PNL-2519
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Semi-Annual Report of the Wind Characteristics Program Element for the Period July 1977 through December 1977

by
C. E. Elderkin - Program Administrator
L. L. Wendell - Technical Manager

January 1978

Pacific Northwest Laboratory
Richland, Washington 99352
Operated for the
U.S. Department of Energy
by

Battelle
Memorial Institute

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NOTICE

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SEMI-ANNUAL REPORT OF THE WIND CHARACTERISTICS PROGRAM ELEMENT FOR THE PERIOD JULY 1977 THROUGH DECEMBER 1977

by

C. E. Elderkin - Program Administrator
L. L. Wendell - Technical Manager

January 1978

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Richland, Washington 99352
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Prepared for the U.S. Department of Energy, formerly the Energy Research and Development Administration, under Contract EY-76-C-06-1830.

SUMMARY

Within the Federal Wind Energy Program, the Wind Characteristics Program Element (WCPE) is a service element established to provide the appropriate wind characteristics information to those involved in energy program planning, design and evaluation of wind energy conversion systems (WECS), selection of sites for the installation of WECS, and the operation of WECS. Pacific Northwest Laboratory (PNL) has been assigned the responsibility for management and technical assistance in the WCPE. The program contributions 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 descriptions of the day-to-day variability and predictability of wind energy for WECS operations. To accomplish these goals, 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

In addition to the four technical program areas listed above, another effort has been established and titled "Special Studies". This effort is designed to provide technical assistance to the Wind Systems Branch and other Federal Wind Energy Program (FWEP) elements on a fast response basis.

This semi-annual report to the Wind Systems Branch (WSB) of DOE's Division of Solar Energy describes the technical progress within the Program Element from July 1977 through December 1977. The technical progress covered in this report includes that accomplished directly by Pacific Northwest Laboratory (PNL), other DOE laboratories (Lawrence Livermore Laboratory and Sandia Laboratories), and contractors funded directly by DOE or through PNL.

The Wind Characteristics for Design and Performance Program area has benefited recently from an increased interaction with designers. A few of

the noteworthy activities in this program area for the current reporting period are listed below.

- Techniques were developed to estimate maximum velocity changes which occur over the disk of a WECS.
- A report was completed on the effect of generalized wind characteristics on estimates of annual power from a WECS.
- Wind data from the circular array of instruments in a vertical plane were reduced to provide a synthesized wind record representing the wind which would be experienced by the rotating blade of a horizontal axis WECS.

The Mesoscale Wind Characteristics Program area has two main goals. The first is to test and apply techniques for analyzing the wind energy potential over large areas. The second is to analyze the wind energy potential at specified locations, e.g., at sites which are candidates for testing and demonstrating wind machines. Major activities for the current reporting period are listed below.

- The development of a task plan entitled "Prototype Techniques for Analyzing Wind Energy Potential over Large Areas" was completed.
- Analyses of candidate site data were prepared in a special summary for the Site Review Board.
- Four different techniques for estimating wind characteristics for potential WECS sites were tested under four separate contracts.

The Development of Siting Methodologies Program area is to devise strategies for selecting specific sites for WECS installation, to develop tools to implement these strategies, and to supply this methodology to WECS users. Major activities during this reporting period are listed below.

- The acquisition of a sufficient data base to enable primary calibration of biological indicators of high wind speed.
- The development of the plan and procedure for the verification of numerical site screening techniques.

- An accelerated effort completing a handbook of siting procedure for small machines in simplified terminology.

The initial objectives of the wind characteristics for WECS operation program area are to identify specific wind forecasting needs of potential WECS users and to determine if current wind forecasting reliability meets these needs. Major activities in this area are listed below.

- Information on the wind forecasting needs of potential WECS users was obtained from 13 representatives of the utility community.
- Information on current wind forecast product and reliability was obtained from 20 different individuals and organizations in the business of producing wind forecasts.
- A working group meeting was held to get representatives of these two groups together for a discussion which would produce some conclusions and recommendations on forecasting for WECS operations.

The major activity in Special Studies during this reporting period has been an effort to provide the Small Systems Test Center at Rocky Flats with wind characteristics information needed for designing and testing small machines.

CONTENTS

SEMI-ANNUAL REPORT
FOR THE
WIND CHARACTERISTICS PROGRAM ELEMENT

1.0 INTRODUCTION

Pacific Northwest Laboratory (PNL) has been providing management and technical support for the Wind Characteristics Program Element (WCPE) of the Federal Wind Energy Program (FWEP) since April 1976. This semi-annual report to the Wind Systems Branch (WSB) of DoE's Division of Solar Energy describes the technical progress within the Program Element from July 1977 through December 1977. Progress during the period from April 1976 through June 1977 has been reported in the Annual Report of the Wind Characteristics Program Element, BNWL-2220 WIND-10.

Within the Federal Wind Energy Program, the WCPE is established to provide the appropriate wind characteristics information to those involved in energy program planning, design and evaluation of wind energy conversion systems (WECS), selection of sites for the installation of WECS, and the operation of WECS. The program contributions 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 descriptions of the day-to-day variability and predictability of wind energy for WECS operations. To accomplish these goals, 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

There is some overlap among these program areas, but careful monitoring and good communications prevent duplication of effort. A discussion of the relationship of the program areas in terms of time and space scales is

provided in the introduction of the annual report mentioned above. However, due to some title changes and shifting of emphasis during this reporting period, the overall goals of each program area will be presented here.

The Wind Characteristics for Design and Performance Evaluation Program area is concerned with the direct interaction between meteorological phenomena and a WECS. It is divided into two subareas. The design portion of the program area will characterize wind and other meteorological phenomena. Performance evaluation will recommend meteorological instrumentation, instrumentation deployment, data collection, and analysis techniques for testing WECS. The WCPE does not intend to design WECS nor to evaluate their performance; it will provide meteorological support to those involved in such activities.

The Mesoscale Wind Characteristics Program area has two main goals. The first is to develop and present analyses of the wind energy potential over large areas. These analyses are to identify smaller areas of favorable wind characteristics and to quantify the wind energy potential over the whole area. The second major goal of this program area is to analyze the wind energy potential at specified locations, e.g., at sites which are candidates for testing and demonstrating wind machines.

The Development of Siting Methodologies Program area is to devise strategies for selecting specific sites for WECS installation, to develop tools to implement these strategies, and to supply this methodology to WECS users. To meet its ojectives, this program area has been divided into three sections:

- Site Screening and Localization Technique Development
- Verification of Siting Techniques
- Documentation of Siting Strategies.

The Wind Characteristics for WECS Operations Program area is a FY-1978 addition to the WCPE. The initial objectives of this program area are to identify specific wind forecasting needs of potential WECS users and to determine if current wind forecasting reliability meets these needs.

In addition to the four technical program areas described above, another effort has been established and titled Special Studies. This effort

is designed to provide technical assistance to the WSB and other FWEP elements on a fast response basis. Each study has a specific end product and a short time duration. New studies initiated in this area, which develop into longer term efforts, are to be transferred to the appropriate technical program area and included in the planning of that area.

The technical progress covered in this report includes that accomplished directly by PNL, other DOE laboratories (Lawrence Livermore Laboratory and Sandia Laboratories), and contractors funded directly by DOE or through PNL. The format of this report is the same as the previous annual report.

What follows is divided into two parts. The first (Section 2.0) describes the overall progress of each of the program areas by briefly covering the more significant items. This should provide an integrated view of the total program's progress during the past six months and the expected progress during the rest of the year. The second part (Section 3.0) contains a breakdown of the progress by individual tasks within the technical program areas. The organization of these tasks within the program areas is defined in the Summary of the Development Plan for the Wind Characteristics Program Element of the Federal Wind Energy Program, BNWL-2501.[1] This summary document contains the essential elements of the October 1, 1977, program development plan for the WCPE. The interrelationships between tasks is described and a proposed projection through FY-1980 of the research in the program areas is presented.

The philosophy behind the semi-annual report is not to provide a wealth of technical detail, but to provide the reader with enough information to lead him to a detailed report or to lead him to a personal contact which will promote a fruitful information exchange.

2.0 PROGRESS IN RESEARCH AREAS

In Section 2.1 technical progress is described for the period July 1977 through December 1977. In Section 2.2 expected progress for the next semi-annual period is discussed.

2.1 PROGRESS DURING REPORTING PERIOD

In managing the WCPE, PNL has continued its efforts to provide the assistance necessary for achieving the goals of the Federal Wind Energy Program as defined in the summary report of the program.[2] The primary role of PNL in this effort is to plan, coordinate, and to monitor research and development activities by industry, universities, and other research organizations. In this reporting period, the WCPE conducted these activities in contractual efforts with 7 universities, 9 private research organizations, in coordinating efforts with 2 government laboratories, and in consulting agreements with one private firm and one private individual. The in-house research effort at PNL is designed to aid in the rounding out of the program effort, to mount initial thrusts where appropriate, and to increase the effectiveness of the coordination activity.

The overall effort of the WCPE is defined in a program development plan submitted annually to the Wind Systems Branch of DoE. The plan for FY-1978 was revised and accepted during the first half of this reporting period. As was mentioned above, a summary version of the document has been prepared for publication.[1] The major change from the previous year's efforts was the establishment of a consolidated management structure with more emphasis on the planning and review processes as well as scheduling and control functions.

At the Third Biennial Conference and Workshop on Wind Energy Conversion Systems in September, the WCPE was well represented in both the presentation and workshop sessions by contractor and PNL personnel. The information exchange and personal contact between the participants with backgrounds in the broad spectrum of disciplines involved in wind energy conversion proved very beneficial to the planning efforts in the WCPE. The proponents of

small machines made a strong case for the need for more attention to this area. In response to this information, an effort was accelerated within the WCPE to produce a siting document in simplified terms for the potential users of small machines.

To promote further the interaction and information exchange between participants in wind energy conversion development and potential users of wind energy, a working group discussion on wind forecasting and WECS operations was held December 15 in Richland, Washington.

2.1.1 Wind Characteristics for Design and Performance Evaluation

One of the major accomplishments in the portion of this program concerned with supporting WECS design efforts was an increased interaction with the designers. This has resulted in a better understanding of their needs and has provided the designers with more awareness of the type of meteorological and environmental information available to them. Further interaction of this type will be pursued to improve the mutual awareness of problems and to avoid duplication of effort.

In the task entitled "Environmental Design Criteria for WECS" (3.1.1), there were several accomplishments worthy of note. Techniques were developed to estimate the maximum velocity changes which are expected to occur over the disk of a WECS during a given period of record. A report was completed on the effect of generalized wind characteristics on estimates of annual power from WECS. Also in this task, measured frequency distributions associated with high annual wind speed sites were documented.

One of the tasks in this program area which has turned out to be of particular interest to designers is the one in which wind flow is measured with instruments arranged in a circular array in a vertical plane (3.1.4). During this reporting period the field test data has been reduced to provide a synthesized wind record simulating the wind which would be experienced by the rotating blade of a horizontal axis machine. Also accomplished was a comparison of the array averaged wind speed with the wind speed at hub height.

2.1.2 Mesoscale Wind Characteristics

This program area has been organized into three general sections. In the first section the major concern is with the analysis of wind energy potential over large areas. Initial analyses of this type were carried out on a national scale in the early phases of the FWEP. The results of these analyses were suited mainly to preliminary planning purposes. More detailed wind energy considerations for areas the size of one or several states require a more stringent analysis than was possible in the time allotted for the initial national assessments.

For this reason, the main task in this section of the program area is to test and apply prototype techniques for the analysis of wind energy potential over large areas (3.2.1). During this reporting period, a plan for this task was developed and coordinated with WSB. After WSB approval of the task description, initial efforts were begun. A data screening technique was developed and testing begun on data sources, untapped in the national assessments, and analytical techniques appropriate for large-scale analyses. Among the latter were techniques which involved the use of biological indicators and the use of satellite imagery.

In the second section of this 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. This section was moved from the special studies effort, because it appeared to have longer term potential. Under this effort last year, PNL staff was involved in preparing reports from site visits to 13 of the 17 candidate sites, as well as the analysis of the data from the sites. During this reporting period, analyses of the site data were prepared in a special summary for the Site Selection Board. Also during this reporting period, a significant effort was devoted to assisting WSB in the preparation of a Program Opportunity Notice for the establishment of a new set of candidate sites.

Also in the second section of this program area is a contract effort to test techniques for estimating wind characteristics for potential WECS sites. The effort involves four separate contractors working independently with different techniques (3.2.3 through 3.2.6). However, all four

techniques are being applied to the same eight sites. Since all eight sites specified are candidate sites, each site will have an excellent data base with which to verify and evaluate the techniques during the next reporting period.

The third general section of the Mesoscale Wind Characteristics Program area is devoted to supplementary studies which will contribute to the overall goals of the program area. These studies provide information which will allow more effective analyses of wind energy potential over large areas and at specific sites. The University of Wyoming is developing and testing techniques for screening large areas with satellite imagery to identify smaller areas of promising wind energy potential (3.2.7). Northwestern University is continuing to investigate the minimum required time period and frequency of data collection to obtain reliable site wind characteristics within specified confidence limits (3.2.8). Sandia Laboratories is examining the long-term variability of wind energy (3.2.9). Georgia Institute of Technology has developed statistical methods with which wind power from large arrays can be simulated from single site statistics (3.2.10). These methods have been tested on several arrays in various areas of the United States.

A PNL study was initiated to conduct a literature review to identify the current state of knowledge of wind characteristics in various types of complex terrain (3.2.11). A draft report has been prepared for review. The report describes current information on wind flow over specific types of terrain features and relevant research required to provide information which will improve analyses of wind energy potential in areas of complex terrain.

