**Annual Report of the
Wind Characteristics Program
Element for the Period
July 1978 Through September 1979**

**L. L. Wendell
W. R. Barchet
J. R. Connell**

**A. H. Miller
W. T. Pennell
D. S. Renne**

May 1980

**Prepared for the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830**

**Pacific Northwest Laboratory
Operated for the U.S. Department of Energy
by Battelle Memorial Institute**

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the Department of Energy, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

The views, opinions and conclusions contained in this report are those of the contractor and do not necessarily represent those of the United States Government or the United States Department of Energy.

PACIFIC NORTHWEST LABORATORY
operated by
BATTELLE
for the
UNITED STATES DEPARTMENT OF ENERGY
Under Contract DE-AC06-76RLO 1830

Printed in the United States of America
Available from
National Technical Information Service
United States Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22151

Price: Printed Copy \$_____ *: Microfiche \$3.00

*Pages	NTIS Selling Price
001-025	\$4.00
026-050	\$4.50
051-075	\$5.25
076-100	\$6.00
101-125	\$6.50
126-150	\$7.25
151-175	\$8.00
176-200	\$9.00
201-225	\$9.25
226-250	\$9.50
251-275	\$10.75
276-300	\$11.00

3 3679 00054 4389

ANNUAL REPORT OF THE
WIND CHARACTERISTICS PROGRAM
ELEMENT FOR THE PERIOD
JULY 1978 THROUGH SEPTEMBER 1979

L. L. Wendell
W. R. Barchet
J. R. Connell
A. H. Miller
W. T. Pennell
D. S. Renne

May 1980

Prepared for
the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

Pacific Northwest Laboratory
Richland, Washington 99352

SUMMARY

As a service element within the Federal Wind Energy Program, the Wind Characteristics Program Element (WCPE) is established to provide the appropriate wind characteristics information to those involved in:

- the design and evaluation of wind energy conversion systems (WECS)
- energy program planning
- selecting sites for WECS installation
- the operation of WECS.

To effectively produce the information needed in these four categories, the WCPE, for which the Pacific Northwest Laboratory (PNL) has the responsibility for management and technical assistance, has been divided into four technical program areas. During this reporting period PNL was also assigned the management responsibility for the data collection at the U.S. Department of Energy's (DOE's) candidate sites, as well as the task of providing technical assistance to DOE evaluation and site selection panels for new candidate sites.

This annual report describes the technical progress within each segment of the program from July 1978 through September 1979. It includes the progress accomplished directly by PNL and by contractors funded directly by DOE or through PNL.

The goal of the Wind Characteristics for Design and Performance Evaluation Program area is to provide descriptions of the wind environment relevant to structural integrity and WECS performance. The following are some of the significant activities and accomplishments for this reporting period.

- Analysis and comparison of several gust models were completed with recommendations concerning the applicability of the models.
- The analysis mentioned above provided the basis for the formulation of guidelines for treating wind variability in wind turbine design. Draft documentation has been distributed for review.

- The circular array of anemometers oriented in a vertical plane provided data for topical reports on wind direction variations and on the consideration of wind fluctuation as discrete events.
- A model for the probability structure of atmospheric turbulence was developed and documented.
- Two reports were completed in the area of wind characteristics for performance evaluation: one for the field testing of wind turbines and one for unsteady performance evaluation.

The Large Area Wind Energy Analyses Program area has two main goals: to develop and test techniques for analyzing the wind-energy potential over large areas and to conduct wind-energy assessments for all regions of the United States and its territories. Some major activities for this reporting period were:

- Prototype techniques for the analysis of wind-energy potential over large areas were developed and tested in the northwest region of the United States.
- A draft atlas of wind-energy potential in the states of Idaho, Montana, Oregon, Washington and Wyoming was prepared and distributed for review.
- An RFP for similar resource assessments was issued for 11 other regions covering the rest of the United States and its territories. Eighty proposals were received from 44 firms. Contractors for four regions were selected in FY 1979.
- Wind records from the National Fire Weather Data Library were evaluated and screened for applicability for use in wind-energy resource assessments.
- Documentation of techniques for the interpretation of wind flow characteristics from eolian landforms was completed.

The Siting Methodologies Program area has three main goals: to devise strategies for selecting specific sites for WECS installation, to develop tools to implement these strategies, and to supply the appropriate documentation on siting methodologies to those who need them. Some of the major accomplishments for this reporting period were:

- A draft version of Volume I of a handbook for siting large wind turbines was submitted to DOE for review.
- A handbook on the use of trees as an indicator of wind-power potential was published.
- A short course for siting small wind turbines was prepared and tested for audience reaction on two occasions. Draft copies of the revised handbook were used as textbooks.
- Data sets were prepared and distributed to participating countries in the international model verification activities.
- Siting techniques involving numerical flow models and physical flow models were documented.

The three major goals of the Wind Characteristics for WECS Operations Program area are: (1) to determine the specific forecasting needs of potential WECS users, (2) to determine the adequacy of current wind-forecasting reliability, and (3) to upgrade the current wind forecast types, formats and reliability when needed. The major activity during this reporting period was to engage eight separate contractors to produce and record 24 hourly wind forecasts for 13 of the original DOE candidate sites. The forecast data obtained in this task will be used in a verification task to determine the applicability of operational wind forecast techniques.

In the Special Studies area the two main activities during this reporting period were the development of a short course for siting small WECS and the wind tunnel testing and calibration of several inexpensive wind measuring systems. A preliminary version of the short course on siting was presented on two different occasions, and the comments received are being used to prepare the course. The wind tunnel testing and calibration is part of a prototype program for testing the reliability and accuracy of inexpensive wind measuring equipment.

The PNL support of the DOE candidate site program involved three major activities: site meteorological measurements and analysis, site selection support, and large machine site evaluation. During this reporting period, the following efforts were conducted.

- Strip chart recorders were replaced with digital cassette data logging equipment at 14 of the original 17 candidate sites.
- PNL established a comprehensive quality assurance program on the candidate site measurement program.
- PNL provided technical support to DOE in the preparation of the Program Opportunity Notice (PON) for the selection of approximately 20 additional candidate sites along with sites for the three MOD-2 wind turbines.
- Technical support was provided to the Site Evaluation Panels at DOE/RL and the Site Selection Official at DOE/HQ for the evaluation of proposals for MOD-2 sites.
- A third level of wind sensors was installed on the meteorological towers at the DOE wind turbine sites.
- Under an agreement with NASA/Lewis, measurements of machine power, yaw discrepancy, nacelle anemometer wind speed and direction were incorporated into the standard meteorological measurements at the DOE wind turbine sites.

One of the major activities and accomplishments of the entire WCPE was the coordination of a Conference and Workshop on Wind Characteristics and Wind Energy Siting held in Portland, Oregon, in June 1979.

CONTENTS

SUMMARY	iii
1.0 INTRODUCTION	1-1
2.0 WIND CHARACTERISTICS FOR DESIGN AND PERFORMANCE EVALUATION . .	2-1
2.1 PROGRESS IN TECHNICAL TASKS	2-5
2.1.1 Environmental Design Criteria for WECS	2-5
2.1.2 Error Band Analyses	2-9
2.1.3 Turbulence Characteristics Over Nonuniform Terrain . .	2-11
2.1.4 Characteristics of Strong Downslope Winds	2-15
2.1.5 Flow Through a Vertical Plane	2-18
2.1.6 Physical Analyses of Wind Speed Distribution Functions	2-20
2.1.7 Characteristics of the Wind Measured at Rocky Flats . .	2-22
2.1.8 Meteorological Guidelines for WECS Design	2-23
2.1.9 Wind Characteristics at Singular Topographic Features	2-25
2.1.10 Wind Shear in the Nocturnal Boundary Layer	2-26
2.1.11 Measurement Methods for Performance Evaluation . .	2-29
2.1.12 Turbulence Effects on WECS Output	2-30
2.1.13 Wind Response Characteristics of Horizontal-Axis Wind Turbines	2-32
3.0 LARGE AREA WIND ENERGY ANALYSES	3-1
3.1 PROGRESS IN TECHNICAL TASKS	3-3
3.1.1 Pacific Northwest Analysis	3-3
3.1.2 Coordination of Large Area Analysis	3-6
3.1.2a Coordination of Large Area Analysis	3-8
3.1.3 Northeast Region	3-10
3.1.4 Southwest Region	3-12
3.1.5 Alaska Region	3-14
3.1.6 Hawaii Region	3-16
3.1.7 Locating High-Wind Areas by Remote Observations . .	3-18
3.1.8 Identifying and Screening Potential WECS Sites	3-20
3.1.9 Coastal Zone Wind Power Studies	3-22

3.1.10	Wind Power Potential in a Coastal Environment	3-28
3.1.11	Agricultural Applications of Wind Resource Assessments	3-30
3.1.12	Statistical Studies of Site Wind Characteristics	3-32
4.0	SITING METHODOLOGIES	4-1
4.1	PROGRESS IN TECHNICAL TASKS	4-3
4.1.1	Sites for Wind Power Installations	4-3
4.1.2	Vegetation as an Indicator of High Wind Velocities	4-15
4.1.3	Assessing the Local Wind Field with Instrumentation	4-21
4.1.3a	Assessing the Local Wind Field with Instrumentation	4-23
4.1.4	Climatological Adjustment of Short-Term Wind Statistics	4-26
4.1.5	Wind Shear in the Nocturnal Boundary Layer	4-29
4.1.6	Coordinate and Interpret Model Verification	4-33
4.1.7	Numerical Model Verification	4-35
4.1.8	Numerical Model Verification	4-44
4.1.9	Small-Scale Terrain Effects	4-52
4.1.10	Update Small WECS Handbook	4-55
4.1.11	Large WECS Handbook	4-56
5.0	WIND CHARACTERISTICS FOR WECS OPERATIONS	5-1
5.1	PROGRESS IN TECHNICAL TASKS	5-3
5.1.1	Wind Forecasts for WECS Operations by MOS	5-3
5.1.2	Real-Time Subjective Wind Forecasts	5-6
5.1.3	Historical Subjective Wind Forecasts	5-8
5.1.4	Wind Forecast Verification	5-12
5.1.5	International Wind-Forecasting Verification Program	5-13
6.0	SPECIAL STUDIES	6-1
6.1	PROGRESS IN TECHNICAL TASKS	6-3
6.1.1	Prototype Program for Reliability/Accuracy Testing of Meteorological Instrumentation	6-3
6.1.2	Siting Short Course for Small WECS	6-4

7.0	METEOROLOGICAL VALIDATION OF PHASE I CANDIDATE SITES	7-1
7.1	PROGRESS IN TECHNICAL TASKS	7-3
7.1.1	Support to DOE's Selection and Evaluation of Candidate Sites (Phase I)	7-3
7.1.2	Application of Refined Techniques for Estimating Wind Characteristics at Candidate Sites	7-5
7.1.3	Meteorological Validation Program	7-11
7.1.4	Data Analysis and Reporting	7-13
8.0	PHASE II TURBINE SITE METEOROLOGICAL VALIDATION ACTIVITIES	8-1
8.1	PROGRESS IN TECHNICAL TASKS	8-3
8.1.1	Evaluation of Phase II Turbine Sites	8-3
8.1.2	Support to DOE's Site Selection Process	8-4
8.1.3	Special Instrumentation and Data Collection Procedures at Phase II Sites	8-5
8.1.4	Turbine Installation (Phase II) Site Data Analysis and Reporting	8-7
8.1.5	Anemometer/Microprocessor Test Program	8-8
9.0	REFERENCES	9-1
	APPENDIX A: Management Overview of the Wind Characteristics Program Element	A-1
	APPENDIX B: Published Reports Given UC-60 Distribution	B-1

1.0 INTRODUCTION

The primary objectives of the Federal Wind Energy Program are: to accelerate the development of reliable and economically viable wind energy systems and to enable the earliest possible commercialization of wind power (U.S. Department of Energy 1978). Information about wind characteristics that directly affect the reliability and economics of wind energy conversion systems (WECS) is one element of this multifaceted federal program. In April 1976, the Pacific Northwest Laboratory (PNL) was assigned the responsibility for management and technical coordination of the Wind Characteristics Program Element (WCPE). This Annual Report of the Program Element outlines the technical progress from July 1978 through September 1979.

