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PROGRAM OVERVIEW FOR THE WIND
CHARACTERISTICS PROGRAM ELEMENT OF THE
UNITED STATES FEDERAL WIND ENERGY PROGRAM

by

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SUMMARY

Within the Federal Wind Energy Program of the United States of America, the Wind Characteristics Program Element (WCPE) has been established with the responsibility for assembling and developing wind characteristics information appropriate to the needs of those involved in energy program planning, design and performance of wind energy conversion systems (WECS), selection of sites for WECS installation, and the operation of WECS. The U.S. Department of Energy (DOE) is addressing this responsibility through a management/research program balancing the expertise in government laboratories, private industry and universities.

The needs for wind characteristics information have been divided into four major categories. These are:

- reliable wind and turbulence descriptions pertinent to WECS design and performance evaluation,
- effective analyses and methods for the determination of wind energy potential over large areas,
- dependable and cost-effective methodologies for the siting of WECS, and
- descriptions of day-to-day wind variability and predictability for WECS operations.

To expedite contributions to the above list of needs, the technical program of the WCPE has been divided into four corresponding areas. Research and development progress and products in each of these program areas are summarized in this presentation.

Introduction

The objectives and organization of the Federal Wind Energy Program of the United States of America have been described in a Summary Report (Ref. 1). The overall objective of the program was stated to be "...to accelerate the development, commercialization and utilization of reliable and economically viable wind energy systems." To achieve this objective, the program was organized into discrete, yet interrelated program elements. The objective of this paper is to present an overview of the Wind Characteristics Program Element (WCPE).

The WCPE is established to provide the appropriate wind characteristics information to those involved in energy program planning, design and performance evaluation of wind energy conversion systems (WECS), selection of sites for the installation of WECS, and the operation of WECS. Some specific contributions of the program element are to consist of reliable estimates of wind characteristics pertinent to WECS design, effective analyses and methods for the determination of wind energy potential over large areas, dependable and cost-effective methodologies for the siting of WECS, and description of day-to-day variability and predictability of wind energy for WECS operations. To accomplish these tasks, the WCPE has been divided into four technical program areas.

- Wind Characteristics for Design and Performance Evaluation
- Mesoscale Wind Characteristics
- Development of Siting Methodologies
- Wind Characteristics for WECS Operations

Each program area has distinct elements and includes responsibility for overseeing, coordinating and conducting work which will provide the results needed to meet the overall objectives of the Federal Wind Energy Program.

The management responsibility for the Wind Characteristics Program Element has been assigned to Pacific Northwest Laboratory (PNL). In close cooperation with the Wind Systems Branch of the Department of Energy, each fiscal year a program planning document is prepared, which provides the framework and basis for communication in planning and carrying out work in the program (Ref. 2). This document is updated as needed to accomplish the overall objectives of the Federal Wind Energy Program.

The primary responsibilities of PNL include planning, placing and monitoring contract research studies, coordinating these studies, and conducting in-house technical work. The major portion of the technical work in the program is conducted by private research firms and universities. The main purpose of the in-house efforts are to fill any gaps in the contract efforts and to pull together various segments of work for presentation in an appropriate format for the intended recipient of the material. To meet these responsibilities requires a significant liaison effort with other program elements in the Federal Wind Energy Program as well as with potential users of the wind characteristics information. The goals and highlights of work in progress, in each area of the WCPE, will constitute the major portion of the body of this paper.

Wind Characteristics for Design and Performance Evaluation

The primary objective of this program area is to provide wind characteristics information for use by WECS designers in catastrophic failure considerations, fatigue analyses and machine output optimization through effective control strategies. A secondary objective is to provide techniques, utilizing wind data and machine output information, to assess the performance of WECS after they have been installed and are in operation.

One of the significant aspects of this program area is the interaction between WECS designers and atmospheric scientists specializing in wind characteristics. This interaction has been mutually beneficial. The wind characteristic investigators have gained a much better understanding of the specific needs of the designers, and the designers have gained more awareness of the type of meteorological and environmental information available to them.

One of the early tasks in this program area was to provide generic estimates of the effect of generalized wind characteristics on annual power estimates from wind turbine generators (Ref. 3). The purpose of this work was to provide tools for preliminary design utilizing with a minimum of wind information. Techniques were presented to estimate a wind turbine's average power, percent down time, and percent time operating at rated power. The required information for these estimates was annual mean wind and the specified cut-in, cut-out, and rated wind speeds of hypothetical wind generators. In most preliminary examinations of wind power feasibility, long-term frequency distributions of wind speeds are not available. For this reason, the annual mean wind speed was used to produce a Rayleigh distribution which was used in place of the actual distribution to compute the power estimates for specified machine characteristics. This procedure was tested on data from fourteen locations in the United States for which the actual frequency distributions were available. Power estimates using the Rayleigh distribution were generally within 10% of estimates using the actual frequency distribution for annual mean wind speeds greater than 5 m/s.

