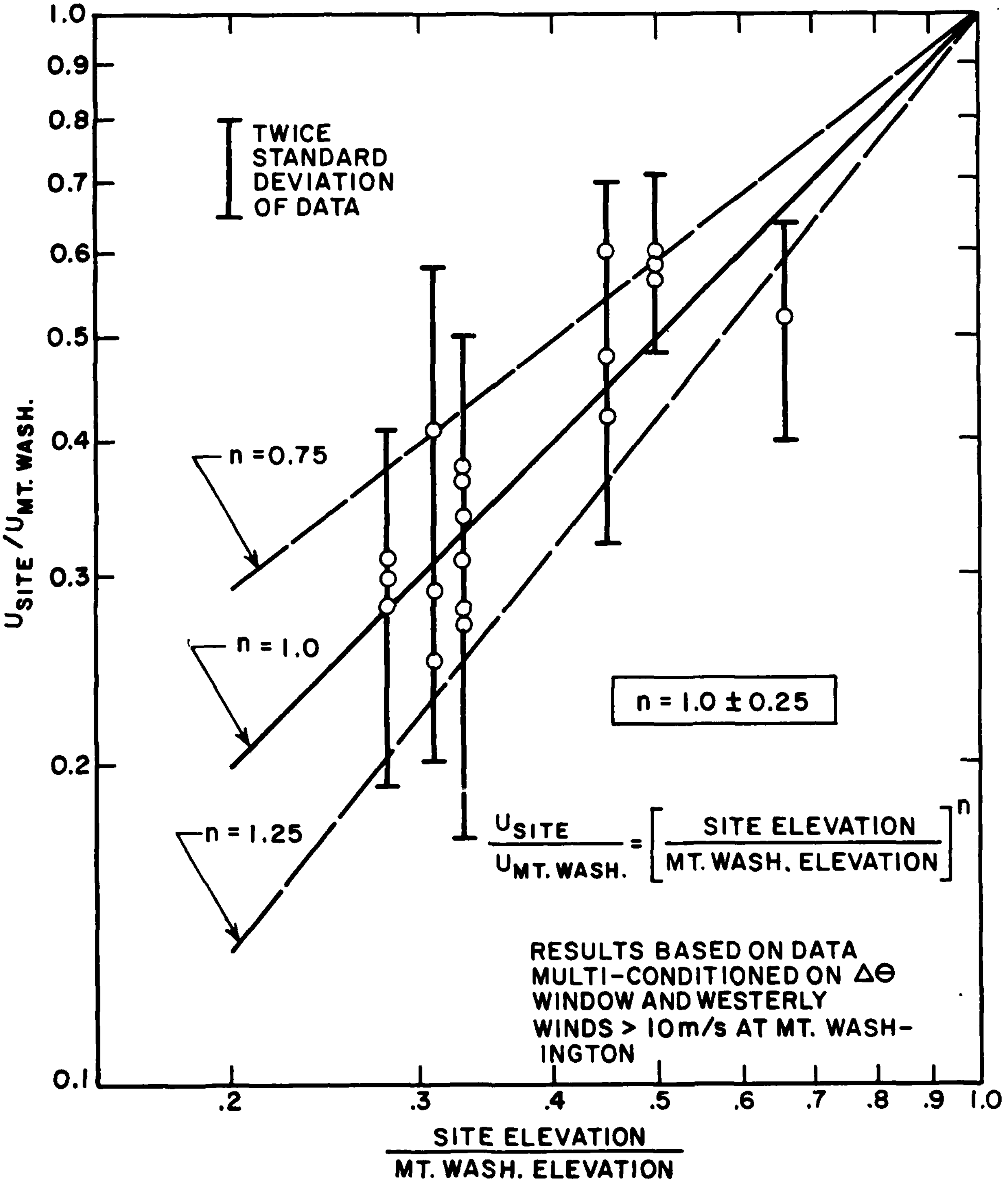


Figure 3.79. Presentation of August 1979 Data with Δθ and Westerly Wind Greater than 10 m/sec Conditioning.

While we recommend a value of η equal to 1.0 for the prediction of the available wind power from various sites in New Hampshire, the value of $\eta = 1.25$ would lead to conservative estimates and $\eta = 0.75$ would lead to optimistic predictions.

Contour plots similar to those shown in Figs. 3.40 through 3.44 are presented in Figs. 3.80 and 3.81 in order to present another technique that aids in the selection of sites and in the orientation of the wind machine at the sites. While the earlier plots presented the results as a percentage of all times, the contours of Figs. 3.80 and 3.81 are different. The results are presented in Fig. 3.80 as a percentage of the time in each wind direction. Therefore, one can find that winds from the north and northeast spend most of the time at very low velocities, i.e., from 0 - 10 m/s. Winds from the west and northwest spend an appreciable amount of the time, i.e., more than 30% of the time, between 5 and 30 m/s. Other important conclusions can also be made from Fig. 3.80. However, representing the data in the manner of Fig. 3.81 leads to better selection of the best orientation of the wind machine. Note that all of these contour plots are based on several years of data from the Mount Washington observatory. Similar long range data must be obtained from any site before this technique can be used.

In Fig. 3.81 the annual average of data is represented for each wind speed range. The contours indicate for each speed range the percentage of time the wind spends in each direction. For example, one finds that wind speeds in the range from 40-50 m/s are almost always, i.e., more than 90% of the time, from the west.

Similar plots for the Winter, Spring, Summer and Fall seasons are presented in Figs. 3.82, 3.83, 3.84, 3.85, respectively. In particular, one notes that very high wind speeds occur about 5% of the time in the winter from the east.

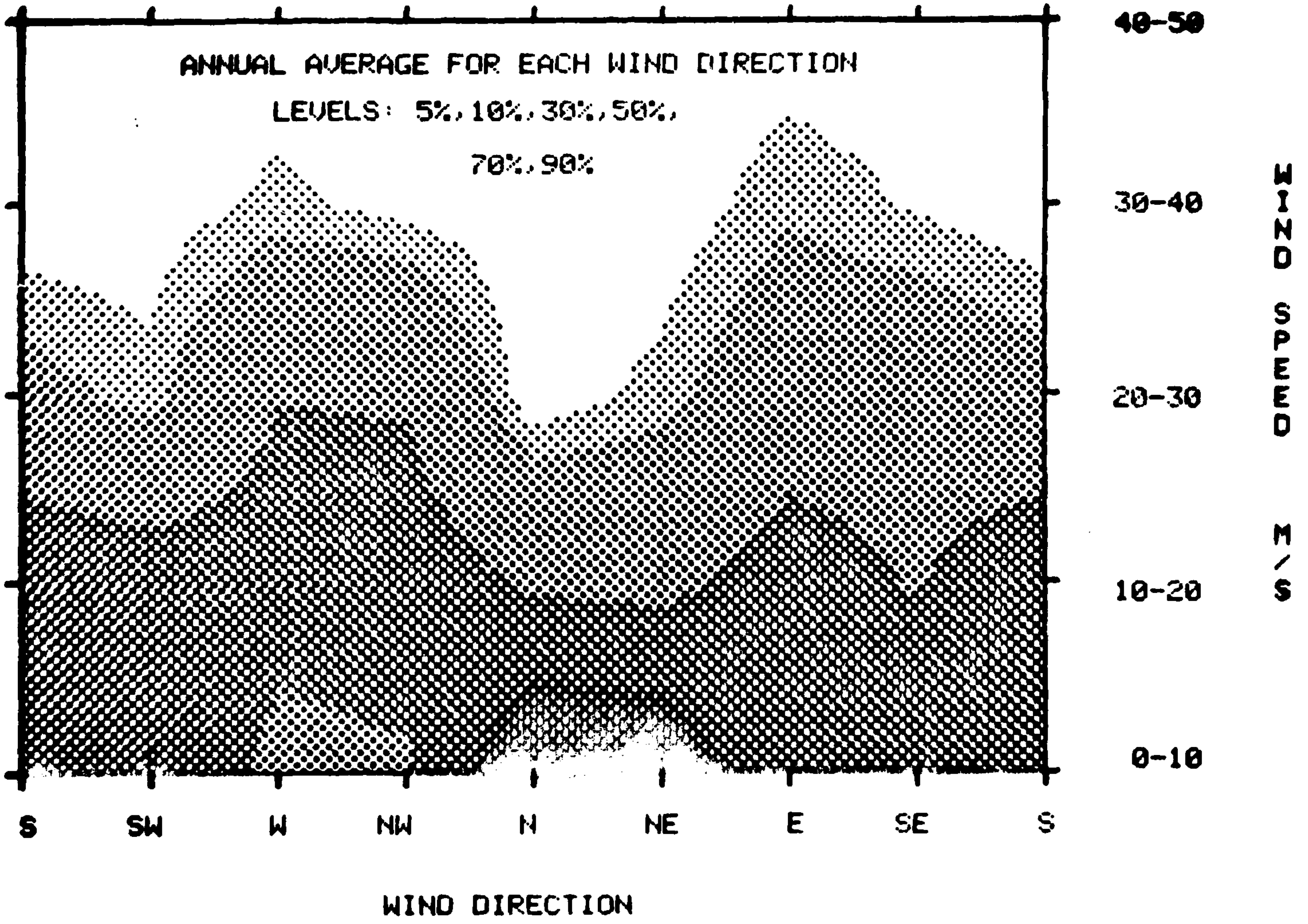


Figure 3.80. Seasonal Wind Speed and Direction Contours for Mt. Washington Averaged for 1977 and 1978

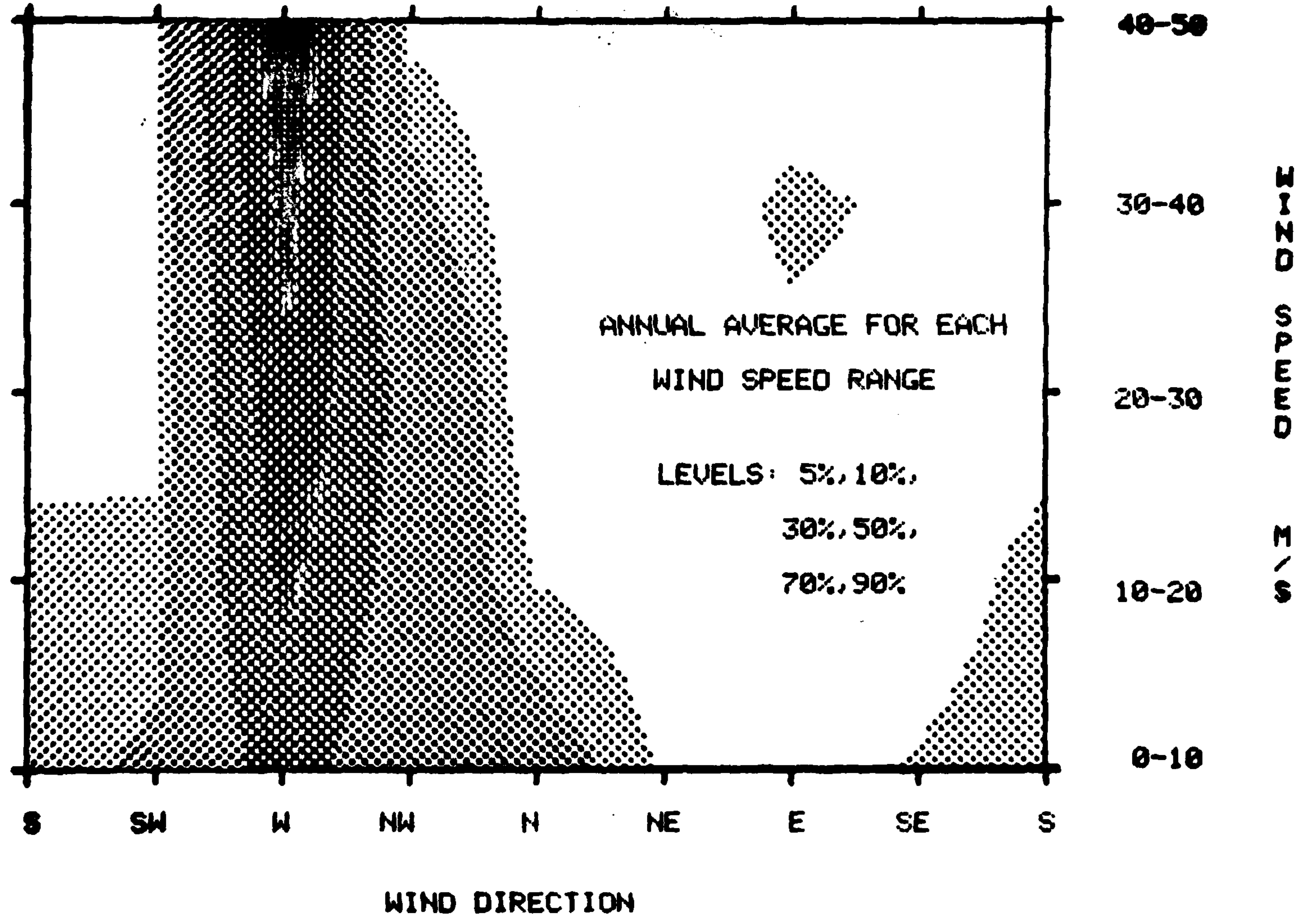


Figure 3.81. Seasonal Wind Speed and Direction Contours for Mt. Washington Averaged for 1977 and 1978

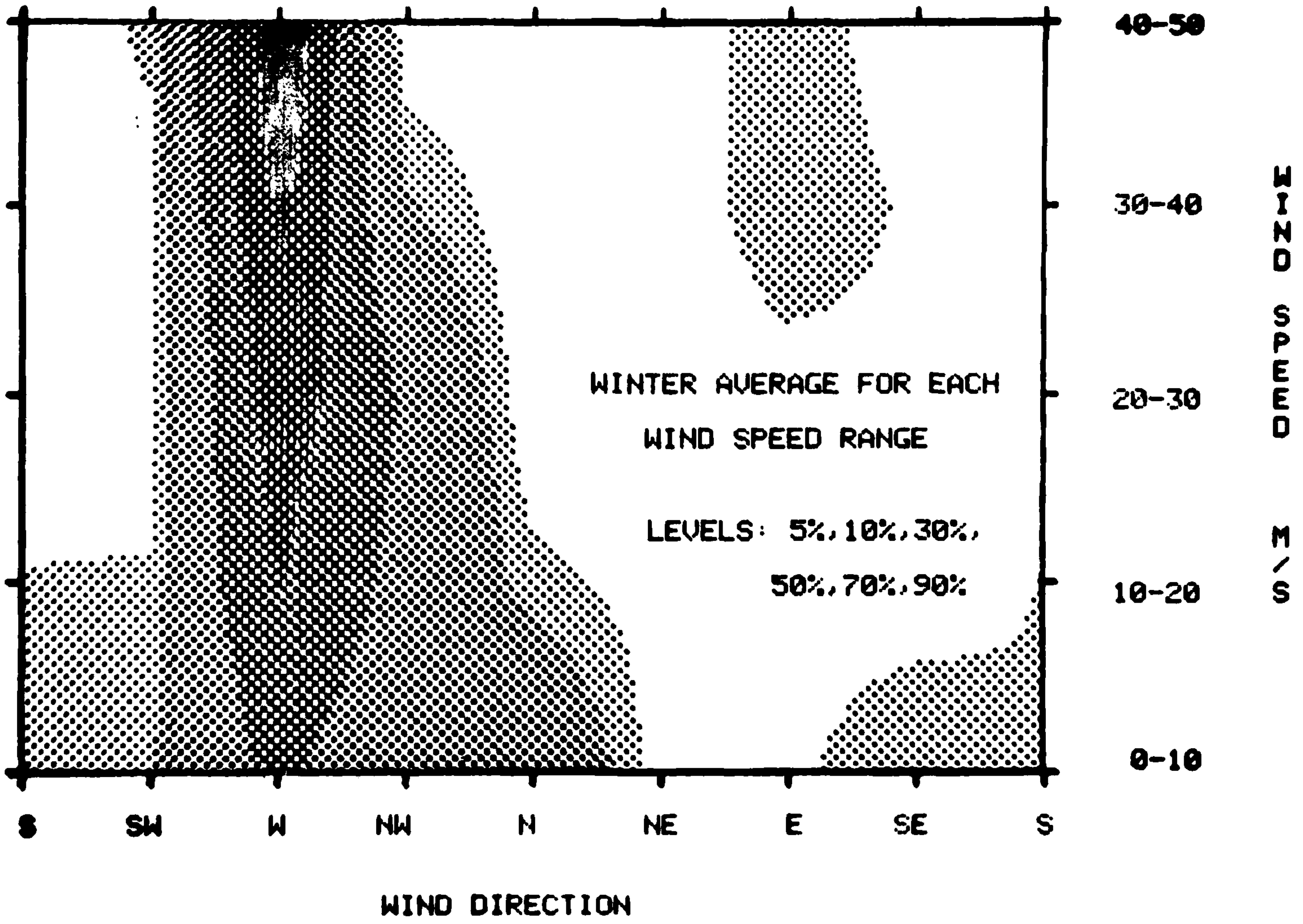


Figure 3.82. Seasonal Wind Speed and Direction Contours for Mt. Washington Averaged for 1977 and 1978

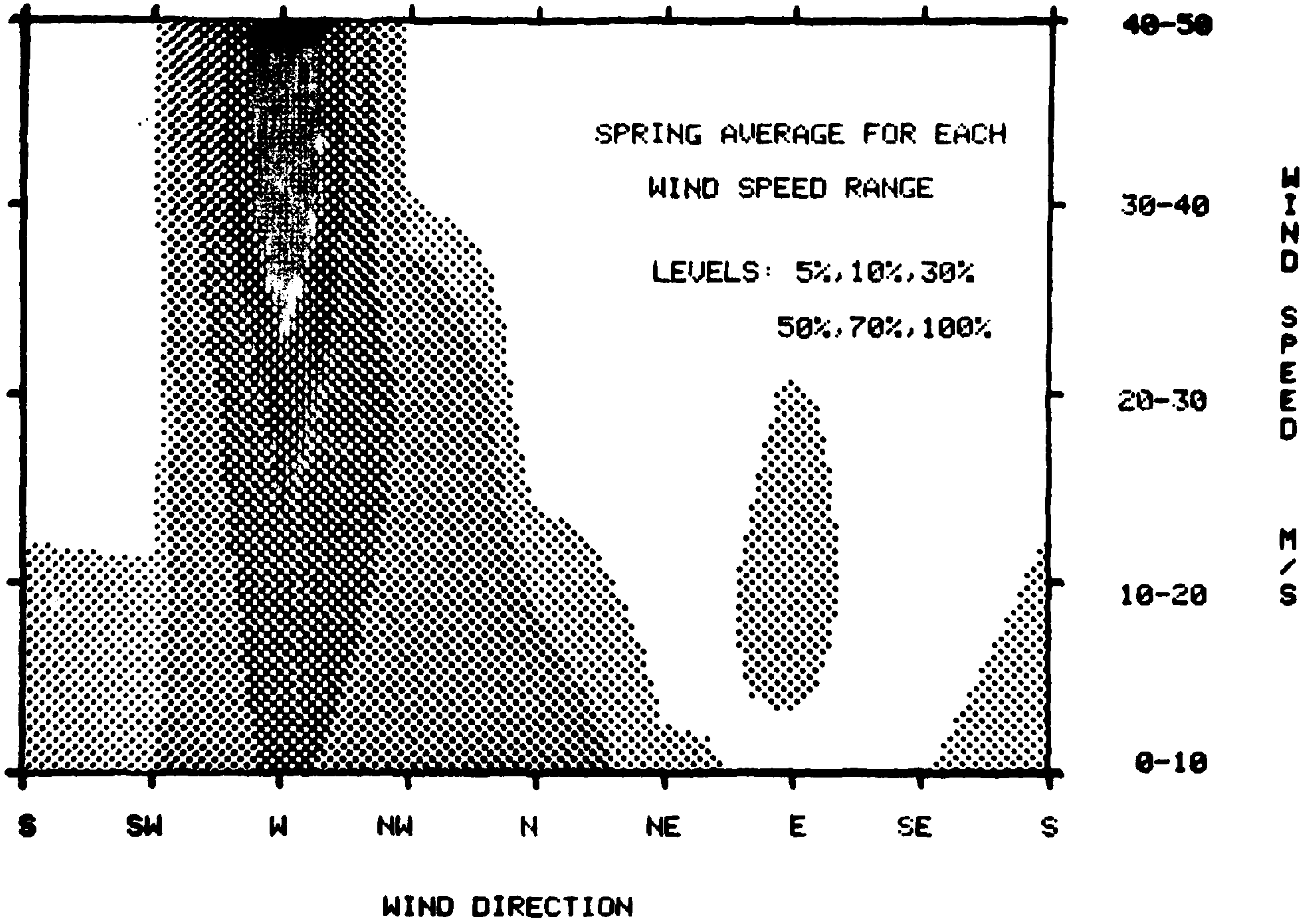


Figure 3.83. Seasonal Wind Speed and Direction Contours for Mt. Washington Averaged for 1977 and 1978

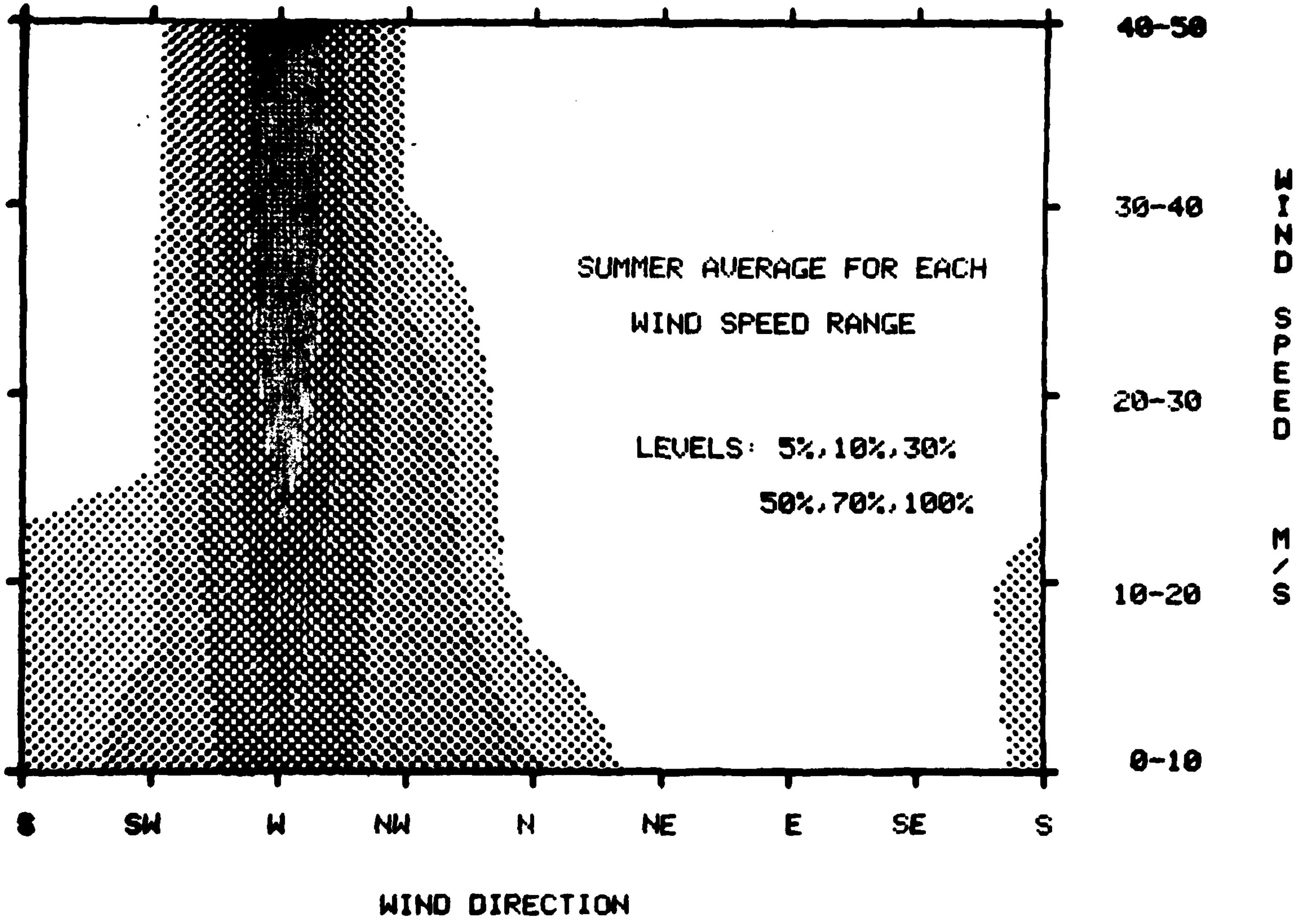


Figure 3.84. Seasonal Wind Speed and Direction Contours for Mt. Washington Averaged for 1977 and 1978

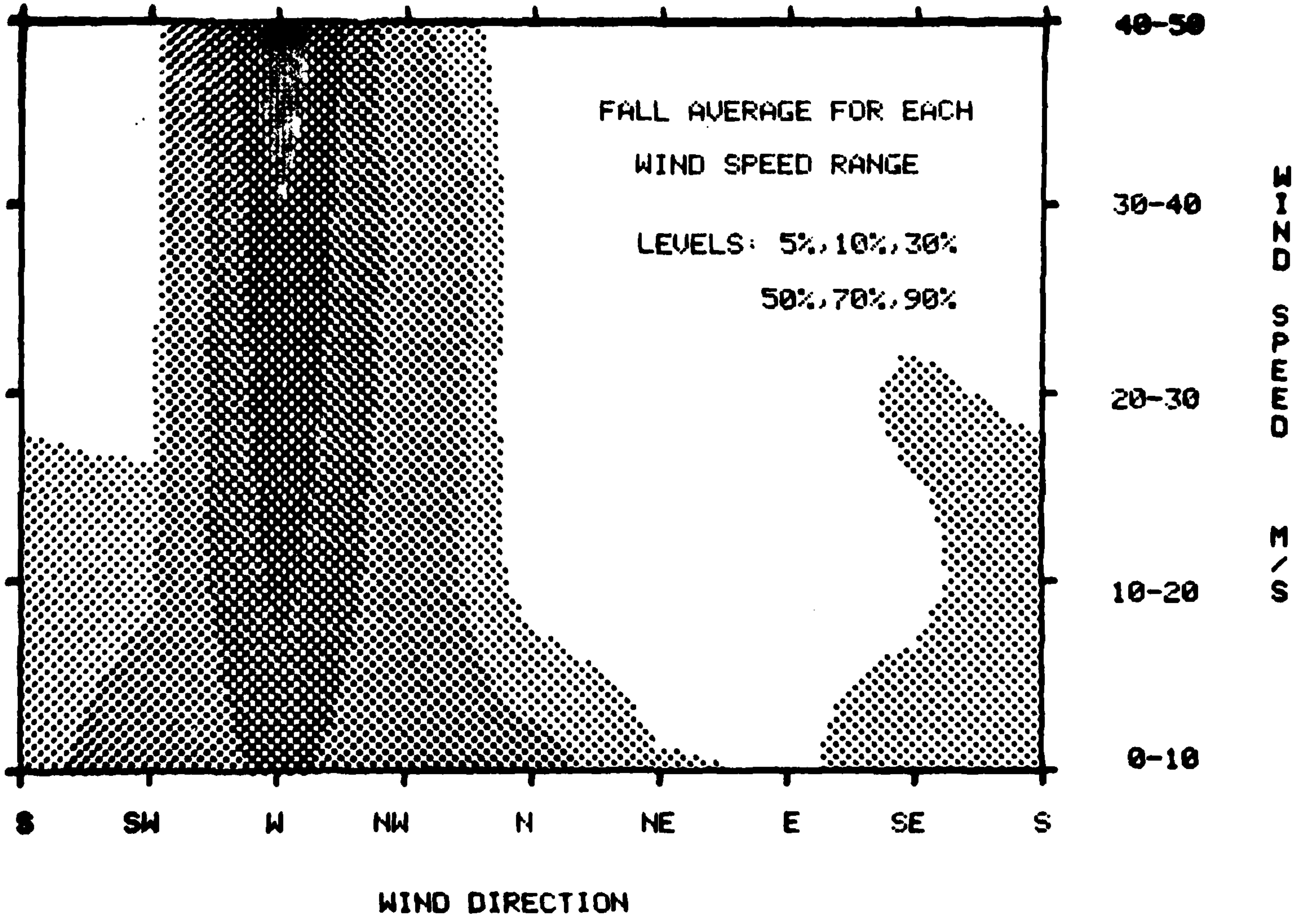


Figure 3.85. Seasonal Wind Speed and Direction Contours for Mt. Washington Averaged for 1977 and 1978

Also, reasonably strong winds of 10-20 m/s occur about 5% of the time in the spring from the east.