The primary objective of the WCPE is to provide, through research and development projects, appropriate information about wind characteristics to those involved in the design and evaluation of WECS, in energy program planning, in selecting sites for WECS installations, and in the day-to-day WECS operations. To more effectively meet these various needs, the WCPE has been divided into the following technical program areas:

- Wind Characteristics for Design and Performance Evaluation
- Large Area Wind Energy Analyses
- Siting Methodologies
- Wind Characteristics for WECS Operations

The Wind Characteristics for Design and Performance Evaluation Program area, which is divided into two subareas, is concerned with the direct interaction between meteorological phenomena and a WECS. The design portion of the program area characterizes wind and other meteorological phenomena. Performance evaluation recommends 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; however, it does provide meteorological support to those involved in such activities.

The Large Area Wind Energy Analysis Program area has the primary responsibility of developing and presenting analyses of wind-energy potential over

large areas. The analyses are to identify smaller areas of favorable wind characteristics and to quantify the wind-energy potential over the entire area. In FY 1979 the emphasis has shifted from the broad national assessment to the more detailed regional assessments.

The 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 objectives, 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 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 October 1978 PNL assumed management responsibility for data collection at the 17 DOE candidate sites as well as the measurement program at a new set of candidate sites to be selected in November 1979. During this period, the effort focused on wind measurement programs at candidate sites and technical assistance to DOE during site selection activities. For FY 1979, the program was established separately from the WCPE and was called the Meteorological Validation Program (MVP).

In addition to the program area tasks, PNL, at the request of DOE/HQ, coordinated a Conference and Workshop on Wind Characteristics and Wind Energy Siting in Portland, Oregon. The purpose of the meeting was to bring together investigators from the many disciplines involved in the commercialization and utilization of wind power for presentations and working group discussions focused primarily on the appropriate wind characteristics. There were over 160 registered attendees at the conference. The proceedings volume will be published by the American Meteorological Society, a cosponsor of the conference.

The technical progress covered in this report includes that accomplished directly by PNL and by contractors funded directly by DOE or through PNL.

Because of the urgency to provide information pertinent to the goals of the Federal Wind Energy Program, highest priority has been given to those projects that answer specific and immediate needs.

This report is divided into eight major parts. Sections 2.0 through 5.0 correspond to the four Program Areas of the WCPE. Section 6.0 deals with special studies, and Sections 7.0 and 8.0 cover the three areas of activity in the Meteorological Validation Program. Each section includes an overview of the progress in the program area as well as the progress in each individual task within that program area. A summary of the administrative aspects of the program is presented in Appendix A.

Because of the number and diversity of projects in the WCPE, this report is not designed to provide a wealth of technical detail, but rather to provide the reader with sufficient information to lead him to a detailed report (see Appendix B) or to personal contact with those directly involved in the work. In this way, one of the important functions of the WCPE, which is to promote fruitful exchanges of information, may be realized.

2.0 WIND CHARACTERISTICS FOR DESIGN AND PERFORMANCE EVALUATION

In this technical area, the goal is to provide appropriate characteristics of the immediate wind environment in which a WECS may operate. To achieve this goal, the kind of wind features and characterizations useful for both current and long-term design and performance evaluations needs to be accurately determined; careful quantitative descriptions of the relevant atmospheric processes need to be provided; and the required wind information needs to be transmitted to designers and evaluators of WECS performance in a useful, accurate and timely fashion.

In FY 1979, real and specific short- and long-term needs for wind characteristics information were reappraised through extensive and detailed discussions with private and governmental WECS design engineering groups. Combined with analyses within PNL of the relevance of wind characteristics to the response of turning wind turbines, these discussions led to further analysis which led to the conclusion that five characteristics needed further extensive work:

- gust models (evaluate, compare, generalize, measure and characterize appropriately)
- turbulence as experienced by a rotating wind turbine (measure spectra, gusts and time series; and relate rotating-turbine wind characteristics to the conventional fixed anemometer wind characteristics)
- wind direction fluctuation (measure and characterize appropriately for fatigue and power optimization strategies)
- vertical shear of the horizontal wind (provide more representativeness of real environments such as diurnal variations, non-classic boundary layers and wind shear fluctuations)
- mean wind probabilities (characterize height variations and effects of specific site conditions).

Within PNL, wind gust characterization and model evaluation have been done extensively. The results of the study will be published in two quantitative

and substantial reports that represent the state of knowledge on gust statistics for use in WECS design.

The PNL constructed and tested a sound, accurate array of anemometers on towers. These anemometers measure the wind in a vertical circular ring. This array will enable better estimates to be made of the characteristics of wind as experienced by a rotating blade of a WECS. The first analyses of measurements indicate that gust probability and the turbulence spectrum are substantially different than that represented by winds measured at nonrotating fixed locations. The implications of this are so great that increased study by both measurements and theory is suggested. Several different theory or combined theory and measurement studies have been initiated.

Prototype studies of wind direction fluctuations and wind shear fluctuations were completed at PNL. The probability distributions developed from measurements have been found to be of immediate use. In the case of wind shear fluctuations, wind that appears rather innocuous, as measured by shears of hourly mean wind, can have large wind shears of 5-sec average winds for significant fractions of the day.

Outside contractors have been obtained for studying mean wind frequency-of-occurrence distributions (see 2.1.6) and for characterizing nocturnal vertical shear of the mean wind and diurnal variation of wind shear (see 2.1.10).

Another key activity in FY 1979 was a set of studies of the usual wind characteristics at significant non-classical sites. These sites often are especially good for wind power, but their modifications of wind characteristics are not known well. Included in these studies were: complex terrain (2.1.3), mountain tops (2.1.9), downslope winds (2.1.4), downslope and canyon wind (2.1.7), central plains nocturnal winds (2.1.10) and east coast barrier island winds (2.1.1).

Studies for determination of the accuracy of wind characteristics in the general literature (2.1.1) and those recommended in the Engineering Handbook on the Atmospheric Environmental Guidelines for Use in Wind Turbine Generator Development (2.1.2) were initiated. The results, which will be forthcoming in FY 1980, will be an aid in the PNL development of a new reference document of wind characteristics for use in WECS design.

The main effort in FY 1979 under performance evaluation was the initiation of a study of WECS response to turbulence by numerical solution of WECS equation of response to turbulence (2.1.13). The initial work will use the spectral transfer function approach and will be tested against measurements of wind and turbine performance at Rocky Flats. One purpose of the study is to obtain information on the importance of various possible measurements and analyses of wind for evaluation of WECS performance.

2.1 PROGRESS IN TECHNICAL TASKS

2.1.1 Environmental Design Criteria for WECS (A1a)

Pacific Northwest Laboratory
Richland, WA 99352

Principal Investigators:

James R. Connell (509)942-4624

J. Chris Doran (509)942-4763

David C. Powell (509)942-4622

Objective:

To provide information rapidly to the Federal Wind Energy Program about wind characteristic parameters important to designers' immediate needs.

Program Status:

Efforts are under way to compare existing gust models. Based on analyzed measurements of wind speed, a gust model is being developed. Wind properties at a fixed point are being related to wind properties such as would be experienced by a WECS rotating blade.

Progress During Reporting Period:

A selected number of available gust models for use in WECS design have been analyzed and compared. A report of the results is currently under review by engineers and scientists.

A prototype study, to be expanded in FY 1980, on the PNL gust model and corresponding measured statistics has been essentially completed. Figure 2.1 shows a probability distribution of PNL $GUST_0$ amplitudes and durations (times). The straight lines represent Gaussian distributions. The data represent observed distributions. Figure 2.2 shows the definition of $GUST_0$ and $GUST_1$. The defining parameters of a gust are amplitude, A, and duration, T.

A theoretical derivation of the spectrum of wind speed fluctuations, as observed by a rotating blade of a horizontal axis wind turbine, has been studied by a consultant.

FIGURE 2.1. Probability Distribution, Basic Frequency Factor and Amplitude -- Time Correlation for $GUST_0$ Speed, 50/5-sec Band-Pass Filter

FIGURE 2.2. Definitions of GUST as a Time Series

A prototypic analysis of wind shear fluctuation statistics has been completed that shows that wind shears are more extreme than designed for. Figure 2.3 contains a probability of occurrence of shear of 4-sec averaged wind across the disc of the PNL vertical plane array of anemometers. The straight line is a Gaussian distribution. The dots represent the observed distribution.

Expected Progress During Next Reporting Period:

Two reports for UC-60 distribution will be completed: one on the comparison of gust models and the other on the PNL gust model.

Reports and Publications:

Cliff, W. C. 1979. Wind Direction Change Criteria for Wind Turbine Design. PNL-2531, Pacific Northwest Laboratory, Richland, WA 99352.

Huang, C. H. and G. H. Fichtl.^(a) 1979. Gust-Rise Exceedance Statistics for Wind Turbine Design. PNL-2530, Pacific Northwest Laboratory, Richland, WA 99352.

(a) Consultant
2705 College Park Circle
Huntsville, AL 35805

FIGURE 2.3. The Probability That the 4-sec Average Shear Between 18 m and 54 m is Less Than a Specific Value

2.1.2 Error Band Analyses (A1b)

Contract No.: B-23461-A-P

FWG Associates, Inc.
R.R. 2, Box 271-A Lakewood Drive
Tullahoma, TN 37388

Principal Investigator:

F. Walter Frost (615)455-1982

Contract Monitors:

James R. Connell (509)942-4624

David C. Powell (509)942-4622

Objective:

To provide quantitative estimates of standard deviation and confidence limits of the design graphs and data sets used in the Engineering Handbook on the Atmospheric Environmental Guidelines for Use in Wind Turbine Generator Development, by Frost, Long and Turner (1978). The specific topics to be addressed in order of priority are: 1) vertical shear of the horizontal wind, 2) wind-speed probabilities, 3) atmospheric wind-speed turbulence spectra and intensity, and 4) gust characteristics.

Program Status:

The final stages of the contract are being completed and a final report is expected in mid-FY 1980.

Progress During Reporting Period:

All papers, reports, graphs and data used in deriving the atmospheric results for the specified topic areas in the Engineering Handbook on the Atmospheric Environmental Guidelines for Use in Wind Turbine Generator Development have been compiled, cataloged and put in an organized file for the contractor's use. Descriptions of the development of each specific topic have been written in sufficient detail to fully describe the reasoning used in developing the engineering criteria.

Data used in verifying the graphical information in the handbook have been tabulated for use in the statistical evaluation of standard deviation about the recommended design curves. Additional data already recorded, but not used in the initial development of the handbook, have been gathered for incorporation into the data sample. A list of the additional references with cataloged, readable copies has been compiled for the contractor's use.

A detailed evaluation of the confidence limits for vertical shear of the horizontal wind has been carried out. Propagation of error analysis has been used to further establish the validity of the models for vertical wind shear given in the handbook.

Expected Progress During Next Reporting Period:

Similar error analysis will be carried out for the turbulence spectra and intensity correlation used in the handbook and for the wind-speed probability curves. Additionally, an assessment of the directional fluctuation models given in Chapter 5.0 of the design handbook will be verified against experimental data currently available on magnetic tape. Directional fluctuations will be statistically analyzed from the experimental data and will be compared against the prediction model developed for use in the handbook.

A final report will be written that will include graphs of recommended relationships, standard error estimates or error bands, and appropriate confidence limits for the specified topics. The report will also contain written justification for the recommended curves, equations and tables.

Reports and Publications:

None.

2.1.3 Turbulence Characteristics Over Nonuniform Terrain (A1c)

Contract No.: ET-78-S-06-1110

Pennsylvania State University
505 Walker Building
University Park, PA 16802

Principal Investigator:

Hans A. Panofsky (814)865-0478

Co-Principal Investigator:

John A. Dutton (814)865-1534

Contract Monitor:

David C. Powell (509)946-4622

Objective:

To investigate characteristics of wind fluctuations needed for the design and operation of WECS. This is accomplished by establishing models for variances, spectra and frequency distributions of velocity fluctuations over uniform terrain and modifying these models to apply to various types of complex terrain.

Program Status:

This project was initiated in September 1978 and is expected to continue through October 1980. A final report on the work during the first half of this period is scheduled for completion by October 30, 1979.