The main objective of the work was not to provide power estimates, but rather to provide a basis for sensitivity analyses and comparisons of various combinations of design parameters. The information was intended for both designers and potential users of wind turbine generators. An example of the type of information provided is shown in Fig. 1. With this diagram a prospective user or designer can examine options for various choices of machine-operating characteristics for a given annual mean wind speed.

To deal more directly with specific needs of wind turbine designers in the area of catastrophic failure considerations and fatigue analyses, the nature of wind gustiness is under investigation. It is critical in this work that results of an investigation be provided to the designers in a form which is not only understandable, but immediately usable. One of the first studies in this area presented preliminary estimates of the number of occurrences of specified gust magnitudes for various values of mean wind speed and terrain roughness (Ref. 4). Estimates of this type over the life of a machine are provided for use in fatigue analysis.

Also very important to designers is information on the change in the speed and direction of the wind as a function of the time interval over which the change occurs. Work has proceeded to establish guidelines for wind turbine designers to use in computing the approximate number of velocity changes per hour which exceed a given value over a specified time interval. This type of information is very important in blade pitch control analyses as well as fatigue analyses. The formulation used in this work compared very favorably with analyses of measured data from a single anemometer.

The tasks previously described have dealt with the wind, as if the measurements by a single anemometer were representative of what is encountered by a wind turbine blade. Because of the lack of information on the nature of the flow field passing through the disk of rotation, a task has been initiated by PNL to place a circular array of anemometers in a vertical plane to obtain measurements consistent with a wind environment encountered by a wind turbine blade (Ref. 5). The initial tower array and anemometer configuration are shown in Fig. 2. Three component wind data from the entire 24.4 m diameter anemometer array were sampled at a rate of ten times per second for several periods of strong winds blowing into the plane of the array.

Preliminary analyses of the data set included comparisons of behavior of the wind speed at hub height (center anemometer) with the wind speed averaged over the disk, as shown in Fig. 3. Another type of analysis possible with the data from the array is the production of a synthesized wind record which represents the wind which a wind turbine blade would experience if it were rotating in the plane of the anemometer array. A sample of the synthesized wind record is shown in Fig. 4. The most striking feature of these data is the magnitude of the rapid change in wind speed encountered by the blade rotating through the vertical shear in the flow field. This type of data has been used by designers in wind turbine simulation models. The data will also be used to provide more comprehensive descriptions of the winds encountered by a turbine blade over the disk of rotation for expected improved input to design applications.

Work is in progress to expand the diameter of the anemometer array to 49 meters, and the possibility of establishing a 100-meter diameter array is under consideration. Also under consideration is the establishment of a 10- to 15-meter array to establish a data set and analyses for small machines.

Mesoscale Wind Characteristics

This program area is organized into three general sections. In the first section the major concern is with the analyses of wind energy potential over large areas (on the order of 1000 x 1000 km). Initial analyses of this type were carried out on a national scale in the early stages of the Federal Wind Energy Program. A study comparing, evaluating, and synthesizing three previous independent national assessments was conducted and reported by Elliott (Ref. 6). The distribution of annual mean wind power estimated at 50 meters above exposed areas in the United States is shown in Fig. 5. The results of these initial analyses are suited primarily to preliminary planning purposes. More detailed wind energy considerations for areas the size of one or several states require more stringent analyses than were possible in the time allotted for the initial national assessments. These analyses will permit an accounting of significant terrain influences and mesoscale climatological features.

To meet the need for more detailed analyses, the initial task in this section of the program area is to test and apply prototype techniques for the analysis of wind energy potential. These techniques may then be applied in a consistent, comparable manner in other regions of the country. One of the techniques under development and testing is a data screening technique which is applied to data sources not utilized in any of the national assessments. In the Northwest area of the United States, selected for a prototype analysis, the total amount of data available is approximately four times the amount of conventional data used in the national assessments for the same area. Analytical techniques which involve the use of biological indicators and satellite imagery, as well as the usage of upper air wind data to extrapolate winds down to exposed ridge tops, are also undergoing testing and application. One of the prime objectives of this work is to provide quantitative estimates of the land area which would be suitable for the effective application of wind turbine generators. This is being pursued with the help of relief maps and stereographic aerial photographs.

In the second section of the program area, the major concern is with analyzing the wind energy potential at specified sites such as those which are candidates for testing and demonstrating wind machines. Site visit reports were prepared by PNL as well as the documentation of the analyses of site wind data. This documentation was prepared in a special summary for a Site Selection Board.