The University of Virginia is conducting a study which is producing information and techniques which will aid in the analysis of wind energy potential in the coastal regime from Texas to Maine (3.2.12).

2.1.3 Development of Siting Methodologies

This program area is organized into three general sections. The major concern of the first section is site screening and localization techniques development. Research and development in this section is being carried out in the areas of numerical modeling (3.3.1, 3.3.2, 3.3.6, 3.3.7), physical

modeling (3.3.3), biological indicators (3.3.4), and direct measurement (3.3.5). The significant accomplishments during this reporting period were the acquisition of a sufficient data base to enable primary calibration of biological indicators of wind speed (3.3.4). Several indicators show promise for providing useful estimates of mean annual wind speed. Another notable accomplishment was the demonstration, in a numerical modeling study, of the sensitivity of intensity and location of maximum winds on a hill to small changes in temperature lapse rate and the height and strength of a low level inversion.

The second general section of this program area deals with the verification of site screening techniques. The major accomplishment in this section was the development of the plan and procedure for the verification of numerical site screening techniques (3.3.8). Data sets for verification exercises have been selected. The verification criteria have been proposed.

The third general section in this program area deals with documentation of siting strategies. One of the prime functions of the WCPE is to disseminate the results of its research and development activities in usable format and as rapidly as possibly. Two siting handbooks, one for large WECS and one for small WECS, were completed and sent out for review during this reporting period. The reviews of these documents indicated a need for some reorganization. In the case of the handbook for small machines, a need for a simplified document was indicated. An accelerated effort was mounted to produce such a document (3.3.10).

2.1.4 Wind Characteristics for WECS Operations

Work began in this program area for the first time during this reporting period. The initial efforts were concerned with identifying the wind forecasting needs of potential WECS users and with determining if current wind forecasting reliability can meet these needs (3.4.1). Information concerning wind forecast needs was gathered from both research and operations personnel of large and small utilities. Information on current forecast products and reliability was obtained from individuals and organizations in the business of producing wind forecasts. A working group discussion meeting was held and a report of findings and recommendations was in preparation at the close of this reporting period.

2.1.5 Special Studies

This effort was established to provide technical assistance to the WSB and other FWEP elements on a fast response basis. During this reporting period the major effort in assistance to another FWEP element has been a liaison activity with the Small Systems Test Center at Rocky Flats. The main thrust of this effort has been to provide Rocky Flats personnel with wind characteristics information needed in the design and testing of small machines.

Another effort conducted under Special Studies has been concerned with gust amplitude estimates (3.5.1). The estimates are of the number of gusts of a given amplitude that will be experienced by a WECS during a given period. A report has been prepared containing a revised format for presenting the estimates.

2.2 EXPECTED PROGRESS DURING NEXT PERIOD

Expected progress during a future period is generally based on a current perception of needs and priorities. Because of the dynamic nature of a new program, especially in the interactions between the development and user communities, expected progress and actual progress will not always coincide exactly. Specific expected progress for each of the tasks is reported in Sections 3.1 through 3.5. In this section highlights of the expected progress in each of the program areas are presented.

2.2.1 Wind Characteristics for Design and Performance Evaluation

The primary products of this program area are reports and documents for use by those involved in machine design. During the next reporting period, documentation of initial velocity change guidelines will be complete. Work will be conducted to show the quantitative effect of turbulence on the estimates of WECS power output.

In the task entitled "Flow Through a Vertical Plane" (3.1.4), a report of the analyses of the data from the 24.4 meter array will be completed and published. The data from the tapes from this initial field test are publicly available. The establishment of the 49 meter array will be accomplished along with initial checkout and preliminary measurements.

2.2.2 Mesoscale Wind Characteristics

The task entitled "Prototype Techniques for Determining Wind Energy Potential over Large Areas" will be moved forward rapidly during this reporting period. A preliminary report of results and recommendations will be prepared in July 1978.

In the effort involving analysis of wind potential at specified sites, the analysis and reporting of the data from the original candidate sites will continue. Support will be supplied as needed in the data analyses and documentation of new candidate sites.

In January 1978, a working group meeting will be held with the four contractors who will have completed their efforts on "Estimation of Wind Characteristics at Candidate Sites." The conclusions and recommendations from this meeting will initiate a task for comprehensively verifying the techniques. A report describing the effectiveness of the techniques and the guidelines for applying the techniques will be prepared in July 1978.

Two studies involving innovative techniques for estimating the locations of high wind areas will be initiated in February 1978.

2.2.3 Development of Siting Methodologies

The first documented site screening methodology employing numerical models will be produced (3.3.2). The plan for verification of site screening by numerical model will be reviewed for approval by all concerned in the exercise. The actual verification exercise will begin during the next reporting period.

The report in simplified terminology for describing a strategy for the siting of small WECS will be completed and submitted for review in January 1978. The interim siting for large WECS will be revised for dissemination.

2.2.4 Wind Characteristics for WECS Operations

The report of the results and recommendations from the working group meeting on wind forecasts for WECS operations will be prepared for review in January 1978. These recommendations, along with information received subsequent to the meeting, will serve as a basis for initiating a research effort into wind forecast applicability and reliability for WECS operations.

2.2.5 Special Studies

The coordination effort with the Small Systems Test Center will be increased to meet the needs of the expanding program at Rocky Flats.

New problem areas will be identified and research plans proposed to meet the needs in these areas.

As clear-cut, sustained task efforts evolve, they will be transferred to the Wind Characteristics for Design and Performance Evaluation area.

3.0 PROGRESS IN TECHNICAL TASKS

In this section progress is briefly described in each of the technical tasks which were active during this reporting period. Tasks are identified by a title and a task identifier from the Development Plan for the Wind Characteristics Program Element, dated October 1, 1977. As was mentioned earlier, the essential information is included in a summary document prepared for dissemination.[1]

Technical tasks are funded on the basis of needs and priorities in the program. Projected completion dates, under the heading of Program Status, which extend beyond the present contract period, have been established for planning purposes only. Funding beyond the period of the present contract is based on a careful review of priorities and previous productivity.

A list of FWEP reports on wind characteristics research, which have been given UC-60 distribution, is provided in Appendix A.

3.1 WIND CHARACTERISTICS FOR DESIGN AND PERFORMANCE EVALUATIONS

3.1.1 Environmental Design Criteria for WECS (A1a)

Battelle, Pacific Northwest Laboratory
Richland, WA 99352

Principal Investigator:
William C. Cliff (509) 942-5066

Objective:

To describe, define and provide to DOE/HQ and other elements of the FWEP the state-of-the-art wind characteristics needed for WECS design.

Program Status:

This effort began in FY-1977 and will continue throughout FY-1978 and FY-1979.

Progress During Reporting Period:

Techniques have been developed which provide velocity change guidelines associated with WECS of various sizes operating in various climatologies.

Measured frequency distributions associated with high annual wind speed sites were documented. A method to estimate the effect that WECS operating characteristics and generalized wind characteristics have on annual power estimates was documented in a PNL report. A state-of-the-art literature survey of turbulence intensity versus surface roughness was completed, from which empirical curves were fit to estimate the turbulence intensity as a function of surface roughness and to show the effect of altitude on turbulent intensity. The results of this turbulent intensity study are presented in Fig. 3.1-1.

Expected Progress During the Next Period:

Documentation of gust rise time evaluation techniques and sample cases will be completed. A model of hourly wind speed persistence will be documented. The development of

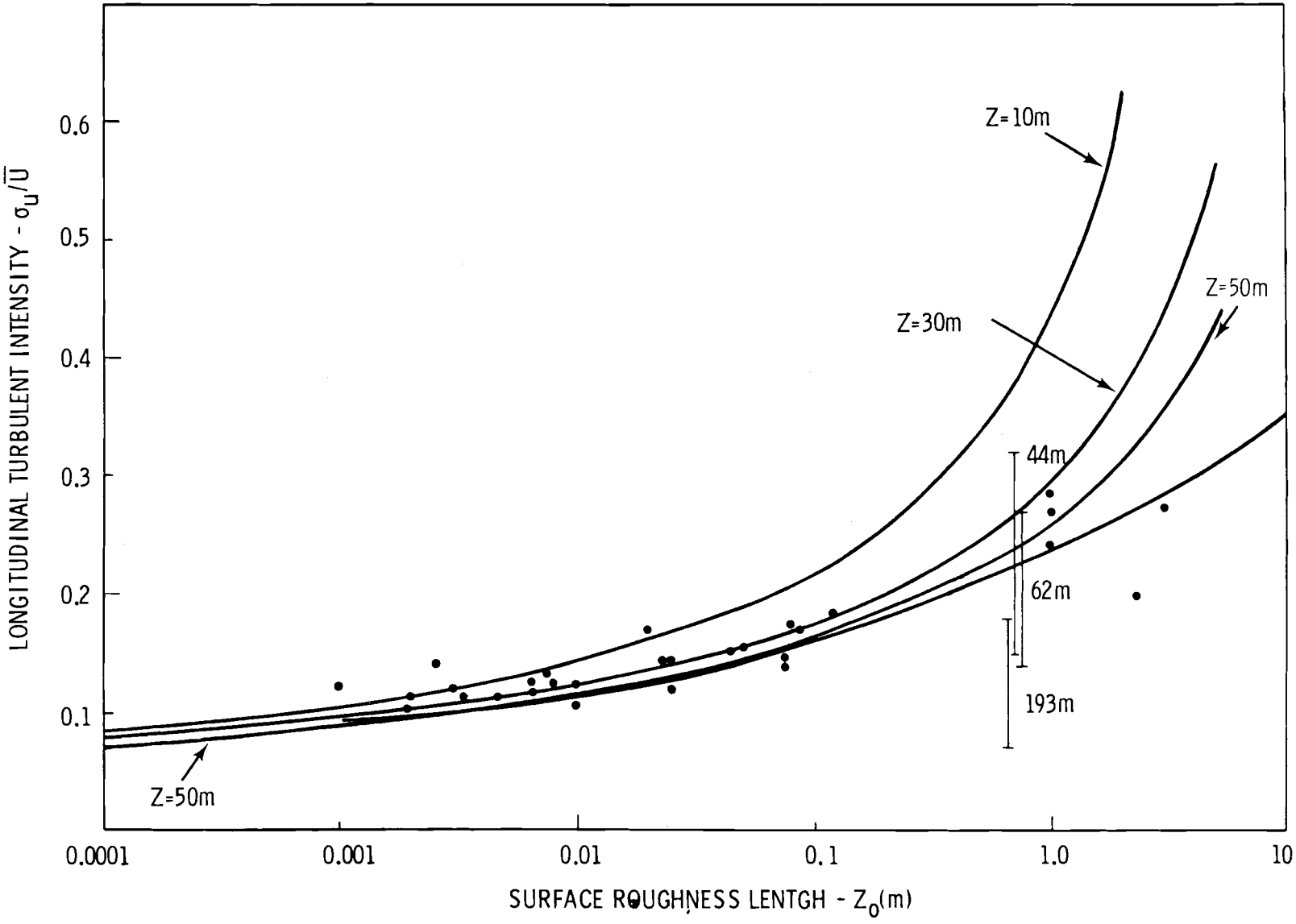

Figure 3.1-1 Variation of the Longitudinal Turbulent Intensity with Surface Roughness Length for Various Heights

techniques for wind direction variability will be started. Comparisons of conventional spectra will be performed.

Reports and Publications:

Cliff, W. C., The Effect of Generalized Wind Characteristics on Annual Power Estimates from Wind Turbine Generators, PNL-2436, Battelle, Pacific Northwest Laboratories, Richland, WA 99352, October 1977.

3.1.2 Error Band Analysis on Conventional Data (A1b)

Battelle, Pacific Northwest Laboratory
Richland, WA 99352

Principal Investigator:
William C. Cliff (509) 942-5066

Objective:

Provide a measure of the data spread, variance and/or statistical confidence intervals associated with empirical curve fits to conventional meteorological data.

Program Status:

Initial efforts began this period and will be accelerated during the next period.

Progress During Reporting Period:

Surveys of the data spread associated with

- turbulent intensity as a function of surface roughness and power law exponent;
- angular variability as a function of stability; and
- power law exponent as a function of surface roughness

were performed (Fig. 3.1-2).

These studies indicate that significant variations can occur with the above topics, which indicates that a system which is sensitive to any of the above parameters should include the spread of the data in the systems analysis. For example, Figure 3.1-2 shows the various empirical curves which have been used to estimate the power law index, p, as a function of surface roughness for neutral atmospheric conditions. The data, taken from existing literature, shows the variance observed in nature which makes it difficult to describe the power law index as a function of surface roughness with a single curve for WECS design.