Progress During Reporting Period:

Variances: Observations of variances of the velocity components from many sites were collected. Generally, nondimensional ratios of standard deviations to friction velocity were plotted against some stability parameters and interpolated for zero Richardson (strong winds). As a result, we have more reliable estimates of σ_u/u_* , σ_v/u_* and σ_w/u_* (where σ stands for standard deviations; subscripts, u, v and w refer to the longitudinal, lateral and vertical directions; and u_* is the friction velocity). These estimates are 2.4, 1.9 and 1.27, respectively, and they refer to 1-hr averages with linear trends

removed. Given these ratios, simple methods have been suggested for the estimation of turbulence intensities σ_u/V , σ_v/V and σ_w/V .

Over rolling terrain, σ_u/u_* and σ_v/u_* may exceed these ratios by 40%, though σ_w/u_* is the same as over uniform terrain. In the lee of hills (wake effect) the ratios σ_u/u_* and σ_v/u_* may even be much larger.

In contrast, σ_u and σ_v decrease rapidly with height on hilltops. Therefore, if these quantities are normalized by surface values of u_* , the ratios σ_u/u_* and σ_v/u_* become much smaller than the standard ratios quoted above. In contrast, σ_w/u_* remains effectively constant with height.

Spectra: Spectra of vertical velocity obey predictions of standard Monin-Obukhov theory. Specific functions have been developed, based on this theory, which fit observations very well in many locations for unstable and neutral (strong-wind) conditions.

Spectra of horizontal wind components are much more complicated because the Monin-Obukhov theory seems to be inadequate at low frequencies, where the height, Z_i , of the lowest inversion becomes an important predictive parameter.

A model has been developed, suitable for uniform terrain, in which the spectrum is composed of two separate functions with weights w_1 and w_2 . The function w_1 is formulated to become large at low frequencies, w_2 at high frequencies. The spectra fit well under neutral and unstable conditions. An example is shown in Figure 2.4.

There is an indication that the limiting form of the spectra for neutral conditions is significantly different when approached from the unstable and stable sides; the limit approached from the stable side contains significantly less low-frequency energy.

Preliminary analysis of spectra over rolling terrain suggests that the additional energy comes from frequencies so low that the resolution is poor and no exact wavelength can be assigned. The additional energy is particularly striking in stable air.

FIGURE 2.4. The Logarithmic U-Spectrum $\log [n S_u(n) u_*^2]$ for $-z/L = 0.10$ as a Function of Log F Minnesota Data (Run 2A1 at $z = 4m$). The model is given by the solid line and Kaimal's (1978) curve is given by the dashed line. Crosses mark the observation.

Velocity Fluctuations: Wind velocity fluctuations are essentially Gaussian, but their deviations have excessive kurtosis. Therefore, a "Gaussian patch" model has been proposed and tested on two sets of meteorological observations. This model is based on the hypothesis that atmospheric turbulence is composed of two (or more) Gaussian distributions with differing standard deviations and autocorrelation functions. Patches with these distributions alternate in a random manner. The probability of occurrence of each distribution can be specified arbitrarily. The tests demonstrated that the model satisfactorily described the Gaussian characters of the velocity components and excessive kurtosis of velocity changes over short periods, but the observed kurtosis exceeded those suggested by the model. Hence, modifications of the model are indicated.

Expected Progress During Next Reporting Period:

During the period November 1979 to October 1980, emphasis will be placed on determining the quantitative differences between turbulence statistics over simple and complex terrain. Observations on hilltops and escarpments will be available from Australia, New Zealand and New Mexico. Additional information from rolling farm land in Pennsylvania will be analyzed.

The results will be presented in terms of models that can be used over various types of complex terrain. Also, the relationship between probability structure of response to probability structure of input will be investigated theoretically and tested in realistic situations.

Reports and Publications:

Dutton, J. A., and J. Højstrup. 1979. "A Model for the Probability Structure of Atmospheric Turbulence." Paper presented at the Conference and Workshop on Wind Characteristics and Wind Energy Siting 1979, June 19-21, 1979, Portland, Oregon.

Panofsky, H.S., M. Vilardo and R. Lipschutz. 1979. "Terrain Effects on Wind Fluctuations." Paper presented at the Fifth International Conference on Wind Engineering, July 8-14, 1979, Fort Collins, Colorado.

2.1.4 Characteristics of Strong Downslope Winds (Ald)

Contract No.: DE-AI06-79ET23115

NOAA/Wave Propagation Laboratory
Boulder, CO 80303

Principal Investigators:

J. Chandran Kaimal (303)499-1000, Ext. 6263

John E. Gaynor (303)499-1000, Ext. 6245

Contract Monitor:

James R. Connell (509)942-4624

Objective:

To concentrate on the development of probability distributions relevant to wind-turbine design considerations from turbulence data recorded on an instrumented meteorological tower 30 km north of Denver, Colorado. The data set for statistical analysis consists of wind turbulence, time differences (accelerations or gusts) in the wind speed and direction, and vertical shear of wind speed and direction (all from up to eight levels of a 300-m tower).

Program Status:

The planning phase of the project began in January 1979 and the analysis work was initiated in April 1979. By July 1979 the initial software for the wind turbulence analysis was completed and preliminary results compiled. A final report will be written in the spring of 1980.

Progress During Reporting Period:

Initial analysis was completed using the 10-sec averaged longitudinal (u) and lateral (v) wind components from the eight levels of sonic and propeller-vane anemometers on the tower. The probability distributions of the u and v components' 10-sec acceleration (gusts) and of the vertical shears between adjacent levels were completed as a function of level. Results for all levels were averaged for data

recorded during September 1978. The 10-sec averaged vertical winds were similarly analyzed. The results of the shear analysis were too preliminary to report. The acceleration distributions showed slightly negative means and negative skewnesses at all levels. The u, v, and vertical wind distributions were close to Gaussian. Figure 2.5 presents an example of u accelerations at 50 m with variance of $4.3 \times 10^{-3} \text{ m}^2 \text{ sec}^{-4}$ and skewness of -0.56.

Expected Progress During Next Reporting Period:

After July 31, 1979, PNL decided that band-pass filtering the data initially to simulate wind turbine response and analyzing the wind speed and direction data for only strong wind cases would be more useful. This work is currently being done and gust rise (acceleration) and shear statistics are being recomputed. Further, from two gust models conceived at PNL, statistics will be calculated using the meteorological tower sonic-anemometer data. All calculations should be completed by early spring 1980, and the final report will be written at that time.

Reports and Publications:

Kaimal, J. C. 1979. "Wind Statistics at the Boulder Atmospheric Observatory." Paper presented at the Conference and Workshop on Wind Characteristics and Wind Energy Siting 1979, June 19-21, 1979, Portland, Oregon.

FIGURE 2.5. An Example of a Probability Distribution for the 10-sec Acceleration of the Longitudinal Component of the Wind for Most of September 1978 at the Boulder Atmospheric Observatory.

2.1.5 Flow Through a Vertical Plane (Ale)

Pacific Northwest Laboratory
Richland, WA 99352

Principal Investigators:

James R. Connell (509)942-4624

J. Chris Doran (509)942-4763

David C. Powell (509)942-4622

Objective:

To measure the two-dimensional space and time variation of the wind across a vertical disk and to describe the mean wind variation and turbulence that large horizontal-axis wind turbines would experience as the blades rotate in the plane of the disk.

Program Status:

Efforts to acquire and analyze data in this task are continuing now that the vertical plane array has been rebuilt and is operating.

Progress During Reporting Period:

The vertical plane array was rebuilt and checked out.

Expected Progress During Next Reporting Period:

Data will be acquired and analyzed for gusts and spectra in the fixed point, fixed disk average and rotating blade frames of reference.

Reports and Publications:

Doran, J. C. 1979. "Wind Direction Variations in Strong Winds." Paper presented at the Conference and Workshop on Wind Characteristics and Wind Energy Siting 1979, June 19-21, 1979, Portland, Oregon.

Kerrigan, T. C. 1978. A Technique for Analyzing the Structure of Atmospheric Turbulence. PNL-2509, Pacific Northwest Laboratory, Richland, WA 99352.

Kerrigan, T. C. 1978. A Verification Statistic for Numerical Wind Models. PNL-2510, Pacific Northwest Laboratory, Richland, WA 99352.

Kerrigan, T. C. 1978. Spectral Estimates of a Wind Fluctuation Statistic Pertaining to Wind Energy Generators. PNL-2511, Pacific Northwest Laboratory, Richland, WA 99352.

Powell, David C. 1979. "Review of Gust Model Concepts." Paper presented at the International Expert Meeting, September 26-27, 1979, Boone, North Carolina.

Powell, David C. 1979. "Wind Fluctuations as Discrete Events." Paper presented at the Conference and Workshop on Wind Characteristics and Wind Energy Siting 1979, June 19-21, 1979, Portland, Oregon.

2.1.6 Physical Analyses of Wind Speed Distribution Functions (A1f)

Contract No.: DE-AC06-79ET23114

Science Applications, Inc.
Colorado Springs, CO 80906

Principal Investigator:

C. Eugene Buell (303)576-0786

Contract Monitor:

J. Chris Doran (509)942-4763

Objective:

To determine the variation of the parameters entering an empirical probability density function for wind speed as a function of height above the ground and as a function of the general station exposure.

Program Status:

Work began May 1, 1979, and will continue through January 31, 1980.
The final report is expected to be completed by mid-FY 1980.

Progress During the Reporting Period:

The probability density function being used is based on the assumption that the bivariate probability density function for the wind vector components can be approximated as a two-part mixture of circularly normal density functions. When the direction of the wind is "integrated out," the resulting probability density function for wind is of the form

$$p(w) = kp_1(w; \sigma_1, w_1) + (1-k)p_2(w; \sigma_2, w_2)$$

where

- $p(w)$ = the probability density function (p.d.f.) of the mixture for wind speeds ($p[w]dw$ is the probability that the speed, w , lies in the range $[w, w+dw]$)

- $p_1(w; \sigma_1, w_1)$ and $P_2(w; \sigma_2, w_2)$ are the p.d.f.'s for the two components of the mixture with parameters σ_1, w_1 and σ_2, w_2 respectively
- k is the fraction of the mixture due to the part with subscript 1 ($1-k$ the fraction due to the part with subscript 2). The parameters σ_1, σ_2 represent the wind-component standard deviations of the part indicated by the subscript, and w_1, w_2 represent the resultant vector wind speed of the part concerned. The parameters concerned (their variation with height and exposure) are $\sigma_1, w_1, \sigma_2, w_2 k$, not all of which may be necessary to obtain an adequate empirical fit to the data.

Data for the analysis of the variation of the parameters with height are being assembled. The data now at hand that appear usable (three or more levels) are: Hanford tower data from BNWL-1605, tower data from nuclear power sites from BNWL-2220 WIND-4 and Patrick tower data (computer printout loaned by Jack Reed, Sandia Laboratories).

Expected Progress During Next Reporting Period:

It is expected that further tower data will be obtained from the White Sands Missile Range, the National Aeronautics and Space Administration (Canaveral) and perhaps other sites.

Data from neighboring locations, but with different surrounding terrain, will be located from BNWL-2220 WIND-11. The analysis should result in information concerning the effect of station exposure on the model required to adequately approximate the wind p.d.f. (or d.f.).

Reports and Publications:

None.

2.1.7 Characteristics of the Wind Measured at Rocky Flats (Alg)

Pacific Northwest Laboratory
Richland, WA 99352

Principal Investigator:

James R. Connell (509)942-4624

Objective:

To provide aid in the measurement and analysis of wind characteristics at the Rocky Flats (R.F.) Small WECS Testing Site, on a continuing basis, in support of the current and anticipated design and testing programs and to collaborate with R.F. to provide wind characteristics support to small WECS designers and performance evaluators.

Program Status:

Efforts in this area are continuing.

Progress During Reporting Period:

Progress was made in the following areas: PNL participated in design reviews at R.F., provided a data logger and analyzed data for the R.F. meteorological tower. A cooperative effort regarding the PNL contract with Robert Thresher at Oregon State University was initiated and the responsibility for continued Georgia Tech work was transferred to R.F.

Expected Progress During Next Reporting Period:

We anticipate: participating in design reviews at R.F., analyzing the turbulence at R.F., continuing the cooperative effort regarding the PNL contract with Robert Thresher at Oregon State University and helping plan R.F.'s small vertical-plane wind array for a 40-kW machine.

Reports and Publications:

None.