Also, in the second section of this program area there is a contract study to test techniques for estimating the wind characteristics at a specified location with wind data available only at surrounding locations. The techniques were tested at eight of the initial candidate sites. Two of the techniques which look most promising for application to sites surrounded by complex terrain involve the application of three-dimensional flow models, which include terrain effects, coupled with regression or eigenvector techniques to establish climatologies of wind characterists at the specified locations. A data base has been collected at each of these locations with which to verify and evaluate the interpolation technique in a follow-on effort.

The third general section of this program area is devoted to supplementary studies. These studies provide information which will allow more effective analyses of the wind energy potential over large areas and at specific sites.

Because of the relative scarcity of appropriate wind measurements over vast areas, a contract study was initiated to develop an efficient means to identify high wind locations from eolian geomorphological features observed in aerial photography and satellite imagery (Ref. 7). Results of this work suggest that stabilized eolian features are reliable indicators of wind patterns and may prove even more useful than active features such as sand dunes because they are more numerous. Work is continuing to quantify the wind energy associated with the observed eolian features. These techniques are best suited to regions with a dry climate, such as those found in large areas of the western United States, and are being tested in a prototype, large area analysis of wind energy potential.

For regions or sites where conventional wind data are available for use in the analysis of wind energy potential, the recurring question is: how long a data record is required to be representative of the long-term climatology? In one contract study, which is addressing this problem, stochastic models have been developed and used to analyze wind data from 20 locations in the United States (Ref. 8 and 9). Results of this work indicate that one year of data is generally sufficient to estimate the long-term seasonal mean wind velocities to within an accuracy of 10 percent with a confidence level of 90 percent. Another result from this study was the preliminary indication that the Rayleigh distribution generated from the mean wind is adequate to describe the probability distribution of velocity. Deviations from observed values appeared to be no larger than the year-to-year variability in the observed statistics.

Along with the concern of year-to-year variability of wind energy is the concern with the spatial variability of wind energy over large areas in an electric utility network. The problem of spatial variability may be partially alleviated by the use of widely dispersed arrays of wind turbines. A study of the wind energy statistics for large arrays has been conducted in a contract effort (Ref. 10). This study estimates the increased wind power available using dispersed arrays rather than arrays at an individual site. A model has been developed to estimate the array power from data at a single location.

Development of Siting Methodologies

The distinction between this program area and the one just described lies in the scale of the areas of concern and the emphasis on developing methods for evaluation as opposed to their application. In the Mesoscale Wind Characteristics Program area, large areas on the order of 1000 to 2000 km on a side are analyzed. One of the goals is to identify, within the large area, high wind areas on the order of 100 km on a side. Promising areas of this size then become the object of specific siting studies through the application of the tools developed within the Siting Methodologies Program area.

This program area is also organized into three general sections. The major objective of the first section is site-screening and localization techniques development. Research and development are being carried out in several directions. Some types of numerical modeling show promise of providing a tool which will allow a reasonably comprehensive analysis of the flow over complex terrain. Both objective analysis and time-dependent models have been adapted for use in screening areas for promising wind energy sites (Refs. 11 and 12). Some controversy still exists concerning the accuracy of numerical model results and to what extent they are reliable in various applications. Verification efforts will be discussed under the second section of this program area.

Another effort in the category of site screening and localization involves the use of biological indicators (Ref. 13). This work has concentrated on calibrating and verifying the three indices established in the early phases of the work. The Griggs-Putnam Index, which involves the degree of flagging of a tree, appeared to give the best estimate of mean annual wind. The mean error was about 25 percent.

Physical modeling was pursued for the purpose of developing localization techniques (Ref. 14). Flow characteristics for specified hill shapes were studied for the purpose of determining the most favorable terrain slopes, generalized locations for optimum wind energy, flow separation, high turbulence and the effect of roughness on terrain-induced speedup. The size of the wind tunnel imposes an upper limit on the vertical extent of the topographic features which must be kept in mind when considering this modeling alternative. Even so, a significant range of features can be examined. This could be especially helpful in the localizing stage of wind turbine siting where specific installation locations are to be identified.

Model results can only be verified by actual measurements, and for localization efforts and the evaluation of predetermined sites, this is probably the most reliable method available. However, the big drawback with direct measurements has been the expense of collecting and handling the data. Some recent developments in electronics have made possible the development of inexpensive data collection devices which directly provide statistical summaries of the wind data at the measurement site (Ref. 15). These developments could make localization studies by direct measurement more attractive, because they will also reduce the cost of the necessary wind characteristics verification effort which must follow the identification of any prospective specific site.