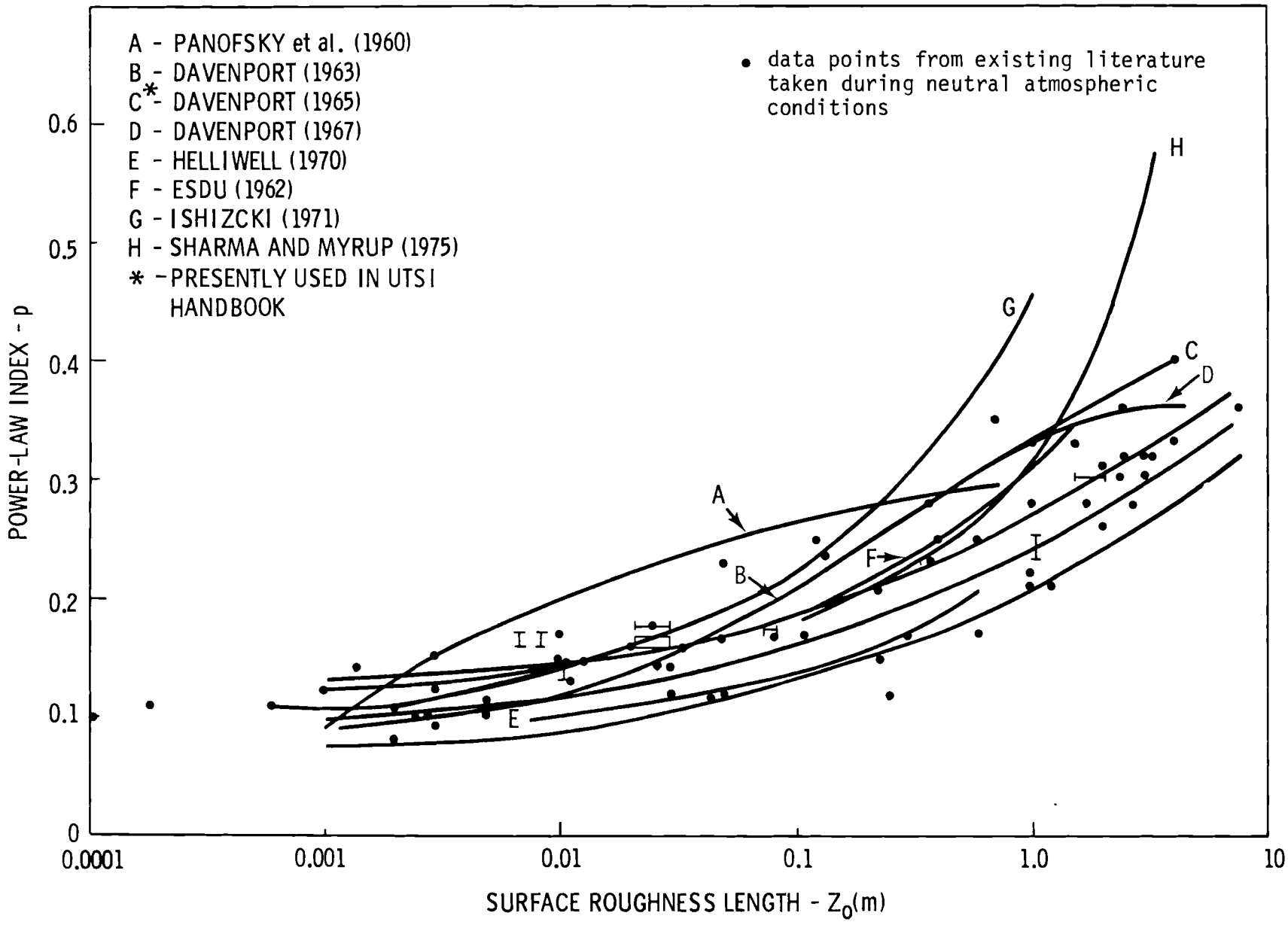

Figure 3.1-2 Variation of the Power-Law Index with Surface Roughness Length

Expected Progress During the Next Period:

Error analysis to be continued and concentrated on environmental guidelines presently used in wind turbine generator design. Variations in techniques used to compute gust rise times will be documented.

Reports and Publications:

None

3.1.3 Departures From WECS Operating Envelope (A1d)

Battelle, Pacific Northwest Laboratory
Richland, WA 99352

Principal Investigator

Thomas C. Kerrigan (509) 942-5038

Objective:

Qualitatively examine the effects of turbulence on control policy.

Program Status:

Postponed; machine specific work originally planned was determined to be the responsibility of the DOE machine development programs.

Progress During Reporting Period:

Computer program completed for a specific control policy.

Expected Progress During the Next Period:

No immediate plans for more general studies.

Reports and Publications:

None

3.1.4 Flow Through a Vertical Plane (A1c)

Battelle, Pacific Northwest Laboratory
Richland, WA 99352

Principal Investigator:
M. Gary Verholek (509) 942-0885

Objective:

Provide a field test program to examine the flow field passing through a disk of rotation to provide measurements consistent with a wind environment that a WECS would encounter.

Program Status:

Initial phase of a 24.4 meter diameter array complete. Documentation of initial phase in progress. Forty-nine meter diameter array test setup is being established.

Progress During Reporting Period:

Data collection was completed and initial analysis was performed, including the development of synthesized wind records corresponding to the wind field experienced by a rotating element at a radius of 12.2 meters and a rotation rate of 75 rpm. Velocity changes, direction changes, for both hub anemometer and average over the disk (arithmetic average of 9 anemometers) have been performed.

Figure 3.1-3 graphically depicts a 15-second record taken during the field program comparing the hub velocity to the velocity averaged over the disk of rotation. Other statistical analyses included spectra for hub anemometer and disk average showing the attenuation of high frequencies which result from spacial averaging.

Expected Progress During the Next Period:

Final report on initial field test program to be completed. Initial check-out and preliminary measurements from 49-meter array will be performed.

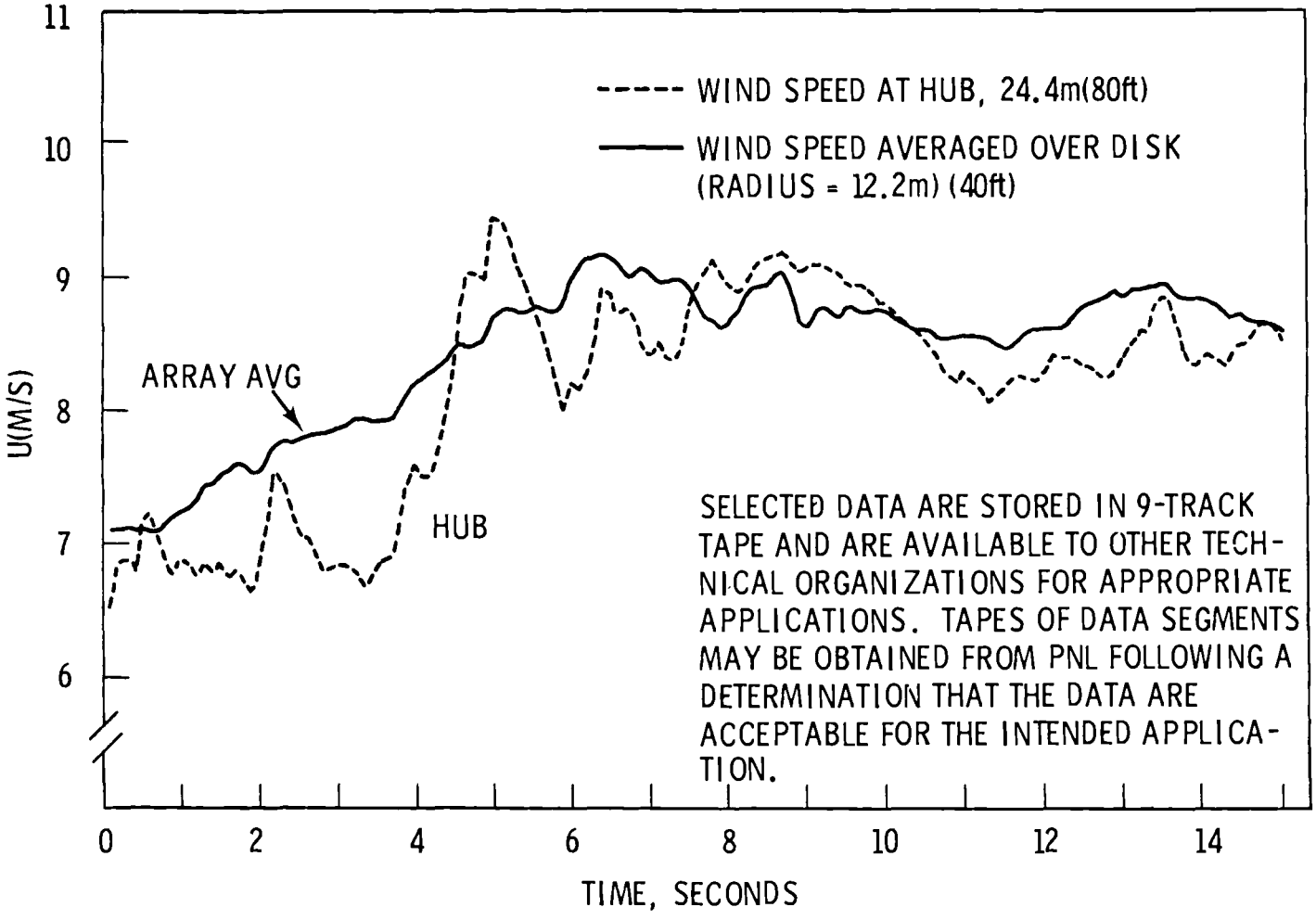

Figure 3.1-3 Wind Speed at Hub Versus Wind Speed Averaged Over Disk

Reports and Publications:

Cliff, W. C., and M. G. Verholek, 1977, Flow Field Analysis, Proceedings of the 1977 Workshop on Wind Turbine Structural Dynamics Conference, Nove. 15-17, 1977, NASA/Lewis, Cleveland, Ohio.

3.1.5 Meteorological Instrumentation and Data Analysis Requirements for Performance Evaluation (A2)

Contract No.: 5189-76-32

Sandia Laboratories
Albuquerque, NM 87115

Principal Investigator:

Robert E. Akins (505) 264-3042

Contract Monitor:

William C. Cliff (509) 942-5066

Objective:

To develop uniform field test procedures, data collection, and data analysis techniques to be used on meteorological measurements for WECS performance evaluation.

Program Status:

Initial efforts underway to develop field test procedures for performance evaluation.

Progress During Reporting Period:

When a single anemometer is used for performance evaluation, its placement at the height of the center of rotation was shown to yield results representative of the average velocity integrated over the disk of rotation for a horizontal axis WECS.

Expected Progress During the Next Period:

Initial proposed field test procedures for WECS performance evaluation will be documented.

Reports and Publications:

Cliff, W. C., and M. G. Verholek, 1977, Flow Field Analysis, Proceedings of 1977 Workshop on Wind Turbine Structural Dynamics Conference, Nov. 15, 16, 17, 1977, NASA/Lewis, Cleveland, Ohio.

3.2 MESOSCALE WIND CHARACTERISTICS

3.2.1 Prototype Techniques for Analyzing Wind Energy Potential Over Large Areas (B1a)

Battelle, Pacific Northwest Laboratory
Richland, WA 99352

Principal Investigator:
Dennis L. Elliott (509) 942-5040

Objective:

To establish prototype techniques for analyzing wind energy potential over large areas and to test these techniques in describing the wind energy potential for a selected area.

Program Status:

The project was initiated in November 1977 and will continue through September 1978.

Progress During Reporting Period:

The Northwest United States, comprising the states of Washington, Oregon, Idaho, Montana, and Wyoming, has been selected for testing various techniques to define areas of high wind energy potential. This area is characterized by diverse climatic and topographic features, allowing a number of techniques to be tested.

All stations with summarized wind data available from the National Climatic Center have been acquired and are being analyzed. Wind data for stations without summaries are being screened to identify additional windy areas. These data will be further evaluated in the most promising areas. In addition, wind data from other sources are also being identified. This data base is now roughly four times the size of the data base used in the national assessments.

Anemometer height and exposure histories have been acquired for all sites (where available) and will be incorporated into the analyses. Other factors being considered include

the site location with respect to local topography, the frequency of observation, and the record period.

Other data sources and analytical techniques are also being tested in this study. These include: 1) use of biological indicators of wind energy, being studied by the Oregon State University (see also Task C1d); 2) use of Landsat imagery of Aeolian features, being studied by the University of Wyoming (see also Task B3a); and 3) use of fire weather wind data available from the U. S. Forest Service, being examined by Marlatt and Associates, Ft. Collins, CO. The distribution of these data are shown in Fig. 3.2-1. In addition, PNL will examine synoptic pressure gradients, terrain characteristics, and upper airflow patterns to identify meteorological and topographical features associated with high wind energy areas and the conditions under which the high wind energy occurs. This study is being coordinated with the needs of other federal agencies in the selected region which are examining the possibility of implementing wind energy. These agencies include the Bonneville Power Administration's study to combine the use of wind energy with hydroelectric power in the Northwest and the Bureau of Reclamation's study of implementing a large array of wind energy conversion systems in the Medicine Bow, Wyoming, region.

Expected Progress During the Next Period:

An analysis of the wind characteristics and wind energy potential of the Northwest based on a synthesis of the data and analytical techniques used in this study will be made. A report will be written which documents the procedures which can be used in analyzing data and implementing various techniques to determine wind energy potential over large areas.