2.1.8 Meteorological Guidelines for WECS Design (A1h)

Contract No.: 5189-76-32

Sandia Laboratories
Albuquerque, NM 87115

Principal Investigator:

Robert E. Akins (703)961-6744

Contract Monitors:

James R. Connell (509)942-4624

David C. Powell (509)942-4622

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:

The work initially planned for this effort was completed as of July 1979.

Progress During Report Period:

Two reports have been completed. One deals with wind characteristics for field testing wind turbines. Topics included in this report are anemometer placement, averaging techniques and resolution of errors involved in the instrument placement and data acquisition. This report has been written from a practical point of view and is in a format that anyone involved with the testing of wind turbines should be able to follow.

The second report, which deals with possible approaches to the evaluation of the effects of atmospheric turbulence on the performance of wind turbines, has been completed and is in the review process. This study outlines a number of techniques that may be useful in unsteady-performance evaluation. Limited examples of the applications of these techniques are also included.

Expected Progress During Next Reporting Period:

The review of the report dealing with unsteady-performance evaluation will be completed and the report will be published as a Sandia Laboratories' report.

Reports and Publications:

Akins, R. E. 1979. Wind Characteristics for Field Testing of Wind Energy Conversion Systems. Sandia Laboratories Report SAND 78-1563, Albuquerque, NM 87115.

2.1.9 Wind Characteristics at Singular Topographic Features (Ali)

Pacific Northwest Laboratory
Richland, WA 99352

Principal Investigator:

James R. Connell (509)942-4624

Objective:

To measure mean and turbulence characteristics of wind at a simple mountain site, which represents one extreme environment in which many WECS may be operated.

Program Status:

Efforts to measure wind characteristics are continuing at a single mountain site.

Progress During Reporting Period:

A 200-ft meteorological tower has been installed at the top of Big Southern Butte in Idaho. Four elevators for anemometers are operational. Access to data from a nearby set of meteorological towers on the surrounding plain has been obtained.

Expected Progress During Next Reporting Period:

The anemometers and recording equipment will be installed and data acquired. The data will be used by PNL and, also, for part of the Pennsylvania State University contracted study.

Reports and Publications:

None.

2.1.10 Wind Shear in the Nocturnal Boundary Layer (Alj)

Contract No.: DE-AT06-79ET23116

Oregon State University
Department of Atmospheric Science
Corvallis, OR 97331

Principal Investigator:

Larry J. Mahrt (503)754-4557

Contract Monitors:

James R. Connell (509)942-4624

David C. Powell (509)942-4622

Objective:

1. To document the frequency of occurrence of various velocity differences over layers appropriate to various wind machines. The proposed study will examine several areas of the United States considered to be of high wind-power potential and will concentrate initially on the high plains and certain promising areas of the northwest United States.
2. To examine and illustrate the diurnal variation of wind-power potential for different seasons and synoptic conditions.
3. To formulate a simple rough model for the purpose of predicting:
 - a. diurnal variations and large low-level shear in data-sparse areas, and
 - b. low-level winds and shears 12 hr in advance, given conventional synoptic forecasts.

Program Status:

This project was initiated in February 1979, and the first contract period will end in February 1980.

Progress During Reporting Period:

Analyses of existing tower, radiosonde and tethered balloon data have begun to document characteristics of mean winds in the lowest few hundred meters of the boundary layer. The sites investigated

Reports and Publications:

Heald, R.C. 1979. "Boundary Layer Wind Shear." Paper presented at the Conference and Workshop on Wind Characteristics and Wind Energy Siting 1979, June 19-21, 1979, Portland, Oregon.

to date are Hay, Australia (the Wangara experiment); Cedar Hill, Texas; and Sangamon County, Illinois. The nearly 1000-hourly observations from the Hay, Australia site are being studied in detail to determine the behavior of diurnal variations in low-level winds and shear.

Preliminary work on modeling low-level winds has just begun. One possible model uses a form of the power law that will describe daytime well-mixed wind profiles, as well as nocturnal wind profiles topped by a low-level jet. Initial work has included relating low-level wind profiles to a layer Richardson number computed over the lowest 100 m of the boundary layer. Power law exponents have been computed by fitting the power law between various heights and for various Richardson number categories in order to assess the behavior of this model. One paper, "Shear in the Diurnally Varying Boundary Layer," by R. C. Heald and L. Mahrt, has been submitted to the Journal of Applied Meteorology.

Expected Progress During Next Reporting Period:

Documentation of low-level winds will continue. Recently acquired data from the KTVY-television tower in Oklahoma City, Oklahoma, will be analyzed extensively. These data were sampled for a whole year at a high rate (six times per minute). They will offer a rare opportunity to study the synoptic and seasonal variability of low-level winds. Long-term wind records at the Risø National Laboratory in Denmark include measurements of turbulent fluctuations. These data will assist in documentation of turbulence characteristics for wind turbine design and operation.

Modeling the low-level wind, especially the nocturnal boundary layer, will become an increasingly important part of future work. Using the large data records from KTVY and the Risø work, various alternatives to the conventional power law will be performed. One aspect not presently considered is that wind direction changes with height. Directional changes may be large at night, acting to increase low-level wind shear.

2.1.11 Measurement Methods for Performance Evaluation (A2a)

Contract No.: DE-AC06-79ET23164

Pacific Northwest Laboratory
Richland, WA 99352

Colorado State University
Fort Collins, CO 80523

Principal Investigators:

James R. Connell (PNL) (509)942-4624

C. Byron Winn (CSU) (303)491-6558

Objective:

To describe the effect of specific measurement methods of wind characteristics on evaluated performance of WECS, to optimize the methods of measuring and analyzing the wind for specific WECS types and sizes, and to provide experience with real-time analysis.

Program Status:

Efforts are under way to develop real-time performance evaluations.

Progress During Reporting Period:

A contract was let with C. Byron Winn at Colorado State University to purchase a smart data-acquisition system computer for DOE and to develop real-time performance evaluation algorithms for use with it.

Expected Progress During Next Reporting Period:

PNL plans to develop real-time performance evaluation algorithms and set up and use a smart data-acquisition system with real-time analysis capability for studies of wind characteristics for performance evaluation.

Reports and Publications:

None.

2.1.12 Turbulence Effects on WECS Output (A2b)

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

Georgia Institute of Technology
Atlanta, GA 30332

Principal Investigator:

C. Gerald Justus (404)894-3890

Contract Monitor:

J. Chris Doran (509)942-4763

Objective:

To develop, test and apply methods for describing wind characteristics and for estimating their effects on various aspects of the performance of a WECS in a large array and as an individual unit.

Program Status:

The current work program is complete, and final and technical report drafts are in review.

Progress During Reporting Period:

A study was conducted on the sensitivity of the Monin-Obukhov similarity model and modified power-law model to different input parameters. The models are sensitive to wind speed at anemometer level and to net radiation (atmospheric stability) but are less sensitive to surface roughness length. For higher wind speeds, such as would be of interest in wind-energy applications, the two models are less sensitive to wind speed and stability. Although the similarity model is theoretically more rigorous than the modified power-law model, it is computationally more complicated. The analysis shows that the largest deviation between the two models occurs at low wind speeds and in very stable conditions.

Data from 14 sites were studied for wind-turning characteristics. Monthly and annual cumulative turns (positive cyclonic) were computed for each site. To simulate the performance of actual wind turbines, various threshold wind speeds were chosen. A threshold

wind speed is one that is below the speed expected to operate a wind turbine. The monthly and annual cumulative turns were found to closely approximate a normal distribution. The direction of wind turning for the majority of the sites was anticyclonic (clockwise), because of the placement of the sites south of the most frequent zone of cyclonic activity. Confidence limits for monthly and annual cumulative turns were also evaluated.

A synthesis of the earlier studies of wind and power distributions for large arrays of wind turbines was formulated in a computer model program. The program can be run with interactive (computer terminal) or batch input (card files, etc.). Based on a generic wind-turbine-power model, input characteristics at a single representative site, and data specifying the size of the array to be simulated, the program computes wind-speed and wind-power-output statistics for the model array. Wind data for the input single site can be at the 10-m level or at hub height. (If the former, a height projection to hub height is performed by the program.) Time series wind speeds at the single input site can also be used by the program to evaluate equivalent time-series wind speeds and output power for the array.

Reports and Publications:

Justus, C. G., K. Mani and A. S. Mikhail. 1979. "Interannual and Month-to-Month Variations of Wind Speed." J. Appl. Meteorol. 18(7).

Justus, C. G., K. Mani and A. S. Mikhail. 1978. Interannual and Month-to-Month Variations of Wind Speed. RLO/2439-78/2, available from NTIS, Springfield, VA 22151.

Justus, C. G., and A. S. Mikhail. 1978. Energy Statistics for Large Turbine Arrays. RLO/2439-78/3, available from NTIS, Springfield, VA 22151.

Justus, C. G., and A. S. Mikhail. 1978. "Energy Statistics for Large Wind Turbine Arrays." Wind Engineering 2:184-202.

Justus, C. G., and A. S. Mikhail. 1978. "Generic Power Performance Estimates and Wind Turbines." Wind Tech. Jour. 2:45-62.

2.1.13 Wind Response Characteristics of Horizontal-Axis Wind Turbines (A2)

Contract No.: DE-AT06-79ET23144

Oregon State University
Department of Mechanical Engineering
Corvallis, OR 97331

Principal Investigator:

Robert W. Thresher (503)754-2535

Contract Monitor:

James R. Connell (509)942-4624

Objective:

To provide estimates for the gust response of wind turbines and to directly address issues associated with a statistical wind input, the resulting aerodynamic loading and the various turbine structural responses.

Program Status:

The project was initiated during July 1979 and is scheduled through February 1981. (The final report is expected to be completed at that time). Actual research has just begun.

Expected Progress During Next Reporting Period:

The early work will involve the use of two fundamentally different wind-turbine aerodynamic wake models, which (it is felt) model two extreme possibilities of wind-turbine wake response. The wind input to both of these will be a general gust disturbance that is characterized in terms of the component gust-power spectral densities and coherencies for a given mean-wind speed. With the structural representation for the turbine, the resulting aeromechanical equations of motion will be linearized and transfer functions determined. From this, the vibrational response and dynamic loading can be determined in terms of the output-power spectral densities. A second phase of this line of research will compare these theoretical models with experimental data from Rocky Flats. From this information, it is expected that the range of parameters over which the models are

valid can be determined. It is hoped that the simple models and approximate results can satisfy some immediate needs and provide the necessary confidence in this approach as a reliable design tool.

Reports and Publications:

None.

3.0 LARGE AREA WIND ENERGY ANALYSES

The goal of this program area is to analyze wind energy potential over large areas to estimate the amount and distribution of the resource. During this reporting period, the prototype techniques that were developed in the previous reporting period were applied to the assessment of the resource in the Northwest region of the United States, i.e., Idaho, Montana, Oregon, Washington, Wyoming (see Task B1a). This assessment produced a wind power atlas to serve immediate needs in planning and marketing analyses and established the format for the assessment atlases for the other regions of the United States and its territories.

To complete the assessment atlases for the other regions, a Request for Proposals (RFP) was prepared (see Figure 3.1 for the regions). Forty-three organizations responded to the RFP with a total of eighty proposals. Contractors for the Northeast, Southwest, Alaska and Hawaii Regions were selected before the end of the reporting period (see 3.1.3 to 3.1.6). Contractors for the remaining seven regions will be selected early in the next reporting period. The assessments for all regions are scheduled for completion before October 1, 1980. The coordination of all these regional assessments was established as a task at PNL and began during this reporting period with the major portion of the activity to be carried out during the next reporting period (see 3.1.2 and 3.1.2a). The main objective of this coordination effort is to ensure timely, comparable assessments from all the regions.

During the course of this reporting period individual support studies were conducted that contributed methods and information important to analyses of wind-energy potential. Wind power in coastal regions was examined with the aid of existing measurements, computational models (see 3.1.9) and the experiences of charter boat captains and commercial fisherman (see 3.1.10). Another small effort was funded to test the appropriateness of the Northwest regional wind-energy assessment in agricultural applications (see 3.1.11). A study of the selected wind statistics was continued in the area of the effects of data sampling techniques on mean wind-power estimates.