The second general section of this program area is devoted to the verification of the site-screening techniques. The main effort initially is an evaluation of the numerical models adapted for site screening. The general approach to verification will be to apply the various techniques to areas where the wind at a number of locations is known as a function of time. Three data sets representing hilly to mountainous terrain have been selected for the verification tests. The models will be rated on their ability to discriminate between high and low wind speed areas. The site-screening techniques will also be rated on their ability to reproduce the general features of the wind speed probability distribution function and the mean diurnal variation of wind speed. The accuracy of the techniques, as a function of the amount of input data and parameter detail, will be determined for various degrees of terrain and climatological complexity.

In the third general section of this program area, siting strategies are documented and disseminated in a usable format as rapidly as possible. An interim handbook with a step-by-step description of a siting method for small machines has been prepared (Ref. 16). This document is intended primarily for the layman interested in wind power for personal application. A compendium of siting strategies and considerations for large machines is undergoing revisions after a first review. This document is aimed at a more technically-oriented audience and is intended more for use by utility companies and other potential users of large machines.

A very comprehensive document has been in preparation under a three-year contract study which deals with siting wind turbines relative to small-scale terrain features (Ref. 17). During the early stages of this effort the effect of flat and two-dimensional terrain features have been assessed. These include single and multiple surface roughness changes, shelterbelts, bluffs, blocks and bumps with smooth contours. Step-by-step procedures have been developed to assist in maximizing wind turbine output as a function of turbine location relative to these terrain features. Further efforts will include three-dimensional smooth and bluff-like terrain irregularities.

Wind Characteristics for WECS Operations

This program area is a Fiscal Year 1978 addition to the WCPE. It became apparent that the work in the first three program areas does not help the dispatching or planning personnel of utility companies to anticipate the availability of wind energy on a day-to-day or hour-to-hour basis. Operations personnel are concerned with the hour-by-hour predictability of wind energy over periods of 24 to 36 hours to allow effective scheduling of the day-to-day operation of their generating resources and periodic maintenance of equipment.

The primary objective of this program area is to determine the predictability of wind characteristics needed for WECS operations in a power grid. The initial efforts were concerned with identifying wind forecasting needs of potential WECS users and determining if current wind forecasting reliability can meet these needs. Information was obtained from both research and operations personnel of large and small utilities. Information on available forecast products and reliability was obtained from individuals and organizations engaged in producing wind forecasts.

A working group discussion was held with attendees from both the utility and forecaster communities. The findings and recommendations from this working group have been reported (Ref. 18). One of the major conclusions was that reliable wind forecasting would be valuable as a planning aid to estimate the generation equipment required to meet forecast load. Work in the area of establishing forecast reliability for 24-36 hours is needed to determine if it is at least as reliable as load forecasting. A request for proposals has been prepared to solicit work on this problem.

Conclusions

The "development, commercialization and utilization of reliable and economically viable wind energy systems" is requiring a unique and multi-faceted investigation of wind characteristics. Atmospheric scientists have been willing and eager to apply their expertise to the problems. It was immediately apparent, however, that the atmospheric scientists, the design engineers and potential users of wind turbines all had much to learn from each other. The educational process, though slow at first, is accelerating. The experience is proving very beneficial to all involved.

One of the major challenges of the Wind Characteristics Program Element, aside from the technical problems themselves, is to maintain the focus of the many contributors on the priorities required to accomplish the overall objectives of the program in a timely fashion. This task has been complicated by the fact that the United States' wind energy program has in recent years undergone a very dynamic period of growth. It is imperative that we maintain the proper priorities in the planning and execution of the work in this program.