3.1.5 Preliminary Selection of Sites

Based on the Corotis and Nagib techniques for evaluating the short term data, an estimate of average wind speed as a function of elevation can be made for isolated peaks in New Hampshire. A graphical representation of this estimate is presented in Fig. 3.86. The speed range was derived by combining the conclusions from the generalized analysis (a one-to-one slope, $\eta = 1$ in Fig. 3.67) and the actual measurements at Mount Washington, the seven August 1979 sites, and Concord, New Hampshire results. Since peaks below 2000 ft have low average wind speeds and peaks above 4000 ft have severe icing and wind gust environments, mountain peaks at about 3000 ft would be appropriate for a WECS site. In order to identify such isolated peaks in New Hampshire, highway maps were studied for the whole state. A list of 59 prospective peaks out of a possible 250 listed mountain peaks is presented in Table 3-4 and in Fig. 3.87. For efficient WECS operation, the selected sites should be reasonably accessible and close to power transmission lines. The possible sites were then reduced according to these factors.

3.1.6 Icing Problems for WECS

The operation of large WECS is limited by icing conditions. For example, the MOD-1 unit operating at Boone, N.C. is shut down when 1/4 inch of ice forms on the blade surfaces. Similarly, the MOD-2 design will be shut down during icing periods. In addition to the basic problems of structural loads from ice formation, the serious question of throwing pieces of ice from rotating blades has been raised. Total power output would be seriously curtailed if a WECS unit had to be shut down during long periods because of ice formation. Since blades are not normally built with heating boots, the time required for melting ice would also degrade performance. For example, the Alcoa

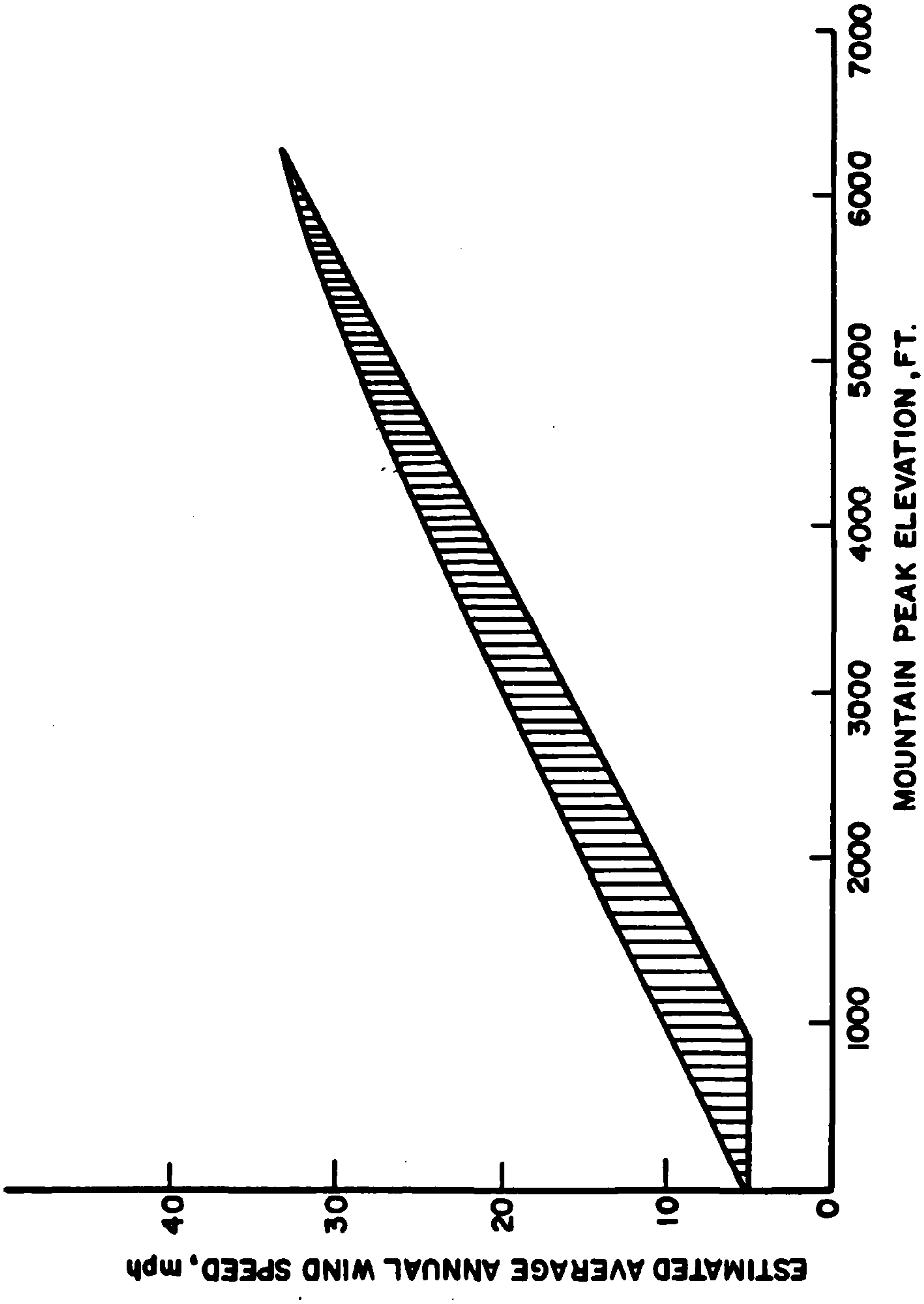


Figure 3.86. Estimated Annual Average Wind Speed for Isolated Peaks in the White Mountains Where No Wind Data Are Available.

TABLE 3-4

POTENTIAL WECS SITES FROM A WIND ENERGY VIEWPOINT

Peak Designation	Name	Elevation ft.
1	Chandler Mountain	3329
2	South Boldface	3569
3	Mt. Willard	2804
4	Mt. Parker	3015
5	Mt. Tremont	3384
6	North Moat Mountain	3201
7	Mt. Paugos	3200
8	Mt. Chocorva	3475
9	Sandwich Mountain	3993
10	Greens Cliff	2915
11	Monadnock Mountain	3165
12	Salmon Mountain	3364
13	Deer Mountain	3005
14	Magalloway Mountain	3360
15	Mt. Pisgah	3074
16	Crystal Mountain	3250
17	Cave Mountain	3185
18	Dixville Peak	3482
19	Rice Mountain	3370
20	Moise Mountain	3610
21	Spruce Mountain	3080
22	Sugar Mountain	2988
23	Blue Mountain	3723
24	Moran Mountain	3143
25	Long Mountain	3615
26	Percy Peak	3220
27	Mt. Kelsey	3449
28	Hutchins Mountain	3710
29	Mt. Cabot	4160
30	Mt. Weeks	3890
31	Mt. Crescent	3230
32	Black Crescent Mountain	3265
33	Mt. Randolph	3070
34	Mt. Success	3590
35	Bald Cap	3090

TABLE 3-4 (Cont'd)

POTENTIAL WECS SITES FROM A WIND ENERGY VIEWPOINT

Peak Designation	Name	Elevation ft.
36	Mt. Starr King	3913
37	Mt. Martha	3554
38	Mt. Deception	3658
39	Mt. Dartmouth	3721
40	Cannon Mountain	4040
41	Mt.Wolf	3200
42	Mt. Cardigan	3121
43	Jerrers Mountain	3000
44	Blue Ridge	3341
45	Mt. Cushman	3105
46	Mt. Kineo	3320
47	Mt. Nancy	3870
48	Mt. Osceola	4326
49	Sear Ridge	3793
50	Mt. Tecumseh	4004
51	Mt. Passaconaway	4060
52	Green Mountain	3360
53	Mt. Cube	2911
54	Smarts Mountain	3240
55	Carr Mountain	3470
56	Pollard Hill	3000
57	Mt. Kearsarge	2937
58	Croydon Peak	2781
59	Grantham Mountain	2661

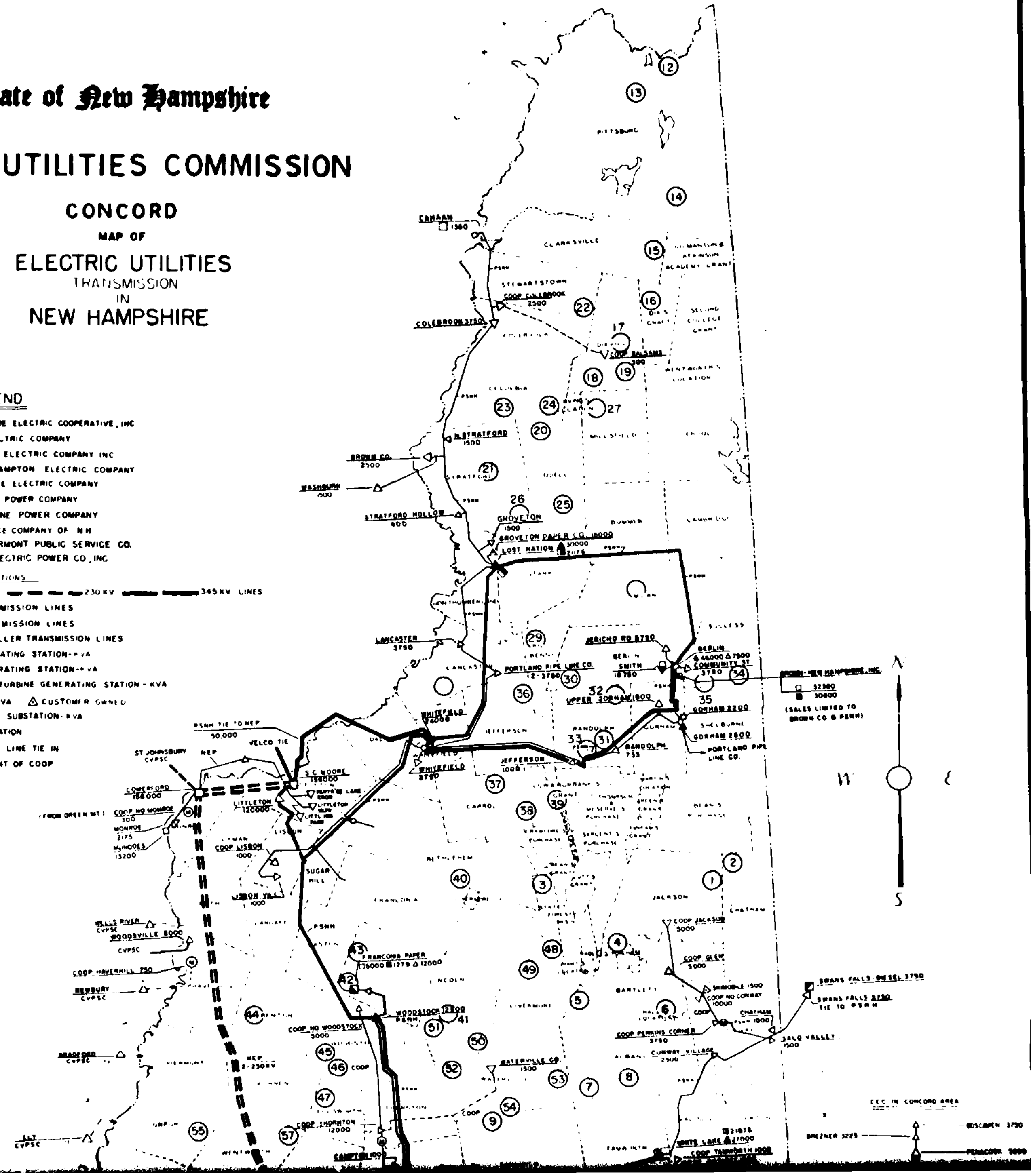
State of New Hampshire

PUBLIC UTILITIES COMMISSION

CONCORD

MAP OF

ELECTRIC UTILITIES
TRANSMISSION
IN
NEW HAMPSHIRE



LEGEND

COOP	NEW HAMPSHIRE ELECTRIC COOPERATIVE, INC
CEC	CONCORD ELECTRIC COMPANY
CVE	CONN VALLEY ELECTRIC COMPANY INC
E & H	EXETER & HAMPTON ELECTRIC COMPANY
GSE	GRANITE STATE ELECTRIC COMPANY
NEP	NEW ENGLAND POWER COMPANY
CMP	CENTRAL MAINE POWER COMPANY
PSNH	PUBLIC SERVICE COMPANY OF N H
CVPSC	CENTRAL VERMONT PUBLIC SERVICE CO.
VELCO	VERMONT ELECTRIC POWER CO, INC

LINES & STATIONS

115 KV — 230 KV — 345 KV LINES

━	66 KV TRANSMISSION LINES
—	33 KV TRANSMISSION LINES
- - -	13.2 KV & SMALLER TRANSMISSION LINES
□	HYDRO GENERATING STATION - KVA
■	STEAM GENERATING STATION - KVA
◧	COMBUSTION TURBINE GENERATING STATION - KVA
△	SUBSTATION KVA △ CUSTOMER OWNED
▲	TRANSMISSION SUBSTATION - KVA
○	SWITCHING STATION
→	TRANSMISSION LINE TIE IN
Ⓜ	METERING POINT OF COOP

THIS
FROM

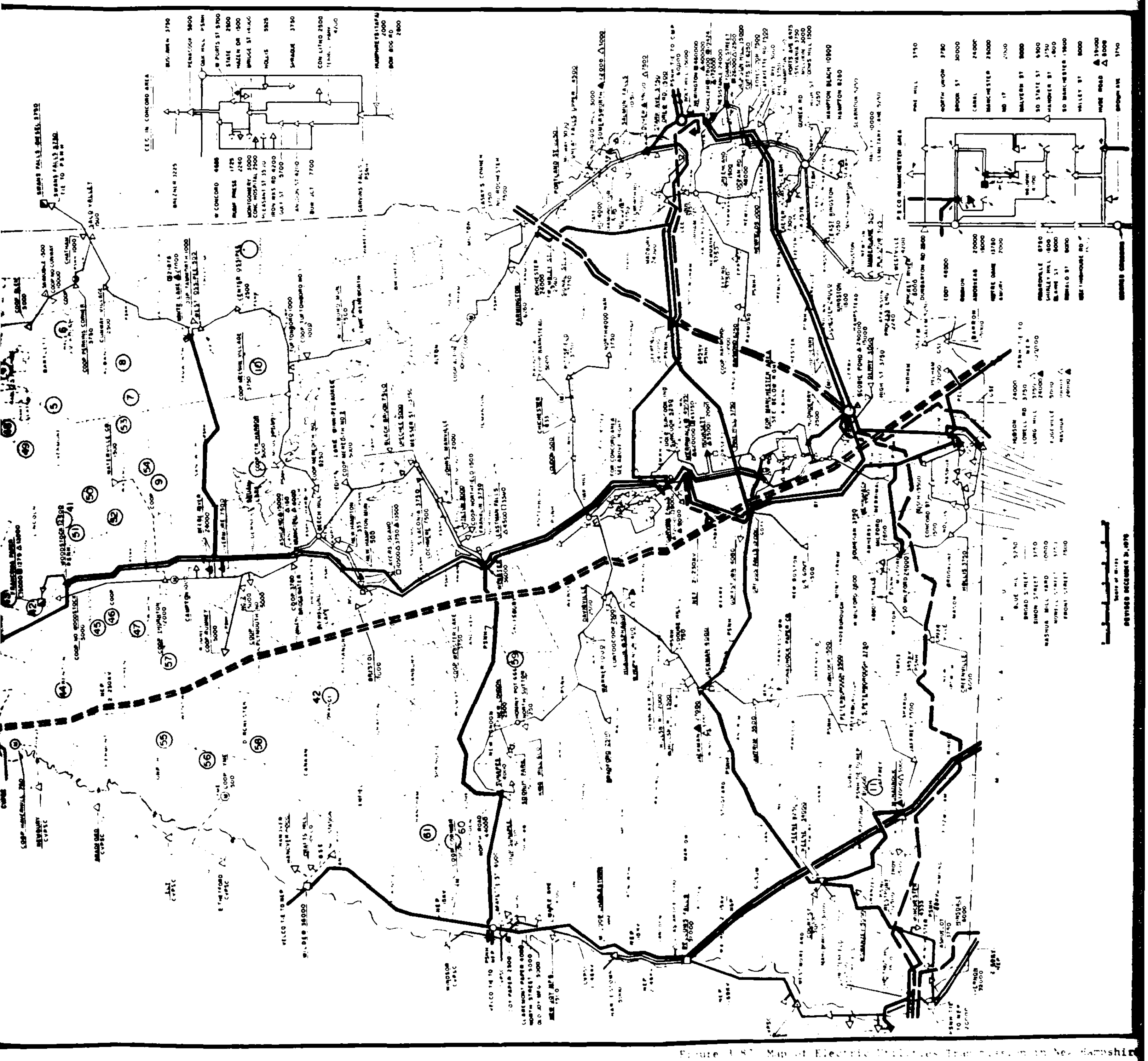


Figure 1.87 Map of Electric Utilities Transmission in New Hampshir

Damiens designs can withstand a static load of 2 inches of ice on the blades. However, there are no methods incorporated to eliminate ice once it has formed.

On Mount Washington, icing conditions are very severe during the winter. Several inches of ice may form on exposed structures. Because of the extreme winds and cold temperatures, ice formations may exist for several days or weeks duration. Consequently, a large WECS would be severly limited by icing conditions at or near the summit of Mt. Washington. Similar conditions exist on other high elevations in the White Mountains. At the ski area of Cannon Mountain (elevation 4040 ft), a cable tramway is affected by icing conditions during the winter season. Unoccupied cable cars are operated during weather periods when rime ice is forming so that cables and wheels do not become frozen. In summary, icing of WECS blades and mechanisms will be a problem in the White Mountains especially at elevations above 4000 ft.

3.2 Social and Environmental Aspects

The political and regulatory climate of New Hampshire is presently favorable to the introduction of new renewable energy power sources in the State. The following sections provide the background which verifies this statement.

3.2.1 Introduction & Summary

The New Hampshire Legislature has recently passed laws and regulations directed to Limited Energy Producers (no more than 5 megawatts) which provide for the public utilities to pay $0.04 or $0.045 per kWh(e) to the Limited Energy Producer. The $0.045 rate is for capacity rather than merely supplemental power. It is not yet clear how much capacity credit a WECS system could claim. However, as discussed in Section 6, an analogy to present rules for hydropower suggests the higher rate could be used.

The environmentalists in New Hampshire appear to be viewing wind energy as a viable and desirable substitute for fossil fuel and nuclear power, while realizing that there will be some undesirable environmental impacts, at least in the aesthetic sense.

The environmental impact of wind turbine machines is estimated to be minimal. Effects on vegetation, wildlife, soils and terrain, antiquities and recreational land will be minimal, provided that certain precautions are taken in siting. Avoidance of wild bird sanctuaries and the normal flight paths of migratory birds is recommended. On most windy sites, the microclimatogical effect of the wind turbine will be dissipated in the normal diurnal climatology of the site.

The aesthetic effects of isolated wind turbine machines could well be pleasing rather than ugly. If the wind energy concept should grow to windmill farms, as it well could, in order to supply adequate energy, then the aesthetic effects could impose a barrier, but not necessarily an insurmountable one when the alternatives are considered. In a similar manner transmission lines may be viewed as necessary, but unseemly intrusions on the countryside.

Interference with microwave transmissions and television reception will pose a problem only if ignored in the siting of an installation. FAA regulations relating to permits and lighting on towers of over 200' will have to be compiled with. Noise is not a problem - under 60 db - and will not permanently affect nearby wildlife. Actually, the noise effects of the machine may be less than the ambient noise of the wind on the peaks or summits.

The effects of maintaining a wind energy machine on soil and water quality are neglible; the effects of construction can be minimized by proper safeguards.

Since the maintenance of these machines requires only one or two persons, the effect on population and employment will be minimal. The substitution of domestically produced power, however, can have a beneficial effect on lowering oil consumption for power purposes in the State of New Hampshire.

As long as state-owned land is utilized - and most mountain tops are state-owned - the legal/institutional barriers to the development of wind energy are minimal. The State of New Hampshire Division of Forests and Lands must issue permits. These applications are passed upon by the Radio Electronics Committee. This agency indicated that any public or non-profit agency, would receive fair consideration for wind energy demonstration sites.

If the site were on private property the New Hampshire Town in which the site is located would have to issue the building permit and the builder and operator would be subject to local zoning restrictions, even in rural areas. Also, easements for transmission lines would have to be negotiated, most likely with several land owners.

3.2.2 Potential Environmental Effects

In 1976, a Battelle study for ERDA on the potential environmental effects of wind energy system development concluded:

"The natural environment is inherently extremely variable even at a given location. This variability is particularly obvious when one deals with harnessing wind in a "windy" location. The biological components occupying these windy environments are generally adapted to fluctuations in wind and other wind-influenced microclimatic parameters such as temperature and humidity. Wind turbines sited within such environments generally are not expectd to alter the local environment beyond the normal fluctuation extremes. Furthermore, identification of wind-turbine-induced environmental effects will be difficult to keep out and quantify within this variable environment."

"While no major effluents, land consumption, mining, or fuels processing and transportation are associated with wind-electrical conversion, these wind energy facilities will influence the physical environment into which they are placed and may also effect the biological environment occupying the same area. The results of this preliminary study indicate that under many, and, in fact, most environmental configurations the effects will be minimal and often not measurable. In two cases, further studies are being made to more clearly define these potential effects through observation of an operating wind turbine. Generally, these effects are (1) ground-level microclimatic alterations induced by the wind turbine and tower and (2) potential collisions of migratory organisms, particularly birds, with the rotating blades." (12)

In the following pages, references to the environmental effects of wind energy machines are not site specific, however, a few selected sites will be discussed later in more specific terms.

3.2.2.1 Land and Land Use

There are about 760,000 acres of National Forests out of the approximately 5 million net land acres in New Hampshire. There are 137,000 acres owned by the State of New Hampshire. 128,000 of these are owned by four agencies: Department of Resources and Economic Development, Fish and Game Commission, Water Resources Board, and the University of New Hampshire. The importance of these Federal and State lands lies in the fact that they include most of the higher sites more likely to be suitable for large wind energy systems.

Wind energy sites of commercial significance in New Hampshire will largely be above 2,500 feet in elevation in order to obtain a satisfactory wind regime. Thus, the lands that could be affected by large-scale wind energy machine installations will most likely be hill tops or mountain summits on State or Federally owned land. The impact of the wind turbine on its surrounding site will depend largely on the characteristics of the site. If the site is heavily forested, then there will have to be unavoidable land clearing to provide adequate access to the wind. If the site is barren, then land clearing can be avoided.

3.2.2.1.1 Effects on Vegetation

Wind turbine machines are likely to have only minimal impact on the surrounding vegetation. In heavily forested mountainous terrain, where clear cutting is necessary, experience is available in the forestry industry to minimize cutting and wind throw of adjacent forests. The chief effects on vegetation other than clearing are microclimatic changes and wind turbulence effects.

The microclimate in the immediate downwind or lee-ward side of the installation could experience lower wind speeds, less evaporation and cooling due to wind with slightly higher humidity. Due to the height of the rotor blade and the diminishing influence of the wake that could reach nearby trees and surface biota, these effects may be unmeasurable. In fact, they will be considerably less than the diurnal climatic changes experienced at the normal windy mountain site and would tend to slightly dampen the diurnal variations presently observed.

Wind turbulence due to the interference of the wind flow by the wind turbine blades and tower is not likely to have any noticeable effect on the surrounding surface biota. This is due to the relatively slow rotational speed of the blades, the height above the ground, and the dissipation of the turbulence due to convergence of the regular wind flow within a short distance from the installation.

3.2.2.1.2 Effects on Wildlife

To the degree that trees and other forest or ground cover are removed to accomodate a wind turbine machine, wildlife will be effected. The cleared area around the installation need not be large and low-lying brush and ground cover need not be disturbed so as to minimize the dislocation of wildlife. The major potential effect on wildlife lies in the damage of airborne organisms (e.g., birds and insects) colliding with the rotor blades or the tower. This potentially negative impact can be minimized by avoiding, whenever possible, sites in the breeding or wintering territory of migratory birds or in the flight paths of migratory concentrations. While in most cases local species learn to avoid stationary flight barriers, experience with the large turbine blades is presently insufficient to claim that no hazards exist.

3.2.2.1.3 Effects on Soil and Terrain

Except for the area upon which the wind turbine machine and the adjacent support structures will be installed, the site should not suffer from soil erosion. Road construction could enlarge the disturbed area, but it can be held to a minimum in the case of a wilderness road. Soil and terrain impact will be minimal provided that care is exercised during the construction period and ground cover replaced after construction. Water erosion during construction could be a problem on certain sites. Where this is the case there are countermeasures that can be taken to reduce runoff and erosion.

3.2.2.1.4 Mineral Resources

The siting of wind turbine generators will have no perceptible effect on the mineral resources of a region or their proper exploitation.

3.2.2.1.5 Antiquities and Recreational Land

Proper site selection would avoid disturbance of antiquities or historical monuments. The impact of the wind turbine machines on recreational lands would be negligible during operation, but would be restrictive during construction. This restriction of access and use of recreational land would be of limited duration and would be largely removed after construction was completed and the landscape restored.