FIGURE 3.1. Geographic Divisions for Regional Wind Energy Resource Assessments

3.1 PROGRESS IN TECHNICAL TASKS

3.1.1 Pacific Northwest Analysis (Bla)

Pacific Northwest Laboratory
Richland, WA 99352

Principal Investigator:

Dennis L. Elliott (509)942-4762

Objective:

To develop resource assessment techniques for the entire United States, to apply these techniques to the Northwest region and to provide information on the distribution of the wind resource suitable for planning for the implementation of WECS.

Program Status:

This program was initiated in FY 1978 and will come to a close early in FY 1980.

Progress During Reporting Period:

Techniques for analyzing digitized, summarized, and non-summarized wind data were developed. Several meteorological/topographical indicators of wind energy were found and investigated. Computer graphics were developed to display the wind characteristics computed from NCC data tapes in a compact format. The techniques for analysis of quantitative data and the techniques developed by PNL and its subcontractors to evaluate wind energy in data-sparse areas were applied to the Northwest region (Idaho, Montana, Oregon, Washington and Wyoming). A draft atlas has been prepared and distributed for review. The narrative for the final report is about 75% complete. Some of the wind power maps in these documents, such as the one shown in Figure 3.2, are available in color.

Expected Progress During Next Reporting Period:

The atlas, in its final form, will be published in early 1980. Color maps for all states and seasons will also be available then. The final report will appear in draft form in mid-FY 1980. The publication of the atlas and final report will conclude this program.

FIGURE 3.2. Northwest Annual Wind Power

Reports and Publications:

Barchet, W. R., and D. L. Elliott. 1979. "Pacific Northwest Regional Assessment." In Proceedings of the Conference and Workshop on Wind Characteristics and Wind Energy Siting 1979, pp. 213-226. American Meteorological Society, Boston, Massachusetts.

Elliott, D. L. 1979. "Meteorological and Topographical Indicators of Wind Energy for Regional Assessments." In Proceedings of the Conference and Workshop on Wind Characteristics and Wind Energy Siting 1979, pp. 273-283. American Meteorological Society, Boston, Massachusetts.

Elliott, D. L., and W. R. Barchet. 1979. "Northwest Regional Wind Energy Assessment." Paper presented at Solar 79 Northwest, August 10-12, 1979, Seattle, Washington.

3.1.2 Coordination of Large Area Analysis (B1b)

Pacific Northwest Laboratory
Richland, WA 99352

Principal Investigators:

W. Richard Barchet (509)942-4621
Dennis L. Elliott (509)942-4762

Objective:

To ensure that all regional assessments are completed in a timely, cost-effective, compatible and comparable fashion.

Program Status:

This task was initiated in February 1979 and will continue until atlases for all regions have been completed (sometime in late 1980 or early 1981).

Progress During Reporting Period:

The computer programs developed for processing National Climatic Center (NCC) data were converted to the UNIVAC system and substantially revised to include additional statistics and streamlined input/output handling for processing the NCC TD-1440 tape series. NCC tape sets covering six regions were received by the close of FY 1979.

Other programs were developed for plotting state boundaries, drawing grids on maps, generating map scales, and plotting data station locations and parameter values at station locations.

The full data set of the National Fire Weather Data Library (NFWDL) was analyzed by Marlatt and Associates (see 3.1.2a).

A coordination meeting was held in October with contractors from the Northeast, Alaska, Hawaii and Southwest regions in attendance.

Expected Progress During Next Reporting Period:

All NCC TD-1440 data tapes will be processed by February 1980 and microfiche of tables and microfilm of graphics will be delivered to

regional assessment subcontractors. All NFWDL analyses will be delivered to these contractors. Software for analyzing and presenting data will be documented.

Reports and Publications:

None.

3.1.2a Coordination of Large Area Analysis (B1b)

Contract No.: B-50369-A-L

Marlatt and Associates
3611 Richmond Drive
Fort Collins, CO 80526

Principal Investigator:

William E. Marlatt (303)226-4857

Contract Monitor:

W. Richard Barchet (509)942-4621

Objective:

To evaluate the wind records of the USFS National Fire Weather Data Library (NFWDL) for estimating the time and spatial distribution of wind energy.

Program Status:

This project was initiated in March 1978 to investigate the applicability of the NFWDL to wind-energy studies for the five north-western states: Idaho, Montana, Oregon, Washington and Wyoming. The project was extended in May 1979 to include the entire United States.

Progress During Reporting Period:

Analysis techniques and computer programs for evaluation of the wind records from the NFWDL, in terms of wind energy, were developed and tested. Fire weather data for approximately 675 stations were evaluated and ranked for wind-energy potential. Results of the analysis were summarized in a report (Marlatt et al. 1979).

Data from the NFWDL for the remainder of the United States have been screened. Computer programs have been modified to provide output formats compatible with analyses being conducted by PNL and Northwestern University.

Summaries of fire weather stations with multiple observations per day were screened for applicability to wind-energy analysis. These

summaries, totaling 741 stations in Washington, Oregon and northern California, cover generally the period 1920 to 1966 and are not included in the NFWDL. During that period most fire weather stations recorded three or four observations daily.

Expected Progress During Next Reporting Period:

The data from the NFWDL will be summarized for the remainder of the United States. These summaries will include mean wind speed, frequencies of observations within velocity and wind-energy increment, and station geographic and topographic information.

A search will be conducted for fire weather stations with multiple observations per day in the remainder of the country, which are not included in the NFWDL. Records from selected stations will be keypunched, reduced and analyzed.

Reports and Publications:

Marlatt, W. E., P. Tierney, P. Mielke, M. Baer and J. Childs. 1979. Assessment of the Applicability of the National Fire Weather Data Library to Wind Energy Analysis. PNL-2538, Pacific Northwest Laboratory, Richland, WA 99352.

3.1.3 Northeast Region (Blc)

Contract No.: B-23452-A-L

GEOMET, Incorporated
15 Firstfield Road
Gaithersburg, MD 20760

Principal Investigator:

Kenneth E. Pickering (301)948-0755

Contract Monitors:

W. Richard Barchet (509)942-4621

Dennis L. Elliott (509)942-4762

Objective:

To provide a detailed assessment of the wind-energy resource available in the northeast region of the country using all available summarized and unsummarized wind data. Sources of data include the National Climatic Center, state and local air pollution control agencies, power companies, the U.S. Forest Service, and universities and research groups. Data will also be obtained through the use of meteorological, topographical, and biological indicators. The final product of the investigation will be a regional wind-power atlas.

Program Status:

The contract began in late July 1979 and is scheduled for completion by April 1980.

Progress During Reporting Period:

Contract has just begun.

Expected Progress During Next Reporting Period:

The work will be performed as follows: (1) all data sources will be identified and the appropriate data will be acquired; (2) screening procedures will be implemented to select the data for inclusion in the analyses based on site characteristics and summary type; (3) wind-power estimates will be made on an annual and on a seasonal basis for heights of 10 m and 50 m; (4) analytical and observational techniques will be used to estimate wind-power potential in data sparse regions;

- (5) wind-power maps will be constructed, gridded, and coded; and
- (6) the regional wind-power atlas will be assembled.

Reports and Publications:

None.

and on a seasonal basis for heights of 10 m and 50 m; (4) analytical and observational techniques will be used to estimate wind-power potential in data-sparse regions; (5) wind-power maps will be constructed, gridded, and coded; and (6) the regional wind-power atlas will be assembled.

Reports and Publications:

None.

3.1.4 Southwest Region (Ble)

Contract No.: B-23452-A-L

Global Weather Consultants, Inc.
12 South First Street, Suite 701
San Jose, CA 95113

Principal Investigator:

Richard Simon (408)287-5032

Contract Monitors:

W. Richard Barchet (509)942-4621

Dennis L. Elliott (509)942-4762

Objective:

To provide a detailed assessment of the wind-energy resource available in the southwest region of the country using all available summarized wind data. Sources of data include the National Climatic Center, state and local air pollution control agencies, power companies, the U.S. Forest Service, and universities and research groups. Data will also be obtained through the use of meteorological, topographical, and biological indicators. The final product of the investigation will be a regional wind-power atlas.

Program Status:

The contract began in mid-September 1979 and is scheduled for completion by June 1980.

Progress During Reporting Period:

Contract has just begun.

Expected Progress During Next Reporting Period:

The work will be performed as follows: (1) all data sources will be identified and the appropriate data will be acquired;
(2) screening procedures will be implemented to select the data for inclusion in the analyses based on site characteristics and summary type; (3) wind-power estimates will be made on an annual

3.1.5 Alaska Region (Blg)

Contract No.: B-87917-A-L

Arctic Environmental Information and Data Center
University of Alaska
707 A Street
Anchorage, AK 99501

Principal Investigator:

James L. Wise (907)497-7607

Contract Monitors:

W. Richard Barchet (509)942-4621

Dennis L. Elliott (509)942-4762

Objective:

To provide a detailed assessment of the wind-energy resource available in Alaska using all available summarized wind data. Sources of data include the National Climatic Center, state and local air pollution control agencies, power companies, the U.S. Forest Service, and universities and research groups. Data will also be obtained through the use of meteorological, topographical, and biological indicators. The final product of the investigation will be a regional wind-power atlas.

Program Status:

Contract began in September 1979 and is scheduled for completion in September 1980.

Progress During Reporting Period:

Contract has just begun.

Expected Progress During Next Reporting Period:

The work will be performed as follows: (1) all data sources will be identified and the appropriate data will be acquired; (2) screening procedures will be implemented to select the data for inclusion in the analyses based on site characteristics and summary type; (3) wind-power estimates will be made on an annual and on a seasonal basis for heights of 10 m and 50 m; (4) analytical

and observational techniques will be used to estimate wind-power potential in data-sparse regions; (5) wind-power maps will be constructed, gridded, and coded; and (6) the regional wind-power atlas will be assembled.

Reports and Publications:

None.

3.1.6 Hawaii Region (B11)

Contract No.: B-23452-A-L

Hawaii Natural Energy Institute
University of Hawaii
2450 Dole Street
Honolulu, HI 96822

Principal Investigator:

Dr. Thomas A. Schroeder (808)948-7944

Contract Monitors:

W. Richard Barchet (509)942-4621

Dennis L. Elliott (509)942-4762

Objective:

To provide a detailed assessment of the wind-energy resource available in Hawaii and the Trust Territory of the Pacific Islands using all available summarized and unsummarized wind data. Sources of data include the National Climatic Center, state and local air pollution control agencies, power companies, the U.S. Forest Service, and universities and research groups. Data will also be obtained through the use of meteorological, topographical, and biological indicators. The final product of the investigation will be a regional wind-power atlas.

Program Status:

Contractor was selected in FY 1979 but the contract did not begin until mid-October 1979 and will be completed by July 1980.

Progress During Reporting Period:

Contract was not awarded in FY 1979.

Expected Progress During Next Reporting Period:

The work will be performed as follows: (1) all data sources will be identified and the appropriate data will be acquired;
(2) screening procedures will be implemented to select the data for inclusion in the analyses based on site characteristics and summary type; (3) wind-power estimates will be made on an annual

and on a seasonal basis for heights of 10 m and 50 m; (4) analytical and observational techniques will be used to estimate wind-power potential in data-sparse regions; (5) wind-power maps will be constructed, gridded, and coded; and (6) the regional wind-power atlas will be assembled.

Reports and Publications:

None.

3.1.7 Locating High-Wind Areas by Remote Observations (B2a)

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. Renné (509)942-4623

Objective:

To develop an efficient way of identifying high-wind-energy sites by inferring wind characteristics from eolian geomorphologic features mapped from LANDSAT and aircraft imagery and to determine the geographic applicability of these techniques.

Program Status:

This program was initiated in September 1976 and research was completed July 31, 1979.

Progress During Reporting Period:

Three tasks were identified in the renewal of contract EY-76-S-06-2343 (Modification A004):

1. to develop interpretation techniques for determining wind characteristics from eolian features,
2. to assess the regional applicability of interpretation of satellite imagery,
3. to demonstrate the techniques in a regional evaluation of eolian features in the Pacific Northwest.

All three of these tasks have been completed. Results are documented in special reports and catalogues that were prepared as each phase of the work was completed.

Expected Progress During Next Reporting Period:

Project results will be summarized in a final report. Other reports, dealing with specific components of this research, are now in the final stages of editing and distribution. They will be completed in the next few months.

Reports and Publications:

Carlisle, W. J., and R. W. Marrs. 1978. Airflow Over Part of the Southern High Plains. RL0/2343-78/4, available from NTIS, Springfield, VA 22151.