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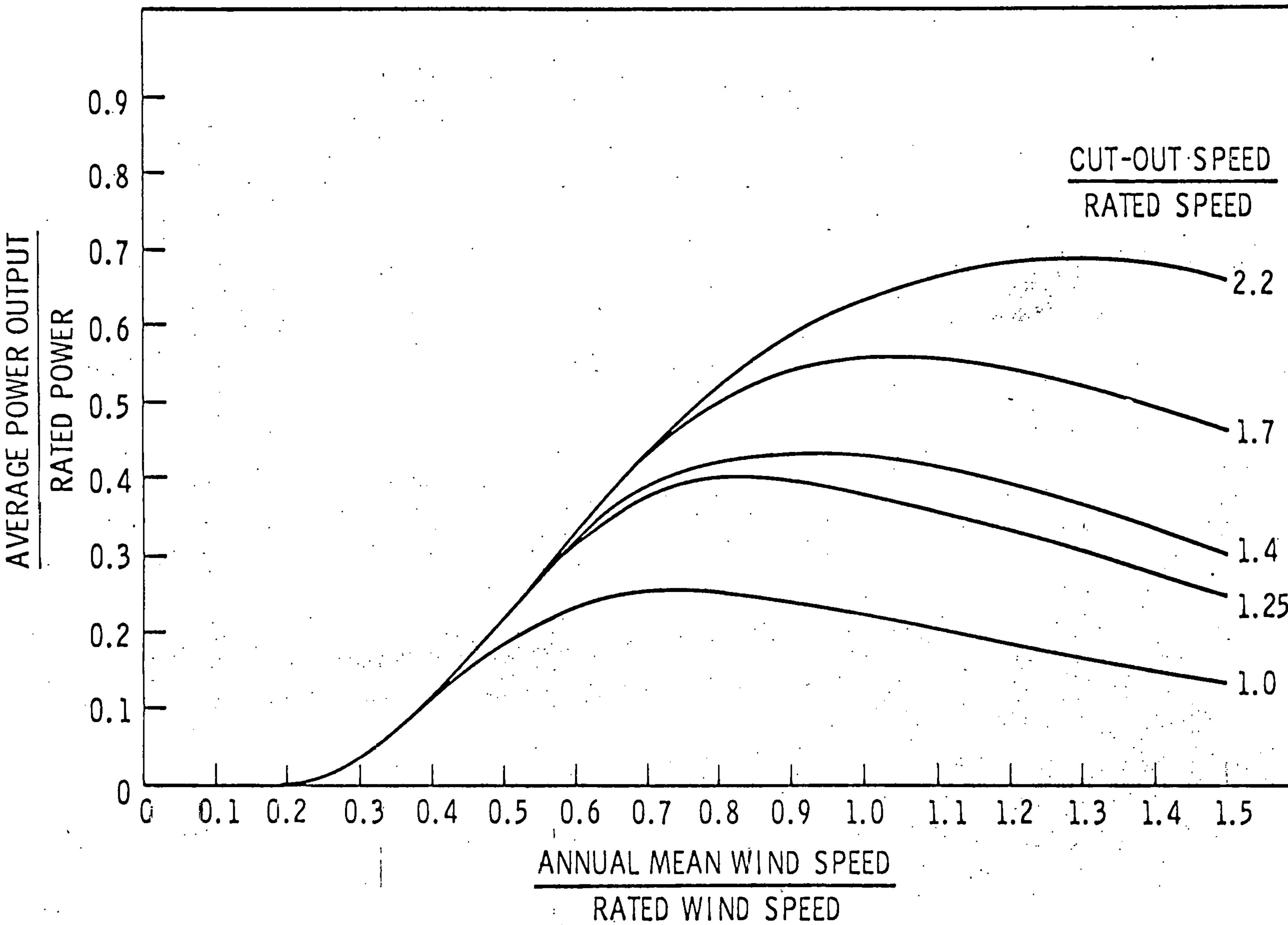

Figure 1. Estimate of Expected Average Power Output for Wind Turbines (Ref. 3)