The wind turbine machines in New Hampshire will probably be installed on high hills and mountain tops where they will be highly visible for many miles. Tower height, color and lighting will enhance this visibility. The aesthetic quality of these installations will undoubtedly be a subject of debate for many years to come. To some, the graceful twirling blades on a streamlined tower will be considered an attractive new land mark while to others, any change in the existing vista will be considered as a scar against nature.

There is not an adequate precedent to determine public reaction to these units, either singly or in groups. An October, 1977 study of "Public Reactions to Wind Energy Devices" conducted by the University of Illinois, Survey Research Laboratory and funded by the RANN Program of the National Science Foundation explored the response of the general public toward different types of wind turbine generators.(13) Personal interviews involving about 1800 people (300 in each of six locations) were conducted in six different sections of the country: western Michigan, southeastern Wyoming, western Washington, eastern Rhode Island, the Chicago area, and the Sandy Hook Unit of the Gateway National Recreation Area in New Jersey.

Most of the people interviewed did not seem to object to locating windmills in scenic areas, but this attitude was strongly correlated with general, overall attitudes strongly favoring renewable power sources such as solar energy, windmills and hydroelectric power. The overwhelming majority of the sample favored the Traditional Dutch-Type design, followed by the horizontal axis machine on an old Dutch Tower, and the horizontal axis machine on a columnar tower. Lattice towers, Darrieus and Giromill were the least preferred.

The Survey Research Laboratory report addressed only obliquely the potential acceptability of "windmill farms." Respondents were asked to choose between strings-of-windmills (horizontal axis on columnar towers) and strings of power lines. Liking for a string of windmills exceeded that for a string of power lines (65% to 53%). The preferred picture was the windmill by 2:1 over the power line site; however, a majority also thought the terrain view would be more pleasing without the power lines (72%) or the windmills (59%). Thus, it appears that the nascent feelings of the American public toward renewable energy sources will have a marked influence on the acceptable aesthetic compromises that will be necessary to realize the latent energy potential of these sources.

3.2.2.2 Air Quality

It is characteristic of windmill turbine generators that they do not pollute the surrounding air. There are no noxious fumes or air contaminants produced by these systems and, therefore, there is no adverse impact on air quality; however, these machines do produce a noise that could be described as a "swish" or a "whoosh." The significance of this noise impact is discussed in the following subsection.

3.2.2.2.1 Noise Pollution Effects

Environmental noise criteria are often defined in terms of the day-night sound level, L_{dn}.

This description is defined as the equivalent A-weighted sound level during a 24 hour time period with a 10 db weighting applied to the equivalent sound level during the nighttime hours.

$$L_{dn} = 10 \log_{10} 1/24 \left| 15(10^{L_d/10}) + 9(10^{(L_n + 10)/10}) \right|$$

where $L_d = L_{eq}$ for daytime (7 a.m. to 10 p.m.)

$L_n = L_{eq}$ for nighttime (10 p.m. to 7 a.m.)

The L_{dn} rating is a way of accounting for the fact that people are more sensitive to noise at night.

The Federal Environmental Protection Agency (EPA) has defined typical ranges of L_{dn} for several residential conditions.(14) In Table 3.5, a summary of these ranges is tabulated. Since large WECS units will most likely be placed in rural or forest areas, the expected L_{dn} values for the background environment will probably be less than 50 dB. In order to compare these 24-hr values of L_{dn} with short term dBA measurements, the following example is instructive:

Table 3.5 ESTIMATED PERCENTAGE OF URBAN POPULATION (134 million) RESIDING IN AREAS WITH VARIOUS DAY-NIGHT NOISE LEVELS (Ref.14)

Description	Typical Range L_{dn}, dB	Average L_{dn}	Estimated Percentage of Urban Population	Average Census Tract Population Density, Number of People per Square Mile
Quiet Suburban Residential	48-52	50	12	630
Normal Suburban Residential	53-57	55	21	2,000
Urban Residential	58-62	60	28	6,300
Noisy Urban Residential	63-67	65	19	20,000
Very Noisy Urban Residential	68-72	70	7	63,200

In an environment where the sound level is constant at 60 dBA for 24-hr, the equivalent L_{dn} level is 66.4 dB.

The dBA scale is used on most sound level meters and is a representation of how the human ear responds to moise.

Noise measurements have been made on the MOD-0 horizontal axis - WECS operating at Sandusky, Ohio. These measurements were made by NASA personnel and are only preliminary in nature. With the MOD-0 producing 30-40 kW(e), the measured sound levels ranged from 64 dBA at 100 ft. to 54 dBA at 400 ft from the unit. Background noise levels were 50-52 dBA. If these levels were extrapolated to 500-600 ft, the MOD-0 noise levels would be approximately equal to the background noise level. When the unit was operated at 90 kW(e) output, a noise level of 64 dBA at 200 ft was recorded. It was estimated that the turbine noise would be equal to background noise at about 800 ft distances.

For vertical axis machines, the noise levels have not been well-documented. Some information is available for the small (5 meter) Darrieus machine operating at Sandia Laboratories (personal communicaton with Mr. E. Kadlec, July, 1979). At a distance of 300 ft from the 5 meter Darrieus machine, the noise level was approximately equal to the background level (60 dBA).

Based on the above limited information, some general guidelines on WECS noise can be defined:

- WECS noise levels are not high nor are there objectionable tones present.
- Beyond 1000 ft from a WECS, the noise level will probably be inaudible.
- Rigorous noise measurements should be made on operating 200 kW(e) and 2000 kW(e) systems (MOD-OA & MOD 1).

The last point is necessary so that more accurate extrapolations can be made to the largest WECS system - the MOD 2 design.

3.2.2.3 Water Quality

Another of the desirable attributes of wind energy machines is their null effect on water quality. The operation of these machines poses no water quality problems since there are no effluents, noxious or otherwise.

Site selection and construction could create problems, but these can be either avoided or mitigated during construction. In selecting a site there should be care to avoid the obstruction of or interference with streamflow regimes. In construction, the disturbance of the terrain could bare soils and clay which could produce considerable turbidity in runoff waters. If the flow of the runoff waters is constrained, the turbidity effects can be avoided and the ground cover restored at the completion of construction. Such restraints, if necessary, would also reduce any serious soil erosion during construction.

The building of roads to access the site may pose similar problems to site construction. These roads should be minimal access roads with proper drainage and preservation of water flow regimes. Serious consideration should be given to the use of helicopters in the construction and maintenance of isolated sites so as to avoid road construction and consequent disturbance of the natural habitat of the area. A similar argument may be made for using helicopters for transmission line construction to provide connection to the nearest power grid. Cost trade-off studies should be made utilizing helicopters versus the conventional construction and supply process.

3.2.2.4 Electromagnetic Interference

The use of large wind turbine devices for generation of electric power represents a potential source of electromagentic interference which could adversely affect radio and television reception in the immediate area of the wind generator. If present, the interference effect would occur due to reflection of the radio or television signals by the rotating metallic blades in such a way as to cause periodically constructive and destructive interference between the reflected and transmitted signals. This effect, if sufficiently severe, could cause unacceptable interference to radio, television, and certain other radio frequency electronic equipment. However if composite glass-resin blades are used this effect would be minimized. Metal-resin or graphite resin system could produce problems.

3.2.2.4.1 General Considerations

In order to quantify and evaluate the potentially undesirable electromagnetic interference effects of windmills, detailed theoretical and experimental studies were conducted for ERDA and the U.S. Department of Energy by the University of Michigan.(13) The studies considered the effects of a horizontal-axis windmill on the following equipment/signals.

- Television
- Radio
- Microwave communication links
- Navigational system (VOR/DVOR).

The published results of these studies are summarized below in the next section.

3.2.2.4.1.1 Television

In considering the possible interference effects of wind turbine generators on television reception, the Michigan scientists observed very early that the airfoil shape of WECS blades is not unlike the shape of aircraft wings, which are widely known to produce television interference. It was thus presumed that windmills could cause such interference and that the problem, where observed, would very likely be more severe than for aircraft interference due to the fixed position of the WECS unit Early speculation considered the possibility that TV interference could arise due to either phase or amplitude modulation of the impinging television signals resulting from reflection from the WECS blades.

Simplified laboratory tests and analyses conducted during the study indicated that virtually no TV interference was produced by phase modulation effects, but that considerable interference could result from amplitude modulation effects. Even at quite low levels of amplitude modulation, distortion of parts of the picture were noted with grey bands moving up the screen. As the modulation level increased, the bands darkened, making viewing difficult, and were sometimes accompanied by "snow." Occasional flipping of the picture occurred due to breakdown of the vertical hold, and further increases in modulation level caused complete picture disintegration.

Continued study of the television interference problem at Michigan using refined techniques and measurements near actual windmills allowed the following conclusions to be developed:

- The rotating blades of the WECS pulse amplitude modulate the total field received in the vicinity of the machine.
- The WECS induced modulation pulses can be sufficiently strong that unacceptable distortion of a television picture is observed.
- WECS television interference effects are increasingly severe with increasing channel number (frequency), and decreasing distance from the WECS, other conditions being equal.

- The observed video distortion in the backward portion of the interference zone (in the direction away from the WECS and toward the TV transmitter) is a horizontal jittering of the received pictures in synchronism with the WECS blade rotation. The observed distortion in the forward portion of the interference zone (away from both the WECS and the TV transmitter) appears as intensity fluctuations of the picture, also in synchronism with WECS blade rotation.

- Television reception near wind turbine generators may be considered acceptable if the amplitude modulation index, m_o, for the received signals does not exceed $m_o = 0.15$. Reception is unacceptable for $m_o > 0.15$.

These conclusions provided the basis for development of techniques for prediction of the television interference zone about a wind generator such that the unwanted effects could be minimized by careful selection of the WECS site. Such techniques were developed during the Michigan Study.

Since television interference is clearly a potential problem area which could affect the acceptability of a selected WECS site, the Michigan prediction techniques were applied to the New Hampshire sites considered within the present study.

3.2.2.4.1.2 Radio

Because of its comparatively low frequency range, 550 to 1600 kHz (and correspondingly large wavelength range, 545 to 187 meters, respectively), no interference effects upon normal broadcast AM radio signals would be expected from even a very large windmill installation. FM radio signals, however, are broadcast at frequencies of 88 to 108 MHz, and have a higher potential susceptibility to interference from a nearby wind turbine generator.

To examine the possible effects on FM radio reception, laboratory experiements on these devices were also carried out at the University of Michigan. A modulation pulse synthesizer was used to simulate the amplitude modulation of radio signals produced by reflection from the slowly rotating blades of a wind generator. This device was developed after careful study, and measurement of the WECS ratio effects observed in both laboratory and field tests, the latter using the NASA/ERDA 100 kW(e) WECS unit at Plum Brook, Ohio. The modulation synthesizer was connected to the input terminals of a typical automobile FM stereo test receiver and the interference effects assessed by listening to the quality of the audio reproduction as a function of the ambient signal level and the applied modulation.

When the ambient level of the input signal was high (signal to noise ratio $S/N \geq 15$ dB), no audio distortion was observed for modulation indices below the high level of 16 dB ($m \leq 0.73$). Even with a weaker ambient signal ($S/N < 15$ dB), there was no significant distortion for $m < 7$ dB ($m \leq 0.38$). As m was increased beyond this level, however, there was an increasing amount of audio distortion in the form of a pulsed high frequency hiss superimposed on the FM sound. These results were observed to be consistent with the known fact that ordinary FM receivers are only susceptible to noise interference when operating in their threshold regions, i.e., for input $S/N \leq$ 12 dB.

Based upon these tests, the Michigan study concludes that the effects of WECS interference in FM radio reception will be negligible except possibly within a few tens of meters of the WECS where the modulation index would be high, and even then the audio distortion will be perceptible only if the WECS is located in a region of low signal-to-noise ratio (S/N) for a given FM station.

The New Hampshire sites considered in the present study would not be expected to produce any perceptible FM radio interference.

3.2.2.4.1.3 Microwave Communication Links

Microwave communication links may operate anywhere within the 300 MHz to 300 GHz portions of the electromagnetic spectrum.

Those in most common use are operated by telephone companies for long distance telephone communication, television signals, and data transmission. The most common telephone company microwave system operates at 4 GHz with an average power of from one to five watts. Highly directional, pencil beam antennas typically having ±0.6° beam widths and 35 dB gain are used for transmission and reception. Path length between the microwave repeater stations is on the order of 30 miles.

The most important source of interference to microwave system performance is multipath caused by reflection of the microwave signal from objects near the direct path between transmitter and receiver. This form of interference is traditionally minimized by path engineering, i.e., the proper choice of receiver and transmitter sites and antenna heights to minimize the possibility of interference between the direct and multipath signals at the receiver. For satisfactory performance of a microwave communication link in the absence of fading, it is sometimes required that any multipath interference be at least 40 dB below the desired direct-path signal strength.

In the University of Michigan study, the above system parameters and interference criteria were used to define a "forbidden zone" about a microwave receiver. Placement of a windmill outside of the forbidden zone would not produce multipath effects exceeding the -40 dB threshold level. The analysis used to determine the forbidden zone is not repeated here, but a plot is given in Fig. 3.88 of the forbidden zone about the receiving station of a 4 GHz microwave link with an 8-foot parabolic dish antenna when in the presence of a MOD 2 windmill for which the effective blade area is approximately 430 m^2. In addition to this determination, the Michigan study indicates that no significant additional interference to microwave communications will be produced by rotation of the WECS blades.

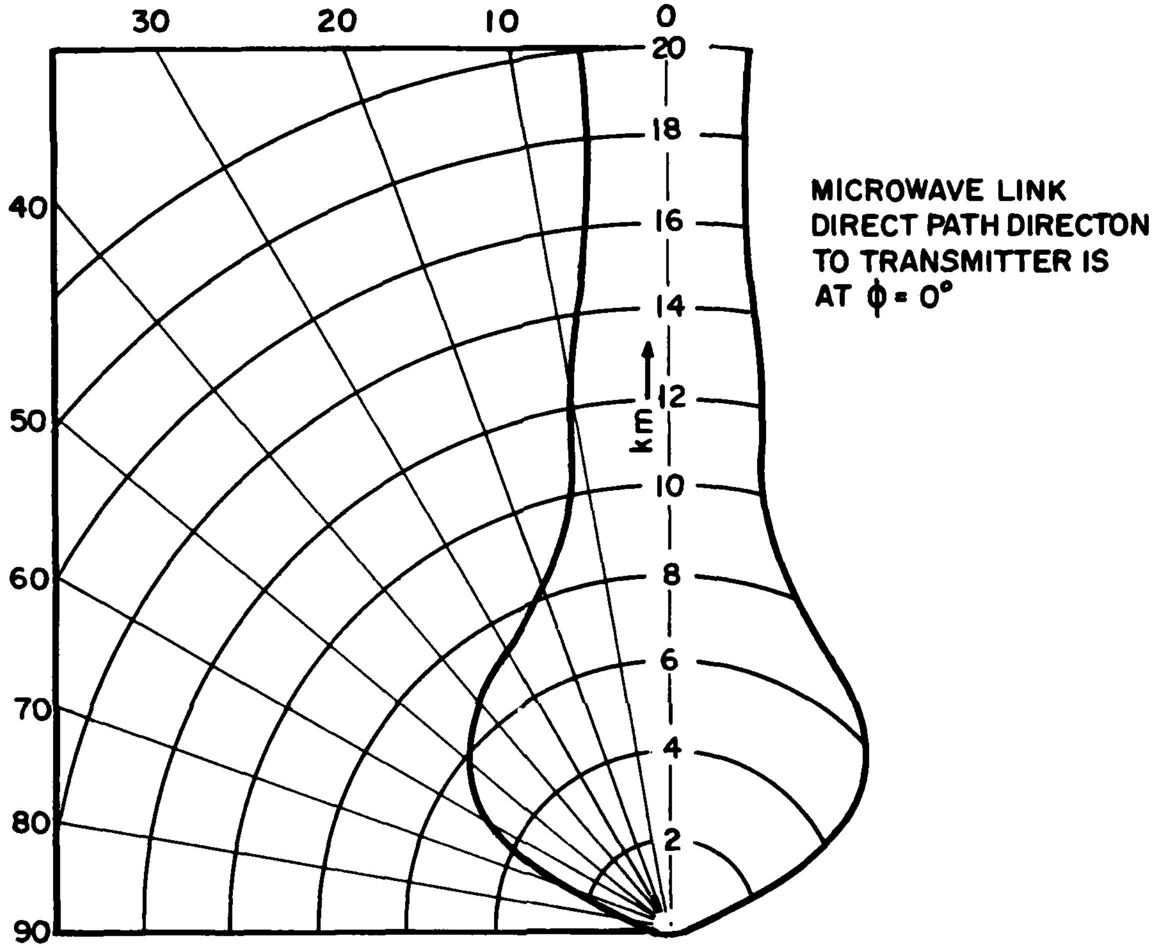


Figure 3.88

Forbidden zone of a 4GHz microwave link receiver using an 8-foot parabolic dish antenna threshold of interference to carrier signal = -40dB

The results of the analysis carried out by the University of Michigan indicates that windmill microwave communications interference effects may be avoided by selection of a WECS site not in the direct path of such communications signals, and removed from a microwave receiver site by distances as shown in Fig. 3.88. These considerations were observed in the present study of New Hampshire WECS sites, and no interference to microwave communications is expected.

3.2.2.4.1.4 Navigational Systems

The VOR is a short-range air navigation system which provides bearing information to a flying aircraft. In an ideal situation the VOR ground station effectively radiates a VHF carrier signal (in the 108-118 MHz frequency range) which contains two synchronous 30 Hz modulation signals for reception by the airborne receiver. One modulation signal known as the reference signal is constant in phase and is independent of the aircraft azimuth position relative to the VOR. The other, known as the variable signal, varies directly in accordance with the azimuth bearing of the aircraft from the VOR ground station. A phase measuring device in the airborne receiver enables the pilot to determine his bearing angle from the station by measurement of the phase difference between these two modulation signals.

In the absence of any multipath between the aircraft and the VOR transmitter, the accuracy of the bearing indications of the airborne VOR receiver is satisfactory. This accuracy can be degraded by multipath effects, producing errors in the bearing indication. The errors, which appear as a series of very slow rhythmic deviations from the desired course, are known as course scalloping.

In the Michigan study, scalloping errors in the bearing indications of VOR systems produced by the rotating blades of a wind turbine generator located near the VOR transmitter were extensively studied in a theoretical and laboratory analysis, using a rectangular flat plate model for the WECS blade. The analysis assumes the system to be in free space, and the VOR receiver in the aircraft to be ideal. It neglects the vertical plane pattern characteristics of the VOR transmitting antenna system and the scattering effects of the WECS tower.

The significant finding of the Michigan study is that stationary WECS blades produce more scalloping errors than rotating ones. The results, therefore, indicate that in choosing a site for a wind turbine generator in the vicinity of a VOR system it is sufficient to consider only the stationary scattering effects of the windmill. It follows that WECS siting can be carried out in accordance with existing FAA guidelines so as to avoid interference to these navigational aids.

Wind Energy Conversion Systems siting in New Hampshire should be carried out so as to avoid any interference to navigational aid facilities.

3.2.2.5 Television Interference at New Hampshire Sites

For a specific wind turbine generator location, the Michigan study has shown that an interference zone can be determined analytically (simplified analysis) for any given television station, within which unacceptable reception can occur. This zone has two regions, one of approximately cardiod shape in the direction of the TV transmitter (backward) and one of sin x/x shape in the direction away from the TV transmitter (forward). These regions are illustrated in Fig. 3.89.

The interference zone sizes may, to a first approximation, be quantified using the expressions:(14)

$$d_1 = \frac{\Delta}{m\lambda} \left(1 - \frac{\Delta}{m\lambda D}\right)$$

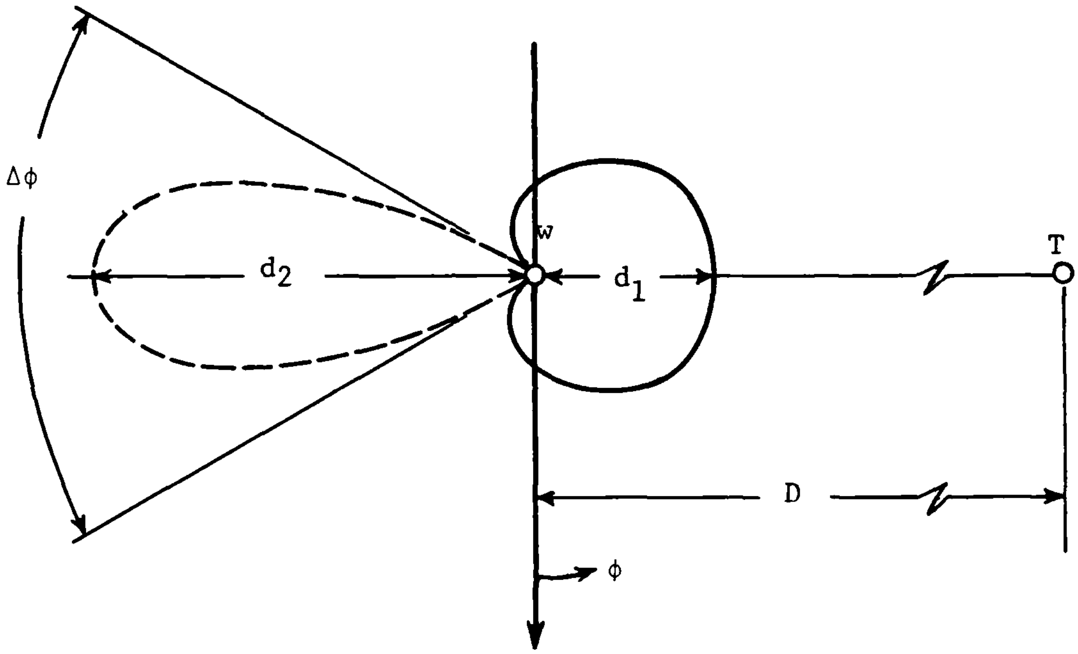


Figure 3.89 Television Interference Zones For A Windmill

and $$d_2 = \frac{\Delta}{m\lambda}\left(1 + \frac{\Delta}{m\lambda D}\right)$$

where: Δ = effective area of windmill blade
λ = television station transmission wavelength
D = distance to television transmitter
m = critical modulation index for interference.

For an initial study of the interference effects which may be present at several candidate WECS sites in New Hampshire, the approximate analysis was further simplified to provide a worst-case comparison of the sites. For this simplified study the interference zone is characterized as a circle whose radius is $\Delta/m\lambda$, but with the center displaced a distance $\Delta^2/(m\lambda)^2 D$ from the windmill. This is illustrated in Fig. 3.90.

In the case of the present study the critical WECS and interference parameters are taken to be:

Δ = 420 sq meters
m = 0.15

Thus $$r = \frac{\Delta}{m\lambda} = \frac{\Delta f}{mc}$$

where, c = speed of light (3.10^8 m/s)
f = TV station frequency (Hz)

or $$r = 9.333 \cdot 10^{-6} f$$

and $$d = \left(\frac{\Delta}{m\lambda}\right)^2 \frac{1}{D} = \frac{r^2}{D}$$

$$d = \frac{8.711 \cdot 10^{-11} f^2}{D}$$

Through map studies and a review of all television station operations in or near the state of New Hampshire, the quantities r and d as defined above were determined for each candidate WECS site and TV station. These are shown in Table 3.6. The analysis indicates that it is possible to experience objectionable television interference at distances from a wind turbine generator of up to 8 km. Beyond that distance, no TV interference could be observed even in a worst-case situation.

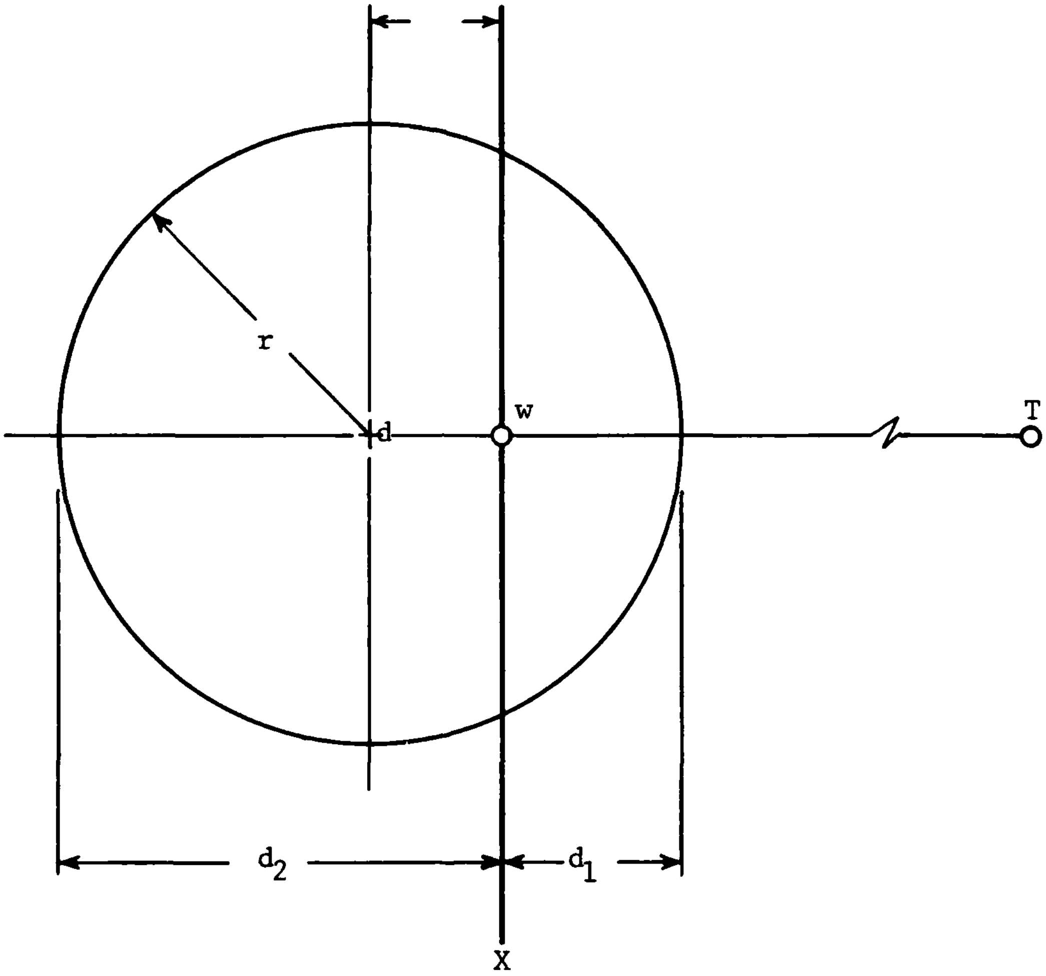


Figure 3.90 Simplified Model of TV Interference Zone

Table 3.6 TELEVISION INTERFERENCE ZONE PARAMETERS FOR SIMPLIFIED ANALYSIS

TV Station	Location	Interference Radius, r (meters)	Interference Renter Displacement from WECS Location, (meters)							
			Mt. Randolph	Mt. Crescent	Bald Cap	Mt. Kearsarge	N. Moat Mountain	Mt. Wolf	Mt. Cardigan	Croydon
WEDB-TV	Berlin	5871	4103	4658	2780	284	947	639	353	271
WO2AC	Claremont	532	34	38	2	7	2	3	6	17
WO6AC	Claremont	793	4	4	4	15	5	7	13	38
WIOAC	Claremont	1820	24	23	21	51	28	36	70	200
WIZAF	Claremont	1932	27	26	24	91	32	41	79	226
W70BP	Conway	7551	1404	1377	1308	591	6131	1094	718	517
WENH-TV	Durham	1876	26	26	25	61	37	32	45	40
WHED-TV	Hanover	4471	198	194	170	462	238	384	980	778
WNNE-TV	Hanover	5367	207	204	185	593	241	320	585	1485
WEKW-TV	Keene	6543	248	245	229	755	294	340	551	835
W65AM	Lebanon (Vt)	7271	468	458	407	1142	547	826	1728	2643
WLED-TV	Littleton	6375	1206	1138	788	375	750	1320	511	390
WMUR-TV	Manchester	1764	20	20	15	63	26	25	40	41
W59AB	N. Woodstock	6935	962	918	725	662	1269	6166	1057	652
WO6AA	Plainfield etc.	793	5	5	4	14	6	8	16	46

3.2.2.5.1 Limitations to Analysis

The simplified analysis presented shows possible television interference effects within distances of 8 km from a wind turbine generator. This places an outer bound on the area which need be considered for interference effects, but should not be considered as accurately defining the region wherein interference effects will, in fact, be observed. Factors which will cause the actual TV interference zone for a given WECS site to be smaller than that indicated in Table 3.6 are:

- the transmitted power of a particular television station--which would not allow its detection near the WECS sites even without interference
- terrain features (e.g., mountains) and propagation effects--which would obscure certain television stations near the WECS sites even without interference
- the nature of the analysis simplification--which enlarges the interference region (compare areas of Figs. 3.89 and 3.90).