Marrs, R. W. 1978. Eolian Features as Indicators of High-Wind Areas in the Pacific Northwest. RL0/2343-78/5, available from NTIS, Springfield, VA 22151.

Marrs, R. W., and D. R. Gaylord. 1979. A Guide to the Interpretation of Windflow Characteristics from Eolian Landforms. RL0/2343-79/2, available from NTIS, Springfield, VA 22151.

Marwitz, J. D., and K. B. Gilkey. 1978. Catalog of Available Wind Data in Idaho, Montana and Wyoming. RL0/2343-79/1, available from NTIS, Springfield, VA 22151.

3.1.8 Identifying and Screening Potential WECS Sites (B2c)

Contract No.: B-50365-A-E

North American Weather Consultants
600 Norman Firestone Road
Goleta, CA 93017

Principal Investigator:

Max W. Edelstein (805)967-1246

Contract Monitor:

David S. Renné (509)942-4623

Objective:

To obtain quantitative estimates of the long-term mean wind speeds at a height appropriate to wind energy conversion systems in data-sparse regions.

Program Status:

This project was completed in December 1978.

Progress During Reporting Period:

The analyses for the two sites, one in moderate terrain and the other in rough terrain, were completed. Two procedures were tested: one with surface winds not available at the site and the other with winds available at one meteorological tower level.

The procedures were tested to determine surface roughness and stability at the sites. These values were then used in power-law computations relating gradient-measured winds to predicted hub-height winds. The Pasquill technique was used in determining stability.

Correlations obtained in this study were not as high as anticipated, largely because of: (1) low frequency of observed tower data greater than 4 m/sec and (2) the nonrepresentativeness of the Pasquill stability, wherein distant National Weather Service cloud-cover data did not appear to provide representative on-site stability values.

Reports and Publications:

None.

3.1.9 Coastal Zone Wind Power Studies (B2d)

Contract No.: DE-AS06-76ET20274

University of Virginia
Department of Environmental Sciences
Charlottesville, VA 22903

Principal Investigators:

Michael Garstang (804)977-3733
Soronadi Nnaji (up to March 1979)
Roger Pielke (804)295-6709

Contract Monitor:

W. Richard Barchet (509)942-4621

Objective:

To develop a procedure for locating optimum regions, within the coastal zone, for wind-energy conversion from a meteorological point of view. The procedure will delineate, on a scale of 10 x 10 km, regions of maximum and minimum wind-power potential for any given coastal location along the East and Gulf coasts of the United States. Methods for verifying the estimates of the wind-energy resources are incorporated as part of the research and results.

Program Status:

This program was initiated in September 1976, funded for a second year in September 1977 with an extension to March 1979, then funded for a further year from March 15, 1979, to March 14, 1980.

Progress During the Reporting Period:

The large- and synoptic-scale velocity fields of the free atmosphere interact locally to produce the observed wind at a given site. During the reporting period, methods were developed which:

- delineated the large-scale wind fields in time and space,
- showed how these wind fields interact under the specific dynamic forcing of a coastline, and
- showed the resultant time- and space-integrated local (10 x 10 km) wind field.

Results of the climatological study showed that the time of year and location along the coast govern the wind fields on these time (seasonal) and space (East and Gulf coast) scales through the frequency distribution of synoptic weather events.

The synoptic control at a site was categorized according to its location, relative to the wave cyclones on the polar front and to the subtropical ridge. Fundamental physical concepts were used to define these classifications. Six categories described almost all situations: (1) in the warm section, (2) ahead of the warm front, (3) behind the cold front, (4) under the polar ridge, (5) west of the subtropical ridge, and (6) under the subtropical ridge. The four seasons were defined quantitatively in terms of the variation of these categories within the year.

Data from the National Aeronautic and Space Administration (NASA) at Wallops Island, Virginia, showed that categorization by synoptic category provides better estimates of the vertical variation of wind energy than a simple $1/7$ power law, as conventionally used. The greatest change of wind with height was in the warm sector, in and west of the subtropical ridge, and ahead of the cold front. This result was to be expected because the atmosphere was more stably stratified for these conditions.

The climatology of large- and synoptic-scale time and space distributions of the velocity and thermal fields was used as a framework to determine the effects of the coastline upon the wind-power potential. The physical processes of interaction between the large-scale fields and the coastlines were described by the three-dimensional University of Virginia mesoscale numerical model. The model provided a 10-km horizontal resolution at 17 levels in the lower atmosphere over a 300 x 300 km domain.

The model was applied in three areas of the Atlantic and Gulf coasts: Chesapeake Bay, Apalachee Bay, and the south Texas coast. Simulation experiments were performed for the dominant regimes of winter and summer as defined by the climatic analysis. In each case, the

model showed detail and complexity which cannot be depicted by existing observations. This was particularly true over the near and offshore waters. Twenty-four-hour integrations over a 100-m depth of the atmosphere above the surface showed important horizontal gradients in the wind field. Figures 3.3, 3.4 and 3.5 show the potential wind power of the integrated wind fields; certain locations contain up to three times more power than other locations. Local areas on the order of a few kilometers on a side can be identified in the model-predicted fields as containing optimum wind-energy potential. The combined climatic and modeling interpretation of the coastal wind fields represents a very powerful tool to assess wind-energy potential.

Expected Progress During the Next Reporting Period:

The results of the climatological classification scheme and model predictions will be combined to produce an assessment of potential wind power for each of the three test sites for the dominant synoptic conditions. An annual estimate of power will be obtained by using the statistical information on occurrence of each synoptic category. The distribution of synoptic categories along the coastline will be used to estimate spatial changes between the test areas.

A field program will be conducted during January and February 1980 in the Chesapeake Bay area to establish the level of confidence that can be placed in the developed approach.

The results of the field program and the previous analysis will be combined to produce a user-oriented method for the evaluation of the wind-energy potential for any part of the East and Gulf coasts.

Reports and Publications:

Garstang, M., S. Nnaji, R. Pielke, J. Gusdorf, C. Lindsey and J. W. Snow. 1979. Coastal Zone Wind Energy. RLO-2344-77/78/79, available from NTIS, Springfield, VA 22151.

Garstang, M., R. Pielke, C. Aspliden and J. W. Snow. 1978. "Offshore Wind Power Model Estimates." Paper presented at the Second International Symposium on Wind Energy Systems, October 1978, Amsterdam, The Netherlands.

CHESAPEAKE BAY

FIGURE 3.3. Daily Average, Layer-Mean Power Density (W m^{-2}), Wintertime Conditions, for the First 100 m of the Atmosphere. All of the 24-hourly average values included equally. Heights above the surface and weightings (in parentheses) used in determination of the layer mean: 10 m (0.20), 30 m (0.20), 50 m (0.35), 100 m (0.25).

APALACHEE BAY

FIGURE 3.4. Daily Average, Layer-Mean Power Density (W m^{-2}), Summertime Conditions, for the First 100 m of the Atmosphere. All of the 24-hourly average values included equally. Heights above the surface and weightings (in parentheses) used in determination of the layer mean: 10 m (0.20), 30 m (0.20), 50 m (0.35), 100 m (0.25).

SOUTH TEXAS COAST

FIGURE 3.5. Daily Average, Layer-Mean Power Density ($W m^{-2}$), Summertime Conditions, for the First 100 m of the Atmosphere. All of the 24-hourly average values include equally. Heights above the surface and weightings (in parentheses) used in determination of the layer mean 10 m (0.20), 30 m (0.20), 50 m (0.35), 100 m (0.25).

3.1.10 Wind Power Potential in a Coastal Environment (B2e)

Contract No.: B-36379-A-E

The University of Texas
Atmospheric Science Group
Austin, TX 78712

Principal Investigator:

Norman K. Wagner (512)471-3611

Contract Monitor:

David S. Renné (509)942-4623

Objective:

To develop a technique for determining the space and time variations of wind speed in data-sparse coastal areas by interviewing appropriate local residents.

Program Status:

This study began in February 1978 and will continue through September 1979.

Progress During the Reporting Period:

Interviews have been conducted with a number of charter boat captains and commercial fishermen who frequent the bay, inshore, and offshore regions in the Corpus Christi-Port Aransas section of the Texas coast. In addition, wind instruments were installed at offshore, bay and coastal sites to supplement Coast Guard, Navy and National Weather Service data taken in the area. Comparison of interview results with available data showed that the interview process has excellent potential for use in the early phase of wind-energy conversion siting. Some interview subjects were able to relate a remarkable amount of detail concerning wind distribution and variability.

Expected Progress During Next Reporting Period:

All data currently on hand for this section of the Texas coast will be summarized and the results presented in the final report on this

contract. The report will include three years of data from a 30-m tower located about 0.5 km inland at Port Aransas, data sets from the Coast Guard, National Weather Service, Naval Air Station, EB-71 (NOAA buoy at 26.0 N and 93.5 W), and data from special installations on oil and gas platforms and a fishing pier.

Reports and Publications:

None.

3.1.11 Agricultural Applications of Wind Resource Assessments (B2f)

Contract No.: B-92893-A-K

Development Planning and Research Associates, Inc.
200 Research Drive
Manhattan, KS 66502

Principal Investigator:

John P. Wagner (913)539-3565

Contract Monitor:

W. Richard Barchet (509)942-4621

Objective:

To assess the adequacy or inadequacy of wind data from the Northwest regional wind-energy assessment as a data source for the Development Planning and Research Associates, Inc./U.S. Department of Agriculture wind energy economic model and to present a paper on this subject at the Conference and Workshop on Wind Characteristics and Wind Energy Siting 1979, held in Portland, Oregon, on June 19-21, 1979.

Program Status:

This project was completed on June 30, 1979.

Progress During Reporting Period:

The work was completed and a final paper was written and presented at the June workshop. A general conclusion was that the Northwest regional wind-energy assessment generally did provide sufficient diurnal and seasonal wind data to permit economic evaluation of agricultural applications of wind electric systems on farms. However, improved geographic resolution of the wind resource assessments, as well as improved wind-speed distributions at various heights, are needed. Economic assessments of wind systems on farms can successfully utilize the regional wind-energy resource assessments.

Reports and Publications:

Johnson, G. L., and J. Wagner. 1979. "Agricultural Applications of Wind Resource Assessments." In Proceedings of the Conference and Workshop on Wind Characteristics and Wind Energy Siting 1979, pp. 293-301. American Meteorological Society, Boston, Massachusetts.

3.1.12 Statistical Studies of Site Wind Characteristics (B2g)

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

Northwestern University
Evanston, IL 60201

Principal Investigator:

Ross B. Corotis (312)492-3453

Contract Monitor:

David S. Renné (509)942-4623

Objective:

The extension of probabilistic and stochastic models to develop a procedure for simulation of array power time series, to study the effect of correlation on predicted wind-speed distributions, to perform a Bayesian analysis of total wind-turbine-performance reliability, to assess the sensitivity of wind-speed data to averaging time and sampling rate, and to verify the applicability of the wind-speed-persistence model to sites with moderately high mean-wind speeds.

Program Status:

This contract began in October 1976 and was completed in September 1977. A renewal was completed in October 1978. The present contract was renewed in October 1978 and will be completed in September 1979.

Progress During Reporting Period:

A report summarizing the previous year's results was published in January 1979. This report presented a candidate site climatological adjustment procedure and discussed its limitations as found by a comparative study of hourly, daily, monthly, and annual spatial correlations. It also described a simplified run duration (wind-speed persistence) model with a single parameter related to the ratio of wind-speed level to site-seasonal mean wind speed. Other findings included the viability of employing a regional annual cycle to correct for seasonal variations at a candidate site, the verification of previously developed models with additional site data, and procedures for the use of relatively sparse data sets.

Additional research during the reporting period will appear in a subsequent report. This research includes the use of NCC hourly data tapes to verify the applicability of previously developed models at moderately windy sites, including some with mean speeds in excess of 7 m/sec. Specifically, the power-exponential wind speed persistence model has been seen to provide a reasonable fit at these sites, and regression equations have been developed for calibration of the model from the seasonal mean wind speed.

Simple approximate procedures have been developed for the time series simulation of wind speed at a single site and of generated power from a regional array of wind turbines. The latter procedure has been verified by comparison with generated power based on actual regional wind-speed data and with a procedure developed by Cliff, Justus and Elderkin (1978), using wind turbines from 45 kW to 2.5 MW.