INSTRUMENT ARRAY FOR
VERTICAL PLANE FIELD PROGRAM

GILL ANEMOMETERS NO. 1-9
TEMPERATURE PROBES NO. 10-12

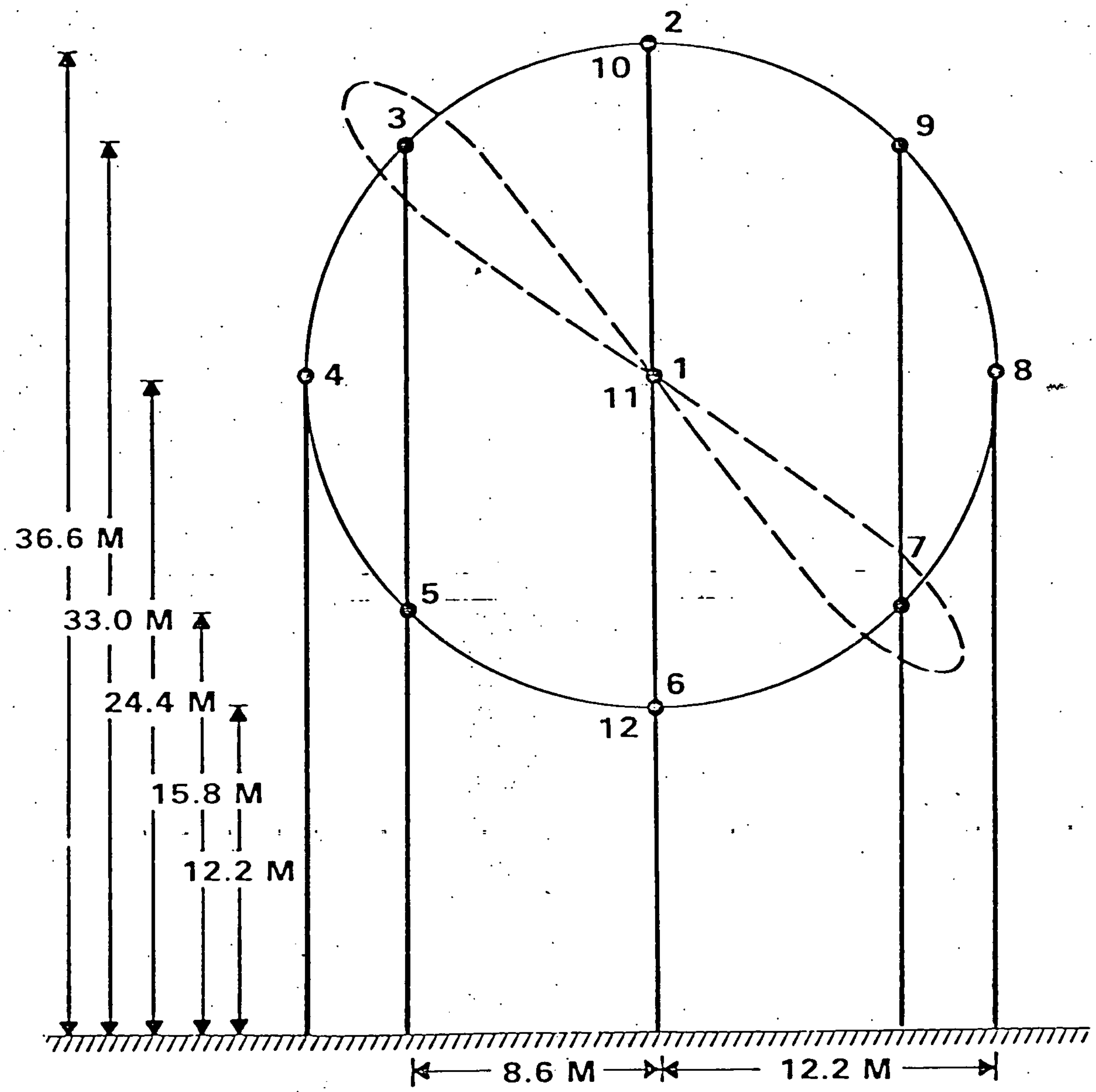

Figure 2. Field Test Setup for Vertical Plane Test (Ref. 5)