Final determination of a wind turbine generator site will require a more detailed interference analysis to calculate the extent and direction of the forward and backward zones for each television station which is receivable at the site. Placement of the WECS would then be adjusted to minimize the number of television receivers which are affected by the interference. For remote areas such as have been chosen for most of the candidate sites, this methodology should allow interference to be limited to a very small number of cases. In those situations where, despite all care in WECS site selection, TV interference is still present, ameliorative measures can be employed.

3.2.2.5.2 Ameliorative Measures

If after a WECS site is selected and developed some objectional television interference is observed in its vicinity, the most expeditious technique for its amelioration is by providing the affected individual with CATV service. This technique will be completely effective and, providing care is exercised in site selection to reduce the number of receivers which could potentially be affected by WECS interference to a very small number, should not represent a strong negative economic effect.

3.2.2.6 Socio-Economic Background and Impact

The State of New Hampshire, commonly known as the "Granite State," with an area of 9,304 square miles lies on the eastern seaboard, north of Massachusetts, south of Quebec, east of Vermont and west of Maine. The state has a short 18-mile seacoast along the Atlantic Ocean at Portsmouth on its southeast corner.

New Hampshire is dominated by the White Mountains, a continuation of the Appalachian system. The highest peak, Mt. Washington, attains an elevation of 6,288 feet. The principal ranges, the Presidential, the Franconia, and the Carter-Moriah have a southwestern to northeastern orientation. On the Presidential range, which is about 20 miles in length, Mt. Washington and nine other peaks exceed 5,000 feet in elevation. On the Franconia, a much shorter range, are Mt. LaFayette, 5,249 feet; Mt. Lincoln, 5,108 feet; and four others exceeding 4,000 feet. The highest peak on the Carter-Moriah range is Carter Dome, 4,843 feet; but seven others exceed 4,000 feet.

North of the White Mountains the ridges rise to 2,000 feet or more. South of the mountains a plateau like surface extends to Merrimac valley. Between the Merrimac valley and the sea is the only low surface in the state.

Many hundreds of lakes and ponds were formed by glacial action. The largest and most widely known is Lake Winnipesaukee, 20 miles long and 12 miles wide, dotted by 274 islands, mostly verdant. The rivers with their numerous falls and the high altitude lakes furnish a vast amount of hydroelectric power to the industries and homes of the state.

The topography of New Hampshire is significant to the utilization of large-scale wind turbines. The hundreds of summits over 2,000 feet provide large areas where the wind regime is most likely to be adequate for dependable performance of these machines in their production of electricity. Thus, New Hampshire may be considered to be an ideal environment for the exploitation of wind energy.

3.2.2.6.1 New Hampshire Government

The State of New Hampshire has 234 communities (13 cities and 221 towns) and 24 unincorporated places. State policy is determined by a bi-cameral legislature in which both houses are apportioned on the basis of population. Administration of the state is by the Governor with all the normal department functions accruing to this post. Local affairs are administered by counties (ten in number), towns (townships), village districts and cities. In each county a convention, composed of representatives from the towns, meets every two years to levy taxes and to authorize expenditures for grounds and buildings whenever more than $1,000 is required.

For the discharge of other county functions, the qualified electors of each county elect every two years three commissioners, a sheriff, an attorney, a treasurer, a register of deeds and a register of probate; two auditors are also appointed annually by the supreme court. The county commissioners have the care of all county property, as well as the county paupers, and once every four years are required to visit each town of their county, inspect the taxable property therein, determine whether it is incorrectly assessed and report to the State Board of Equalization.

In each town a regular annual meeting of the qualified electors (citizens) is called on the second Tuesday of March for the transaction of miscellaneous business and the election of town officers.

The democratic tradition of New Hampshire is strong. This tradition holds well for the introduction of renewable energy sources since there is a growing groundswell among the people favoring renewable energy sources. It will be important to share plans and progress reports with the citizens in these towns where WECS sites are developed, even though not a requirement of the law.

The State of New Hampshire has no income or sales taxes. State revenue is derived from gasoline taxes, vehicle licenses, operator license fees, tobacco and liquor taxes as well as taxation on horse racing. Additional funds for education are derived from a state sweepstakes lottery. Local property taxes provide the major funding for local governments.

3.2.2.6.2 Population of New Hampshire

The population of New Hampshire is today (1979) estimated to be 871,000 by the New Hampshire Office of State Planning. Since the population was 737,681 in 1970 this estimate would indicate that there has been an 18% growth in 8-1/2 years since 1970 which is comparable to New Hampshire's 22% growth from 1960 to 1970.

New Hampshire has 81.3 people per square mile compared to a national average of 57.3 The lower plains counties are the most heavily populated with Hillsborough county leading with 223,941 persons (and a 25% growth between 1960 and 1970) followed by Rockingham county with 138,951 persons (and a 40% growth between 1960 and 1970). This southern and southeastern portion of New

Hampshire is the most heavily urbanized section of the state. Manchester and Nashua in Hillsborough county had 87,000 and 55,000 residents, respectively, in 1970, making this county 71.4% urbanized. Rockingham county contains the city of Portsmouth with over 25,000 residents (1970) as well as the northern suburbs of the industrialized Larrence-Haverhill area of northern Massachusetts.

Several decades ago, closure of textile mills and leather product plants encouraged considerable migration from the state; however, in recent years the influx of new industries into the state together with an influx of retirees have reversed the migration and the population is again increasing. A favorable tax base for industry and individuals is proving attractive to both industry and retirees since New Hampshire imposes no income or sales tax on its citizens or industries.

The following Table 3.7 shows the distribution of the population of New Hampshire by counties for the Census Year 1970 together with the population per square mile. Note that even in the more sparsely populated counties the high percentage of urbanization, indicating that the rural and mountainous areas are sparsely populated.

Table 3.7 New Hampshire Population by Counties (1970)

County	Population	Pop/sq. mile	% in urban areas
State Total	737,681	81.7	56.4
Hillsborough	223,941	252.5	71.1
Rockingham	138,201	201.1	46.3
Merrimack	80,925	87.0	52.2
Staefford	70,431	187.3	82.2
Grafton	54,914	31.7	42.2
Cheshire	52,364	19.8	39.1
Coos	34,291	18.8	44.5
Bilkap	32,367	80.9	46.0
Sullivan	30,949	57.4	56.5
Carroll	18,548	19.8	-

Source: 1970 Census of Population

The significance of developing renewable energy sources, and, more especially, wind energy, to population is not that this new technology will provide any great quantity of jobs within the State, but that utilization of wind energy will provide additional electrical energy at a reasonable cost to help serve the growing demands of an expanding industrial base in southern New Hampshire.

3.2.2.6.3 Economy of New Hampshire

The economy of New Hampshire is based on agriculture, forestry, fisheries, minerals, manufacturing, transportation and communication. There were 2,412 farms in N.H. in 1974 covering 700,000 acres. Production of vegetables, fruits and dairy products together with livestock and poultry contributes 80% of all agricultural sales. The balance of farm income is derived from hay, apples, sweet corn and potato sales. Produce sales were valued at $72.2 millions in 1974 (1974 Farm Census).

More than half of the state is forested. Pine, hemlock maple, beech, and oak grow in the south; spruce, balsam and birch on the moutain slopes and spruce, pine, maple and cedar in other parts of the north. Two-thirds of the harvested timber is used for saw logs, one-fifth is used for pulpwood and the balance for firewood.

Rockingham county fisheries accounted for 19% of the total New England catch in the 1960s.

New Hampshire was the leading supplier of granite to the rest of the country until concrete and steel designs diminished the requirement. Now sand, gravel, stone, clays and feldspar head the mineral production figure. Mica production, large in the 19th century, has also largely diminished.

The chief source of income and employment has been manufacturing. There are currently some 1434 firms employing 90,000 people who earn over 664 million in wages. The added value of production is $1,280 million. Production in the 1940s of textiles and leather goods has been largely replaced in this decade by electronic goods, electrical and other machinery, wood producers, and pulp and paper products. Most of the manufacturing centers are south of Lake Winnipesaukee.

The breakdown of New Hampshire industry follows in Table 3.8 which shows number of establishments, number of employees, payroll, value added and shipment values by major SICs. The 1977 Census of Manufacturers will undoubtedly show considerable growth in the electronics, machinery, and instrument industries.

3.2.2.6.4 Legal/Institutional Barriers

3.2.2.6.4.1 Public Utilities Regulatory Policy Act (PURPA)

The greatest potential barrier to the introduction of wind turbine machines for the generation of electronic power is the potential inability of the small power producer to connect to the power grid and sell his surplus product (electricity) to the public power company servicing this area at a reasonable price or at all. The National Energy Act (1978), building a base for the development of solar and renewable energy sources, calls for Federal Energy Regulatory Commission (FERC) rules favoring industrial cogeneration facilities and requiring utilities to buy or sell power from qualified cogenerators at just and reasonable rates. Two of the provisions of PURPA are especially relevant to the introduction of wind turbine machines as important future contributors to the energy bank of the future.

TABLE 3.8

NEW HAMPSHIRE INDUSTRY BY STANDARD INDUSTRIAL CODES (1972)

SIC		ESTABLISHMENT	EMPLOYEES 1000	PAYROLL $M	VALUE ADDED $M	SHIPMENT VALUE $M
---	Industry Total	1434	89.8	663.5	1279.7	2290.0
22	Food & Kindred Prod.	96	2.8	24.4	86.2	232.0
22	Textile Mill Prod.	65	7.6	45.7	93.0	177.8
23	Apparel, Textile Prod.	40	2.1	10.2	17.4	29.0
24	Lumber and Wood Prod.	259	4.5	28.3	50.0	112.9
25	Furniture & Fixtures	42	2.0	13.4	24.8	42.0
26	Paper & Allied Prod.	39	6.1	254.9	118.8	246.9
27	Printing & Publishing	167	4.7	37.0	68.5	103.6
28	Chemicals & Allied	23	0.7	5.8	13.1	33.5
30	Rubber, Plastic Prod.	51	6.5	39.9	79.3	143.7
31	Leather & Leather Prod.	89	12.8	70.5	123.1	245.0
32	Stone, Clay, Glass Prod.	70	2.5	20.8	41.5	67.2
33	Primary Metal Industry	30	2.5	21.6	40.4	64.8
34	Fabricated Metal Pts.	96	3.6	30.0	48.1	93.2
35	Machinery Except Elect.	161	9.8	84.6	176.4	247.2
36	Electric, Electronic	73	12.3	106.0	169.3	257.0
37	Transportation Equipment	20	1.8	14.6	25.5	42.9
38	Instruments, Rel. Prod.	39	4.6	34.3	82.7	113.1
39	Misc. Manufacturing	52	1.9	11.8	19.8	33.4

Source: 1972 Census of Manufactures

Cogeneration Provisions

The Act provides for a variety of activities which will lead to greater realization of the Nation's potential for recovering and using waste heat energy through cogeneration (i.e., the simultaneous production of process steam and electricity).

The FERC will develop regulations requiring electric utilities to offer to sell or buy power at just and reasonable rates from qualified cogenerators and small power producers (up to 30 megawatts) who are eligible under the criteria established by FERC pursuant to this Act.

In addition, FERC will prescribe rules by which qualifying cogenerators and small power producers may be exempted from certain State and Federal regulations which currently apply only to electric utilities, if the Secretary of Energy determines that such exemption is necessary.

Wholesale Provisions

Interconnection - New authority is provided by FERC to order the physical connection of electric power transmission facilities to allow for the sale or exchange of energy across the interconnection. The Federal Power Act is amended to empower FERC to order such electric utility interconnections on its own motion or upon application.

Prior to issuing such an order, FERC must find that it is in the public interest, and that it will improve one or more aspects of energy and economic conservation, efficiency, or overall utility systems reliability. Furthermore, FERC must determine that the interconnection order will not adversely affect reliability and ability to render adequate service or result in a burdensome economic loss for a utility affected by the order.

More specifically, Sections 201 and 210 of Title II - "Certain Federal Energy Regulatory Commission and Department of Energy Authorities" of the Public Utility Regulatory Policies Act of 1979 (PURPA) relate to new regulations governing the purchase and sale of electrical energy to and from cogenerators and small power producers (210) and definitions pertinent thereto (201). In summary, this Act exempts from many PURPA regulatory procedures cogenerators and small power producers which produce electrical energy "solely by the use, as a primary energy source, of biomass, waste, renewable resources, or any combination thereof" and whose total capacity at the same site is not greater than 80 megawatts. This Act also provides that new regulations shall be promulgated and adopted to require public utilities to provide interconnection and purchase power "at reasonable rates" from the cogenerator and small power producers under acceptable conditions. Section 201 and Section 210 of Title II are reproduced in part in Appendix A for reference purposes.

A proposed regulation, Docket No. RM79-54, issued June 27, 1979 and requiring comments by August 1, 1979, prescribed the suggested rules under which small power production facilities and cogeneration facilities can obtain "qualifying" status. PURPA (1978) mandates that the Commission (FERC) prescribes such rules. The benefits of "qualification" under Section 210 are stated to be:

> "Having delineated by Section 201 and the Commission rules promulgated thereunder the class with which it was dealing, the Congress provided certain substantial benefits of qualification in Section 210. Broadly stated, these benefits are the following:
>
> (1) Electric utilities (defined as any person, State Agency or Federal agency which sells electric energy) can be compelled to buy power from qualifying facilities. The price applied to such required purchases must be just and reasonable to the customers of the purchasing

utility and in the public interest. The Commission may not prescribe a price for such sales that "exceeds the incremental cost to the electric utility of alternative electric energy." The price shall not discriminate against the selling qualifying cogenerator or small power producer.

(2) Utilities can be compelled to sell to qualifying facilities. The price applied to such required sales shall be just and reasonable and in the public interest and shall not discriminate against the qualifying cogenerator or small power producer.

(3) Qualifying small power production facilities whose size does not exceed 30 megawatts of capacity and all qualifying cogeneration facilities may be exempted in whole or in part by Commission rule from the Federal Power Act, from the Public Utility Holding Company Act, and from State laws and regulations respecting the financial or organizational regulation of public utilities, if the Commission determines such exemption is necessary to encourage cogeneration and small power production.

Rules embodying these principles are to be issued by the Commission within one year after enactment; viz, by November 8, 1979. The law provides that the State regulatory authorities and nonregulated utilities are to implement the Commission's rules within a year after they are prescribed.

The proposed regulation, Docket No. RM79-54, "Proposed Regulations Providing for Qualification of Small Power Production and Cogeneration Facilities Under Section 201 of the Public Utility Regulatory Policies Act of 1978," and Docket No. RM79-55, "Staff Paper Discussing Commission Responsibilities to Establish Rules Regarding Rates and Exemptions to Qualifying Congeneration and Small Power Production Facilities Pursuant to Section 210 of the Public Utility Regulatory Policies Act of 1978" are reproduced in the Appendix hereto.

While the PURPA rules are to be promulgated by November 9, 1979, the individual State regulatory authorities have an additional year to implement the Commission rules as promulgated.

3.2.2.6.4.2 State of New Hampshire Acts

The State of New Hampshire has taken the lead among the States in passing a series of acts that would implement the basic philosophy of PURPA in encouraging small power producers of not more than five (5) megawatts of total developed output capacity. These acts, in general, conforming with PURPA, may require minor modifications after the PURPA rules are finalized.

H.B. 35

This Act provides for exemptions from public utility status for certain electrical energy producers and for setting rates for sale of power generated by those exempted producers. The purpose is declared to be "to provide for small scale and diversified sources of supplemental electrical power to lessen the state's dependence upon other sources which may, from time to time, be uncertain."

This Act exempts the producers of electrical energy, not involving the use of nuclear or fossil fuels, with a developed output capacity of not more than 5 megawatts from rules, regulations and statutes applying to public utilities. The Act further requires that "the entire output of electrical energy of such limited producers, if offered for sale, shall be purchased by the electric public utility which serves the franchise area in which installations of such producers are located."

Payment by Public Utilities for purchase of output from limited electrical energy producers shall be a price per kilowatt hour to be set, from time to time, by the public utilities commission. The commission will adjudcate any disputes arising between parties as defined in the Act.

H.B. 771

This Act provides that a limited producer of electrical energy shall have the authority to sell its produced electrical energy to not more than 3 purchasers other than the franchised electric utility. The commission shall review and approve all contracts concerning a retail sale of electricity. The Act also provides that any franchised electrical public utility in the transmission area shall transmit electrical energy from the producer's facility to the purchaser's facility and that the producer shall compensate the transmitter for all costs incurred in wheeling and delivery of the current to the purchaser. There are some provisions to protect the public interests as well as both parties to a wheeling transaction.

This Act repeats the requirement that the entire output of electrical energy of limited electrical energy producers, if offered for sale to the electric utility, shall be purchased by the electric public utility which serves the franchise area in which the installations of such producers are located.

Order No. 13,589

This order establishes the price which the public electric utilities shall pay for the entire output of electrical energy from limited producers as defined in the above Acts from May 1, 1979 to April 30, 1980.

Non-dependable capacity basis:	4¢ per kWh
Dependable capacity basis:	4-1/2¢ per kWh

The Commission states that it will reexamine the PURPA issues upon the issuance of rules by FERC and that annual adjustments will be made.

This order contains a record of the public hearings which were held preceeding the issuance of the order. A supplemental report and Supplemental Order No. 13,744 were issued in July, 1979 providing rules for establishing dependable capacity ratings for small scale hydroelectric facilities. Wind turbine generated power is not covered in this regulation. See Appendix for details.

H.B. 922

In one additional action the State of New Hampshire has demonstrated its resolve to encourage renewable energy sources for the homes, offices, farms, and factories of the State. This Act permits each city and town to adopt an exemption from "property tax for persons owing real property which is equipped with a wind-powered energy system. At the time of preparing this report only 3 towns have approved the wind energy referendum while about 30 out of 256 have approved an earlier and similar solar energy referendum.

All Acts, Regulations and Reports referenced above are contained in their entirety, in the Appendix.

The method of computing capacity for an individual small power producer is not valid for a "system of small power producers." For example, each hydroelectric producer may have slightly different slack periods or periods of low water. As a group they may have a significant percentage of capacity at any given time. This will also be true of wind turbine generators located in different geographical areas. While any individual WECS may not earn much of a capacity credit, a system of WECS could well earn a significant capacity credit.

The New Hampshire Committee has had a glimpse of the potential of not only a system of hydroelectric generators of a system or wind turbine generators, but of a combined system of hydroelectric and wind energy that could achieve an even greater capacity credit for the combined system. The following is quoted from Dr. Gerald Koeppl's[*] statement on "Wind Energy - The Prospects for Vermont," which was circulated to the New Hampshire Committee.

> "In Vermont, there is a great deal of interest in the development of adding hydroelectric capacity. In a utility expansion with the inclusion of WECS in the mix of generating equipment, a higher peak power capability at a specified availability level may be achieved through a purchase of WECS less capital intensive peaking equipment instead of more capital intensive baseload equipment. Given a network which includes a hydroelectric capability, additional hydroelectric turbines may be added in place of new baseload capacity to effect a capital savings in the addition of conventional equipment. The hydroelectric power is not used when WECS are producing electricity, but are used at a higher power level when the wind is not blowing. The total hydroelectric energy produced during the year is the same, but the capacity factor is lower and the capacity rating higher. It is advantageous, therefore, to study existing potential hydroelectric capacities when making plans for the inclusion of WECS in a given system - the presence of hydroelectric capability increases the economic attractiveness of WECS."

Further, when the public utility receives a capacity credit for such a system as described above, this credit should be passed back to the small power producers as a capacity credit.

3.2.2.6.4.3 Regulations Relating to Use of State and Federal Land

In the State of New Hampshire the Division of Forests and Lands has the authority to issue permits. Applications are passed upon by the Radio Electronics Committee of this agency. Discussions with the agency indicate that approval is based upon purpose, compatibility with present or intended land use by the State, and the nature of the applying organization. Non-profit and public agencies are preferred. This

---

[*] Associate Professor, Queens College, Flushing, New York.

agency stated that the U.S. Navy would receive fair considerations should it desire to apply for a permit to locate a wind energy machine on a New Hampshire site controlled by the State. Since most of the summits under consideration are State controlled the general attitude exhibited by the New Hampshire authorities would seem to provide siting on State lands as a problem area.

Should sites be selected in National Parks or Forests then the cognizant Federal agency would have jurisdiction and their regulations would apply. The Federal Land Policy Management Act and regulations issued under this Act would also apply. These regulations are not reviewed herein since there appears to be no involvement of Federal lands at this time. The cognizant Federal agencies would most likely be the Department of the Interior while wetlands would be under the jurisdiction of the Army Corps of Engineers.

The decision as to whether or not public lands will be made readily available for the siting of wind energy machines will depend, to a major extent, on the seriousness of our national commitment to the development and utilization of renewable energy sources.

3.2.2.6.4.4 Preservation of Historic Sites

At this stage in the development of wind energy machines, it is recommended that any site of historical significance be avoided in initial siting studies. In the State under study, all viable sites are over 2,500' in altitude and do not involve any historic shrines.

3.2.2.6.4.5 Local Zoning Laws

New Hampshire has 234 communities (13 cities and 221 towns) and 24 unincorporated places. The Office of State Planning reports that, as of Town Meeting, March 1979, 99% of New Hampshire's communities have planning boards, 95% had subdivision regulations and 74% have enacted zoning ordinances.

Growth of industry in southern New Hampshire together with attendant population growth is spurring the development of community-wide masterplans. Ninety-two communities (39%) have a completed master plan while 64 more communities (27%) have a master plan in process. Nineteen percent of the communities have a designated Historic District Plan; 88% of the communities require building permits and 80% have a Conservation Commission. The regulations are not uniform throughout the State so that individual communities are likely to have different regulations governing the siting of wind turbine machines.

Most building codes limit the height of structures by lot size although some contain overall restrictions on height. A 350-400' wind machine may not be within the code even when located on several acres of ground. It also could be construed to be a "public hazard" or a "public nuisance" under some codes. It is unlikely that any construction of large-scale wind turbines will be proposed at this time in a heavily populated area; however, it suggests a decision that many communities may have to face in the future if the potential of wind energy is to be achieved as a viable alternate energy source. A full discussion of possible zoning and building code problems relating to wind energy is available in the study: "Legal Institutional Implications of Wind Energy Conversion Systems (WECS)," by the Program of Policy Studies In Science and Technology of George Washington University (September 1977). This report to the National Science Foundation was funded under NSF Grant APR75-19137.

In a letter attached hereto from the Office of State Planning, it is stated that "a community cannot override a land use decision made by a State or Federal Agency on public land managed by that unit. To maintain good will, however, agencies frequently meet with town or city officials and/or participate in a public hearing(s), to appraise local interests

OFFICE OF STATE PLANNING
STATE OF NEW HAMPSHIRE
2 BEACON STREET — CONCORD 03301
TELEPHONE 603-271-2155

August 27, 1979

Mr. Jack P. Kornfeld
IIT Research Institute
10 West 35th Street
Chicago, Illinois 60616

Dear Mr. Kornfeld:

This is in reference to your request of August 22, 1979 concerning local jurisdiction on State or Federally owned property. In answer to your question a community cannot override a land use decision made by a State or Federal agency on public land managed by that unit. To maintain goodwill, however, agencies frequently meet with town or city officials and/or participate in a public hearing(s), to appraise local interests of the proposed project.

A project on State property should be introduced to the appropriate agency when it is in the concept stages. The agency may further choose to bring the proposal before the Council on Resources and Development for additional discussion and coordination with other agencies. It may also be necessary to gain project approval from the State Radio/Electronics Committee who review applications for mountain top uses. A major project may require concurrence of the Governor and Council. After approvals, a leasing/fee arrangement between the lessee and the State is a final necessary step.

A review, approvals and leasing agreement or similar steps are probably required at the Federal level if the property in question is in their jurisdiction.

Please find enclosed the report you requested.

Sincerely,

Melissa Bailey

Melissa Bailey

P.S. The Inventory of Outdoor Recreation Planning report was ruined in the recent fire, no copies are available for distribution.

of the proposed project." This policy is consonant with the need for encouraging public support of and participation in programs to develop renewable energy sources. A copy of the above referenced letter follows.

3.2.2.6.4.6 Federal Aviation Authority Regulations

FAA standards govern the height of obstructions and are of two types, notice standards and obstruction standards. Wind energy machines of greater than 200 feet in height, no matter where located, require the filing of a notice with the FAA before construction. Installations of lesser height are required to file such a notice if they are sited within certain distances (the maximum being roughly four miles) from airport runways or helioports, or in an instrument approach area.

The FAA action taken after a notice is filed depends on how the proposed structure relates to its obstruction standards. Wind turbine machines between 200 and 500 feet in height may be deemed obstructions if they are sited within three to six nautical miles of the established reference point of an airport. The effect of an obstruction (or even the filing of a notice) will be to trigger FAA lighting and marking requirements. No serious obstacles to the large-scale WECS are likely except for sitings within six miles of an airport.