FIRE WEATHER STATIONS IN THE NORTHWEST

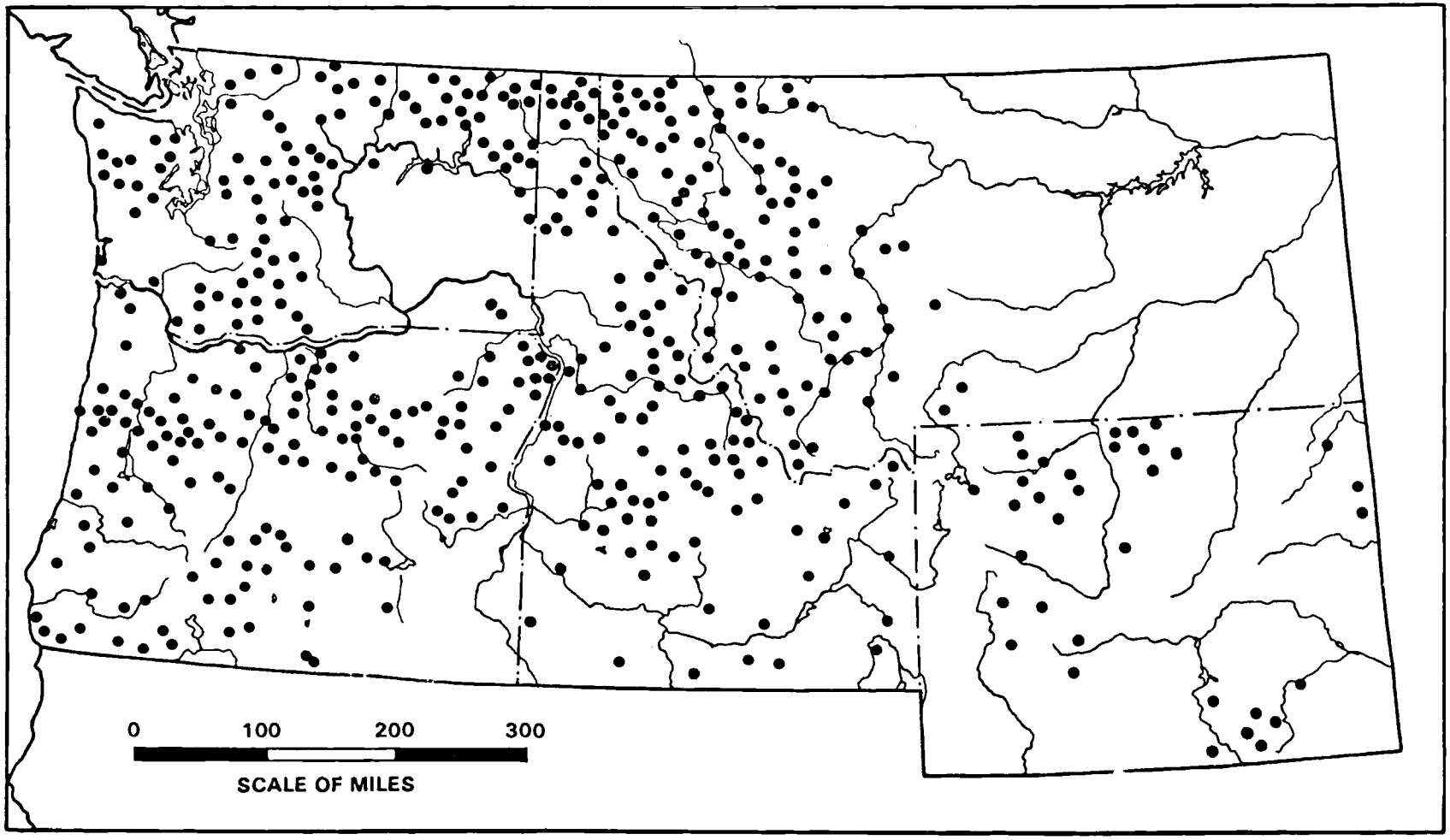

Figure 3.2-1 USDA Forest Service Data in the Northwest

Reports and Publications:

Elliott, D. L., An Overview of the National Wind Energy Potential, to be presented at the Conference on Climate and Energy: Climatological Aspects and Industrial Operations, May 8-12, 1978, Asheville, North Carolina.

3.2.2 Candidate Site Meteorological Documentation (B2a, B2b)

Battelle, Pacific Northwest Laboratory
Richland, WA 99352

Principal Investigator:

M. Gary Verholek (509) 942-0885

Objective:

To provide assistance to DOE in selecting sites for testing of large wind machines by analyzing and summarizing onsite meteorological data.

Program Status:

The program began in April 1976 and is continuing for the 17 candidate sites. Identification and meteorological documentation of additional potential sites for testing DOE-sponsored wind machines is anticipated.

Progress During Reporting Period:

Monthly reports on the data analyses based on published summaries provided by NASA/LeRC continue to be prepared for DOE. A special summary of candidate site data was prepared to provide assistance in the selection of the first Mod-1 testing site.

Expected Progress During the Next Period:

Analysis and reporting of summarized data collected at the original 17 candidate sites will continue. It is anticipated that additional potential testing sites will be acquired through publication of a Program Opportunity Notice, and that these sites will be instrumented for meteorological documentation.

Reports and Publications:

None

3.2.3 Techniques for Estimating Wind Characteristics at Potential WECS Sites (B2c)

Contract No.: B-29083-A-E

Geomet, Incorporated
15 Firstfield Road
Gaithersburg, MD 20760

Principal Investigator:
Robert C. Koch (301) 948-0755

Contract Monitor:
David S. Renne (509) 942-6717

Objective:

The objective of this study is to provide a description of a technique for estimating wind characteristics at a site on the basis of available data at other locations, and to provide estimates of pertinent hub-height wind characteristics at 8 specified locations.

Program Status:

This contract began in July 1977 and will terminate in January 1978.

Progress During Reporting Period:

All available station wind data from around each of the candidate sites has been obtained from the National Climatic Center and from private sources. The data from the NCC is on TDF-14 tapes. The location of these stations and of the candidate sites has been plotted on USGS topographic maps. The hourly station wind data is first extrapolated to the 150-foot hub height using a power law formula that is a function of the surrounding terrain roughness. The wind data is then interpolated to the candidate site using an interpolation scheme that is a function of the inverse square of the distance from the station to the site. For sites in complex topography, a simple analytical equation which estimates a wind speed-up factor as a function of

terrain height at the candidate site and the gradient wind level is applied. The gradient wind level is determined from a relationship published in Haltiner and Martin (1957)*. Wind characteristics statistics at the candidate site are then determined by interpolating the hourly data values for a ten-year period.

Frequency distributions of gusts are determined by investigation of strip chart records of wind speeds from selected National Weather Service Stations. These strip chart records are available at the National Climatic Center.

Expected Progress During the Next Period:

The analyses for the 8 candidate sites will be completed and a final report summarizing the techniques and the results of the analysis will be submitted. In addition, the Principal Investigator will attend a working group meeting on this task in Richland, Washington, on January 26, 1978.

Reports and Publications:

None.

*Haltiner, G.L. and F. L. Martin, 1957: Dynamical and Physical Meteorology, McGraw-Hill, New York.

3.2.4 Techniques for Estimating Wind Characteristics at Potential WECS Sites (B2c)

Contract No.: B-29105-A-E

SRI International
333 Ravenswood Avenue
Menlo Park, CA 94025

Principal Investigator:

Chandrakant M. Bhumralkar (415) 326-6200

Contract Monitor:

David S. Renne (509) 942-6717

Objective:

The objective of this study is to provide a description of a technique for estimating wind characteristics at a site on the basis of available data at other locations, and to provide estimates of pertinent hub-height wind characteristics at 8 specified locations.

Program Status:

This contract began in July 1977 and will terminate in January 1978.

Progress During Reporting Period:

During this period, data from three or four National Weather Service stations around each of the eight candidate sites (Boardman, OR; San Gorgonio Pass, CA; Huron, SD; Russell, KS; Ludington, MI; Boone, NC; Holyoke, MA; and Montauk Point, NY) were acquired from the National Climatic Center. After extrapolating the data to hub height using a power law formula, eigenvectors of u and v wind components are developed for each station from the hourly data. These eigenvectors are used to obtain a u and v component at each grid point around the site using a simple interpolation model. From these initial u and v components, a three-dimensional complex terrain objective analysis model called SIGMA is applied to generate wind statistics at the candidate

site. Use of the eigenvectors, instead of actual hourly data, allows statistical wind characteristics to be developed without the need for extensive model runs. This technique has been applied to the Boardman site as an initial test.

Expected Progress During the Next Period:

The technique will be applied to the other seven sites to generate wind characteristics. It will be validated using available meteorological data collected for a specific purpose (e.g., licensing of a proposed power plant). Gust statistics will be developed for the eight sites using observed gust data obtained from the National Climatic Center. A final report will be prepared, and the Principal Investigator will participate in a working group meeting on the subject to be held in Richland, Washington, on January 26, 1978.

Reports and Publications:

None.

3.2.5 Techniques for Estimating Wind Characteristics at Potential WECS Sites (B2c)

Contract No.: B-29084-A-E

Center for the Environment and Man, Inc.
275 Windsor Street
Hartford, CT 06120

Principal Investigator:

Marshall A. Atwater (203) 549-4400

Contract Monitor:

David S. Renne (509) 942-6717

Objective:

The objective of this study is to provide a description of a technique for estimating wind characteristics at a site on the basis of available data at other locations, and to provide estimates of pertinent hub-height wind characteristics at eight specified locations.

Program Status:

This contract began in July 1977 and will terminate in January 1978.

Progress During Reporting Period:

A technique was developed which utilizes existing data around a candidate site and interpolates the statistical summary of these data to the candidate site using an inverse-distance interpolation scheme modified by a weighting factor which accounts for data quality, topographical effects, and effects of nearby water bodies. By utilizing this weighting factor, no other distance effect is applied in the interpolation scheme. The data at the nearby measuring stations was acquired from the National Climatic Center for each candidate site. Prior to incorporating these data into the interpolation scheme, wind statistics at hub height at each weather station were generated using an application of Deacon's profile in the first 40 m (the atmospheric

surface layer), and a power law profile to the free air height identical to the hub height at the candidate site. These statistics are then horizontally interpolated to the candidate site. Peak gusts are determined by assuming they are dependent upon the fluctuation statistics of the longitudinal velocity component and are a function of height, surface roughness, mean wind speed, and atmospheric stability. It is further assumed the magnitude of these gusts decreases with height to the hub height of the machine.

Expected Progress During the Next Period:

A final report will be submitted summarizing the technique and the results of its application to the eight candidate sites. In addition, the Principal Investigator will attend a working group meeting on this task in Richland, Washington, on January 26, 1978.

Reports and Publications:

None.

3.2.6 Techniques for Estimating Wind Characteristics at Potential WECS Sites (B2c)

Contract No.: B-29082-A-E

Meteorology Research, Incorporated
Box 637
Altadena, CA 91001

Principal Investigator:
Steven M. Howard (213) 791-1901

Contract Monitor:
David S. Renne (509) 942-6717

Objective:

The objective of this study is to provide a description of a technique for estimating wind characteristics at a site on the basis of available data at other locations, and to provide estimates of pertinent hub-height wind characteristics at eight specified locations.

Program Status:

This contract began in July 1977 and will terminate in January 1978.

Progress During Reporting Period:

All available stations for possible use at each candidate site were surveyed. For each site, a "primary" data station was selected based on data availability and distance from the site. "Secondary" data stations were also selected. Many of these data were obtained from the National Climatic Center. A correlation of the wind at the primary with the secondary station was determined for each site. A hydrodynamic wind flow model which incorporates terrain effects, was run for selected primary station wind speed and direction values at each site. The input to this model is a three-dimensional wind field determined by extrapolating the measured data to the hub height at the candidate site using a power law formula that allows for variation in

stability. The height of the gradient wind level was input to the model subjectively based on the prevailing height of the surrounding terrain. Regression relationships between the primary wind station and the candidate site at the 150 ft level were computed, and a wind climatology at each candidate site was developed from 15 years of hourly primary wind data. Peak gusts were estimated using previously-derived relationships.

Expected Progress During the Next Period:

A final report will be submitted summarizing the results of the study. The calculated wind speed distributions, distribution of wind speed with direction, diurnal distributions, run duration statistics, and gusts for each candidate site will be summarized. The Principal Investigator will participate in a working group meeting on this task in Richland, Washington, on January 26, 1978.

Reports and Publications:

None.

3.2.7 Locating High Wind Areas by Remote Observations of Aeolian Features (B3a)

Contract No.: EY-76-S-06-2343

University of Wyoming
Department of Geology
Laramie, WY 82071

Principal Investigator:

Ronald W. Marrs (307) 766-2330

Contract Monitor:

David S. Renne (509) 942-6717

Objective:

To develop an efficient way to identify high wind energy sites by inferring wind characteristics from aeolian geomorphologic features mapped from LANDSAT and aircraft imagery, and to determine the applicability of the techniques for other areas.

Program Status:

This program was initiated in September 1976 and was continued through October 1977. Recommendation has been made to extend the contract through September 1978.

Progress During Reporting Period:

This research effort has been divided into three tasks: 1) determine the utility of stabilized aeolian features as indicators of present-day wind characteristics, 2) develop techniques for quantitatively estimating wind characteristics from the aeolian features, and 3) assess the regional applicability of LANDSAT imagery for locating areas of high wind energy potential.

The purpose of Task 1 is to determine if stabilized aeolian features can be used to estimate wind characteristics as well as active aeolian features. Image interpretation and field work in the Seminoe test area was completed. A

comprehensive technical report summarizing that work is now in preparation. Results of this work suggest that stabilized aeolian features are reliable indicators of wind patterns and may prove even more useful than active features because they are considerably more wide-spread.

The purpose of Task 2 is to quantify the wind energy associated with aeolian features observed from aircraft and satellite imagery. Aircraft measurements of the three-dimensional wind field at the Killpecker and Seminoe test areas confirm directions of flow and relative velocities inferred from the satellite images of the dunes and playas in the Wyoming test region. Calculations of mean wind velocities based on migration rates of active dunes in the Killpecker field give values which compare reasonably well with measurements at nearby weather stations. However, local variation in the calculated mean wind velocities cannot be confirmed without long-term monitoring of the winds at those same sites.

The purpose of Task 3 is to demonstrate applicability of image interpretation to assessment of wind-energy potential by examination of aeolian features in other regions. A wind-energy prediction map was first constructed for southern Wyoming by use of wind/landform relationships observed in the smaller test areas which lie within this region. These same procedures have since been applied to the area surrounding Richland, Washington, and a portion of north Texas.