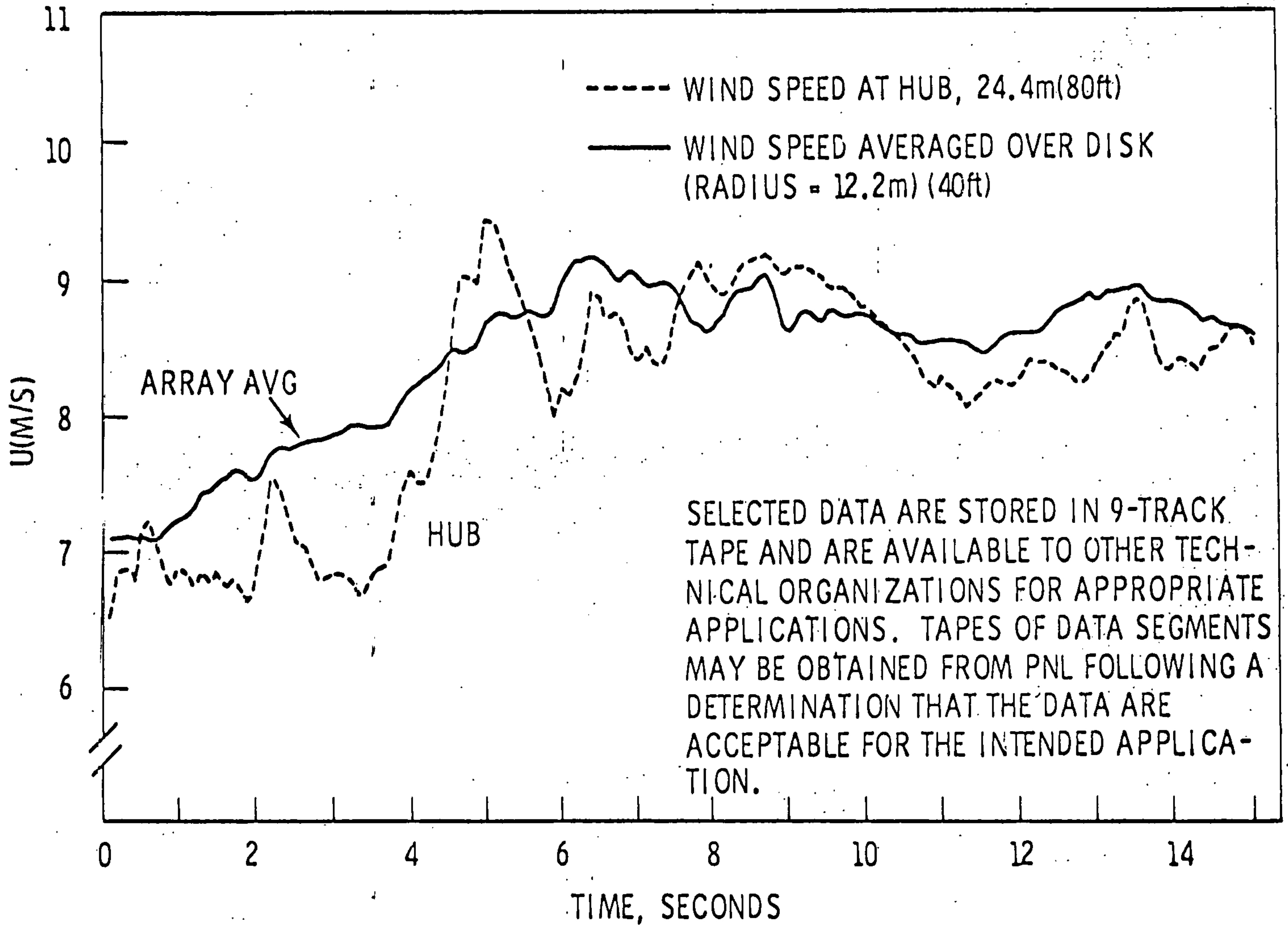

Figure 3. Wind Speed at Hub Versus Wind Speed Averaged Over Disk (Ref. 5)

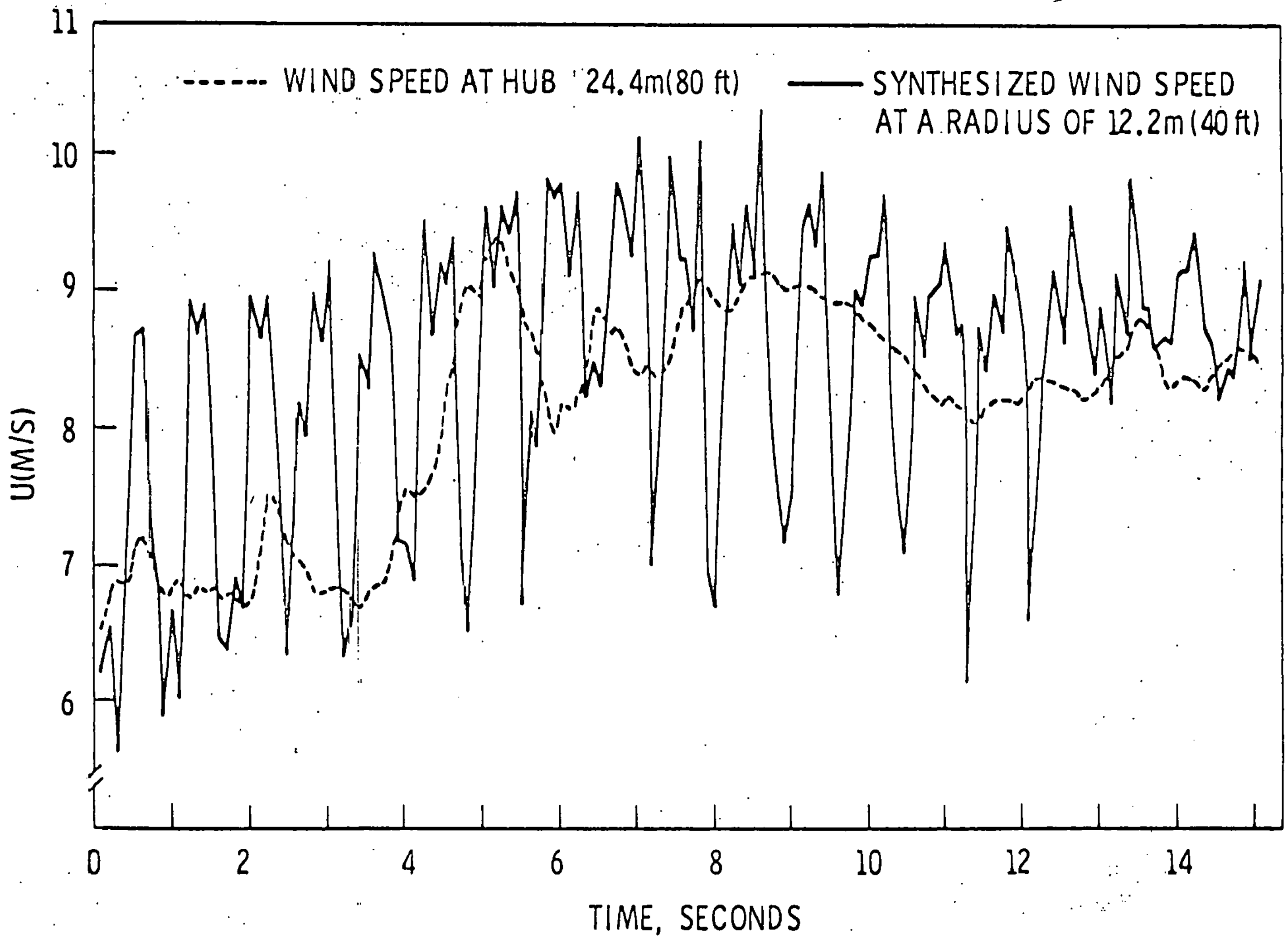

Figure 4. Synthesized Wind Speed Versus Wind Speed at Hub (Ref. 5)