3.2.2.6.4.7 Federal Communication Commission Regulations (FCC)

Wind turbine airfoils will cause electromagnetic interferences. The significance of this interference has already been discussed along with mitigating measures to be taken, especially in siting. The FCC regulates "incidental radiation devices" emitting "radio frequency energy" causing "harmful interference." The only substantive standard seemingly relevant to WECS as incidental devices reads as follows:

> "An incidental radiation device shall be operated so that the radio frequency that is emitted does not cause harmful interference. In the event that harmful interference is caused, the operator of the device shall promptly take steps to eliminate the harmful interference."

A failure to do so could cause operation of the offending unit to be prohibited.

FCC requests for technical information and for testing are also possible. The future of widespread implementation of large-scale wind turbine machines may well hinge on the successful siting of demonstration units so as to mitigate and avoid these effects. Even so, these effects could limit the available range of siting options.

3.2.3 Specific Effects at Selected Sites

In this section each selected site will be separately presented, together with site characteristics and potential impact on the environment. The wind regimes at these sites are presented in Section 3.1.4 of this report. It should be clearly understood that 59 sites over 3,000 feet in altitude have been identified as potential sites. The selected sites are considered to be feasible and worthy of further study. This selection does not preclude the selection of additional sites, especially after site selection criteria are more fully developed and the wind regime data base more fully expanded.

3.2.3.1 Mt. Randolph

Mt. Randolph is 3,070 feet in elevation above sea level. It is located in the Crescent Range southwest of Berlin and northwest of Randolph. It apparently is not within the borders of the White Mountain National Forest but lies between two sections of the Forest. Precise ownership was not determined. Two roads available from U.S. Hwy. 2 approach to 1-1/4 miles of the summit. The closest habitations are seasonal dwellings 1-1/2 or more miles from the summit. Use of helicopters for construction maintenance is recommended to avoid road construction.

AD-A086 506 IIT RESEARCH INST CHICAGO IL F/G 10/2
NAVY-NEW HAMPSHIRE WIND ENERGY PROGRAM.(U)
NOV 79 S A BORTZ, R A BUDENHOLZER N00014-79-C-6503
UNCLASSIFIED IITRI-M6052 NL

3 of 3
AD A
086506

END
DATE
FILMED
8-80
DTIC

Mt. Randolph is in Coos County which has a population of 34,291 persons and in which the largest urban center is Berlin City with a population of 15,256. The town of Randolph has a population of 169. Thus, the area surrounding Mt. Randolph is sparsely populated.

Coos County had a total of 87 manufacturing establishments of which only 19 employed 20 or more persons. Chief industries are logging and wood products and paper and allied products. Total employment is 12,513 with 5,455 persons employed by manufacturing as compared with 427 in agriculture, forestry and fishing. Coos ranks eighth (out of ten) in the State in the value of farm produce. Coos County is largely a vast recreational area.

The installation of a wind energy turbine on Mt. Randolph will have little or no adverse effects on the ecology of the mountain. Clearing of the site would be the minimal required for the tower, the maintenance building and a helicopter pad - since the brush and trees are dwarfed by the climate of the mountain - seldom rising over thirty feet. Effects on the economy of the area would be very minimal with no more than a dozen jobs in construction over a six month period and two or three permanent maintenance jobs thereafter. Possible impact of electromagnetic interference has been discussed in Section 3.1.4 and it should be recognized that initial installations of large-scale wind turbine generators will most likely be a tourist attraction for a time until the novelty wears off and thus the installation will most likely promote tourism in the area.

3.2.3.2 Mt. Crescent

Mt. Crescent is 3,230 feet above sea level. It is located in the Crescent Range southeast of Berlin and northwest of Randolph. One fourth of the westerly portion of the summit apparently lies in the White Mountain National Forest while the ownership of the remainder of the summit has not been identified. A road off of U.S. Hwy. 2 extends to within a mile of the summit. The closest habitations are seasonal and lie one mile or more from the summit. Use of helicopters for construction and maintenance is recommended to avoid ecological damage which would result from expensive road construction.

Refer to 3.2.3.1, the write-up on Mt. Randolph, for demographic data and comments on ecological impact. All comments in Section 3.2.3.1 apply to Mt. Crescent.

3.2.3.3 Bald Cap

Bald Cap is 3,090 feet in elevation above sea level. Bald Cap is in the Mahoosuc Range about five miles east of Berlin and northeast of Gorham. A road, off of U.S. Hwy. 2 runs parallel to within three miles of the summit and a trail runs almost to the top. The closest habitations are seasonal and are located about three miles from the summit. Depending on the adequacy of the trail for an all-terrain vehicle, the use of helicopters for construction and maintenance could be recommended. The ownership of Bald Cap and the surrounding terrain was not determined. It does not show as being within a State or National Park.

Refer to 3.2.3.1, the write-up on Mt. Randolph, for demographic data and comments on ecological impact. All comments in Section 3.2.3.1 apply to Bald Cap except that the immediate area of the summit is more remote.

3.2.3.4 Mt. Cardigan

Mt. Cardigan is 3,121 feet above sea level. It is located in Cardigan State Park (Mt. Cardigan State Forest) in the town of Orange. This summit is barren and will require no clearing to access to the wind. The summit is about three (3) miles east of Lebanon, N.H., and one (1) mile east of Canaan (on U.S. Hwy. Rt. 4) and about two (2) miles west of Welton Falls State Forest. A graded and drained road runs from Canaan to the State Forest Building, about one (1) mile WSW of the summit. An all-terrain vehicle can follow a trail to the summit. Light power lines presently run to the summit.

Mt. Cardigan is in Grafton County which had a population of 54,914 persons in 1970 with no large urban centers Lebanon is the largest city in Grafton with a population of 9,725 in 1970. The Town of Orange, in which Mt. Cardigan is located, had a population of 103 in 1970.

Grafton County had a total of 93 manufacturing establishments in 1972, of which 32 had twenty or more employees. Most of the data regarding employment and value of product were withheld to avoid disclosing information about individual companies. Chief industries are rubber and plastic products, leather and leather products, stone, clay and glass products and non-electrical machinery. The principal employers in Grafton County are manufacturers, retail trade and education. Grafton County ranks third in New Hampshire in agricultural product, $9.7 million in 1974.

The installation of a wind energy turbine on Mt. Cardigan will have no adverse effects on air or water quality nor on the biota of the area. Effects on the economy of the area will be minimal with no more than a dozen jobs in construction over a six month period and two or three permanent maintenance jobs after the installation is completed. Possible impact of electromagnetic interference has been discussed in Section 3.1.4. The installation could prove to be a tourist attraction and thus could encourage tourism in this area.

3.2.3.5 Mt. Kearsarge

Mt. Kearsarge is 2,937 feet above sea level. The summit of Mt. Kearsarge is barren and, therefore, will require no clearing of trees to provide access to the wind. It is located in Winslow State Park, partly in the town of Warner and partly (westerly 1/4 of mountain) in the Town of Wilmot. The summit is about three (3) miles southeast of Wilmot Flat. A surfaced road runs southeast from FAS 11 in Wilmot Flat to Halfway House, which is about 3/4 mile from the summit. Another surfaced road runs north through Rollins State Park to within 3/8 mile of the summit. The terminus of this road is about ten (10) miles from the Village of Warner and winds north past Mission Ridge and Black Mountain in Rollins State Park. There is a trail to the summit which an all-terrain vehicle can manage.

Mount Kearsarge is in Merrimack County, which in 1970 had a population of 80,925 persons, of which over 30,000 resided in the City of Concord. Wilmot Town had a population of 516 in 1970 and Warner Town had a population of 1,441. Warner had 720 housing units of which 121 lacked some or all plumbing facilities, indicating that almost 20% of the housing of this town was somewhat primitive (or resort) housing. Printing and publishing, leather and leather products, instruments, lumber and wood products, and fabricated metal products are the major industries of Merrimac County. Manufacturing, construction, education and public administration are the principal employers of labor. Altogether there are 160 manufacturing establishments reported for Merrimac County in the 1972 Census of Manufacturers. Merrimac County had agricultural sales of about $7.7 million in 1974 and was the fifth ranked agricultural county in the State of New Hampshire.

The installation of a wind energy turbine machine on Mt. Kearsarge will have no adverse impacts on the ecology of the mountain and virtually no impact on the economy of the area. Mt. Kearsarge already has several microwave installations which need be no problem in siting. Also, there is a transmission line on this mountain. Possible impact of electromagnetic interference has been discussed in Section 3.1.4.

The installation could well prove to be a tourist attraction and thus could encourage tourism in this area. Construction work over a six month period could add up to a dozen jobs for the labor force of the area and maintenance could add two or three jobs over an extended time period (30 years).

3.2.3.6 North Moat Mountain

North Moat Mountain is 3,201 feet in elevation above sea level. It is located in the White Mountain National Forest about five (5) miles west of North Conway (on U.S. Hwy. 302). The closest point to the summit from Hwy. 302, east of Bartlett, is about three (3) miles. North Moat is also about 2-1/2 miles west of Echo Lake State Park. No trails to the summit were identified as possible for all-terrain vehicles. Use of helicopters for construction and maintenance is recommended to avoid extensive and expensive road construction.

North Moat is in Carroll County which has a population of 18,548 and virtually no urban centers. The summit is in the town of Bartlett which has a population of 1,098. North Conway, referenced above, has a population of 1,723 (1970). Carroll County has 48 manufacturing establishments with only 11 employing 20 or more persons. No industry breakdown was provided in the 1972 Census of Manufacturers for Carroll County. Out of 7,190 employed in industry, 1,194 were employed in manufacturing and 852 in construction. Also, Carroll County ranked ninth, next to last, in the value of agricultural produce. If all the data were properly presented in the Census, Carroll County would appear to largely depend on the recreational industry and tourism, especially since Lake Winnipesaukee is also in Carroll County.

The installation of a wind energy turbine on North Moat will have little or no adverse effects on the ecology of the mountain. Clearing of the site would be the minimal required for the tower, the maintenance building and a helicopter pad since the brush and trees are dwarfed by the climate of the mountain - seldom rising over thirty feet. Effects on the economy of the area would be very minimal with no more than a dozen jobs in construction over a six month period and two or three permanent maintenance jobs thereafter. Possible impact of electromagnetic interference has been discussed in Section 3.1.4. It should be recognized that initial installations of large-scale wind turbine generators will most likely be a tourist attraction for a time until the novelty wears off and thus the installation will most likely promote tourism in the area.

3.2.3.7 Mt. Wolf

Mt. Wolf is 3,200 feet in elevation above sea level. It is located in the White Mountain National Forest four miles NW of Lincoln. The summit is 3-1/4 miles west of U.S. Hwy 3, north of Lincoln and slightly more than two (2) Miles NE of H.H. 112 (FAS 2.7), site of the Wildwood Forest Camp in the town(ship) of Easton. The Forest Camp is also the nearest seasonal habitation. No trails to the summit have been identified as passable for all-terrain vehicles. Use of helicopters for construction and maintenance is recommended to avoid extensive and expensive road construction which could be ecologically damaging.

Mt. Wolf is in Grafton County which has a population of 54,914 persons (1970) with Lebanon as its largest urban center with 9,725 (1970) population. Mt. Wolf is located in the Town of Lincoln which had a population of 1,341 persons in 1970.

Grafton County had a total of 93 manufacturing establishments in 1972, of which 32 had twenty or more employees. Most of the data regarding employment and value of product were withheld due to avoid disclosing information about individual companies. Chief industries are rubber and plastic products, leather and leather products, stone, clay, and glass products and non-electrical machinery. The principal employers in

Grafton County are manufacturers, retail trade and education. Grafton County ranks third in New Hampshire in agriculture produce, $9.7 million in 1974.

The installation of a wind energy turbine on Mt. Wolf will have no adverse effects on air or water quality nor on the biota of the area. Clearing of the site would be the minimal required for the tower, the maintenance building and a helicopter pad since the brush and trees are dwarfed by the climate of the mountains - seldom rising over thirty feet. Effects on the economy of the area will be minimal with no more than a dozen jobs in construction over a six month perid and two or three permanent maintenance jobs after the installation is completed. Possible impact of electromagnetic interference has been discussed in Section 3.1.4. The installation would likely prove to be a tourist attraction and thus could encourage tourism in this area.

3.2.3.8 Croydon Peak

Croydon Peak is 2,781 feet above sea level. It is located in Carbin Park, but is largely on a privately owned game preserve controlled by the Board of Directors of the Blue Mountain Reservation. The summit of Croydon is barren and would require no clearing for access to the wind. About 1-3/4 miles to the ESE of the summit is a graded and drained road west of the Village of Croydon. 1-3/4 miles to the west of the summit is a graded and drained road running out of the Village of Cornish Flat. The peak is about four (4) miles west of Croydon and 3-1/4 miles east of Cornish Flat. The State Forest Service advised that an all-terrain vehicle could follow trails to the summit. A light power line presently runs to the summit.

Croydon Peak is in Sullivan County which has a population of 30,949. The largest urban center is Claremont City with a population of 14,221. The Town of Croydon had a population of 396 in 1970. No population was shown for the Village of Croydon separate from the township. Textiles and non-electrical machinery are the principle industries of Sullivan County, which has 74 manufacturing establishments of which 26 employ 20 or more persons. Manufacturing provides about 45% of all jobs in Sullivan County. The value of farm produce for this county is $4.3 million, putting the county in the seventh ranked position (out of ten) for agricultural production in New Hampshire (1974).

The installation of a wind energy turbine on Croydon Park will have no adverse effects on the ecology. Effects on the economy will be minimal with construction jobs (about a dozen) contributing to the local economy for about six months and two or three maintenance jobs on a permanent basis. Possible impact of electromagnetic interference has been discussed in Section 3.1.4. The installation could prove to be a tourist attraction and thus could encourage tourism in this area.

3.2.4 Ameliorative Measures

3.2.4.1 Siting

Before discussing ameliorative measures it again should be emphasized that solar and wind energy, two major basic renewable energy sources, are not ecologically harmful. They do not pollute either the air nor the water. They provide a minimum of disturbance of the natural environment and have virtually no adverse impact upon the flora or fauna of the area surrounding their installation. Intrinsically, these are "safe" energy sources. Wind energy could only be abused by careless siting, sloppy construction procedures or excess road building.

Proper siting can avoid areas where large flights of birds normally congregate, avoiding insofar as possible, any destruction of winged wildlife. These areas would be either nesting areas or areas in the normal flight path of migratory species.

Proper siting can also greatly mitigate or totally avoid electromagnetic interference to microwave transmissions, TV transmissions and FAA control transmissions. Other mitigating measures are discussed in the section on electromagnetic interference.

Siting in remote areas also avoids problems of safety, controlled zoning and creating a public nuisance. The optimal siting areas of New Hampshire, areas above 2,500 feet in altitude are generally sufficiently isolated and remote to mitigate most siting problems.

3.2.4.2 Proper Construction

Proper construction dictates that only the barest minimum of land will be cleared to provide space for the installation and an adequate (not necessarily maximum) access to the wind. If short trees, like stunted mountaintop growth, are left standing and low lying brush is planted to replace cleared areas, the soil will be left largely undisturbed; wildlife will retain the cover necessary for its continued existence and run-off pollution will be avoided.

If economically feasible, and IITRI believes that it can be so proved, it is recommended that helicopters be used for both construction and maintenance of wind turbine generator units. If roads must be constructed to mountain summits, they should be primitive, providing access only for all-terrain type vehicles and they must carefully conserve the general water flow regime of the area.

3.2.4.3 Aesthetics

Undoubtedly the first installations will be attractive in their novelty, but it will behoove the engineers and designers to work towards aesthetically pleasing designs for wind turbine generators and especially, their towers. Public acceptance of wind energy may ultimately depend on public appreciation of their beauty rather than their utility.

3.2.5 Alternatives to the Development of Wind Energy

Wind and solar energy and hydroelectric power are the only renewable energy sources at our disposal over any lengthy time frame. Energy shortages involving fossil fuels, especially oil and natural gas, have already beset many sections of our country in the past few years. Since fossil fuels are limited in their extent and are depletable resources, we cannot depend upon them to supply our energy needs indefinitely. Every kilowatt of energy produced by a renewable energy source will help to conserve our present stocks of fossil fuel and uranium.

It will undoubtedly take several decades for the American economy to adjust to using wind and solar energy as major energy sources. Continuing research and development will be needed to improve the efficiency and utilization of these energy sources; however, practical demonstrations of the advantages and economy of renewable energy must begin now to achieve the desired growth over the next decade.

Unfortunately, at this time, there are no viable alternatives to the long term utilization of renewable energy sources. The alternatives to the development of wind energy are to ignore the "free gift" of the wind and place all energy developmental efforts into solar energy, or to ignore renewable energy sources completely and fully exploit the remaining fossil fuel sources available to us while developing atomic energy to its limits, thereby ensuring the eventual complete exhaustion of the conventional energy sources upon which our economy and our way-of-life are based.

4.0 TURBINE PERFORMANCE

One of the constants imposed upon this investigation has been the integration of economical wind energy conversion systems (WECS) as a primary or augmentative energy source in the near future. In order for a turnkey operation to initiate by say 1985, and to supply the order of magnitude of electric power required economically, selection of a suitable system can only come from the large WECS systems currently under advanced development, namely the horizontal axis wind turbine (HAWT) designated MOD by NASA-Lewis Research Center and the vertical axis wind turbines (VAWT) of the Darrieus type pioneered at Sandia Laboratories. Other types of WECS systems are available and have been proposed but either are not sufficiently economical or are primarily in the conceptual or early design phases of development and will not be ready at the present rate of development for large-scale implementation by 1985. For this reason, present efforts have been placed upon utilization of the well-developed Darrieus systems.

This section will present design parameters and operational characteristics of these two types of WECS. A brief discussion of wind characteristics will lead to an analysis of annual turbine output based upon several idealistic wind models currently in use. Results of this analysis, coupled with economic or financial modeling, will make possible the selection process from several chosen possible sites for turbine location.

It is further assumed in this study that units will be purchased "off-the-shelf" and that only minimal engineering will be necessary to integrate the turbine into a utility grid. In essence, the units will be complete with aerodynamic performance rigidly defined so that units will not be altered greatly to maximize output for any particular site condition.

4.1 Wind Turbine Characteristics

When considering a particular application of a wind turbine the single most important and perhaps most reliable performance characteristic as far as the system owner is concerned, is the power output as a function of steady wind speed. Power output depends heavily upon aerodynamic and mechanical performance of the rotor, including blade tip speed, airfoil section, drag, system losses, attack angle, etc. Most of these factors are grouped into a single parameter - the coefficient of performance, C_p - which is defined as the ratio of output power to available wind power. The coefficient of performance is generally not constant for any turbine but rather varies with windspeed. The curve is bell-shaped with a peak value between 0.4 and 0.5 for most turbines available (Fig. 4-1). The design speed is designated as the speed at which C_p is greatest and the turbine will extract the maximum percentage of available energy passing through the swept area of the blades. Note that this does not necessarily mean maximum energy is extracted at this speed, only the maximum percentage.

The most highly developed large scale systems available today are the MOD series horizontal axis turbines. Early designs (MOD-0, MOD-0A, MOD-1) are constructed using open truss towers and as a result are considered quite expensive, exceeding $1000/kW(e) for unit costs. Present design trends have moved toward a flexible tubular tower in the MOD-2, reducing costs considerably through both increase in scale as well as increase in design efficiency.

With this in mind, the investigation will consider only the MOD-2, and the most advanced Darrieus turbine as the most cost-effective and advanced systems for this application.

Output power as a function of hub height wind velocity for the 2500 kW(e) MOD-2 system is shown in Fig. 4-2. Three wind

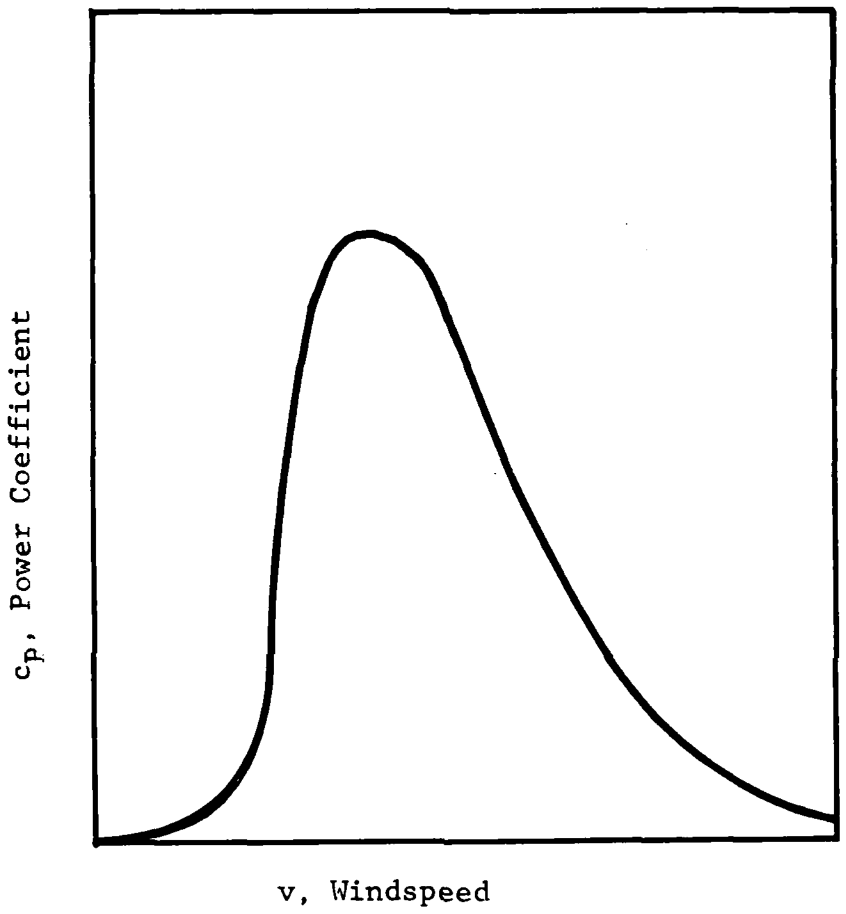


Figure 4.1 Typical power coefficient, c_p, as a function of windspeed.

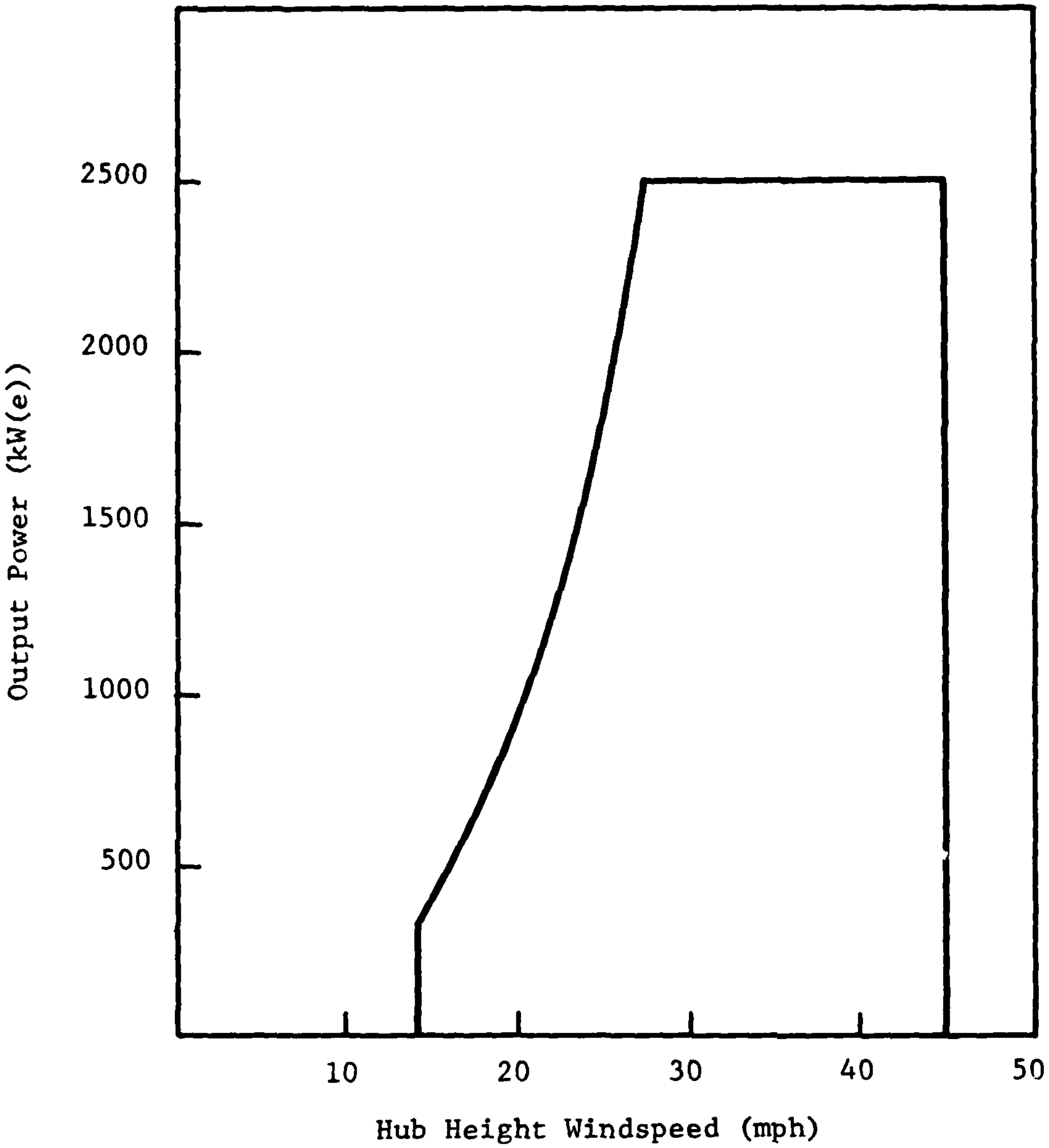


Figure 4.2 Power output of MOD-2 turbine.

velocities are important:

- Lower cut-in velocity at which time power is generated by the turbine and directed to the utility grid
- Rated velocity at which time power output equals rated power
- Upper cutout velocity at which point the rotor is stopped.

The MOD-2 is a regulated turbine in that once rated power is attained, it is maintained constant for higher wind velocities. Control is achieved by aerodynamic means principally blade tip feathering to maintain a constant 17.5 rpm. Once the maximum feathering is achieved, the rotor is stopped to prevent damage to the structure and blades. Ultimate maximum structural survivability is limited to winds up to 125 mph. Hub height for the MOD-2 is 200 feet with a 300 foot rotor diameter.(14)

At the present time, the largest Darrieus system available is a 500 KW(e) unit under development at Alcoa. Its power output is depicted in Fig 4.3. Because of the aerodynamics of vertical axis wind turbines, power or torque does not increase continuously but peaks at a rated power. Rotation and speed is a constant 41 rpm for this power output and the system is termed synchronous. Asynchronous Darrieus systems have been developed so that rotational speed is not constant but depends upon wind speed.(15) There is an advantage to synchronous systems, however. The turbine is self-regulating and does not require blade feathering or other aerodynamic effects to limit torque. Once again, maximum allowable wind speed is 125 mph. Important velocities are summarized in Table 4.1.