A relaxation of the basic assumption inherent in the Rayleigh distribution has led to a wind-speed probability distribution based on vector components with unequal variance and non-zero correlation. The resulting distribution is well-modeled by the Rayleigh.

The Bayesian approach has been used successfully to combine the basic Rayleigh wind-speed distribution (reflecting inherent variability) with a prior and derived posterior distribution of sample mean wind speed (modeling sampling uncertainty). The resulting wind-speed distribution can be used to directly assess the effect of candidate-site data collection procedures on generated power computations.

Two separate 24-hr wind-speed records composed of contiguous 20-sec averages have been used to provide a preliminary assessment of sampling biases. It appears that neither averaging time nor sampling rate has a critical effect on computed means and variances (variances decrease somewhat with increasing averaging time), that averaging time has a pronounced effect on computed autocorrelation functions, and that sampling rate has a dominant effect on persistence.

Expected Progress During Next Reporting Period:

A report will be written to detail the results from the present reporting period. Additional wind-speed records with relatively high sampling rates will be obtained to study further the effect of averaging time and sampling rate on computed wind-speed statistics. Studies related to wind turbine performance will be made and spectral techniques will be investigated.

The Bayesian technique will be explored further to assess the effects of duration of data collection and to apply the techniques to wind-speed persistence. The procedures for obtaining site wind speed and array power simulation will be verified with additional comparisons, including histogram analysis and autocorrelation functions. Sensitivity of the procedures to various parameters will also be investigated. Techniques to improve computed spatial correlations by including selected wind climatology will be studied.

Reports and Publications:

Corotis, R. B. 1979. "Simulation of Correlated Wind Speeds for Sites and Arrays." Paper presented at the International Congress, International Solar Energy Society, May 1979, Atlanta, Georgia.

Corotis, R. B. 1979. Statistical Models for Wind Characteristics at Potential Wind Energy Conversion Sites, RL0/2342-79/1, available from NTIS, Springfield, VA 22151.

Corotis, R. B. 1979. "Statistical Reliability of Wind Power Assessments." In Proceedings of the Conference and Workshop on Wind Characteristics and Wind Energy Siting 1979, pp. 311-321. American Meteorological Society, Boston, Massachusetts.

Sigl, A. B., R. B. Corotis and D. J. Won. 1979. "Run Duration Analysis of Surface Wind Speeds for Wind Energy Applications," Jour. of Applied Met., 18(2):156-166.

Additional research during the reporting period will appear in a subsequent report. This research includes the use of NCC hourly data tapes to verify the applicability of previously developed models at moderately windy sites, including some with mean speeds in excess of 7 m/sec. Specifically, the power-exponential wind speed persistence model has been seen to provide a reasonable fit at these sites, and regression equations have been developed for calibration of the model from the seasonal mean wind speed.

Simple approximate procedures have been developed for the time series simulation of wind speed at a single site and of generated power from a regional array of wind turbines. The latter procedure has been verified by comparison with generated power based on actual regional wind-speed data and with a procedure developed by Cliff, Justus and Elderkin (1978), using wind turbines from 45 kW to 2.5 MW.

A relaxation of the basic assumption inherent in the Rayleigh distribution has led to a wind-speed probability distribution based on vector components with unequal variance and non-zero correlation. The resulting distribution is well-modeled by the Rayleigh.

The Bayesian approach has been used successfully to combine the basic Rayleigh wind-speed distribution (reflecting inherent variability) with a prior and derived posterior distribution of sample mean wind speed (modeling sampling uncertainty). The resulting wind-speed distribution can be used to directly assess the effect of candidate-site data collection procedures on generated power computations.

Two separate 24-hr wind-speed records composed of contiguous 20-sec averages have been used to provide a preliminary assessment of sampling biases. It appears that neither averaging time nor sampling rate has a critical effect on computed means and variances (variances decrease somewhat with increasing averaging time), that averaging time has a pronounced effect on computed autocorrelation functions, and that sampling rate has a dominant effect on persistence.

Expected Progress During Next Reporting Period:

A report will be written to detail the results from the present reporting period. Additional wind-speed records with relatively high sampling rates will be obtained to study further the effect of averaging time and sampling rate on computed wind-speed statistics. Studies related to wind turbine performance will be made and spectral techniques will be investigated.

The Bayesian technique will be explored further to assess the effects of duration of data collection and to apply the techniques to wind-speed persistence. The procedures for obtaining site wind speed and array power simulation will be verified with additional comparisons, including histogram analysis and autocorrelation functions. Sensitivity of the procedures to various parameters will also be investigated. Techniques to improve computed spatial correlations by including selected wind climatology will be studied.

Reports and Publications:

Corotis, R. B. 1979. "Simulation of Correlated Wind Speeds for Sites and Arrays." Paper presented at the International Congress, International Solar Energy Society, May 1979, Atlanta, Georgia.

Corotis, R. B. 1979. Statistical Models for Wind Characteristics at Potential Wind Energy Conversion Sites, RL0/2342-79/1, available from NTIS, Springfield, VA 22151.

Corotis, R. B. 1979. "Statistical Reliability of Wind Power Assessments." In Proceedings of the Conference and Workshop on Wind Characteristics and Wind Energy Siting 1979, pp. 311-321. American Meteorological Society, Boston, Massachusetts.

Sig1, A. B., R. B. Corotis and D. J. Won. 1979. "Run Duration Analysis of Surface Wind Speeds for Wind Energy Applications," Jour. of Applied Met., 18(2):156-166.

4.0 SITING METHODOLOGIES

Selecting the specific locations best suited for siting wind turbines on the basis of wind characteristics information is the primary objective of this program area. The strategy has been first to develop and then to test techniques and tools for incorporation into siting methods for both large and small wind turbines. The activities of this reporting period primarily involved the testing and verification of previously developed techniques and the documentation of the information for dissemination.

Physical modeling techniques were tested over models of complex terrain (see 4.1.1). A short field-measurement program was conducted in the Rakaia Gorge in New Zealand to provide a basis for comparison with the wind tunnel results. Wind tunnel model results from the Kahuku Point area in Hawaii were compared with field measurements from the University of Hawaii and empirical formulae with reasonable agreement. The development of techniques for using vegetation as an indicator of wind speed began in June of 1976 (see 4.1.2). Several species of trees were calibrated and a handbook on the use of trees as an indicator of wind-power potential was completed. The use of wind measurement equipment in assessing a local wind field for siting purposes was addressed in two separate studies (see 4.1.3 and 4.1.3a). The studies were designed to integrate different types of wind measurement equipment into a siting strategy that would allow an evaluation of the equipment as well as the strategy as a whole.

A common concern about the use of wind measurement equipment for short periods of time in siting activities is that the wind statistics are probably not representative of the long-term climatology. The results of one study show that spacing 3 or 4 one-month measurement periods throughout a year will remove the bias that may be present in the results of a continuous 3- or 4-month measurement period (see 4.1.4). Another area of concern about the representativeness of a wind measurement is in the change of speed with height above the ground. A study of the frequency of occurrence of nocturnal, low-level wind maxima addresses a unique phenomenon that could be important to the siting of large wind turbines (see 4.1.5).

Numerical flow modeling as a wind-energy site-screening technique has been under development in the Federal Wind Energy Program since 1975. During this reporting period the emphasis has shifted to the verification of these techniques. A coordination effort has been established to select the data sets, establish the verification criteria and objectively interpret the results (see 4.1.6). The two wind-field models, developed under the Federal Wind Energy Program were involved in this verification (see 4.1.7 and 4.1.8).

For the selection of a specific location for an individual turbine or a cluster of turbines there are many atmospheric and terrain related considerations. A task produced a documentation of small-scale terrain effects on wind flow that could enhance or diminish the power output of a wind turbine depending on its placement (see 4.1.9). Selected information produced in previous years from this task was included in a siting handbook for small wind turbines written primarily for a nontechnical audience. Review comments on the first edition of this handbook were incorporated into a revised edition (see 4.1.10).

A more technically oriented document for use in siting large wind turbines was under compilation during this reporting period (see 4.1.11). The objective of this document is to provide siting strategies, critical evaluation of available siting techniques and other meteorological information that can be used to site single units or clusters of large wind turbines.

4.1 PROGRESS IN TECHNICAL TASKS

4.1.1 Sites for Wind Power Installations (C1a)

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

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

Principal Investigators:

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

Contract Monitor:

William T. Pennell (509)942-4620

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 continued through September 1979.

Progress During Reporting Period:

The purpose of this research was to improve techniques for predicting wind velocities over ridges and hills in general, as well as to evaluate the efficacy of site-specific model structures over complex terrain. Studies were made to determine local wind profiles and turbulence over two- and three-dimensional hills or ridges as influenced by hill or ridge profile, upwind surface roughness, stratification, hill slope or aspect ratio. A site-specific field/laboratory program for Rakaia Gorge, New Zealand, was evaluated (Meroney et al. 1978a).

An additional test of physical modeling as a site screening technique was undertaken during the period July 1978 to July 1979. A site on the state of Hawaii was chosen where a MOD-OA horizontal axis windmill is to be constructed.

Tropical islands, such as Oahu, located in the persistent trade-wind belt and adorned with ridges and hills that accelerate the surface winds are attractive locations for WECS machines. The Kahuku Point on northern Oahu has good exposure and annual-mean-wind speeds near 8 m/sec (18 mph). Lindley (1979) has proposed a WECS cluster for the locality capable of generating 450 MW. The Department of Meteorology, University of Hawaii, proposed an extensive field program in this area; hence, a parallel laboratory program was prepared to extend the measurement domain in the vertical and to survey additional sites.

The area studied by means of a laboratory model is located along the northeast end of the Koolau Range on the island of Oahu, Hawaii. The primary terrain features consist of a fan-shaped set of ridges opening to the north from the mountain ridge itself. The trade wind approaches most of the year from the east or northeast and passes over sparsely vegetated, abandoned cane fields and shrub-covered foothills. A model section 12,730 m in dia centered over the northern end of the mountain ridge was constructed to a scale of 1:3840. Graded gravel was added to the model surface to represent orchards and forested areas noted on maps from a land-use survey.

The Kahuku model was examined in the environmental wind tunnel at Colorado State University. Laboratory measurements included a series of vertical profiles of mean wind velocity, longitudinal turbulence and turbulence spectra utilizing hot wire anemometry for three different wind directions. An example set of vertical profiles at selected points is shown in Figure 4.1. Isotachs of normalized wind speed at 10- and 50-m reference heights over the Kahuku model for three wind directions are displayed in Figure 4.2.

Field measurements were performed by the University of Hawaii in the fall of 1978, utilizing a series of mobile vans equipped with 10-m telescoping masts. Vans were parked at a series of measurement sites for periods ranging from several days to several weeks. Wind speed and wind direction at 10 m above the local ground surface were recorded on a standard cassette tape. Humidity and solar insolation

FIGURE 4.1. Vertical Profiles of Mean Wind Velocity for Three Different Wind Directions.

FIGURE 4.2. Isotachs of Normalized Wind Speed at 10 m Reference Height over the Kahuku Model (45° wind direction).

FIGURE 4.2 (Continued). Isotachs of Normalized Wind Speed at 50 m Reference Height over the Kahuku Model (45° wind direction).

FIGURE 4.2 (Continued). Isotachs of Normalized Wind Speed at 10 m Reference Height over the Kahuku Model (66.7° wind direction).

FIGURE 4.2 (Continued). Isotachs of Normalized Wind Speed at 50 m Reference Height over the Kahuku Model (66.7° wind direction).

FIGURE 4.2 (Continued). Isotachs of Normalized Wind Speed at 10 m Reference Height over the Kahuku Model (90° wind direction).

at cab height were also recorded. Each tape was subsequently analyzed by computers at the University of Hawaii to provide average wind speed, wind direction at different wind speeds and wind direction -- all referenced to a site located at Opana, a flat-topped hill at the northern end of one of the minor ridges extending seaward from the northern Koolau Range. The hill falls away rather steeply toward the flat coastal belt. Local exposure is good toward the northeast.

A series of vertical profiles of amplification factor A were prepared from the laboratory velocity measurements over typical Kahuku survey sites. These factors have been compared against the prediction formula proposed by Bouwmeester, Meroney and Sandborn (1978), as well as the average field amplification factor for the wind speeds in excess of 10 mph at the 10-m height.