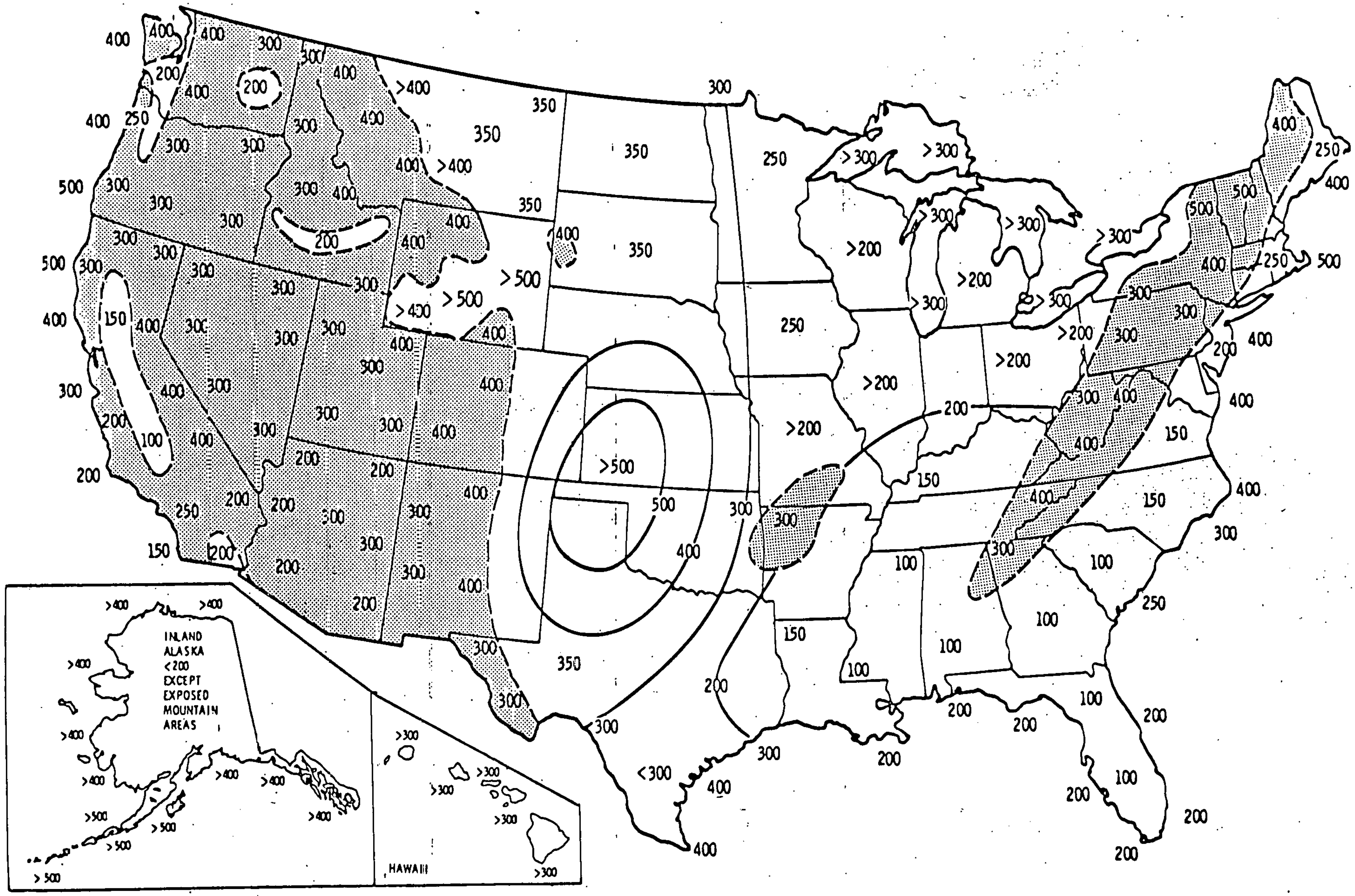

Figure 5. Mean Annual Wind Power (W/m^2) Estimated at 50 m Above Exposed Areas. Over mountainous regions (shaded areas), the estimates are lower limits expected for exposed mountain tops and ridges. (Ref. 6)

LIST OF FIGURES