4.2 Current Availability of WECS

The current state-of-the-art horizontal axis system, the 2500 kW(e) MOD-2, is an optimized prototype system developed after three previous MOD systems (MOD-0, MOD-OA and MOD-1). The MOD-2

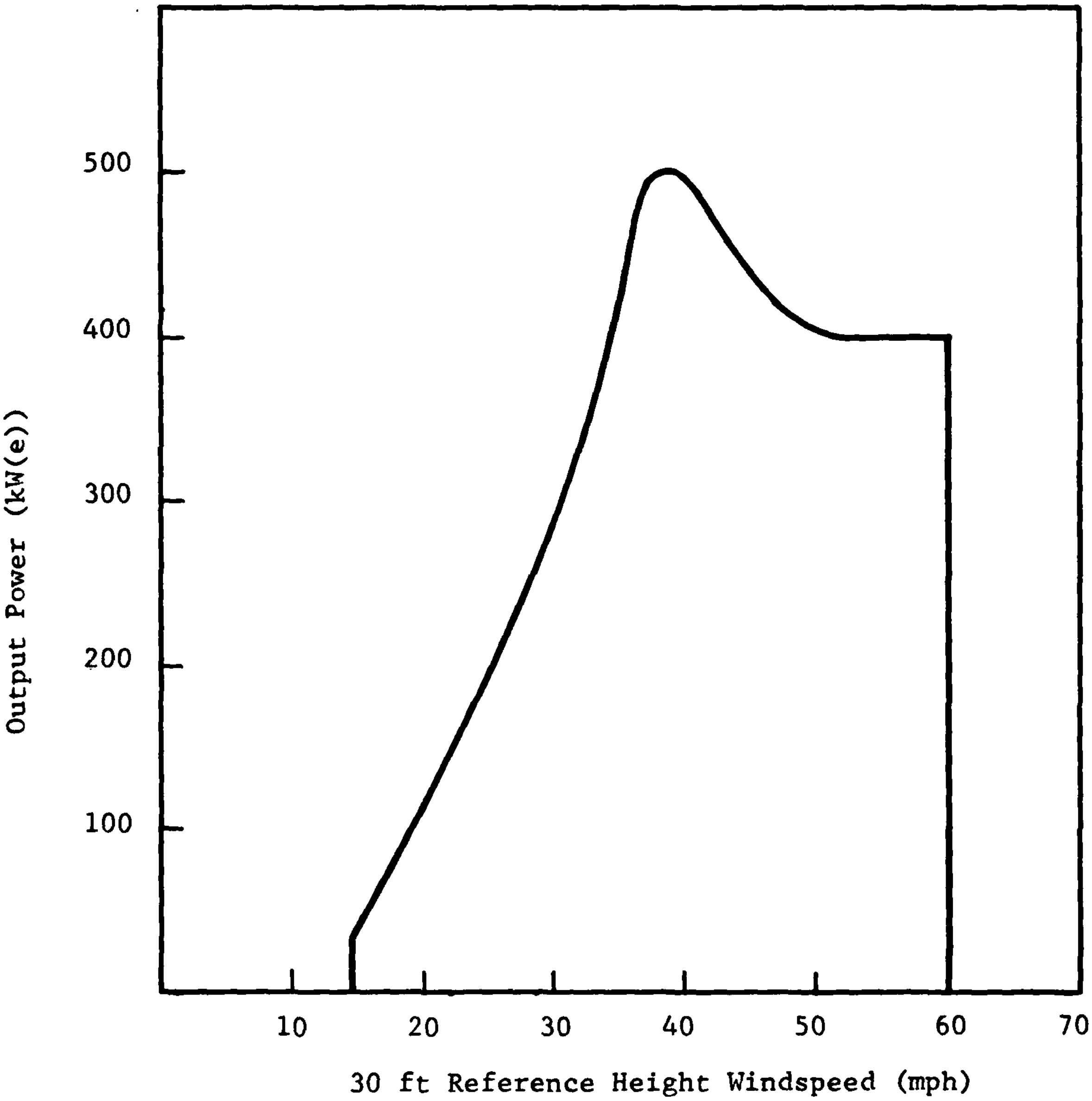


Figure 4.3 Power output of 500 kW(e) Darrieus turbine.

Table 4.1 - Turbine Design Velocities, Standard Atmosphere at Sea Level Velocity (mph)

	Mod-2* (2500 kW)	Darrieus** (500 kW)
Cut-in	14	12
Rated	27.5	35
Cut-out	45	60
Maximum	125	125

*At hub height (200 ft)

**At 30 ft. reference height

has been designed and is presently under construction for testing in 1980. Its one cost is estimated at $4 million (1979 dollars) while the cost of the 100th unit is estimated to be about $1 million. A capital investment cost of $1.72 million(12) (1979 dollars) per unit including installation costs has been assumed for the economic analysis carried out in Section 6. Lead time for orders is estimated to be about 1 year.

The largest Darrieus system available is a 500 kW(e) system developed at Alcoa. It is also scheduled for testing in 1980. As a smaller unit, its one-off cost is estimated at $190,000 or $940,000 for 2500 kW(e) (5 units). Lead time after testing is complete will also be about 1 year.

Maintenance plans, both scheduled and unscheduled, have been developed for each system. Safety considerations both during construction and during operation have also been established. The units are anticipated as off-the-shelf systems and should be available for turnkey operation by 1985.

4.3 Wind Characteristics

For statistical and other methods of analysis of wind powered or wind loaded systems, the characteristics of natural lower atmospheric winds near the earth's surface may be considered as composed of a fluid of a mean velocity increasing with height. Superimposed upon this mean velocity profile are turbulent fluctuations in the direction of streamlines as well as in directions perpendicular to them. The surface wind model is treated as a deep boundary layer with turbulence.

At any particular fixed reference height, the wind speed and direction (collectively referred to as velocity) is not constant but can fluctuate greatly. Measurements of those quantities are generally not instantaneous readings but are rather mean wind speeds averaged over some period of time that can range from 1 second to 1 hour or more. The mean velocities are generally counted and tabulated so that a velocity frequency curve can be drawn. Actual field measurements of wind velocity can be mathematically approximated by several probability density functions, most notably the Weibull and Rayleigh distributions. The latter is a special case of the former.

4.3.1 Wind Speed Probability Density

The Rayleigh distribution for some long-term mean wind speed, $\bar{v}$, is given by

$$P(v) = \frac{v\Pi}{2\bar{v}^2} e^{\frac{-v^2\Pi}{4\bar{v}^2}}$$

where $P(v)$ = probability or percent time wind is of velocity v
v = windspeed
$\bar{v}$ = long term mean windspeed

For any particular mean windspeed a Rayleigh distribution can be developed. A normalized Rayleigh distribution is depicted in Fig 4.4. Once an actual annual velocity frequency distribution is determined, an ideal mathematical model can be adjusted to fit the experimental data.

Just as the Rayleigh distribution is used as a probabilistic wind frequency model, the Weibull distribution is also used. Its general form is (17)

$$P(v) = \frac{k[\Gamma(1+\frac{1}{K})]^K v^{K-1}}{\bar{v}^K} \; e^{-[\Gamma(1+\frac{1}{K})\frac{v}{\bar{v}}]}$$

where Γ = Gamma function
k = constant = 1.09 to 0.0894 $\bar{v}$ (in mph)

Note that if k equals 2, the distribution reduces to Rayleigh. The Weibull is a much more general model with velocity dependent parameters. Available wind data from several sites show a slightly greater trend toward following the Weibull distribution and it will be used most frequently in this study.

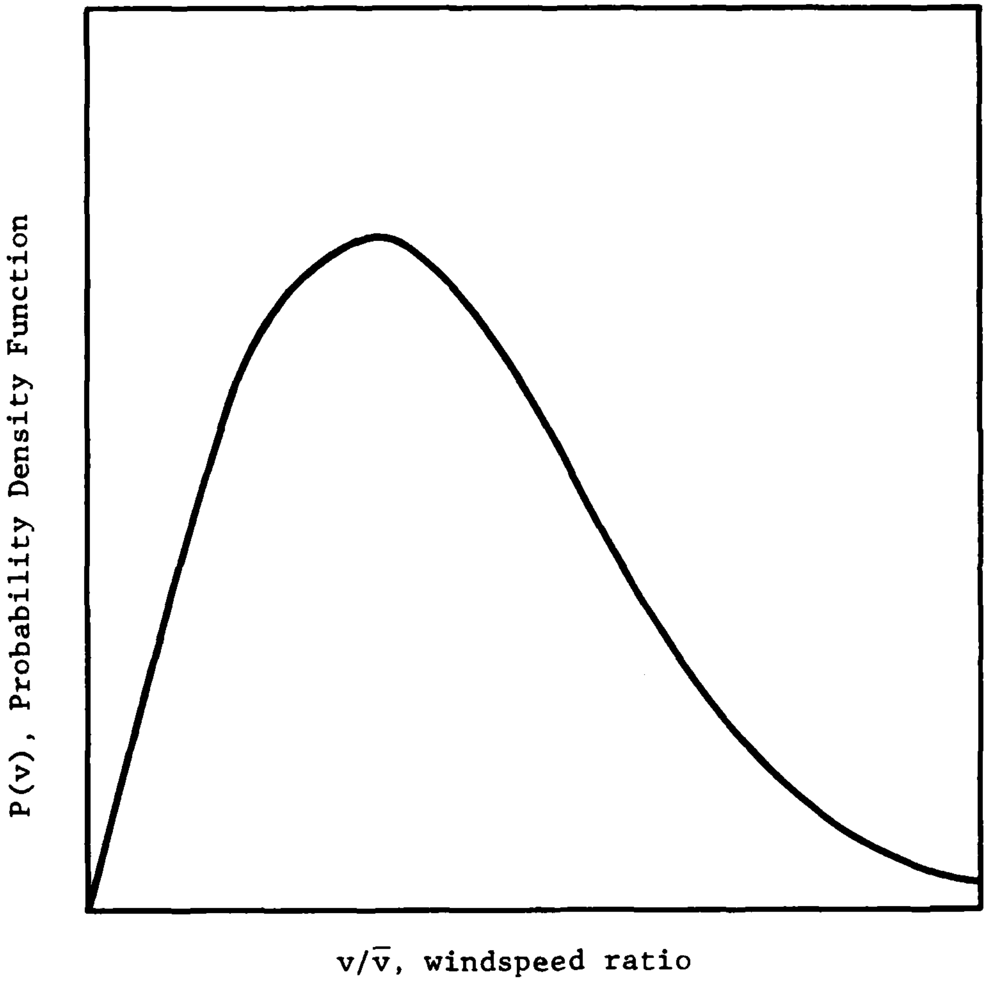


Figure 4.4 Normalized Rayleigh distribution.

4.3.2 Wind Shear

Obstructions on the earth's surface act to hinder and alter flow in the immediate vicinity of the surface. For this reason a wind velocity is not constant with height above ground but rather follows an empirical relation(17)

$$v = v_r(h/h_r)^{\alpha}$$

where v = velocity at height h

v_r = velocity at reference height h_r

α = wind shear exponent

$= \alpha_o(1-\log v_r/\log v_o)$

$\alpha_o = (Z_o/h_r)$

Z_o = surface roughness length ≈0.2 ft

v_o = 150 mph

Because turbine characteristics are often given for hub height velocities and windspeeds are measured at some reference height (usually 30 ft) and these two heights can differ greatly (hub height for the MOD-2 is 200 ft.), a means to convert a velocity at any given height to any other is necessary.

Wind shear is developed due to this distribution in velocity, and design loads upon structures must realize this fact. In general, all wind turbines are designed to accept wind shear both structurally and from performance standpoints. Performance characteristics usually reflect an average velocity through the blade-swept area and hub height velocity is accepted as standard. In the case of vertical axis machines with no hub height, performance velocities are given at reference height of 30 ft or at mean rotor height.

4.3.3 Effect of Elevation and Temperature

The final variable effecting turbine performance is change in air density attributed to elevation and temperature variations.

All likely candidate locations for wind turbine siting in the study area range in elevation between 2700 and 3300 feet above sea level with similar seasonal variations in temperature.

The effect of temperature starts with the equations of state for ideal gases:

$$\rho = \frac{P}{RT}$$

where P = absolute barometric pressure
ρ = mass density
R = gas constant
T = absolute temperature

Since R is constant, two states can be linked in the following relation

$$\frac{P}{\rho T} = \frac{P_o}{\rho_o T_o}$$

where subscript o denotes sea level standard condition. Thus

$$\frac{\rho}{\rho_o} = \frac{P}{P_o} \frac{T_o}{T}$$

and given a P/P_o for any change in geometric altitude and the corresponding T_o/T at that site, a density ratio can be derived. Assuming a barometric pressure change is independent of temperature, then from the U.S. Standard Atmosphere (Table 4.2) temperature corrections for sites can be made. Resulting density ratios are presented in Table 4.3. The values for mean annual temperature at each site were obtained by interpolation between two known cases of Mts. Washington and Concord. The P/P_o ratio is obtained by interpolating the Standard Atmosphere for the desired elevation.

TABLE 4.2 U.S. Standard Atmosphere

Geometric Altitude (ft)	Temperature (°R)	P/P_o*	ρ/ρ_o**
0	519.0	1.000	1.000
500	517.2	0.982	0.985
1000	515.4	0.964	0.971
2000	511.9	0.929	0.943
3000	508.3	0.896	0.915
4000	504.7	0.864	0.888
5000	501.2	0.832	0.862
6000	497.6	0.801	0.836
7000	494.0	0.772	0.811

*$P_o = 14.696$ psi_a

**$\rho_o = 1.225$ $Kg/m^3 = 0.002378$ $slug/ft^3$

TABLE 4.3 Site Data

Site	Elev. (ft.)	Mean Yearly Temp. (°F)	P/P_o	ρ/ρ_o *	Mean Annual Horizontal Wind Speed (mph)
Mt. Washington	6200	30.3	0.795	0.842	34.2
Mt. Concord	104	44.5	0.995	1.024	-
Mt. Croydon	2781	38.0	0.903	0.941	16
Mt. Kearsarge	2937	37.9	0.898	0.936	17
Mt. Randolph	3070	37.6	0.894	0.932	18
Bald Cap	3090	37.5	0.893	0.932	18
Mt. Cardigan	3121	37.4	0.892	0.931	19
Mt. Wolf	3200	37.3	0.890	0.929	19
N Moat Mt.	3201	37.3	0.890	0.929	19
Mt. Crescent	3230	37.2	0.889	0.928	19

*ρ_o = 1.225 kg/m^3 = 0.002378 slug/ft^3

The effect of air density on turbine performance is twofold. Cut-out velocity is governed by wind pressure

$$P = \frac{1}{2} \rho v^2$$

so that for similar maximum allowable pressures,

$$\rho v^2 = \rho_o v_o^2$$

where subscript o denotes sea level standard conditions.

Thus

$$v = v_o \sqrt{\rho/\rho_o}$$

for cut-out velocity.

Cut-in and rated velocities depend on available wind energy density which is proportional to the cube of velocity so that

$$v = v_o \sqrt[3]{\rho/\rho_o}$$

for rated and cut-in velocity. Since total available wind energy,

$$W = 1/2 \, \rho v^3 A$$

where ρ = density
v = velocity
A = swept area of turbine blades

is proportional to both air density and the cube of the velocity, in order to achieve the same power at any elevation (different density), the following relation must hold:

$$\rho_o v_o^3 = \rho v^3$$

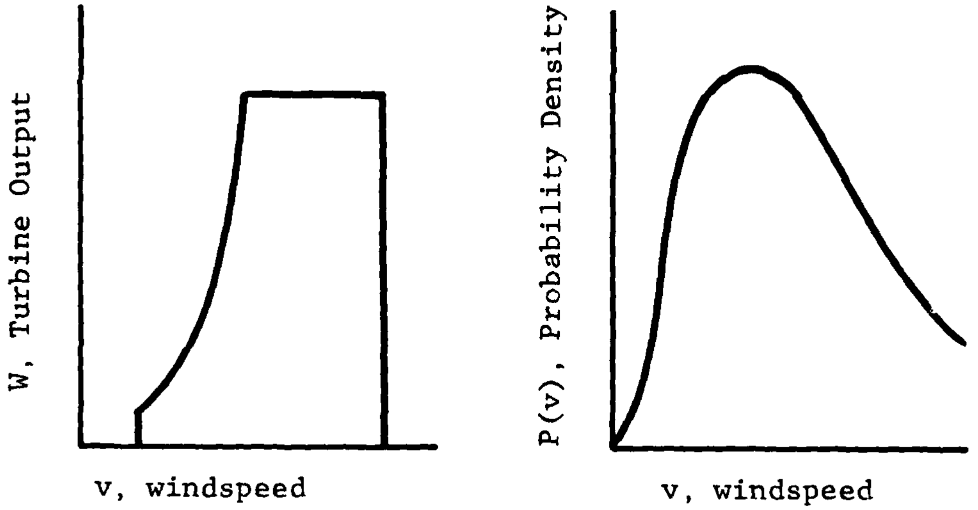
4.4 Annual Energy Output

After both wind and turbine models have been formulated, the total predicted annual turbine output can be calculated.(16) For a specific windspeed duration curve, computing the output power at that particular windspeed and integrating over the appropriate time duration for that windspeed will yield annual energy output. A family of wind duration curves for various mean annual velocities will yeild a relationship between annual output and mean velocity. The process is illustrated in Figure 4.5.

Results of the analysis are presented in Figs. 4.6-4.8. Figure 4.6 contains data for the MOD-2 turbine. Utilization factors, the ratio of total average annual power to rated power [in this case 2500 kW(e)] is plotted against mean annual windspeed for both Rayleigh and Weibull windspeed distributions at 30 ft reference height at sea level on a standard day. It is readily apparent that the Rayleigh distribution is much more conservative than the Weibull distribution. NASA uses the latter in assessing turbine performance and presently available site wind data indicate that a Weibull distribution may be more indicative of actual performance.

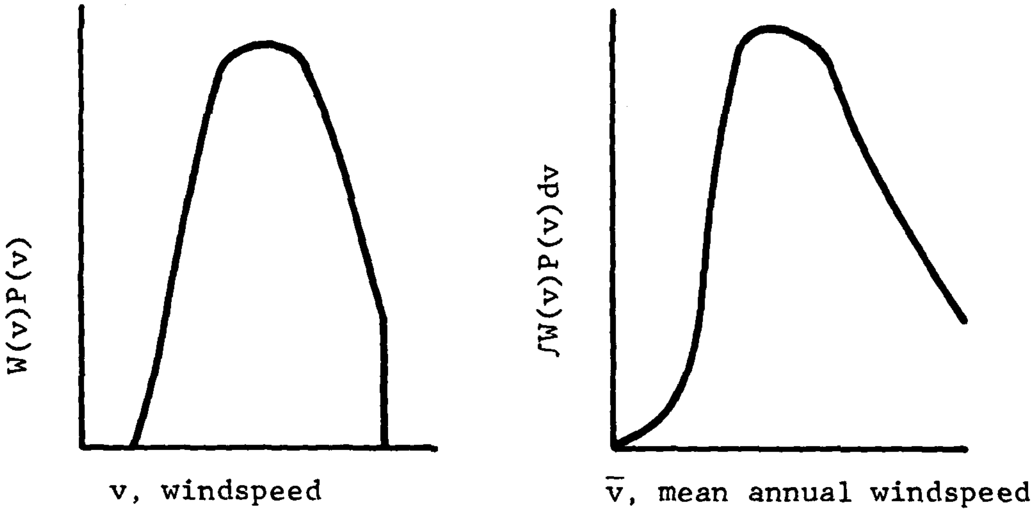
A similar curve for the 500 kW(e) Darrieus is presented in Fig 4.7. Notice that because of its higher rated speed the curve is shifted to the right indicating that for windspeeds under about 30 mph this particular Darrieus has lower utilization factors.

The effect of elevation and temperature on the utilization function is shown in Fig 4.8 for the MOD-2 (Weibull distirbution) at sea level and at 3500 feet. Lower air density increases the turbine cut-in, rated, and cut-out velocities and tends to shift the curve to the right so that for mean annual windspeeds up to about 30 mph (at a reference height of 30 feet) the utilization factors are lower at greater altitude,



a) Turbine output

b) Annual windspeed density @ $\bar{v}$



c) Convolution of output and wind probability @ $\bar{v}$

d) Output power

Figure 4.5 Development of power output versus mean annual windspeed (utilization factor)

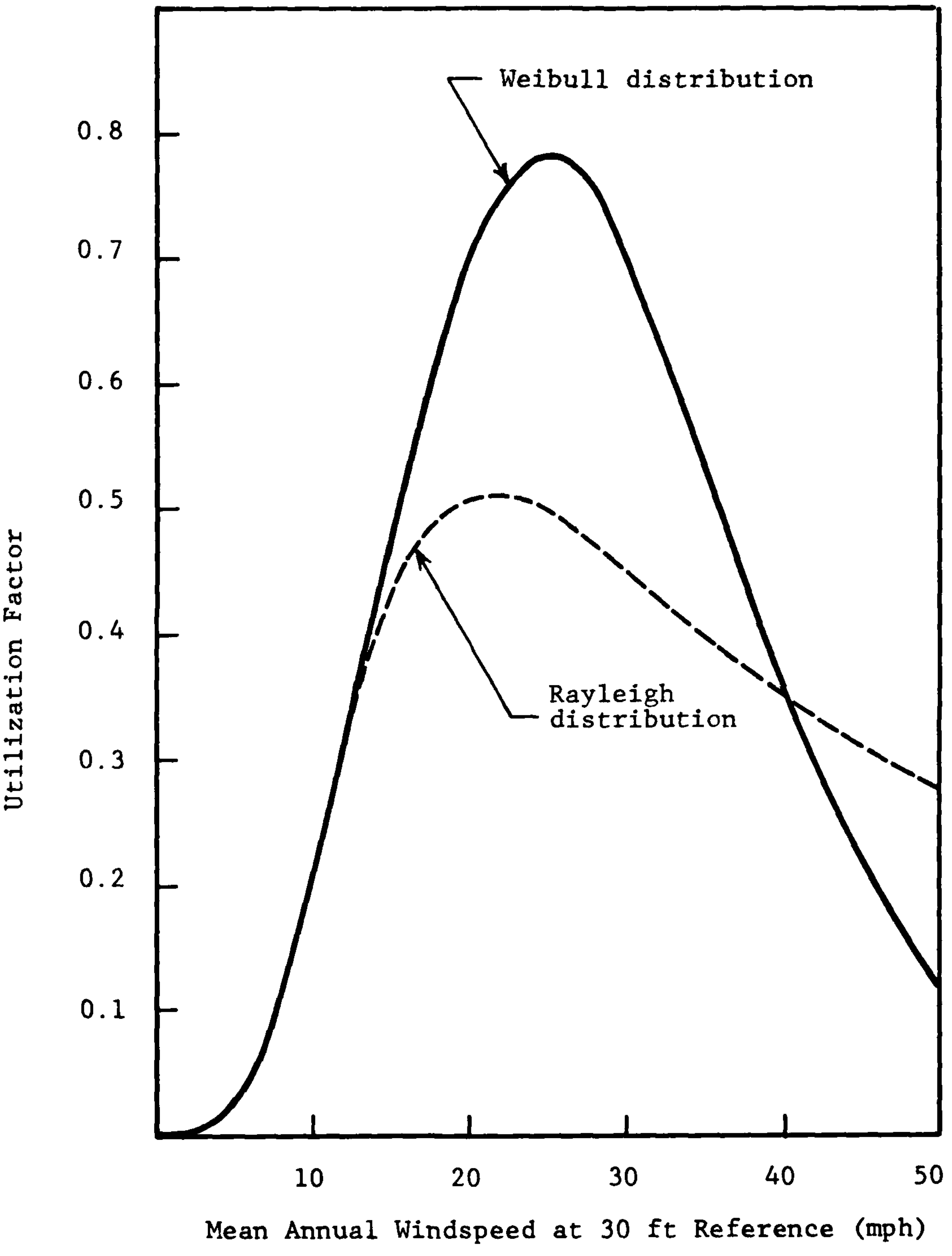


Figure 4.6 MOD-2 utilization factors.

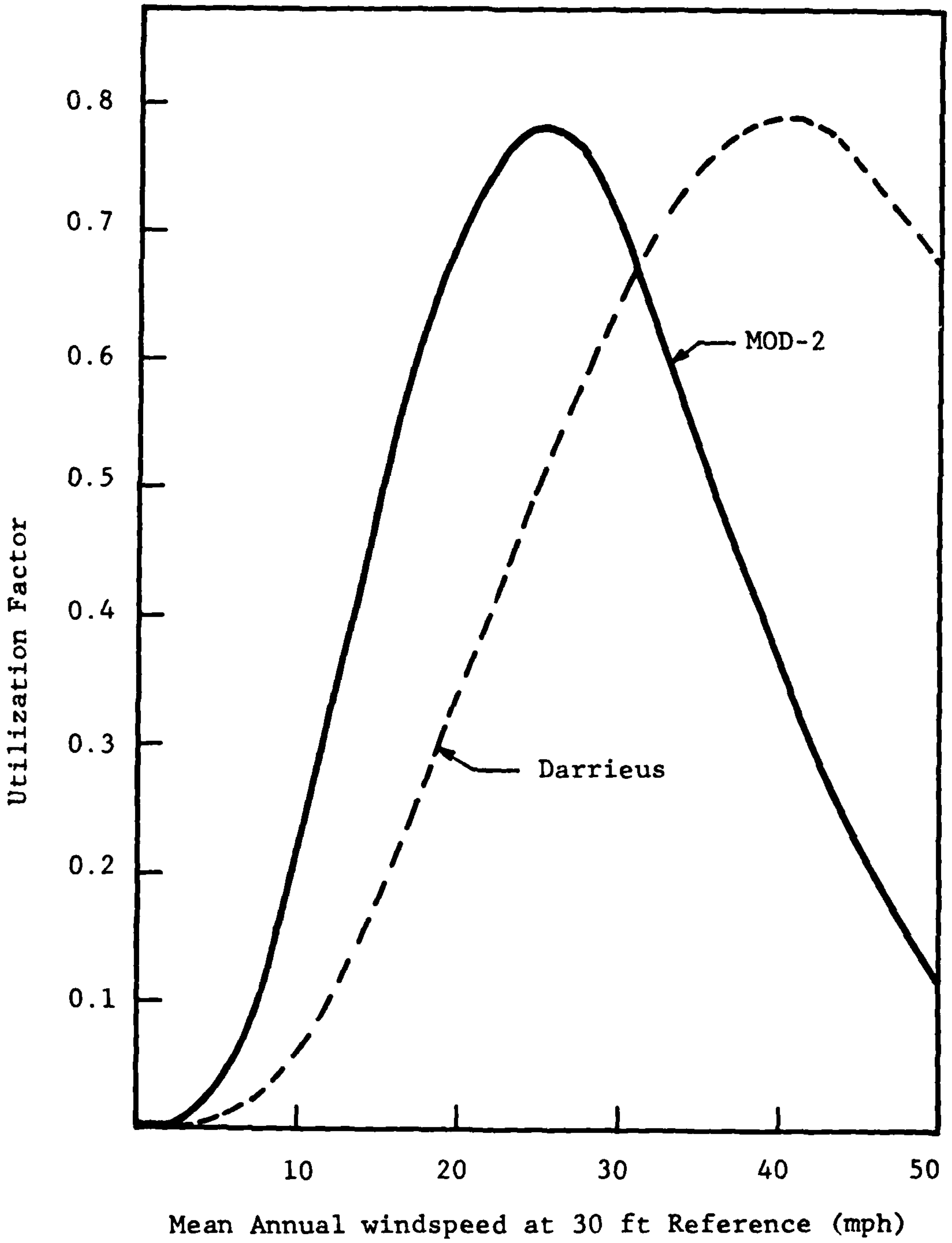


Figure 4.7 Utilization factors for MOD-2 and Darrieus systems at sea level.