Expected Progress During the Next Period:

Work proposed for the next semi-annual period includes continued effort to evaluate the procedures for quantitatively estimating mean wind velocities. This will include further evaluation of calculations from dune migration rates and grain size. Special flow conditions indicated by "spaced"

and "aligned" aeolian features will be examined through continued analysis of charts obtained by aircraft flights. These charts should also prove useful in evaluating local variations in wind velocity predicted by grain size analyses and migration of aeolian features. Investigators will begin compilation of a user's manual describing the procedures for interpreting wind characteristics from image data. Reports on the work in the Seminoe test area and north Texas will be completed.

The techniques will be applied to the Pacific Northwest as part of an overall program to develop prototype techniques for determining wind energy potential over large areas. Interpretations of LANDSAT imagery will be compiled as "wind characteristics" maps. Investigators will also assist in locating and indexing climatic data for the Pacific Northwest.

Reports and Publications:

The following were prepared during the reporting period:

Carlisle, W., Marrs, R. W., and Marwitz, J., 1977, Airflow Near Richland, Washington, Inferred from Eolian Features, Technical Report, September 1977, RLO/2343-77/4, University of Wyoming, Laramie 82071.

Marrs, R. W., and Marwitz, J., 1977, Locating Areas of High Wind-Energy Potential by Remote Observation of Eolian Geomorphology and Topography, presented at the 3rd Wind Energy Workshop, Washington, D.C., September 1977.

Kolm, K. E., and Marrs, R. W., 1977, Predicting the Surface Wind Characteristics of Southern Wyoming from Remote Sensing and Eolian Geomorphology, Final Report for October 1976 thru October 1977, RLO/2343-77/3, University of Wyoming, Laramie 82071.

3.2.8 Survey Methodology and Reliability Analysis for Site Wind Characteristics (B3c)

Contract No.: EY-76-S-06-2342

Northwestern University
Evanston, IL 60201

Principal Investigator:

Ross B. Corotis (409) 942-3453

Contract Monitor:

J. Chris Doran (509) 942-2861

Objective:

To develop and apply complete procedures for site evaluation, using probabilistic and statistical methods and models, including the establishment of the reliability of the characteristics.

Program Status:

This contract was begun in October 1976 and was completed in September 1977. A renewal contract was begun in September 1977 and will be completed in August 1978.

Progress During Reporting Period:

Data from a total of 20 sites were analyzed in terms of the statistical and probability models previously developed, and a number of conclusions were reached which are essentially independent of specific site locations. They include:

- One year of data is sufficient to predict the long-term seasonal mean wind velocities to within an accuracy of 10 percent with a confidence level of 90 percent.
- The Chi-2 or Rayleigh distribution is adequate to describe the velocity probability distribution. Deviations from observed values are generally no

larger than the year-to-year variability in the observed statistics themselves.

- A combination power law-exponential run duration or persistence model yields generally accurate results. This model depends upon a single parameter which can be obtained solely on the basis of the mean wind speed.
- In smooth terrain, for distances up to 100 km, the criteria developed for representativeness of data and the run persistence model can be applied throughout.

Expected Progress During the Next Period:

Additional data will be secured from U. S. Forest Service sites, candidate wind turbine test sites, and other sources of hourly or shorter-term data. The models already developed will be applied to these data sets. Model reliability will be determined. Techniques for the enhancement of short-term data from a potential WECS site by utilization of nearby long-term data will be investigated.

Reports and Publications:

Corotis, R. B., Stochastic Modelling of Site Wind Characteristics, Final Report, Northwestern University, Evanston, IL, November 1977.

Corotis, R. E., A. B. Sigl, and M. P. Cohen, Variance Analysis of Wind Characteristics for Energy Conversion, Journal of Applied Meteorology, 11, 1149-1157, 1977.

3.2.9 Meteorological Studies for Wind Power (B3d)

Contract No.: 5189-76-32

Sandia Laboratories
Sandia, NM 87115

Principal Investigator:

Jack W. Reed (505) 264-3042

PNL Contact:

David S. Renne (509) 942-6717

Objective:

The objective of this study is to develop various data-processing techniques for utilizing standard National Weather Service observations in defining various aspects of wind power availability, including time-dependent statistics, wind turbine speed limit effects, and run duration statistics.

Program Status:

This program started in 1973. The current study will be completed in September 1978.

Progress During Reporting Period:

A report has been prepared describing the data processing techniques and application of the various methodologies to 15 selected National Weather Service Stations around the United States. The first step in applying the methodology is to adjust the wind speed measurements to one common anemometer height of 6 m. From these data, wind speed distributions at four standard heights (anemometer height, 10 m, 20 m, and 50 m) at each of the selected stations has been developed. Time-dependent statistics of wind power availability have also been examined by studying the availability by months, seasons, years, and 10-year periods. In addition, assumptions about turbine cut-in, rated, and cut-out speeds have been studied to determine the effect on the

total available wind power for different climatic regimes. Run duration statistics have also been calculated from the data.

Expected Progress During the Next Period:

Additional reports will be submitted summarizing the data analysis and techniques. In addition, a revised printing of the document "Wind Power Climatology of the United States" will be distributed. Additional studies of wind statistics for the fifteen stations, including a study of the interannual variability in wind power, will be made.

Reports and Publications:

Reed, J. W., Wind Speed Distribution Changes with Height at Selected Weather Stations (Draft), SAND 76-0714, Sandia Laboratories, Sandia, NM, October 1977.

3.2.10 Energy Statistics for Large Wind Turbine Arrays (B3e)

Contract No.: EY-76-S-06-2439

Georgia Institute of Technology
Atlanta, GA 30332

Principal Investigator:

C. G. Justus (404) 894-3014

Contract Monitor:

D. S. Renne (509) 942-6717

Objectives:

To study wind energy statistics for large arrays of wind turbines such as those examined in New England, Central U.S., Great Lakes, and Pacific Coast areas. These array analyses produce information on time autocorrelation, spatial cross correlation, mean, seasonal and diurnal wind power output, wind power frequency distribution (reliability without storage), and wind power run durations (length of power outage periods).

Program Status:

The current contract began in May 1977 and continues through May 1978.

Progress During Reporting Period:

Statistical methods have been developed whereby the wind power output of large arrays can be simulated from single site statistics without resort to costly and time consuming time series analysis. Array analysis is continuing with emphasis on: larger arrays (multiregion) to take maximum benefit of diversity, refinement and verification of the simplified array simulation not requiring time series analysis of many sites. Parallel experimental studies are being conducted with a Grumman Windstream 25 installed on the Georgia Tech campus. A study of inter-annual variability of monthly mean winds has also been initiated.

The full continental array plus sub-arrays for Eastern plus Great Lakes, Great Lakes plus Central, and Central plus Pacific Coast have been analyzed and averaged for the years 1971 through 1973. These results have been analyzed, tabulated, and graphed in preparation for their reporting.

Data collection of monthly mean winds from approximately 40 sites with mean winds ≥5 m/s (11 mph) has been essentially completed for the interannual variability study. The program has been written and checked out which will be used to compute probability distribution of interannual changes in monthly mean winds, and time autocorrelation of monthly mean winds.

Experimental studies with the Grumman Windstream 25 have been hampered by electronic problems in the primary data logger and tape deck interface. Some data have been obtained on the back-up strip chart recorders. A further set-back is the recall by Grumman of the rotor hub assembly to replace blade retaining pins which have been found faulty (not provided up to MIL-SPEC's by the pin supplier).

Expected Progress During the Next Period:

Analysis of the multiple region array simulation output and the study of interannual variation of monthly mean winds will be completed. These results will be reported in the May annual progress report. Experimental studies of wind power effects of shear and gusts will continue.

Reports and Publications:

Justus, C. G., "Wind Energy Statistics for Large Arrays of Wind Turbines (New England and Central U.S. Regions)," scheduled for publication in Solar Energy.

Justus, C. G., W. R. Hargraves, Amir Mikhail, and Denise Graber, "Methods for Estimating Wind Speed Frequency Distribution," scheduled for publication in J. Appl. Meteorol.

3.2.11 Mesoscale Wind Characteristics in Mountainous Terrain (B3g)

Battelle, Pacific Northwest Laboratory
Richland, WA 99352

Principal Investigator:

Montie M. Orgill (509) 942-3341

Objective:

To identify, through an extensive literature review, our current state of knowledge of wind characteristics in various types of complex terrain, and to document the type of additional information that needs to be acquired for estimating wind characteristics and identifying high wind regimes over large areas of complex terrain.

Program Status:

This study began in July 1977 and will be completed in February 1978 upon final revision of a draft final report that was submitted in December 1977.

Progress During Reporting Period:

An extensive review of the literature was undertaken. This review screened journal articles and reports describing results of field measurements, wind tunnel studies, and theoretical studies of wind flow in complex terrain. Based on this review, a draft report was written discussing our current knowledge of wind flow characteristics over specific types of terrain features. The report includes a discussion of relevant research requirements to improve our understanding of wind characteristics in complex terrain in a generic fashion so that high wind areas within regions of complex terrain can be identified despite a lack of extensive measurements.

Expected Progress During the Next Period:

A final report will be published upon completion of the review of the draft report that was written in December 1977.

Reports and Publications:

None

3.2.12 Coastal Zone Wind Energy (B3h)

Contract No.: EY-76-S-06-2344

University of Virginia
Dept. of Environmental Sciences
Charlottesville, VA 22903

Principal Investigator:

Michael Garstang (804) 977-3733

Contract Monitor:

Dennis L. Elliott (509) 942-5040

Objective:

To determine space and time subdivisions of the East and Gulf Coast wind regimes, through the use of climatological data, analytical techniques, and mesoscale numerical models. Storm and interstorm contributions to the coastal zone wind energy are also being examined.

Program Status:

This program was initiated in September 1976 and will continue through September 1978.

Progress During Reporting Period:

Revisions to the final report on the first year's work have been completed. The wind regime of the coastal zone from Texas to Maine is described in terms of observations from onshore and offshore stations and a two-dimensional numerical model. The report is divided into two parts:

Part I: Synthesis and Results -- This part contains the major results from the climatological study and presents the numerical model experiments and results.

Part II: Climatology -- This part contains a description of the data used and the detailed tabulations and graphical presentations of the coastal wind and wind energy climatology.

In this year's work, the regional and temporal classification of coastal wind energy zones is being upgraded using statistical analyses and additional data sources. The mesoscale numerical model is being applied to determine the variation of winds with height and with distance normal to the coastline for more extensive conditions and locations than in the previous year's work. Long sections of uniform coastline are being handled differently from coastlines configured by capes and bays.

Storm and inter-storm periods over a ten-year data record have been categorized for the coastal zones. The amount of wind energy is being determined separately for the storm and inter-storm periods.

Expected Progress During the Next Period:

Analyses of the wind characteristics in each of the coastal zones will be made. Also, a description of the wind characteristics and power predictions for storm and inter-storm periods will be included. Description of annual power duration curves shall also be provided. A three-dimensional version of the numerical model will be employed for some portions of an investigation of the impact of local coastal topography on the speeding up or retardation of the winds.

Reports and Publications:

Garstang, M., C. I. Aspliden, S. Nnaji, and R. Pielke, Coastal Zone Wind Energy, Report No. RLO-2344-76/77-5, Dept. of Environ. Sci., University of Virginia, Charlottesville, VA 22903, January 1978.

3.2.13 Alaskan Wind Power Study (B3i)

Contract No.: E(45-1)-2229 #12

University of Alaska
Geophysical Institute
Fairbanks, AK 99701

Principal Investigator:

Tunis Wentink, Jr. (907) 479-7607

Contract Monitor:

Dennis L. Elliott (509) 942-5040

Objective:

To determine, by analysis and experiment, the potential of Alaskan wind power and its possible applications.

Program Status:

This program was initiated in May 1976 and is to continue through August 1978.

Progress During Reporting Period:

A report on the first phase (May 1976 - August 1977) has been reviewed by WSB and is being revised. Wind data have been analyzed for many additional sites throughout Alaska. Many promising locations have been identified along Alaskan coastal areas, and a few good sites in inland areas. The recent publication by the National Climatic Center: "Index - Summarized Wind Data" has been used to identify additional locations with wind summaries. Anemometer heights have been acquired and winds are being adjusted to standard heights. Instrument and site exposure are being examined where available. Wind duration curves have been developed from the data for numerous sites throughout Alaska. Annual and seasonal wind power estimates are being made.

Wind measurements were continued at Cold Bay, a windy coastal site on the Aleutian Peninsula, and Ft. Greely, a windy interior location.

Expected Progress During the Next Period:

1. Analyses of the wind characteristics for all areas of Alaska will be continued and maps, figures, and tables summarizing the analyses will be prepared.

2. Power predictions will be made for horizontal axis WECS and one or two state-of-the-art vertical axis WECS.

3. Wind data collected at Cold Bay and Ft. Greely will be analyzed to examine the wind speed variation with height.

4. A handbook for small machine siting will be prepared.

Reports and Publications:

Wentink, T., Jr., Alaskan Wind Power Study, Annual Report (draft), Geophysical Institute, University of Alaska, August 1977, ERDA report RLO/2220-T12-2.

3.3 SITING METHODOLOGIES

3.3.1 Wind Power Studies (C1a)

Contract No.: UCRL-50034-76

Lawrence Livermore Laboratory
University of California
Livermore, CA 94550

Principal Investigator:
Christine A. Sherman (415) 422-8986

Contract Monitor:
William T. Pennell (509) 942-6034

Objective:

To develop and demonstrate a methodology for the assessment of wind power in hilly or mountainous areas.

Program Status:

This program started at the beginning of FY-1976 and will continue through FY-1978.