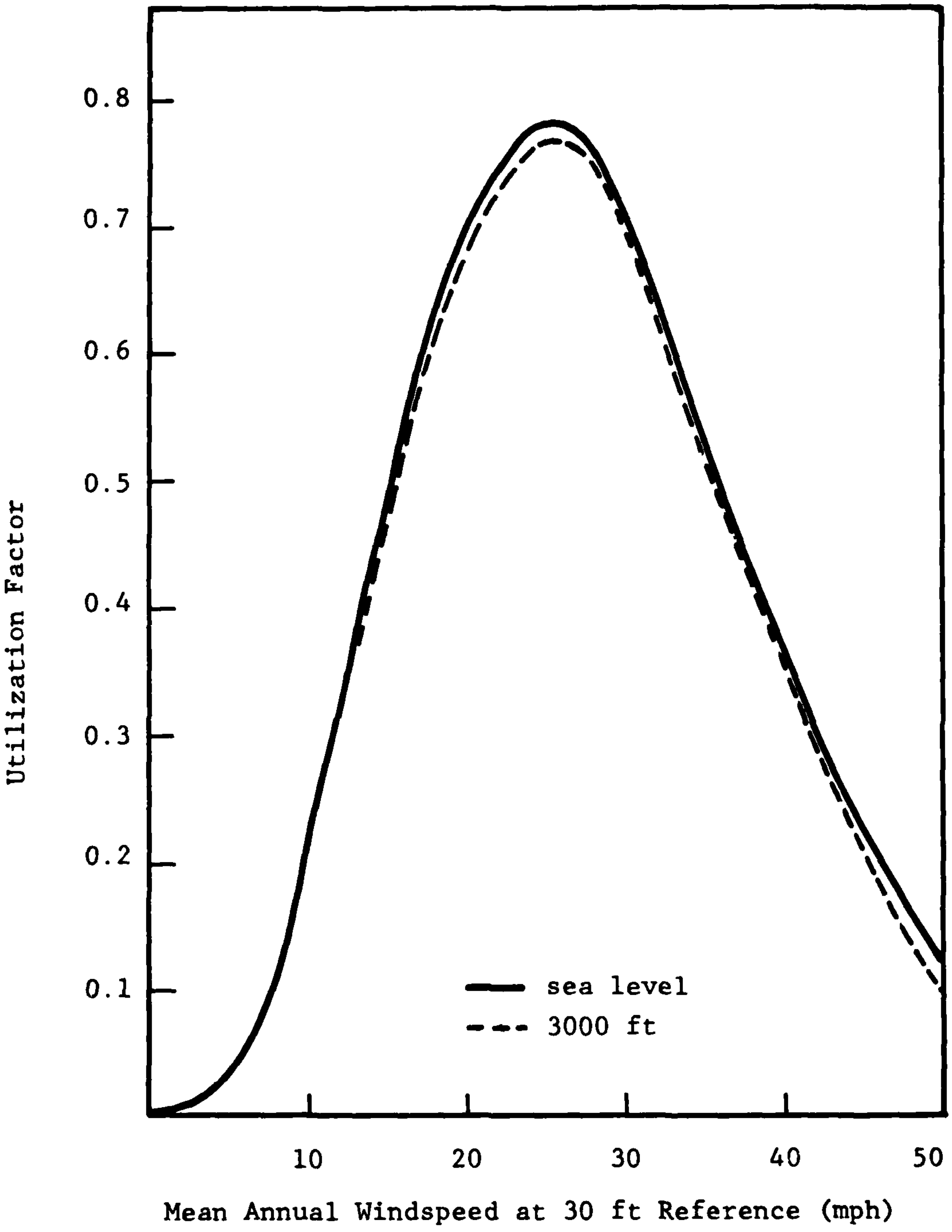


Figure 4.8 Effect of elevation on MOD-2 utilization factors.

The utilization factors derived from this analysis are used to predict the total annual energy for a particular turbine as follows:

$$T = 8766\ U_f\ W_r$$

where T = Total energy output (kWh(e))
U = Utilization factor
W = Rated power of turbine
= 2500 kW(e) for
= 500 kW(e) for

The utilization factors derived have been based upon a 100% availability for the turbine throughout the year. This availability does not fall under a no wind category, but reflects reliability and maintenance. Actual figures of availability of 90% are realistic and are often used.

4.5 Selection of Turbine

While the foregoing analysis indicates a higher utilization factor for the MOD-2 turbine in the range of mean windspeeds of interest to this study (20-30 mph), it may not be the economic choice because of higher cost and other factors. Only after a complete economic analysis (including output power, initial cost, operation and maintenance costs, salvage value, insurance rates, interest rates, and escalation rates) can a sound decision be made concerning the selection of the best overall system.

5.0 POWER REQUIREMENT CHARACTERISTICS

A major objective of the present study is to determine the technical feasibility, economic considerations and social and environmental aspects of generating electric power in New Hampshire using wind turbine generators. A possible user of this power is the Portsmouth Naval Shipyard, Portsmouth, New Hampshire.

The shipyard performs the function of overhaul, conversion and repair of nuclear submarines. Among the important tasks performed at the shipyard is the preparation of highly purified water suitable for use in nuclear submarines. There are also many other activities associated with operation of the base that require steam.

5.1 Steam Supply

Steam for the shipyard is presently obtained from a power plant that generates steam in three boilers operating in parallel at 600 psig and 700F. Most of the steam is fed to two 3500 kW Westinghouse automatic extraction turbines having extraction points at 195 psig and 5 psig with exhaust steam going to condensers. The steam from the extraction points is required for various operations in the shipyard and for heating buildings and shops during the winter heating season. When steam requirements exceed those available from the extraction points, the extra steam is obtained directly from the boilers by bypassing the turbine-generators through a pressure reducing station.

5.2 Electric Power Supply

Electric power is obtained from two sources as follows:

- Power generated by the two 3500 kW(e) Westinghouse automatic extraction turbine-generators.
- Power purchased from Public Service Company of New Hampshire.

The two Westinghouse turbine-generators have a combined design capacity of 8750 kVA at 13200 volts, which represents a power output of 7000 kW(e) at 80% power factor. Should either of the two turbine generators be forced out of service, only one would remain in operation. The plant can therefore be considered to have a firm capacity of only 4375 kVA or 3500 kW(e).

To augment this capacity, a new 7500 kW(e) automatic extraction turbine generator is being installed that will increase the design capacity of the plant to 18125 kVA or 14500 kW(e) at 80% power factor. This will still represent a future firm capacity of only 8750 kVA, since the largest unit (9375 kVA) may at times have to be out of service for overhaul or repair.

In addition to the self generated power discussed above, the shipyard purchases power from Public Service of New Hampshire. This power is furnished to the base through two 15 kV submerged cable ties each rated at 300 amps. Under normal conditions a maximum of 8000 kVA can be purchased from the utility, but under prearranged emergency conditions, up to 10,000 kVA can be purchased, if available. However, since it is inadvisable to overload the cables, purchased power normally ranges from about 5,000 to 6,000 kW(e).

A summary of the electric power capacity at the shipyard at present and after installation of a new 7,500 kW(e) automatic extraction turbine generator scheduled for 1980 is presented in Table 5.1. The table shows that at present total capacity of the system is 13,400 kW(e), but that firm capacity is only 9,900. With the installation of the new turbine-generator, however, total capacity of the system will be increased to 20,900 kW(e), well in excess of the shipyard's projected power requirements for 1986.

Table 5-1. Summary of Present and Future Electric Power Supply at Portsmouth Naval Shipyard

	Present Time (1979)		After Installation of New Turbine Generator (1980)	
	kVA	kW(e)*	kVA	kW(e)*
Turbine-Generator No. 1	4,375	3,500	4,375	3,500
Turbine-Generator No. 2	4,375	3,500	4,375	3,500
New Turbine-Generator			9,375	7,500
Normal Peak Power Generation	8,750	7,000	18,125	14,500
Firm Purchased Power	8,000	6,400	8,000	6,400
Total Normal Peak Capacity	16,750	13,400	26,125	20,900
Less Largest Generator	4,375	3,500	9,375	7,500
Total Firm Capacity	12,375	9,900	16,750	13,400

*Assuming a power factor of 80%.

5.3 Cost of Electric Power

Table 5.2 shows the quantities and costs of both self-generated and purchased power used by the Portsmouth Naval Shipyard during the year 1978. The quantities are on a monthly basis and the costs are in \$/kWh(e) for each month of the year.

From the table it can be seen that the amount of power purchased varied from a low of 1,346,000 kWh(e) in May to a high of 2,520,000 kW(e) in October but that the cost was almost uniform, varying from a low of \$0.03110/kWh(e) in July to a high of \$0.03830/kWh(e) in September. The weighted average cost of purchased power for the year was \$0.0338/kWh(e).

The reason for the variation in cost per kWh(e) from month to month is that the price of electricity varies with amount of electricity used as well as with maximum kVa demand. Since the year 1978 may be taken as typical, and since the unit cost of purchased power does not vary greatly from month to month, the cost of purchased power may be taken as \$0.034/kW(e) in 1978 dollars.

The monthly quantities and cost of self-generated power as computed by the shipyard taking into account fuel costs and other costs attributable to the generation of power in the shipyard power plant are also tabulated in Table 5.2. These costs are seen to be quite variable from month to month and are larger during the summer, spring and fall months than during the winter. One reason for this is that some of the cost of fuel for generating steam can be charged to the heating system during the winter months, thereby reducing the fraction chargeable to the production of electricity. In any case, costs for 1978 are seen to vary from a low of \$0.03846/kWh(e) in January to a high of \$0.06610/kWh(e) in October. It should be noted that the lowest cost of self-generation is greater by a

Table 5-2. Monthly Cost of Electric Power at Portsmouth Naval Shipyard for 1978.

Month	Net Plant Production MWh(e)	Cost of Plant Produced Power $/kWh(e)	Purchased Power MWh(e)	Cost of Purchased Power $/kWh(e)	Cost of Power Produced Plus Purchased $/kWh(e)
January	3,921	0.03846	1,958	0.03130	0.0361
February	3,803	0.04298	2,045	0.03577	0.0405
March	3,885	0.05292	2,138	0.03200	0.0445
April	3,466	0.05135	1,714	0.03830	0.0470
May	3,639	0.05777	1,346	0.03430	0.0514
June	3,328	0.05417	1,462	0.03370	0.0479
July	2,338	0.06571	2,246	0.03110	0.0488
August	2,596	0.06472	2,066	0.03190	0.0502
September	2,884	0.06298	1,800	0.03580	0.0525
October	2,080	0.06610	2,520	0.0344	0.0487
November	2,336	0.05334	2,390	0.0334	0.0433
December	3,157	0.03849	2,182	0.0348	0.0370
Full Year	37,433	0.05267	23,867	0.0338	0.0453

very small amount ($0.00016/kWh(e)) than the most expensive purchased power. More importantly, the average cost of self-generated power of $0.05267/kWh(e) is 55.8% greater than the $0.0338/kWh(e) average cost of purchased power.

This leads to the question of why the shipyard should generate power at all since it would apparently be a great deal cheaper to purchase all electric power than to generate a portion of it as is done at present. The answer is that the shipyard needs a large amount of steam year round to carry out its operations and that it would probably be more expensive to generate steam solely for the purpose, than it is to co-generate as at present. Only a very careful economic analysis taking into account the rapidly escallating cost of fuel and other pertinent factors could determine just how much power should be purchased and how much self generated. A study carried out by Pope, Evans, and Robbins in 1977 indicates that the minimum total cost of electric power tends to occur when the amount of electric power generated by the plant is about equal to that purchased, and that the total cost per kW(e) increases rapidly as more power is self-generated. This is especially pronounced as the cost of fuel increases.

Important ingredients in determining the true cost of self-generated power are the proper inclusion of additional costs besides fuel, and giving proper credit for energy extracted from the bleedpoints and used for other purposes. Included in the additional costs are the operational and maintenance costs other than that of fuel, and costs associated with the capital investiment in plant and equipment that can be allocated to power generation. It is assumed that all these have been properly taken into account in computing the costs of self-generated power.

From the figures in Table 5.2 it is clear that once the requirements for steam have been satisfied and the corresponding amount of co-generated power produced, it is cheaper to purchase as much of the remaining power requirements as possible. In some instances this may be limited by the capacity of the submerged cables, or on the ability of Public Service Company of New Hampshire to furnish all that is desired.

Since our study of wind characteristics of New Hampshire indicates that the Portsmouth Naval Shipyard is not a satisfactory site for a wind energy conversion system, it follows that if such a system were to be built, it would have to be on some site where the electricity produced can be fed into the lines of the Public Service Company of New Hampshire, if the shipyard is to be supplied from this source. This means that the Naval Shipyard would experience no direct benefit since it would continue to operate in exactly the same manner as at present, dividing its needs between self-produced and purchased power at the most economic value. However, it would be contributing to saving of fuel oil since the power generated by the wind-generator could take the place of what would otherwise be generated by oil. This would be of indirect benefit not only to the shipyard but to the state of New Hampshire as well as the nation. This being the case, the question to be answered is whether or not it is economically feasible to generate power with a wind-generator system at a site close enough to a Public Service Company of New Hampshire line to be attractive. This will be discussed in the next section.

6.0 ECONOMIC ANALYSIS

This section considers the economics of wind-turbine generators at a number of sites and for three ownership options: public (i.e., a governmental tax-exempt body), utility (investor owned) and private (nonutility). The base case considered was based on 2.5 MW(e) of rated capacity: one 2.5-MW(e) MOD-2 machine or five 0.5-MW(e) Darrieus machines. Two methods of analysis were applied depending on the ownership: Levelized Total Cost (\$/kWh(e)) and Rate of Return on Investment (after taxes). Certain parameters were varied for a selected site to reflect the effects of size of installation (i.e., 5 MW(e)), lack of capacity credit (operation in fuel-saver mode), and escalation of certain costs relative to general inflation.

6.1 Site Selection

Based on the analysis of wind characteristics and proximity to existing transmission lines, seven sites were selected (Table 6.1). The sites are distinguished by their average wind speeds, which determines the utilization factor, and by their distance from the particular transmission line (Fig. 3.88).

It became evident early in the study that the Portsmouth Navy Yard itself was not a viable site due to the low average wind speed.

6.2 Ownership Options

A critical factor in economic analysis is definition of to whom the economic benefit or penalty accrues. Had the Portsmouth Navy Yard been a viable site, there would have been considerable advantage to the Navy in owning and operating a wind-turbine generator in order to reduce oil consumption, reduce costs, provide a secure power source, etc. However, it would appear that a remote site could be justified only on the basis of using existing utility transmission lines, owing

Table 6.1. Selected Sites for Economic Analysis

Site	No.	Average Wind Speed (mph)	Distance to Line (mi)	Line Voltage (kVa)
North Moat Mtn.	6	19	3	34.5
Mt. Crescent	31	19	2	34.5
Mt. Randolph	33	18	1	34.5
Bald Cap	35	18	2	34.5
Mt. Wolf	42	19	1	34.5
Mt. Kearsarge	59	17	2	115
Mt. Croydon	60	19	4	115

to their high cost per mile. These lines could be employed under the terms of the New Hampshire Limited Energy Producers Act wherein power is purchased by the utility at $0.04-0.045/kWh(e), as discussed later. The Navy could then repurchase the power under its current rate structure.

Reflection indicates that operation of the wind-turbine generator would be independent of any purchase within this scenario. The question could be asked: "Why should the Navy generate power for the grid?" No advantage would be gained in terms of security, and power could be purchased from the existing system if it is more economic to do so. Nevertheless, wind power may be beneficial to the State of New Hampshire and may lead to a more stable and economic environment which Portsmouth Navy Yard could share.

As a consequence of these considerations, alternate ownership options were assumed:

public (tax exempt)
utility (taxable)
private (taxable)

The public owner in principle could be the Navy. However, it may be desirable to consider local municipal electric utilities or other tax-exempt bodies which would operate the system essentially for their own use. Nevertheless, we assume that the existing transmission lines would be used and that power would be sold to the utility and purchased back under the current rate structure. In the case of public ownership, the levelized total cost of electricity ($/kWh(e)) is of special interest both in relation to the price at which it can be sold to the utility and in relation to present generation or purchase costs. However, we shall only compare with the price at which it can be sold to the utility because the generation or purchase costs are independent of wind-power considerations.

The utility ownership might be justified on the basis of a lower cost of production compared with present methods. The Electric Power Research Institute (EPRI, 1978)(18) recommends a simplified version of the levelized total cost method in order to evaluate alternate energy sources in terms of cost in \$/kWh(e).

Private ownership, and to an extent utility ownership, might be justified economically on the basis of the rate of return on investment after taxes being greater than a minimum acceptable value. For example, a recent study indicated that 50 percent of U.S. industries will invest if the rate of return after taxes is 22 percent or more. Conversely, the same fraction of electric utilities would require only 13 percent or more rate of return after taxes (Thermo Electron Corp., 1976).(19)

In order to provide a means of comparison of ownership options, the methods of economic analysis were applied as follows:

Levelized Total Cost (\$/kWh(e))
    Public Ownership
    Utility Ownership

Rate of Return on Investment (after taxes)
    Utility Ownership
    Private Ownership

It should be noted, however, that the criteria for an acceptable investment will also depend on the owner. Further, the values of parameters used in the present study are only estimates indicative of general trends. If additional study is pursued, a more detailed economic analysis should be employed with more carefully defined parameters.

6.3 Methods of Economic Analysis

Both methods utilized here are based on dollars of fixed purchasing power. Because most of the costs associated with power at the Portsmouth Navy Yard were available for 1978, dollars for 1978 were selected as the base line. The following cost indices were assumed to relate costs defined for other years:

1979	1.10
1978	1.00
1977	0.92
1976	0.85

based on recent trends reflected in the Engineering News Record. An escalation of certain costs relative to general inflation was also considered. This will be discussed later.

6.3.1 Levelized Total Cost

The levelized total cost method refers all costs to an annual basis. By knowing the annual energy production, the levelized cost in \$/kWh(e) may be determined. This cost for the wind-turbine system may be compared with alternate costs of production by the utility owner and with the value of the electricity as sold to the utility by the public owner.

The levelized total cost method used here employs a fixed charge rate for cost of capital investment in the manner normally applied by electric utilities. The fixed charge rate includes interest, depreciation, insurance, all taxes, dividends, etc. The value of input parameters are deferred until both methods are discussed since a number of them are shared in common with the rate of return on investment method.

The levelized annual cost A_C is

$$\bar{A}_C = f\,P_o + A_o P_A(e_o,i,n)A_p(i,n) - L[A_p(i,n) - i] \qquad (6.1)$$

where

$\bar{A}_C$ = levelized annual cost of electricity
f = fixed charge rate

P_o = initial capital investment

A_o = initial annual operating cost

L = salvage value of system

i = present-worth interest rate

n = life of system

e_o = escalation rate of operating expense

and where the present worth of a series of annual payments of unity escalated by an annual compound rate e is

$$P_A(e,i,n) = \sum_{j=1}^{n} \left[\frac{1+e^j}{1+i}\right] \qquad (6.2)$$

$$= \frac{1 - \left[\frac{1+i}{1+e}\right]^{-n}}{\left[\frac{1+i}{1+e}\right] - 1}$$

For the case of e=o, P_A is the present worth of an annuity of one. The present-worth factor determined by Eq. (6.2) is levelized in Eq. (6.3) by using the (uniform) annuity for a present worth of one

$$A_p(i,n) = \frac{i}{1 - (1+i)^{-n}} \qquad (6.3)$$

In terms of \$/kWh(e), the levelized total cost is

$$\bar{A}_C' = \bar{A}_C/(a\ WUN) \qquad (6.4)$$

where

$\bar{A}_C$ = levelized cost of electricity (\$/kWh(e))

W = rated power of wind-turbine system

U = annual average utilization factor

N = 8766 hr/yr

a = availability

In the present study, escalation of operating expenses was neglected. Similarly, salvage value beyond termination costs was neglected. In this case

$$\bar{A}_C = f\ P_o + A_o \tag{6.5}$$

In a more detailed study, the more general formula may be employed.

The value of electricity (alternate cost to utility or price received by public or private owner) is defined as A'_E (\$/kWh(e)). While operating costs may indeed remain constant in terms of purchasing power, electricity may escalate in value due to rising fuel costs. Using the aforementioned functions, the levelized value of electricity based on the present value A'_E is

$$\bar{A}'_E = A'_E\ P_A(e_E, i, n) A_p(i, n) \tag{6.6}$$

where

$\bar{A}'_E$ = levelized value or alternate cost of electricity (\$/kWh(e))

A'_E = present value or alternate cost (\$/kWh(e))

e_E = annual compound escalation rate of electricity

6.3.2 Rate of Return on Investment

Here all cash flows after taxes, adjusted for tax credits and deductions, are brought to present worth assuming an interest rate i. We assume 100 percent equity financing. Thus, for costs

$$\begin{aligned} P_C = {} & (1-t_{TC})P_o + (1-t)\ [P_o\ I\ P_A(0,i,n) + \\ & A_o\ P_A\ (e_o, i, n)] - \frac{L}{(1+i)^n} - \\ & t\ d\ P_o\ P_A(0,i,n) \end{aligned} \tag{6.7}$$

where

P_C = present worth of cost of wind energy after taxes

t_{TC} = investment tax credit

t = tax rate

I = insurance rate

d = annual depreciation rate for tax purposes

Similarly, the alternate cost or value of electricity after taxes is

$$P_E = (1-t)\ A_E\ P_A\ (e_E, i, n) \tag{6.8}$$

where

$$A_E = A'_E\ aWUN \tag{6.9}$$

If we regard $P_C = P_C\ (i)$ and $P_E = P_E(i)$, then the rate of return on investment is the root $i=r$ such that

$$P_C(r) - P_E(r) = 0 \tag{6.10}$$

where

r = rate of return on investment after taxes

It is interesting to note that the levelized total cost of electricity equals the levelized total alternate cost or value of electricity when a fixed charge rate based on $i=r$ is employed. However, we have made no further attempt to actually correlate the two methods of analysis with each other.

6.4 Economic Parameters

The economic parameters for determining cost may be classified as general, site-related machine-related and ownership related, although there is some interrelationship as noted below.

The assumed general parameters are given in Table 6.2. No net salvage value was taken. It was presumed that land would be leased and that the cost of removal of the equipment would be recovered by the gross salvage value of that equipment. In the base case considered, no escalation relative to the general inflation rate was assumed. However, later we discuss the effect of increasing the alternate cost or value of electricity by 6 percent, compounded annually, to reflect

Table 6.2 General Economic Parameters

	Parameter	Value
n	Life of System - yr	30
i	Present-Worth Interest Rate-%	10
L	Salvage Value	0
e_o	Annual Escalation Rate for Operating Expenses - %	0
e_E	Annual Escalation Rate for Alternate Cost or Value of Electricity - %	0*,6,-6**
d	Depreciation Rate for Tax Purposes - %	3.3

*Base case assumed.

**Public and private ownership only, alternate case.

increased fuel and environmental-control costs. In the case of public or private ownership, we also consider the case of -6 percent escalation based on a frozen purchase price paid by the utility. That is, the rate of general inflation is taken as 6 percent above the purchase price.

The wind-turbine cost parameters are given in Table 6.3. In the case of the capital investment

$$P_o = P_{o_W} + P_{o_T} \qquad (6.11)$$

where

P_{o_W} = capital cost of wind-turbine generator

P_{o_T} = capital cost of transformer and transmission

The capital and operating costs for the MOD-2 unit were based on Ramler and Donovan (1979).(20) For the 100th production unit

$$P_{o_W}(2.5\ \text{MW(e), MOD-2}) = \$1.72\text{M (1977\$)}$$

The operating costs were based on a 1-man operation

$$A_o(2.5\ \text{MW(e)}) = \$48.6\text{k (1977\$)}$$

For the Darrieus machine, we assume

$$P_{o_W}(0.5\ \text{MW(e), Darrieus}) = \$0.19\text{M}$$

in first-quarter 1979 dollars. We assume that the cost of operation would be the same as that of the MOD-2 unit, per unit rated power. It will also be assumed that machine costs per unit rated power are the same for 2.5 and 5 MW(e) capacity.

The factors related to the sites are given in Table 6.4. The transformer and transmission costs depend on the output voltage of the wind-turbine generator, the distance to the nearest transmission line and the voltage of the line. We

Table 6.3 Wind Turbine Generator Parameters
(1978$)

	Parameter	Machine MOD-2	Darrieus
P_{o_W}	Capital Cost - $/MW(e)	748,000	371,000
A_o	Annual Operating Cost - $/MW(e)	21,100	21,000

Table 6.4 Economic Parameters of Site*

		6	31	33	35	42	59	60
U	Annual Utilization Factor							
	Mod-2	0.704	0.704	0.674	0.674	0.704	0.638	0.598
	Darrieus	0.346	0.346	0.314	0.314	0.346	0.284	0.254
P_{o_T}	Transformer and Transmission Cost 1978 k $/MW(e)							
	at 2.5 MW(e)							
	MOD-2	64.4	50.5	36.4	50.4	36.4	76.0	10.4
	Darrieus	66.8	52.8	38.8	52.8	38.8	80.0	10.8
	at 5.0 MW(e)							
	MOD-2	35.0	28.0	21.0	28.0	21.0	38.8	52.8
	Darrieus	42.8	35.8	28.8	35.8	28.8	49.0	63.0

---

*Transmission costs estimated as $35,000/mile.

Transforming to line voltage at the site. Estimated transformer costs, installed:

	2.5 kW(e)		5 kW(e)	
	34.5 kVA	115 kVA	34.5 kVA	115 kVA
MOD-2	$56,000	$120,000	$ 70,000	$124,000
Darrieus	62,000	130,000	109,000	175,000

assumed that the cost of the land lease of the site is included in the transformer and transmission cost.

The economic parameters related to ownership are given in Table 6.5. The fixed charge rate for public ownership (11%) reflects their tax-exempt status and their lack of requirement to generate a profit. The rate for the utility (18%) was suggested by Public Service of New Hampshire based on a 30-yr life. It should be noted, however, that the computed rate of return on investment is independent of the fixed charge rate used in the levelized cost method.

Table 6.5 Economic Parameters of Ownership

	Parameter	Public	Owner Utility	Private
f	Fixed Charge Rate %	11	18	--
t	Income Tax Rate %	--	46	46
t_{TC}	Investment Tax Credit %	--	10	10
I	Insurance and Property Tax %	--	2	2
A'_E	Alternate Cost or Value of Electricity 1978 $/kWh(e)			
	with capacity*	0.045	0.0292 + 0.0230U	0.045
	without capacity	0.040	0.0292	0.040

*Base case

As previously discussed, the value of electricity for public or private ownership is based on the price paid by the utility. Under New Hampshire law, the price paid by the utility to small producers for electric power up to 5 MW(E) capacity is $0.040/kWh(e) without a capacity credit and $0.045/kWh(e) with a capacity credit. A recent ruling for hydropower (Iacapino, 1979)(21) required that the capacity be defined as the 2-hr minimum power output over a 4-month period (November to February) substantiated by a 20-yr history of water flow. Power produced up to the defined capacity would receive \$0.045/kWh(e) credit and power in excess would receive \$0.040/kWh(e) credit. Using the analog of (variable) hydro and wind power, the full rated capacity of a wind-turbine generator would likely be achieved for at least 2 hrs. We assume that the regulatory commission would use hydro power as a precedent and apply the same criteria to wind power. Thus, \$0.045/kWh(e) is taken as the base case. However, as an alternate assumption, we will also consider the case without capacity credit, \$0.04/kWh(e) for a selected site. In any case, the actual value of electricity would no doubt be bounded between these cases. Because the credit for capacity is small (\$0.004/kWh(e)), there should not be much difference either way.

The alternate cost of electricity to the utility is more involved. First we consider only operating costs without capacity credit. The operating statistics for Public Service of New Hampshire were reviewed for 1978.

Operation	=	\$71,996,000
Maintenance	=	31,490,000
Other	=	17,502,000
O&M		\$120,988,000

The energy generated was 4,141,825k kWh(e). Thus

$$A_E' \text{ (O\&M) Utility} = 120{,}998{,}000/4{,}141{,}825{,}000$$
$$= \$0.0292/\text{kWh(e)}$$

in 1978 dollars based on system-average generation. We use this value for the alternate cost of electricity without capacity credit. It should be noted that wind power would be substituted for power produced by existing plants with the highest operating cost. In general, these would be the older less efficient plants and/or those using expensive fuels in short supply such as oil.

The system average would tend to be conservative on this basis. However, certain maintenance and other costs may not depend solely on operation. Further, we note that the average price of purchased power was only \$0.0212/kWh(e) based on \$43,422,000 cost for 2,048,582,000 kWh(e). If the utility would replace purchased power with wind power, only \$0.0212/kWh(e) could be claimed. In summary, the assumed \$0.0292/kWh(e) is an average value and the actual allowance would depend on the strategy used by the utility to substitute wind power for conventional power.

The question of capacity credit is even more involved. First, it is apparent that the full rated capacity is not available 100% of the time. However, if it were the value of capacity credit would depend on the cost of alternate capacity (\$/kWh(e)) and the fixed charge rate. For new nuclear plants or fossil-fueled plants with scrubbers, a value of \$1000/kWh(e) is frequently assumed. This enormous cost in part reflects the long delay until actual startup, typically 10 yrs. While oil burning plants are less costly, the present view is that they will be avoided in the future. Thus, the credit for 100% capacity would be

$$\begin{aligned} &\$1000/\text{kWh(e)} \times (0.18\$/\$\text{-yr})/(8766\ \text{hr/yr}) \\ &\quad = \$0.0205/\text{kWh(e)} \end{aligned}$$

We now consider how much of this can be claimed for wind-turbine generators. On the average, an operating machine would produce a fraction U (utilization factor) of the rated power. If the wind speeds and demand correlate in the most favorably way, the full rated capacity would be available on this basis. Conversely, if the most unfavorable correlation occurs, no capacity would be available. Thus, the fraction U appears to be a reasonable estimate. If we assume that the wind turbine is available 90% of the time (Marsh, 1979(22) and Ramler and Donovan, 1979(20)) and that the alternate system is available 80.5% of the time, then the "effective capacity credit" is

$$\$0.0205 \times U \times 0.90/0.805 = \$0.0230U/\text{kWh(e)}$$

The estimate of alternate system availability was based on the current system of Public Service of New Hampshire with the following mix:

15%	nuclear	at 72%	estimated availability
27%	coal	at 75%	estimated availability
53%	oil	at 84%	estimated availability
5%	hydro	at 100%	estimated availability

The availability for nuclear-, coal-, and oil-fueled plants were based on Spencer and Gildersleeve (1978).(23) The assumption of hydro availability is probably not realistic but has little effect on the result.

As pointed out by the GE study (Marsh, 1979),(22) wind power does provide a capacity credit but the value to be assumed is uncertain due to uncertainty in the wind. The present estimate is believed neither conservative nor optimistic. However, we will also consider an alternate assumption of no capacity credit in order to assess sensitivity to this variable.

While wind power will require additional spinning reserve due to lack of predictability of the wind in advance by the dispatcher, the cost of this reserve appears negligible for small initial penetration into the system. For large penetration, a method developed by JBF Scientific Corp. (Goldenblatt)(23) may be employed to estimate the penalty for additional spinning reserve.

6.5 Results of Economic Analysis

The results of the economic analysis for the base case applied to the seven sites, two machines and three ownerships are summarized by sites in Tables 6.6 through 6.12. The evaluation is based on levelized cost of wind power compared with the levelized alternate cost or value of electricity, both in $/kWh(e), and on rate of return on investment after taxes in percent. As a basis of evaluation of the latter, the

Table 6-6. Economic Evaluation of Site 6 Based on 2.5 MW(e) Rated Capacity and Capacity Credit (1978$).

	MOD-2 Machine			Darrieus Machines		
	Public	Utility	Private	Public	Utility	Private
Levelized Alternate Cost or Value - $/kWh(e)	0.045	0.045	0.045	0.045	0.037	0.045
Levelized Cost of Wind Energy - $/kWh(e)	0.020	0.030	-	0.026	0.037	-
Rate of Return on Investment - %	-	26	26	-	17	21

Table 6-7. Economic Evaluation of Site 31 Based on 2.5 MW(e) Rated Capacity and Capacity Credit (1978 $).

	MOD-2 Machine			Darrieus Machines		
	Public	Utility	Private	Public	Utility	Private
Levelized Alternate Cost or Value - $/kWh(e)	0.045	0.045	0.045	0.045	0.037	0.045
Levelized Cost of Wind Energy - $/kWh(e)	0.020	0.022	-	0.024	0.035	-
Rate of Return on Investment - %	-	27	26	-	17	22

Table 6-8. Economic Evaluation of Site 33 Based on 2.5 MW(e) Rated Capacity and Capacity Credit (1978 $).

	MOD-2 Machine			Darrieus Machines		
	Public	Utility	Private	Public	Utility	Private
Levelized Alternate Cost or Value - $/kWh(e)	0.045	0.045	0.045	0.045	0.036	0.045
Levelized Cost of Wind Energy - $/kWh(e)	0.020	0.031	-	0.026	0.037	-
Rate of Return on Investment - %	-	25	26	-	15	20

Table 6-9. Economic Evaluation of Site 35 Based on 2.5 MW(e) Rated Capacity and Capacity Credit (1978 $).

	MOD-2 Machine			Darrieus Machines		
	Public	Utility	Private	Public	Utility	Private
Levelized Alternate Cost or Value - $/kWh(e)	0.045	0.045	0.045	0.045	0.036	0.045
Levelized Cost of Wind Energy - $/kWh(e)	0.020	0.031	-	0.028	0.039	-
Rate of Return on Investment - %	-	25	25	-	15	19

Table 6-10. Economic Evaluation of Site 42 Based on 2.5 MW(e) Rated Capacity and Capacity Credit (1978 $).

	MOD-2 Machine			Darrieus Machines		
	Public	Utility	Private	Public	Utility	Private
Levelized Alternate Cost or Value - \$/kWh(e)	0.045	0.045	0.045	0.045	0.037	0.045
Levelized Cost of Wind Energy - \$/kWh(e)	0.019	0.028	-	0.024	0.034	-
Rate of Return on Investment - %	-	27	27	-	18	23

Table 6-11. Economic Evaluation of Site 59 Based on 2.5 MW(e) Rated Capacity and Capacity Credit (1978 $).

	MOD-2 Machine			Darrieus Machines		
	Public	Utility	Private	Public	Utility	Private
Levelized Alternate Cost or Value - $/kWh(e)	0.045	0.044	0.045	0.045	0.036	0.045
Levelized Cost of Wind Energy - $/kWh(e)	0.023	0.034	-	0.033	0.049	-
Rate of Return on Investment - %	-	22	22	-	11	15

Table 6-12. Economic Evaluation of Site 60 Based on 2.5 MW(e) Rated Capacity and Capacity Credit (1978 $).

	MOD-2 Machine			Darrieus Machine		
	Public	Utility	Private	Public	Utility	Private
Levelized Alternate Cost or Value - $/kWh(e)	0.045	0.043	0.045	0.045	0.035	0.045
Levelized Cost of Wind Energy - $/kWh(e)	0.023	0.035	-	0.035	0.051	-
Rate of Return on Investment - %	-	20	21	-	10	14

accumulative percentage of utilities and private industries that would invest at a given rate of return on investment is given in Figure 6.1 (Thermo Electron Corp., 1976).(19)

A review of the data shows that the MOD-2 machine appears consistently superior to the Darrieus device in all cases. This is due to the higher utilization factor of the MOD-2 machine for the present sites. A high utilization factor reduces costs of wind power. It also increases the effective alternate cost of power to the utility by increasing the capacity credit.

However, even so the Darrieus machine would seem to be an attractive investment for all cases except utility and private ownership on Mt. Kearsarge and Mt. Croydon. In these cases the utility wind-energy costs exceed alternate costs, and the private owners rate of return on investment after taxes is less than the 22% minimum acceptable rate of return that 50% of U.S. industries would require, according to Figure 6.1. It should be noted, however, that the Darrieus machine may have other desirable features. Further, the present economic analysis is approximate and may not fully credit that particular machine. It is suggested that in any final site selection, the Darrieus machine be considered further. However, in the present preliminary study, the remaining economic evaluation will focus on the MOD-2 device in order to assess variation in ownership and values of parameters. The Darrieus machine appears to be dependent on these variations in a similar manner as the MOD-2 device.

The results for the MOD-2 machine are summarized in Table 6-13 with a ranking of merit according to the site. In each case the savings in levelized cost (wind energy being less costly than alternate cost or value of energy) is greater for public ownership than utility ownership, because of the lower fixed charge rate (11% versus 18%). The rate of return on investment for the private owner is slightly greater than

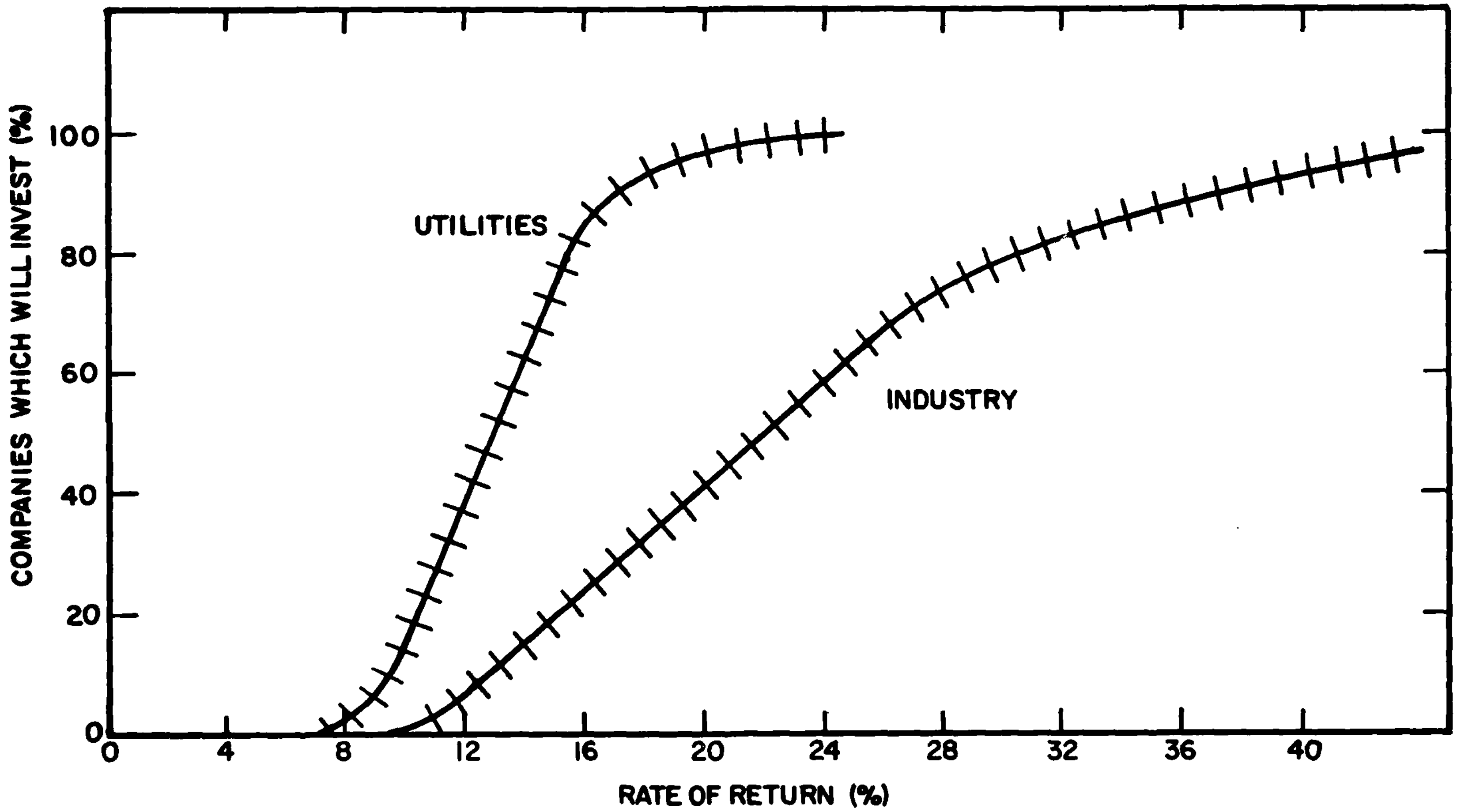


Figure 6.1 Accumulative Distribution of Industry and Utilities Willing to Invest vs Rate of Return

Table 6-13. Ranking of Sites by Base Economic Analysis, 2.5 MW(e), MOD-2 Machine (1978 $).

		Savings - $/kW(e)		ROI* - %	
Site	Mountain	Public	Utility	Utility	Private
42	Wolf	0.026	0.016	27	27
31	Crescant	0.025	0.016	27	26
6	North Moat	0.025	0.015	26	26
33	Randolph	0.025	0.014	25	26
35	Bald Cap	0.025	0.014	25	25
59	Kearsarge	0.022	0.010	22	22
60	Croyden	0.022	0.008	20	21

*Return on investment.

that of the utility owner, but they are within about 1%. However, the criteria for acceptable rate of return is much lower for the utility than the private owner, say 13% versus 22% at 50% acceptability (Figure 6.1). Thus, the results appear to favor public ownership over utility ownership on a savings basis (\$/kWh(e)) and utility ownership over private ownership on a rate of return on investment basis compared with minimum acceptable rate of return for the respective case.

The savings in levelized cost range from 0.022 to 0.026 \$/kWh(e) for the public owner. This would seem attractive for all sites. The savings for the utility is in the range of 0.014 to 0.016 \$/kWh(e) for all sites except Kearsarge and Croydon where it is 0.010 and 0.008, respectively. Similarly the rate of return on investment is 25% to 27% for utility and private owners for all sites except Kearsarge and Croydon where the range is 20% to 22% for the utility and 21% to 22% for private ownership.

While all sites, except Kearsarge and Croydon are relatively close in economic merit, Mt. Wolf is consistently the superior site. Therefore, this site was selected for variation of economic parameters. Data are summarized in Table 6.14.

First, we consider escalation of the alternate cost or value of electricity due to rising fuel and environmental control costs, for example. The rate is assumed 6% compounded annually above general inflation relative to 1978 dollars. Under this scenario, the attractiveness of wind power is intensified according to each criteria considered. For example, the rate of return on investment increases from 27% to 35% for both utility and private ownerships. Using the data of Figure 6.1, the fraction of private owners that would choose to invest would increase from about 71 to 87%. The fraction of utilities is near 100% in both cases. We conclude

Table 6-14. Variation of Economic Parameters for Mt. Wolf with MOD-2 Machine (1978 $).

	Savings - $/kW(e)		ROI - %	
Variation	Public	Utility	Utility	Private
Base	0.026	0.016	27	27
$e_E = 6\%$ (1)	0.065	0.056	35	35
$e_E = 6\%$ (2)	0.008	-	-	18
W = 5 MW(e) (3)	0.026	0.017	28	28
No Capacity Credit (4)	0.021	0.000	17	24

(1) Alternate cost or value escalates 6% compounded annually above general inflation rate.

(2) Alternate cost or value lags 6% compounded annually below general inflation rate.

(3) Base case is 2.5 MW(e).

(4) Base case assumed an effective capacity credit based on a fraction 1.12 U of rated capacity being available.

that increasing conventional energy costs above inflation levels would help but is not essential to the viability of wind energy in New Hampshire.

Second, we assume that the rate paid by the utility under New Hampshire law to public and private producers lags behind the general inflation rate by 6%, say due to a frozen level of 0.04 to 0.045 $/kWh(e) or insufficient escalation of that level. In this case, the public owner would still save $0.008/kWh(e) in 1978 dollars compared with the levelized escalated value of electricity. However, the private owner's rate of return drops to 18%. Even so, the data of Figure 6.1 suggests that about 32% of industries would still invest. However, it is clear that more successful implementation would occur if the sales rate for alternate energy producers were at least maintained with inflation.

The effect of doubling the size of the generating unit from 2.5 to 5.0 MW(e) can be inferred by referring to Table 6.4. In the present analysis, the savings due to increased rated capacity accrues mainly as a result of no increased transmission cost and only a slight increase in transformer cost as reflected in the data of Table 6.4. The additional benefit relative to the base case is very slight owing to the small size of the transformer and transmission costs. At present, only a maximum of 5 MW(e) was considered as this is the limit under the current small producers act. The utility could benefit from larger capacity however. It is also possible that substantially larger capacity will be permitted consistent with pending federal legislation, perhaps 80 MW(e). Reduced costs would be achieved in operation and maintenance, and a greater availability could be claimed (Ramler and Donovan, 1979).(20) However, penetration of wind power into the utility grid of this magnitude may involve a significant penalty for additional spinning reserve (Goldenblatt).(24)

The above cases all assumed that a capacity credit could be claimed. However, the magnitude of the credit that is appropriate is uncertain. Therefore, as a limiting case, no capacity credit was assumed (Table 6.5). Compared with the base case with capacity credit, the savings in \$/kWh(e) drops from 0.026 to 0.021 for the public owner and from 0.016 to 0.000 for the utility owner. The rate of return on investment after taxes drops from 27% to 17% for the utility and from 27% to 24% for the private owner. The latter is less significant because the capacity credit was taken as only \$0.005/kWh(e). However, for the utility the alternate cost of electricity drops from 0.045 to 0.0292 \$/kWh(e). Nevertheless, the rate of return still appears substantial from the point of view of market penetration. Nearly all utilities and about 58% of private industries would choose to invest according to Figure 6.1.

6.6 Summary

The present economic analysis has attempted to assess wind energy in New Hampshire according to site, machine, owner and variation of economic parameters. Two distinct methods of economic analyses were applied depending on the owner. Of all seven sites, five appeared quite favorable for all cases considered: Mts. Wolf, Crescent, North Moat, Randolph and Bald Cap (listed in declining order of merit).

The MOD-2 turbine generator appears consistently superior to the Darrieus machine under the present assumed conditions. Thus, the MOD-2 machine and Mt. Wolf appear to be the best combination. A public owner could produce power at \$0.019/kWh(e) and sell it to the utility at \$0.045/kWh(e). A private owner would receive a 27% rate of return on investment after taxes at the latter price. Up to 5 MW(e), two MOD-2 units, would be allowed under present law although larger capacities up to perhaps 80 MW(e), thirty-two MOD-2 units, are anticipated. The utility owner could generate power at \$0.028/kWh(e) which would cost \$0.045/kWh(e) to replace, including capacity credit.

The latter rate closely agreed with the allowance under New Hampshire law for small producers, at least for the MOD-2 machine. The utility could employ larger numbers of MOD-2 units but would encounter some penalty due to increased spinning reserve requirements.

The other four sites mentioned above are nearly as good economically as Mt. Wolf. Other factors may justify their choice. Consideration of escalated alternate cost or value of electricity showed an even greater justification of wind power. This escalation above general inflation may occur as fuel and environmental-control costs accelerate. Even a frozen value of the price of electricity paid to the small producer by the utility seems to not exclude wind power, although it is definitely less attractive under that condition. Therefore, the legislature should provide for escalation of price under the small producers act.

Either one or two MOD-2 units could be installed with very similar economic justification. Lack of capacity credit definitely reduces the attractiveness of wind power to the utility. However, the price paid by the utility to the small producer is little effected by capacity credit.

In closing, it is pointed out that the present analysis is only approximate, and should be considered only preliminary in nature. First, a number of effects were not included. For example, in the case of the utility the state franchise tax was neglected. Only equity financing was assumed for the private owner. Second, the various economic parameters should be defined more precisely by the owners concerned. In the case of the electric utility, a more detailed study of capacity credit and more detailed analysis of power-dispatch substitution strategy are warranted in order to better define the alternate cost of power compared with wind power.

Nevertheless, the results suggest that both public and private owners could generate wind power economically under the terms of the small producers act with purchase by the electric utility. Alternatively, it appears that the utility could benefit directly by owning and operating the system, thereby reducing present operating costs and reducing the need for other generating capacity to the extent of a significant fraction of the wind-energy capacity.

In short, wind power appears beneficial to New Hampshire and would improve the economic and energy environment in the State. The Portsmouth Navy Yard would benefit accordingly, because they share in that environment.

References

1. "200-kilowatt Wind Turbine Project," NASA-Lewis Research Center, Cleveland, Ohio, Document E-8785, July 1978.

2. Remler, J.R. and Donovan, R.M., "Wind Turbines for Electro Utilities: Development Status and Economics," NASA TM-79170, AIAA Conference, Orlando, Florida, June 1979.

3. Robbins, W.H., and Thomas, R.L., "Large Horizontal Axis Wind Turbine Development," NASA TM-79174, Wind Energy Innovative Systems Conference, Colorado Springs, Colorado, May 23-25, 1979.

4. "2500 kW Wind Turbine System,: Mod-2 Project, Boeing Engineering & Construction Co. Report, Dec. 8, 1978.

5. Kadlec, E.G., "DOE/Sandie Darrieus Program Status," Sandia Laboratory, Albuquerque, N.M., DOE Contract AT(29-1)-789, 1979.

6. Vosburgh, P.N., "Alcoa Vertical Axis Wind Turbines," American Wind Energy Association Spring Conference, San Francisco, California, April 1979.

7. World Book Encyclopedia, 1975.

8. Corotis, R.B., "Stochrotic Modelling of Site Wind Characteristics," ERDA Contract No. EY-76-S-06-2342, September 1977.

9. Corotis, R.B., "Statistical Models for Wind Characteristics at Potential Wind Energy Conversion Sites," DOE Contract EY-76-S-06-2342, January 1979.

10. Widger, W.K. and Derrickson, R.A., "New England Wind Power - Coastal or Mountain," Power Engineering, December 1976.

11. Corotis, R.B. (1974), "Statistical Analysis of Continuous Data Records," Transportation Engineering Journal, ASCE, Vol. 100, No. TEI, Proc. Paper 10362, Feb., pp. 195-206.

12. D.L. Sengupta and T.B.A. Senior, Electromagnetic Interference by Wind Turbine Generators, University of Michigan for U.S. Department of Eenrgy, Contract EY-76-S-02-2846, March 1978

13. Senior, T.B.A., D.L. Sengupta and J.E. Ferris, TV and FM Interference by Windmills, University of Michigan for ERDA, Contract E(11-1)-2846, February 1977.

14. "2500 kW Wind Turbine System for Electric Power Generation," Boeing Engineering and Construction, Seattle, Washington, Dec. 8, 1978.

15. Banas, J.B. and Sullivan, W.N., "Engineering of Wind Energy Systems," Sandia Laboratories Report No. SAND75-0530, January 1976.

16. Cliff, W.C., "The Effect of Generalized Wind Characteristics on Annual Power Estimates from Wind Turbine Generators," Battelle Pacific Northwest Laboratories Report No. PNL-2436, October 1977.

17. Ramler, J.R. and Donovan, R.M., "Wind Turbines for Electric Utilities: Development Status and Economics," Paper presented at the Terrestrial Energy Systems Conference, AIAA, Orlando, Florida, June 4-6, 1979.

18. EPRI, June 1978. "Technical Assessment Guide," EPRI Special Report EPRI-PS-866-SR, EPRI, Palo Alto.

19. Thermo Electron Corp., June 1976. "A Study of Inplant Electric Power Generation in the Chemical, Petroleum, Refining and Paper and Pulp Industries," Prepared for FEA, NTIS Document PB-255 659.

20. Ramler, J.R. and Donovan, R.M., June 1979. "Wind Turbines for Electric Utilities: Development Status and Economics." NASA TM-79170, Also AIAA Paper 79-0965.

21. Iacopino, V.J., July 1979. "Supplemental Order No. 13,744, Public Utilities Commission of New Hampshire.

22. Marsh, W.D., January 1979. "Requirements Assessment of Wind Power Plants in Electric Utility Systems," Report ER-798-SY, Vol. 1, General Electric Company, Schenectady, New York.

23. Spencer, D. and Gildersleeve, O., May 1979. "Market Potential for New Coal Technologies," EPRI Journal, p. 19-26.

24. Goldenblatt, M. "A Method for Estimating the Impact of WECS on Utility Operating Reserve Requirements," JBF Scientific Corp., Wilmington, Mass.