Progress During Reporting Period:

Work during the last six months has concentrated on processing the data from the Oahu field measurement program and preparing for verification of the siting methodology and the numerical techniques which make up the methodology. A data set has been generated for Oahu covering the period 1 August 1976 to 31 July 1977. Data acquisition is continuing on the island. A second data base covering the period 1 August 1977 to 31 July 1978 will be prepared. A verification of the principal components analysis (PCA) technique has been completed for a San Francisco Bay area data set. Procedures for verifying the objective analysis technique (MATHEW) have been drafted. Both MATHEW and the PCA will be verified for Oahu and other data sets obtained in areas exhibiting more complex climatologies (such as the San Francisco Bay area).

Expected Progress During the Next Period:

Initial verification tests of MATHEW and the PCA will be completed. Work will begin on verification of the methodology for Oahu.

Reports and Publications:

Sherman, Christine A., A Mass-Consistent Model for Wind Fields Over Complex Terrain, UCRL-86171, September 1977. Submitted for publication to the Journal of Applied Meteorology.

Hardy, Donald M., Numerical and Measurement Methods of Wind Energy Assessment. Preprint Volume of the Third Biennial Conference and Workshop on Wind Energy Systems, September 19-21, 1977, Washington, D.C.

3.3.2 Development of a Wind Energy Site Selection Methodology (C1b)

Contract No.: EY-76-C-06-2440

Science Applications, Inc.
1200 Prospect Street
P. O. Box 2351
La Jolla, CA 92038

Principal Investigator:

Richard M. Traci (714) 459-0211

Contract Monitor:

William T. Pennell (509) 942-6034

Objective:

To develop, verify, and demonstrate a WECS siting methodology for complex terrain. The methodology is based on mathematical windfield models which are used to define the wind characteristic of sites within the region.

Program Status:

The program is in the final phase of a three-year program which began in May 1975, and is scheduled for completion in July of 1978.

Progress During Reporting Period:

Progress in the last six months can be summarized as follows:

- Graphics output packages have been improved.
- An improved turbulence model has been incorporated into SIGMET (the primitive equation model).
- The objective analysis code (NOABL) has been modified so that it is now terrain conformal.
- Improved numerics have been incorporated into NOABL.
- The effects of atmospheric stability, zoning and initial conditions on the modeled windfield have been examined for both SIGMET and NOABL.

- A start has been made on model verification. SIGMET and NOABL results have been compared with two-dimensional flows in a wind tunnel (data obtained from Colorado State University) and with field data (White Sands Missile Range).
- A preliminary application of the methodology to the Tehrehapi Mountain area in Southern California has been made.

Expected Progress During the Next Period:

Work in the next period will involve:

- Continued improvements in SIGMET efficiency;
- Investigation of ways to include boundary layer effects in NOABL; and
- Continued verification of model accuracy with wind tunnel results and field data.

Reports and Publications:

Traci, R. M., Phillips, G. T., Patnaik, P. C., and Freeman, B. E., Development of a Wind Energy Site Selection Methodology, RLO/2440-77/11, Science Applications, Inc., Report No. SAI-77-776-LJ, June 1977.

Traci, R. M., Phillips, G. T., Patnaik, P. C., and Freeman, B. E., The Utility of Mathematical Windfield Models in a WECS Siting Methodology: A Case Study. Preprint Volume of the Third Biennial Conference and Workshop on Wind Energy Systems, September 19-21, 1977, Washington, D.C.

3.3.3 Sites for Wind Power Installations (C1c)

Contract No.: EY-76-S-06-2438

Colorado State University
Department of Civil Engineering
Fort Collins, CO 80523

Principal Investigator:

Robert N. Meroney* (303)491-8572
Virgil A. Sandborn (303) 491-8551

Contract Monitor:

William T. Pennell (509) 942-6034

Objective:

To verify wind tunnel techniques for determining the influence of topography on the near-surface wind field.

Program Status:

This program was initiated in June 1975 and will continue through May 1978.

Progress During Reporting Period:

Work in this period has concentrated on completing the analysis of data collected in the previous reporting period (particularly the results on the effect of stable stratification on flow over two-dimensional ridges) and commencing studies of flow over three-dimensional hills.

Expected Progress During the Next Period:

During the next period research will concentrate on:

- Effect of the shape of the downstream portion of a two-dimensional ridge on separation.
- Flow over three-dimensional hills for neutral stability.
- Criteria for determining the conditions under which a three-dimensional hill will have the same effects on the near-surface wind as a two-dimensional ridge.

*In New Zealand until February 1978.

- Effect of escarpment shape on the wind profile.
- Effect of upstream velocity profile on speedup.
- Comparing wind tunnel simulation and field data.

Reports and Publications:

Boumeester, Reiner, The Influence of Hill Shape on Wind Characteristics Over Two-Dimensional Hills, paper presented at the Third Biennial Conference and Workshop on Wind Energy Conversion Systems, September 19-21, 1977, Washington, D.C.

Sandborn, V. A., Sites for Wind-Power Installation, paper presented at Wind Energy Symposium, October 17, 1977, University of Regina, Regina, Alberta, Canada.

Sandborn, V. A., Placement of Wind-Power Systems, paper presented at Wind Energy Symposium, October 17, 1977, University of Regina, Regina, Alberta, Canada.

Sandborn, V. A., Atmospheric Boundary Layer Model for Wind Power Sites, paper presented at a short course on Wind Energy Conversion Machines, November 28 - December 2, 1977, University of Tennessee Space Institute, Tullahoma, Tennessee.

Ridger, M. A., Measurements of Mean and Longitudinal Turbulent Velocities over Varying Hill Shapes, M.S. Thesis, Colorado State University, August 1977.

3.3.4 Vegetation as an Indicator of High Wind Velocities (C1d)

Contract No.: EY-76-S-06-2227

Oregon State University
Atmospheric Sciences Department
Corvallis, OR 97331

Principal Investigator:

E. Wendell Hewson (503) 754-4557

Contract Monitor:

William T. Pennell (509) 942-6034

Objective:

To calibrate various indices of wind effects on vegetation in terms of wind characteristics.

Program Status:

This is the second year of a program which began in July 1976.

Progress During Reporting Period:

Work has concentrated on calibrating and verifying the indices of wind effects that were identified in the first year. Three indices have been calibrated at twelve locations in the Pacific Northwest. These indices are: the Griggs-Putnam index, the deformation ratio, and the compression ratio. Figure 3.3-1 is an illustration of one of these indices -- the Griggs-Putnam Index. The interim calibration of this index is shown in Figure 3.3-2. The numbers next to the data points denote the number of trees sampled at each site. An initial verification of all three indices has been accomplished by comparing predicted and observed mean annual wind speeds at locations that were not used in the calibration. These preliminary results show the Griggs-Putnam and the deformation indices giving the best estimate:mean error ~25%.

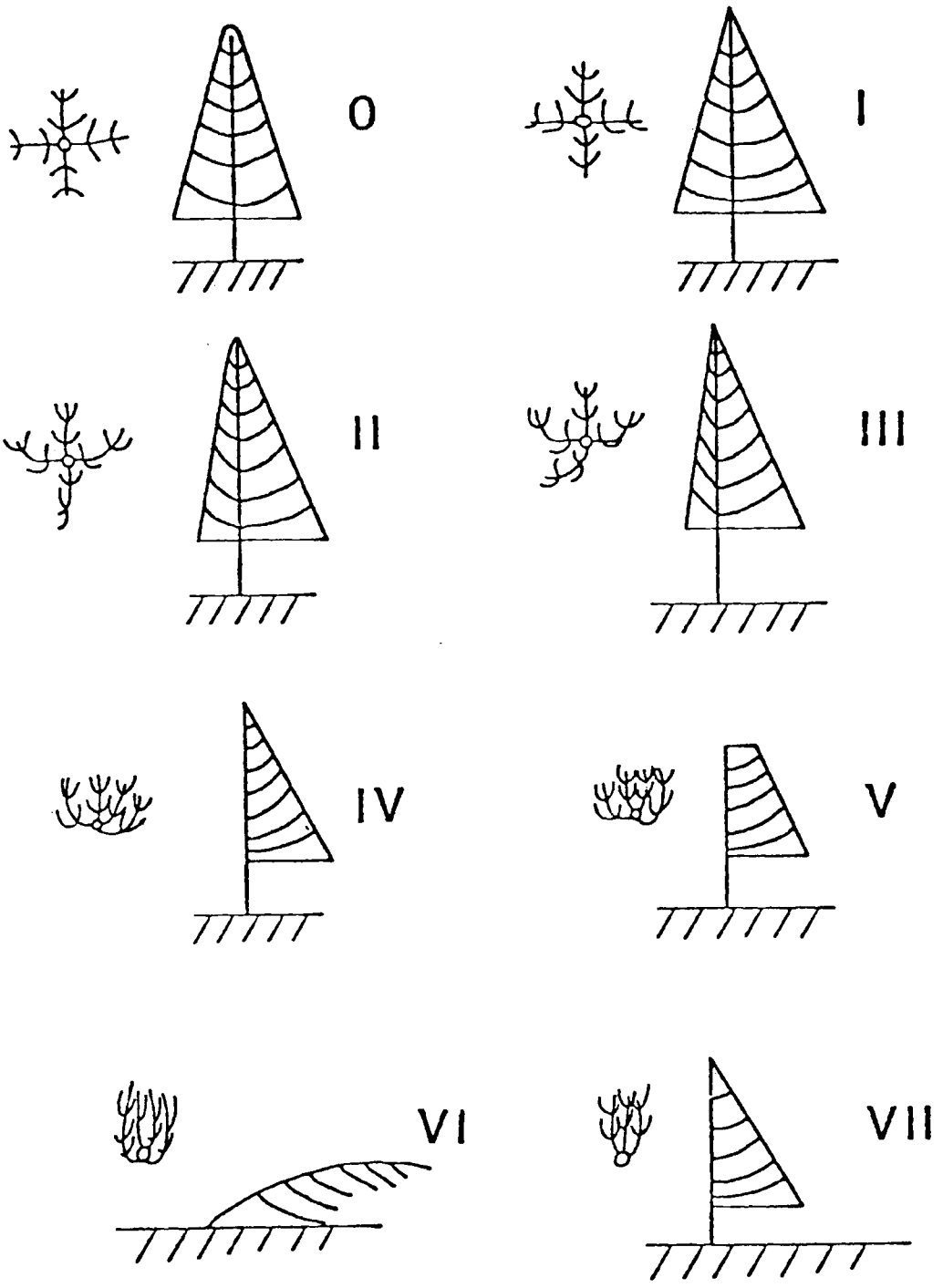

Figure 3.3-1 Griggs-Putnam Index

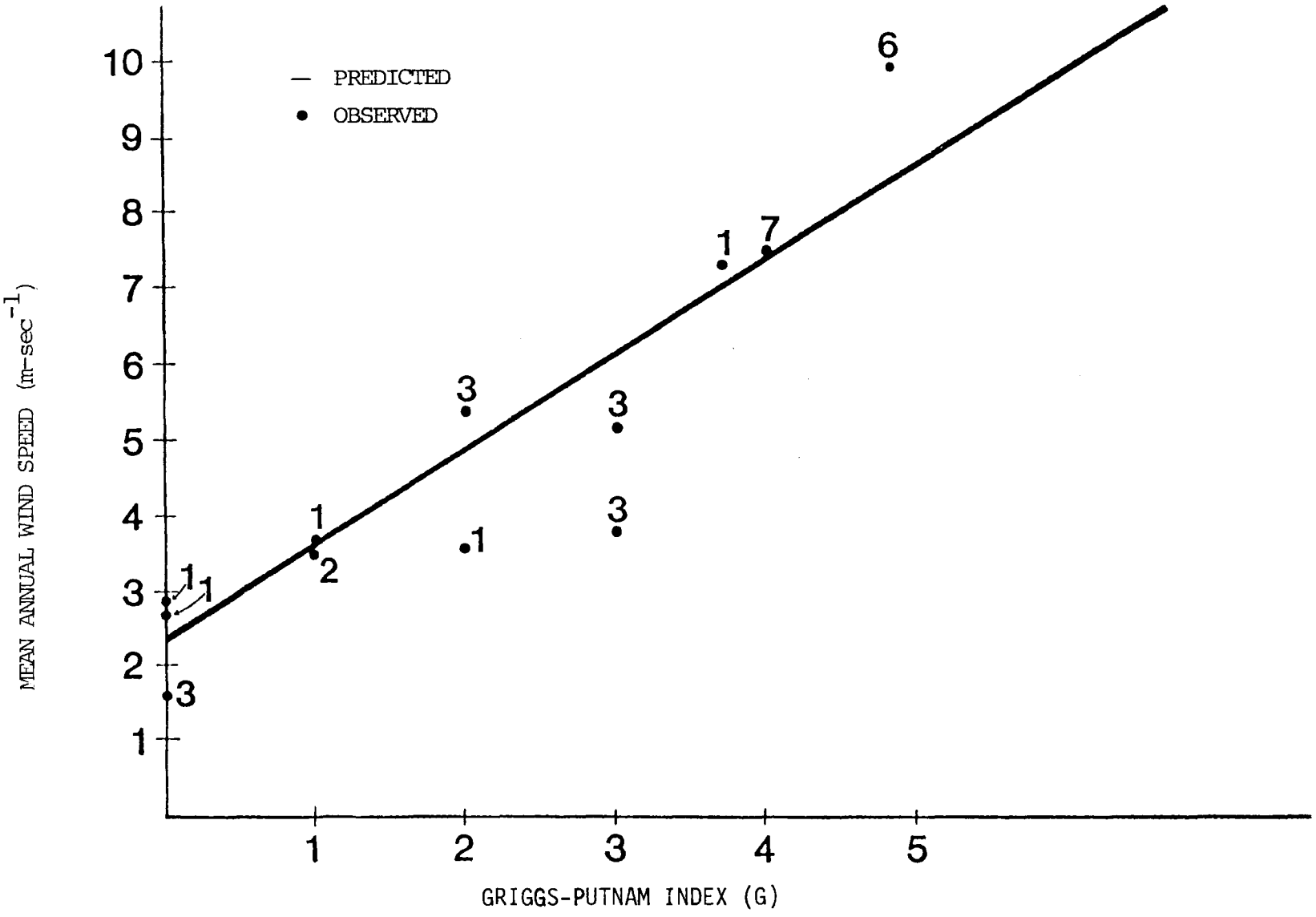

Figure 3.3-2 Interim Calibration of the Griggs-Putnam Index

Expected Progress During the Next Period:

More trees will be sampled, and the three indices mentioned above will be recalibrated and reverified with additional data. The suitability of two more indices - eccentricity and shape ratio - will also be tested.

Reports and Publications:

Hewson, E. W., and J. E. Wade, Biological Wind Prospecting. Preprint Volume of the Third Biennial Conference and Workshop on Wind Energy Systems, September 19-21, 1977, Washington, D.C.

3.3.5 Assessing the Local Wind Field (Cle)

Contract No.: EY-76-C-06-2441

AeroVironment
145 Vista Avenue
Pasadena, CA 91107

Principal Investigator:

Paul B. MacCready, Jr., (213) 449-4392

Contract Monitor:

Ronald K. Hadlock (509) 946-2961

Objective:

To observe, with dual doppler acoustic radar systems, the three-dimensional flow over complex terrain features to an altitude of 100 m above the surface.

Program Status:

This project was completed in August 1977. The draft final report has been submitted and has been reviewed. It is awaiting revision before publication.

Progress During Reporting Period:

Data describing the wind profiles from the surface to 100 m at two locations in the mountains near Pasadena, California, were obtained in June 1977. This data was analyzed and the results summarized.

Reports and Publications:

MacCready, P. B., Assessing the Local Wind Field for Siting, Preprint Volume of the Third Biennial Conference and Workshop on Wind Energy Systems, September 19-21, 1977, Washington, D.C.

3.3.6 Technique for Siting Using Statistics on Primitive Equation Model Results (C1f)

Contract No.: EY-76-C-06-2445

Research Triangle Institute
Geosciences Department
Research Triangle Park, NC 27711

Principal Investigator:

Fred M. Vukovich (919) 541-6946, Ext. 2657

Contract Monitor:

Larry L. Wendell (509) 942-6677

Objective:

To determine the feasibility of using historical wind data from a synoptic weather station, together with simulated wind fields in the vicinity of that station to predict the wind distribution at nearby locations where wind data are not available.

Program Status:

This project started September 20, 1977, and continued through December 1977. The draft final report for this project has been submitted and reviewed and is awaiting revision for publication.

Progress During Reporting Period:

A reasonably comprehensive error analysis was performed to determine the sources of the discrepancies between the predicted and observed wind characteristics. Results of the analysis indicated about 5% of the total discrepancy was attributable to the statistical modeling procedures. The remaining 95% was accounted for by two major contributors. Approximately 60% was attributed largely to the fact that Lambert field data were one-minute observations recorded to the nearest whole knot and nearest ten degrees. The remaining 35% of the total discrepancy was reported to occur because the actual RAPS data and the simulated data

from the hydrodynamic model do not yield comparable parameter estimates in the statistical models.

The one-minute data from one RAPS station were used to produce one-hour average values for comparison with one-minute values rounded to the nearest whole knot and nearest 10°. The correlation between these to data strings from the same station was 0.845.

The conclusions of this study suggest that the proposed technique for developing wind statistics in remote locations is feasible, provided reasonably accurate simulation data can be produced. This qualification becomes extremely important when the area of interest is in terrain more complex than relatively flat terrain around St. Louis. Results from other techniques under development need to be examined before work of this type is resumed.

Expected Progress During the Next Period:

Revision and publication of the final report of this effort.

Reports and Publications:

Vukovich, F. M., and C. A. Clayton, On a Technique to Determine Wind Statistics in Remote Locations, Preprint volume of the Third Biennial Conference and Workshop on Wind Energy Systems, September 19-21, 1977, Washington, D.C.

3.3.7 The Effect of Atmospheric Density Stratification on Wind-Turbine Siting (C1g)

Contract No.: EY-76-C-06-2443

Poseidon Research
11777 San Vincente Blvd.
Suite 64
Los Angeles, CA 90044

Principal Investigator:

Steven C. Crow (508) 826-5543

Contract Monitor:

William T. Pennell (509) 942-6034

Objective:

To study the effect of atmospheric density stratification on wind turbine siting through the use of a simple method for computing the locations of maximum wind velocity over a given terrain feature. Areas with adverse pressure gradients, which are expected to be poor wind turbine sites, are also to be identified.

Program Status:

The program is a fifteen month effort that was initiated in September 1976 and is now complete. A draft of the final report is being prepared and will be sent to Battelle, Pacific Northwest Laboratories, for review.

Progress During Reporting Period:

Numerical codes for density-stratified airflow over two-dimensional and three-dimensional mountains were developed. Computations were performed for a wide selection of atmospheric conditions. Parametric studies were performed to evaluate the sensitivity of the near-ground airflow as a function of ambient wind speed and direction, mountain height and shape, height of the troposphere, stratification in the troposphere, and different inversion conditions. For the three-dimensional computations, mountains of Gaussian form were considered.

For flow over both two-dimensional and three-dimensional mountains in neutral atmospheric conditions, the wind speed maximum is located at the peak of the mountain if no temperature inversion is present above the mountain. During stable atmospheric conditions and neutral conditions with an inversion, the wind speed maximum moves to the lee side of the mountain. The location of the wind speed maximum is a function of the stratification in the troposphere and the freestream wind speed.

An example of this effect is shown in Figure 3.3-3. The figure illustrates the surface wind speed distribution over a two-dimensional ridge which is 200 m high. In this example it is assumed that the lapse rate of the atmosphere (temperature decrease with height) is constant. Two situations are shown: one is for an adiabatic (i.e., neutral) lapse rate and one is for a stable lapse rate which is equal to the mean lapse rate of the troposphere. The example illustrates the downstream shift of the surface wind speed maximum very clearly. Although there is still some speedup at the ridge crest, it is less than for the neutral case. Another interesting feature is the wind speed distribution on the windward side of the ridge. Here, the surface wind speed remains lower than the approach wind speed until very near the crest of the ridge. This wind speed depression is also much larger for the stable case than for neutral stability.

Possible regions of flow separation occur on the windward as well as on the leeward side of the mountain. On the leeward side of the mountain they occur just downstream of the location of maximum wind speed.

Expected Progress During the Next Period:

During the remaining portion of the contract the final report will be prepared and released on UC-60 distribution.

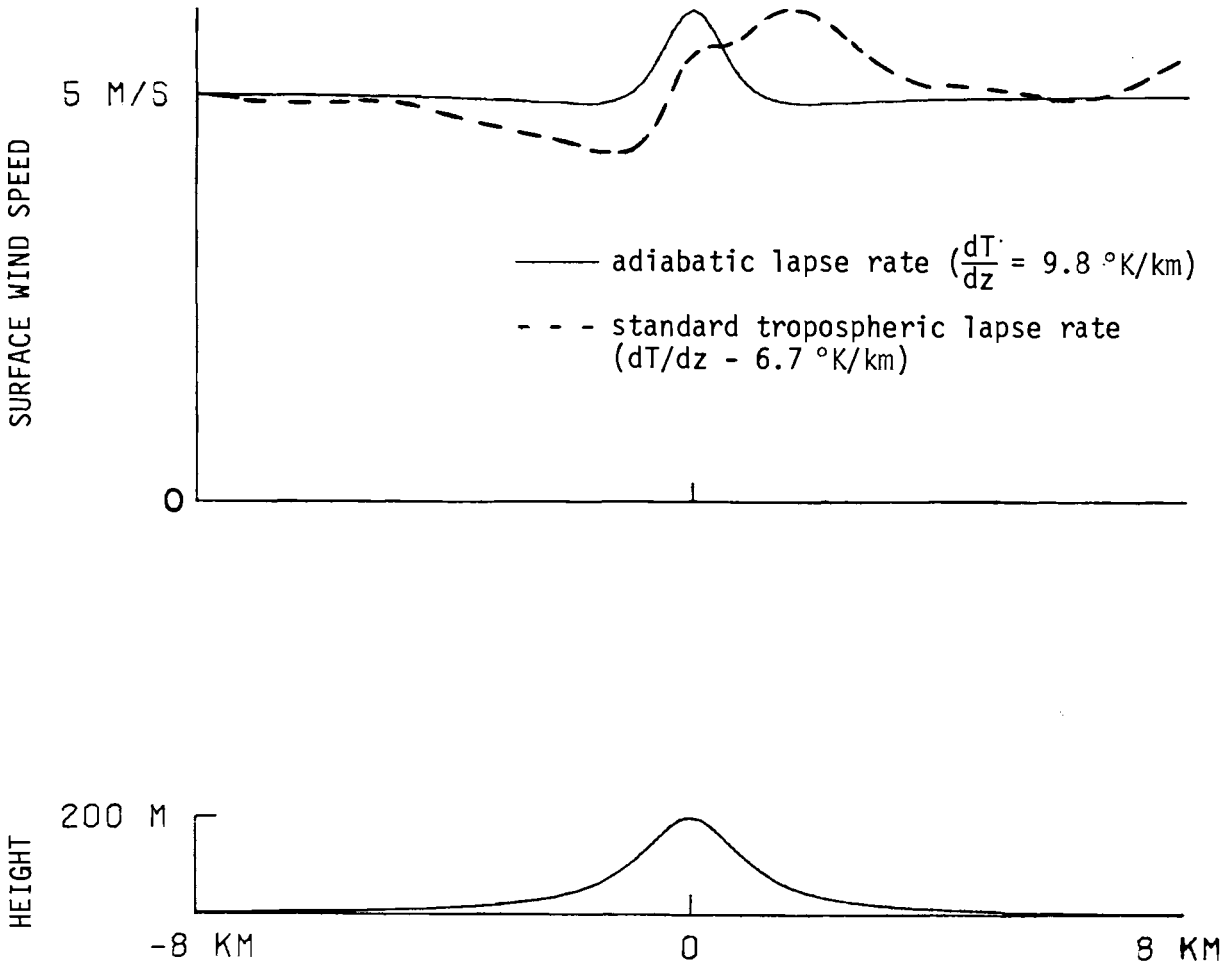

Figure 3.3-3 Surface Wind Speed Distribution Over a Two-Dimensional Ridge. The solutions are for a one-layer atmosphere with constant lapse rate. The shape of the ridge is shown in the lower figure.

Reports and Publications:

Agopian, K. G., and S. C. Crow, The Effect of Atmospheric Density Stratification on Wind Turbine Siting, Progress Report for the Period October 1976 through March 1977, Poseidon Research, Los Angeles, CA, 43 pp.

Agopian, K. G., The Effect of Atmospheric Density Stratification on Wind Turbine Siting. Preprint Volume of the Third Biennial Conference and Workshop on Wind Energy Systems, September 19-21, 1977, Washington, D.C.

3.3.8 Plan Site Screening Technique Verification and Comparison (C2a)

Battelle, Pacific Northwest Laboratory
Richland, WA 99352

Principal Investigator:

William T. Pennell (509) 942-6034

Objective:

To evaluate the accuracy of numerical site screening techniques.

Program Status:

The evaluation criteria, data sets, and procedures have been identified and developed.

Progress During Reporting Period:

Criteria for evaluating numerical site-screening techniques in complex terrain were developed. The data sets with which the various numerical techniques will be compared are:

- The Island of Oahu
- Vandenberg Air Force Base
- Nevada Test Site

The techniques will be evaluated according to:

- How well they reproduce the wind speed field over a given section of terrain.
- How accurately they predict certain "climatological" wind characteristics, such as the wind speed probability distribution function or the mean diurnal wind speed variation at a specific location.
- What is the sensitivity of the models to the amount of input data.

A draft plan for the verification task has been completed.

Expected Progress During the Next Period:

The draft plan for technique verification will be reviewed by the participants in the verification exercise, and technique verification will begin in the Spring of 1978.

Reports and Publications:

None

3.3.9 Technology Development for Assessment of Small-Scale Terrain Effects on Available Wind Energy (C3a)

Contract No.: EY-76-C-06-2443

FWG Associates, Inc.
R. R. 3, Box 201-B
Tullahoma, TN 37388

Principal Investigator:
Walter Frost (615) 455-1982

Contract Monitor:
Thomas W. Horst (509) 942-2861

Objective:

To develop the technology for siting wind energy machines relative to small scale terrain features contained within a region (i.e., a mountain, valley, etc.) selected for wind energy utilization and to develop techniques for wind energy enhancement based on microscale site modification.

Current Status:

This is a 3-year program: the initial 12-month period began in August 1976.

Progress During Reporting Period:

During the first year, the effects 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. A draft annual report was submitted and is under review.

Expected Progress During Next Period:

During the second year, the study will be extended to include three-dimensional smooth and bluff-like terrain irregularities. In addition, experimental requirements

will be defined for the measurement of wind energy potential at a site. Techniques will be developed for wind energy enhancement based on small-scale site modifications.

Reports and Publications:

Frost, Walter, Siting of Wind Turbine Generators Relative to Small Scale Terrain Features. Preprint Volume of the Third Biennial Conference and Workshop on Wind Energy Systems, September 19-21, 1977, Washington, D.C.

3.3.10 Update Small System Siting Handbook (C3b)

Battelle, Pacific Northwest Laboratory
Richland, WA 99352

Principal Investigator:

Harry L. Wegley (509) 942-0666

Objective:

The objective of this task is to revise the Interim Handbook for Siting Small WECS and to update it by incorporating new information.

Program Status:

The rough draft of the updated handbook has been written and is ready for review.

Progress During Reporting Period:

Reviews of the initial draft of the interim siting handbook indicated the need for a more concise and less technical siting handbook. Employing this philosophy, new siting information was gathered, reviewed, and appropriate material was incorporated into the rough draft of the updated handbook.

Expected Progress During the Next Period:

The rough draft of the updated version of the handbook will be submitted for review early in the next reporting period. The final report will be issued by July 1978.

Reports and Publications:

None

3.3.11 Update Large System Siting Handbook (C3c)

Battelle, Pacific Northwest Laboratory
Richland, WA 99352

Principal Investigator:
William T. Pennell (509) 942-6034

Objective:

To produce a handbook which describes a strategy and the techniques which can be used to site large WECS or farms of small WECS.

Program Status:

An interim handbook has been completed and is currently being revised.

Progress During Reporting Period:

The first iteration of a large WECS siting handbook, An Interim Handbook for Siting Large Wind Energy Conversion Systems, was submitted for review. As the result of requests from public utilities, work was commenced on a document describing the kind of data and the measurement systems required for evaluating a specific location as a WECS site. The document also describes instrumention needed for wind energy prospecting within a small area. This second document will form part of the siting handbook.

Expected Progress During the Next Period:

The revised handbook will be completed and reviewed.

Reports and Publications:

None

3.4 WIND CHARACTERISTICS FOR WECS OPERATIONS

3.4.1 Identification of Needs and Liaison Activities (D1)

Pacific Northwest Laboratory
Richland, WA 99352

Program Leader:

L. L. Wendell (509)942-6677

Objective:

To identify specific wind forecasting needs of potential WECS users and to determine if current wind forecasting reliability meets these needs.

Program Status:

This effort was initiated in October 1977 and is proposed to continue through September 1978. If warranted, contract monitoring and coordinating efforts would continue into FY-1979.

Progress During Reporting Period:

Telephone contacts were made with personnel from nine utility companies with inquiries concerning needs and interest in wind forecasting for WECS operations. Invitations to a working group discussion on this topic to be held in Richland, WA, December 15, 1977, were extended.

An investigation of current types of wind forecasts available was also begun. Forecast product descriptions were obtained from the National Weather Service, Air Weather Service, Global Weather Central, Naval Fleet Weather Central, and 14 private consulting firms. Invitations to the working group discussion were extended in all these contacts.

Due to a combination of factors, many who had expressed interest in attending the discussion meeting were unable to attend. The meeting was held on December 15, 1977. The

attendees included only one utility representative and four members of the wind forecasting community. The attendees were provided a briefing on the information which had been obtained in the telephone conversations with those who did not attend the meeting. Three main points resulted from the discussions:

1. Wind forecasting would probably be valuable in the same sense as load forecasting. That is, in the area of planning for the use of various generation equipment to meet the upcoming demands for the power. Work on establishing forecast reliability for 24-36 hours is needed to determine if it is at least as reliable as the load forecasting.

2. Wind forecasting for hour-by-hour load following could be of great value. However, since there is essentially no margin for error, current wind forecasting reliability makes this an unrealistic goal.

3. Comprehensive information on wind forecast reliability is very meager and certainly inadequate to evaluate the potential of wind power forecasting.

Expected Progress During the Next Period:

A report of the findings of this preliminary investigation as well as the recommendations for further work in this area. A sampling of the needs of the users of small machines will also be obtained. These needs will also be factored into the recommendations for further work.

Reports and Publications:

None

3.5 SPECIAL STUDIES

3.5.1 Gust Amplitude Estimates (E2)

Battelle, Pacific Northwest Laboratory
Richland, WA 99352

Principal Investigator:

J. V. Ramsdell (509) 946-2749

Objective:

To provide estimates of the number of gusts of a given amplitude that will be experienced by a WECS during a given period.

Program Status:

The study of gust amplitudes was begun in May 1977 as one of several programs to analyze existing wind data and present the results in formats usable for WECS design and the development of design criteria.

Existing turbulence information has been combined with an assumed wind speed distribution to prepare preliminary estimates of the number of large amplitude gusts which occur under various combinations of terrain and annual mean wind speed. The estimates are a function of gust amplitude and hourly average wind speed. Positive and negative gusts are treated separately.

A report has been prepared which presents these estimates in tabular form. It is currently under review.

Progress During Reporting Period:

The gust amplitude information presented in the WCPE Annual Report was reviewed by small WECS designers. They suggested a revised format for presenting the estimates. The revised format is shown in Table A-12 taken from the report under review.

Table A-12

TERRAIN: Hilly

ANNUAL MEAN WIND SPEED: 6 M/S

HOURLY AVERAGE SPEED (M/S)	GUST AMPLITUDE (M/S)										
	-10	-8	-6	-4	-2	2	4	6	8	10	12
2					1.89+00	6.12+01					
4				2.57+00	2.10+04	5.29+04	8.32+01				
6			2.51+00	1.47+03	1.85+05	2.77+05	7.42+03	8.11+01	4.40-01		
8		1.83+00	2.49+02	1.50+04	3.35+05	4.16+05	3.77+04	1.89+03	5.93+01	1.26+00	
10	1.06+00	5.70+01	1.86+03	3.42+04	3.11+05	3.54+05	6.17+04	6.98+03	5.63+02	3.42+01	1.61+00
12	1.41+01	2.88+02	4.02+03	3.63+04	1.92+05	2.09+05	5.43+04	1.01+04	1.45+03	1.68+02	1.59+01
14	4.82+01	5.21+02	4.17+03	2.36+04	8.83+04	9.32+04	3.16+04	8.22+03	1.73+03	3.06+02	4.62+01
16	6.93+01	4.82+02	2.62+03	1.08+04	3.16+04	3.27+04	1.34+04	4.40+03	1.21+03	2.90+02	6.07+01
18	5.46+01	2.75+02	1.13+03	3.69+03	9.03+03	9.26+03	4.35+03	1.70+03	5.72+02	1.70+02	4.54+01
20	2.72+01	1.08+02	3.59+02	9.80+02	2.10+03	2.13+03	1.11+03	4.96+02	1.94+02	6.85+01	2.20+01
22	9.37+00	3.08+01	8.70+01	2.07+02	4.00+02	4.04+02	2.29+02	1.13+02	5.00+01	2.01+01	7.46+00
24	2.36+00	6.67+00	1.66+01	3.53+01	6.29+01	6.34+01	3.84+01	2.06+01	9.99+00	4.47+00	1.86+00
26	4.49-01	1.13+00	2.52+00	4.93+00	8.21+00	8.24+00	5.27+00	3.02+00	1.59+00	7.74-01	3.55-01
28		1.51-01	3.10-01	5.65-01	8.90-01	8.91-01	5.96-01	3.61-01	2.02-01	1.06-01	
30											

This table presents the estimated number of times per year that gust of the tabled amplitude will be exceeded when the hourly mean wind speed has the given value. The table is specifically for a hilly location where the annual mean wind speed is 6 m/s (13.4 mph).

Expected Progress During the Next Period:

During the next period the review process will be completed and the report will be revised. Publication of the revised report will complete work on gust amplitudes. Work will begin on directional variations.

Reports and Publications:

Ramsdell, J. V., Estimates of the Number of Large Amplitude Gusts, PNL-2508, Battelle, Pacific Northwest Laboratories, Richland, WA 99352, January 1978, 44 pp. in Review.

4.0 REFERENCES

1. Summary of the Development Plan for the Wind Characteristics Program Element of the Federal Wind Energy Program, BNWL 2501, February 1978, Battelle, Pacific Northwest Laboratories, Richland, WA 99352.

2. Summary Report, Federal Wind Energy Program, ERDA-77-32, January 1, 1977. ERDA Div. of Solar Energy, Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

APPENDIX A

PUBLISHED REPORTS
GIVEN UC-60 DISTRIBUTION

WIND CHARACTERISTICS PROGRAM ELEMENT (WCPE)

Reports published, given UC-60 distribution, and available from:

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The WCPE is coordinated for DOE/Wind Systems Branch by Battelle, Pacific Northwest Laboratories, Richland, WA 99352. The attached listing has been prepared by:

Eric H. Phinney
WCPE Reports Schedule & Control Coordinator

Phone: FTS 444-2061
Commercial: (509) 942-2061

Author	Title	Document No.	Affiliation & Address	Date	No. of Pages
Wentink, T., Jr.	Wind Power Potential of Alaska: Part I, Surface Wind Data From Specific Coastal Sites	NSF/RANN Grant GI-43098	University of Alaska Geophysical Institute Fairbanks, AK 99701	August 1974	134
Wentink, T., Jr.	Study of Alaskan Wind Power and Its Possible Applications	NSF/RANN/SE/AER74-00239/FR-76/1	University of Alaska Geophysical Institute Fairbanks, AK 99701	February 1976	181
Freeman, B. E.	Mathematical Modeling of Topographic Effects on Wind Energy Systems (paper)	BNWL-SA-5935	Science Applications, Inc. P. O. Box 2351 La Jolla, CA 92037	April 1976	Microfiche
Freeman, B. E.	A New Wind Energy Site Selection Methodology	SAI76-614-LJ (NSF Grant)	Science Applications, Inc. P. O. Box 2351 La Jolla, CA 92037	May 1976 (SAI) December 1977 (TIC) (in printing)	233
Meroney, R. N., et al.	Sites for Wind Power Installations: Wind Tunnel Simulation of the Influence of Two-Dimensional Ridges on Wind Speed and Turbulence	ERDA/NSF/00702-75/1	Colorado State University Dept. of Civil Engineering Fort Collins, CO 80523	July 1976	88
Justus, C. G. et al.	Wind Energy Statistics for Large Arrays of Wind Turbines (New England and Central U.S. Regions)	ERDA/NSF-00547/76/1	Georgia Institute of Technology School of Aerospace Engineering Atlanta, GA 30332	August 1976	126
Justus, C. G. et al.	Reference Wind Speed Distributions and Height Profiles for Wind Turbine Design and Performance Evaluation Applications	ORO/5108-76/4	Georgia Institute of Technology School of Aerospace Engineering Atlanta, GA 30332	August 1976	103
Wentink, T., Jr.	Wind Power Potential of Alaska: Part II - Wind Duration Curve Fits and Output Power Estimates for Typical Windmills	RLO/2229-T12-76/1	University of Alaska Geophysical Institute Fairbanks, AK 99701	August 1976	89
Corotis, R. B.	Stochastic Modelling of Site Wind Characteristics	ERDA/NSF-00357/76/1	Northwestern University Dept. of Civil Engineering Evanston, IL 60201	November 1976	305

Meroney, R. N. et al.	Sites for Wind Power Installations: Wind Tunnel Simulation of the Influence of Two-Dimensional Ridges on Wind Speed and Turbulence--Tabulated Experimental Data	RLO/2438-76/1	Colorado State University Department of Civil Engineering Fort Collins, CO 80523	December 1976
Freeman, B. E. et al.	Development of a Wind Energy Site Selection Methodology	RLO/2440-76/4	Science Applications, Inc. P. O. Box 2351 La Jolla, CA 92037	December 1976
Elderkin, C. E. Ramsdell, J. V.	Semi-Annual Report of the Wind Characteristics Program Element for the Period April 1976 Through December 1976	BNWL-2220 WIND-2	Battelle P. O. Box 999 Richland, WA 99352	January 1977
Verholek, M. G.	Summary of Wind Data from Nuclear Power Plant Sites	BNWL-2220 WIND-4	Battelle P. O. Box 999 Richland, WA 99352	March 1977
Orgill, M. M.	Survey of Wind Measurement Field Programs	BNWL-2220 WIND-3	Battelle P. O. Box 999 Richland, WA 99352	May 1977
Justus, C. G. et al.	Wind Energy Statistics for Large Arrays of Wind Turbines (Great Lakes and Pacific Coast Regions)	RLO/2439-77/2	Georgia Institute of Technology School of Aerospace Engineering Atlanta, GA 30332	May 1977
Duchon, C. E.	Measurement and Analysis of Wind Flow in Complex Terrain with Application to Siting of WECS	ERDA/NSF-00619/75/1	University of Oklahoma School of Meteorology Norman, OK 73019	May 1977 (in printing)
Elliott, D. L.	Synthesis of National Wind Energy Assessments	BNWL-2220 WIND-5	Battelle P. O. Box 999 Richland, WA 99352	July 1977
Elderkin, C. E. Ramsdell, J. V.	Annual Report of the Wind Characteristics Program Element for the Period April 1976 Through June 1977	BNWL-2220 WIND-10	Battelle P. O. Box 999 Richland, WA 99352	July 1977
Changery, M. J.) Hodge, W. T.) - NOAA Ramsdell, J. V. - PNL	Index- Summarized Wind Data	BNWL-2220 WIND-11	National Oceanic and Atmospheric Adm. National Climatic Center Federal Building Asheville, NC 28801	September 1977
Corotis, R. B.	Stochastic Modeling of Site Wind Characteristics	RLO/2342-77/2	Northwestern University Department of Civil Engineering Evanston, IL 60201	September 1977 (in printing)

Cliff, W. C.	The Effect of Generalized Wind Characteristics on Annual Power Estimates from Wind Turbine Generators	PNL-2436	Battelle P. O. Box 999 Richland, WA 99352	October 1977 (in printing)
Doran, J. C. et al.	Accuracy of Wind Power Estimates	PNL-2442	Battelle P. O. Box 999 Richland, WA 99352	October 1977
AWEA	Survey of Historical and Current Site Selection Techniques for the Placement of Small Wind Energy Conversion Systems	BNWL-2220 WIND-9	American Wind Energy Association c/o Windworks P. O. Box 329, Route 3 Mukwonago, WI 53149	December 1977 (in printing)

PNL

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