The model data and calculative techniques consistently agree. The model data and field data agree to simple correlation coefficient levels equal to 0.55. If field data are eliminated from the comparison that have abnormally high turbulence levels, which include approach wind directions outside the range of 45° to 90° or for which a site visit suggested strong influence at 10-m of nearby vegetation, the sample correlation coefficient equals 0.79.

Crest velocities over ridges have been compared against the empirical formulae proposed by Bouwmeester, Meroney and Sandborn (1978) and an airfoil approximation suggested by Hunt (1978). Laboratory results consistently agree with these prediction formulae.

Expected Progress During Next Reporting Period:

The report on the Kahuku Point, Oahu, model study will conclude this program.

Reports and Publications:

Bouwmeester, R. J. B., R. N. Meroney, V. A. Sandborn. 1978. Sites for Wind Power Installations: Wind Characteristics Over Ridges: Final Report (Part I). RLO/2438-77/3, available from NTIS, Springfield, VA 22151.

FIGURE 4.2 (Continued). Isotachs of Normalized Wind Speed at 50 m Reference Height over the Kahuku Model (90° wind direction).

Meroney, R. N. 1979a. "Field Verification and Laboratory Simulation of Airflow Patterns in Complex Terrain." Paper presented at the Fourth Symposium on Turbulence, Diffusion and Air Pollution, January 15-18, 1979, Reno, Nevada.

Meroney, R. N. 1979b. "Prospecting for Wind: Windmills and Wind Characteristics." Paper presented at the ASCE Spring meeting, April 2-6, 1979, Boston, Massachusetts.

Meroney, R. N. 1979c. "WECS Site Screening by Physical Modeling." Paper presented at the Conference and Workshop on Wind Characteristics and Wind Energy Siting 1979, June 19-21, 1979, Portland, Oregon.

Meroney, R. N. 1979d. "Wind Tunnel Simulation of the Flow Over Hills and Complex Terrain." Prepared for Special Issue of J. of Indus. Aerodynamics, Fall 1979.

Meroney, R. N., A. J. Bowen, D. Lindley and J. Pearse, 1978a. Wind Characteristics Over Complex Terrain: Laboratory Simulation and Field Measurement at Rakaia Gorge, New Zealand. RLO/2438-77/2, available from NTIS, Springfield, VA 22151.

Meroney, R. N., D. Lindley and A. J. Bowen. 1979. "Physical Modeling of Flow Over Complex Terrain." Paper presented at the Fifth International Conference on Wind Engineering, Colorado State University, July 8-14, 1979, Fort Collins, Colorado.

Meroney, R. N., D. Lindley, J. Pearse and A. J. Bowen. 1979. "Wind Tunnel Modeling as a Prospecting Tool for Wind Energy Site Selection: A Field Assessment." Paper presented at the First British Wind Energy Association Wind Energy Workshop, Cranfield Institute of Technology, April 19-20, 1979, Cranfield, England.

Meroney, R. N., V. A. Sandborn, R. J. B. Bouwmeester, H. C. Chien and M. Rider. 1978b. Sites for Wind Power Installations: Physical Modeling of the Influence of Hills, Ridges and Complex Terrain of Wind Speed and Turbulence: Final Report (Part II). RLO/2436-77/3, available from NTIS, Springfield, VA 22151.

Meroney, R. N., V. A. Sandborn, R. J. B. Bouwmeester, H. C. Chien
and M. Rider. 1978c. Sites for Wind Power Installations: Physical
Modeling of the Influence of Hills, Ridges and Complex Terrain of
Wind Speed and Turbulence: Final Report (Part III, Appendix).
RLO/2438-77/3, available from NTIS, Springfield, VA 22151.

4.1.2 Vegetation as an Indicator of High Wind Velocities (C1b)

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

Oregon State University
Corvallis, OR 97331

Principal Investigators:

E. Wendell Hewson (503)754-4557

John E. Wade (503)754-4557

Contract Monitor:

William T. Pennell (509)942-4620

Objective:

To develop appropriate indices to represent the degree of vegetation deformation by the wind (with special emphasis on trees), to calibrate these indices in terms of wind speed and to investigate the feasibility of using remote sensing methods to assist in reconnaissance for ecological indicators of wind-power potential.

Program Status:

This project was initiated in June 1976 and will continue through June 1980. Calibration of the indices for deciduous trees and an examination of the feasibility of using photo reconnaissance methods are scheduled for completion by June 1980.

Progress During Reporting Period:

A handbook on the use of trees as an indicator of wind-power potential has been completed. This handbook describes techniques for using trees in wind-power surveys as a site screening tool. Results of calibrations of three indices of wind deformation of two species of trees, Douglas fir and Ponderosa pine, have been developed. During the contract period, calibrations of indices of wind deformation of trees by genus have been attempted since separate generic calibrations appear appropriate in most cases. Genera calibrated include *Juniperus* (juniper), *Picea* (spruce), *Abies* (fir), *Pinus* (pine) and *Quercus* (oak). A special index has been developed for deciduous

trees called the Barsch Index (see Figure 4.3). An initial calibration of this index for oaks, which is a widely distributed genus of deciduous trees, is shown in Figure 4.4; the geographical distribution of oaks in the United States is shown in Figure 4.5.

A methodology for using remote sensing in wind-power prospecting has also been developed. This research is centered on an evaluation of remote sensing and associated interpretational techniques to assist in the reconnaissance for ecological indicators of wind-power potential.

FIGURE 4.3. Barsch Index for Deciduous Trees

FIGURE 4.5. The Distribution (shaded area) of Selected Species of Oaks in the United States

FIGURE 4.4. Barsch Index B for Oaks

The primary tasks of any such investigation include:

- an identification of the type of wind indicator phenomena that may be identified on remote sensing imagery;
- the optimum imagery type, scale and format for each of the indicators identified;
- the environmental or physical conditions that facilitate the imaging of such phenomena; and
- the imagery interpretation of techniques best suited to the identification and mapping of key indicators.

In an effort to produce an increasingly specific nested hierarchy of imagery-based prospecting techniques, key indicators were grouped into four basic categories, and remote sensing platforms were listed in increasingly larger scales. Different sensor types, often associated with specific platforms, were then matched with the indicators at appropriate scales, as shown in Table 4.1. The resulting classification employs a variety of natural indicators of wind-power potential in an effort to provide the broadest basis for evaluation in various environments.

Expected Progress During Next Reporting Period:

Vegetation data from other areas of the United States are being collected to validate the techniques that have been developed primarily for Northwest trees. Regional field trips are planned for New England, the mid-Atlantic Coast, southeast Texas and southeast Alaska. During each of these field surveys, seminars will be presented to describe the techniques within that region. The product of these field trips will be a comprehensive handbook on the use of vegetation as an indicator of wind-power potential that contains data collected during the regional field trips and suggestions that resulted from the seminars. Generic calibrations of indices for important types of trees will be included in this handbook.

Also, a handbook on the use of remote sensing imagery to identify ecological indicators of wind-power potential will be produced. This handbook will describe the various types of ecological indicators such as wind-deformed vegetation, areas of persistent wind sweep of snow, eolian land forms, cloud formations and topographical features that can be identified from various scales of imagery. This handbook will describe types of imagery available, where each can be obtained and the information that can be appropriately derived from this imagery.

Electronic image processing techniques to aid in the identification of specific wind indicators will be discussed. Such processing includes density slicing of shade variations, edge enhancement and digital processing of photographs.

Reports and Publications:

Hewson, E. W., J. E. Wade and R. W. Baker. 1979. A Handbook on the Trees as an Indicator of Wind Power Potential. RL0/2227-79/3, available from NTIS, Springfield, VA 22151.

Wade, J. E., and E. W. Hewson. 1979. "Trees as an Indicator of Wind Power Potential." Paper presented at the Conference and Workshop on Wind Characteristics and Wind Energy Siting 1979, June 19-21, 1979, Portland, Oregon.

TABLE 4.1. The Various Scales of Remote Sensing and the Parameters at Each Scale That May Be Used to Indicate Wind-Power Potential

PLATFORM INDICATOR	REGIONAL ASSESSMENT		AREA EVALUATION		SITE SELECTION	
	1:10 ⁶ SATELLITE	1:10 ⁵ SATELLITE	1:10 ⁴ U-2	1:10 ³ AIRCRAFT	1:10 ² LIGHT PLANE/ HELICOPTER	1:10 GROUND OBSERVATION
VEGETATION	LOCATE DISTINCTIVE COMMUNITY BOUNDARIES (LANDSAT MSS COMPOSITES)	IDENTIFY WIND SHAPED COMMUNITIES (LANDSAT RBV)	IDENTIFY AREAS OF KRUMHOLTZ VEGETATION (CIR)	LOCATE WIND DEFORMED FOREST STANDS; CROP WIND DAMAGE; AND, PLANTED WIND BREAKS (AERIAL PHOTOS)	SPOT INDIVIDUAL FLAGGED TREES; ESTIMATE GRIGGS-PUTMAN INDEX FROM PHOTOS (OBLIQUE PHOTOS)	MEASURE GRIGGS-PUTMAN INDEX AND DEFORMATION RATIO (CALIBRATED SPECIES)
SNOW COVER	IDENTIFY ELEVATION OF REGIONAL SNOW-LINE (LANDSAT MSS)	IDENTIFY AREAS OF REPETITIVE HIGH WIND SWEEP (LANDSAT RBV)	IDENTIFY DRIFT AREAS AND SLACK VECTORS (CIR)	MEASURE DRIFT FEATURES FOR DIRECTION AND STREAMLINE CONVERGENCE, VELOCITY RANGE FROM SHAPE. (AERIAL PHOTOS)	SPOT VARIATIONS IN SNOW COVER, CORNICES, SNOW CURLS, ETC., FOR VELOCITY ESTIMATES	MEASURE DEPTH, HOARFROST, ICING, TREE-WELL ELIPTICITY, ETC.
EOLIAN FEATURES	LOCATE AND CLASSIFY LARGE EOLIAN FEATURES (SAND, SEA, ETC.) AND DETERMINE WIND FIELDS. (LANDSAT MSS & RBV)		LOOK FOR STABILIZING VEGETATION (CIR)	IDENTIFY AND MEASURE ACTIVE FEATURES.	CHECK FOR OTHER INDICATORS, I.E. VEGETATION, SCOURED BUILDINGS, ETC.	MEASURE WIND COMPETENCE BY MINIMUM PARTICLE SIZE ON SURFACE, LOCAL VENTIFACTS
TOPO-CLIMATIC INDICATORS	STUDY LOW LEVEL CLOUD FORMATIONS, OROGRAPHIC BARRIERS, TOPOGRAPHIC NOTCHES, ETC. (LANDSAT MSS & RBV)		LOOK FOR LEEWARD SIDE "WIND SHADOWS" (SLAR)	CHECK FOR CONFIRMING INDICATORS; FOG BANKS, OROGRAPHIC CLOUD FORM, KATABATIC OR VALLEY WINDS (PHOTOS, OBSERVATION)	MEASURE CONFIRMING INDICATORS.	

4.1.3 Assessing the Local Wind Field with Instrumentation (C1c)

Contract No.: B-92864-A-H

AeroVironment Inc.
145 Vista Avenue
Pasadena, CA 91107

Principal Investigator:

Thomas G. Zambrano (213)449-4392

Contract Monitor:

Thomas R. Hiester (509)942-4129

Objective:

To demonstrate and evaluate, in the field, a concept represented by an equipment system and a methodology to assess wind characteristics of an area that may become the site for an array of large wind energy conversion systems (LWECS).

Program Status:

The program began in December 1978 and will conclude in March 1980.

Progress During the Reporting Period:

The wind field in a 500 km² area of the Tehachapi Mountains of southern California is being investigated. The approach to data collection is in two phases: an initial data and field assessment, followed by an evaluation phase. Sixteen candidate anemometer sites were identified after an assessment of available weather station records from Bakersfield and Sandberg, California, a study of topographical maps (1:250,000 and 1:24,000) and a one-day site inspection trip. The 16 potential sites were screened during a field survey between April 27 and May 2, 1979. Three separate estimators of site wind characteristics were used to rank the sites for wind power potential: flagging of nearby trees, the assessment of local topography and a wind survey. The wind survey used a portable Gill propeller anemometer mounted on a telescoping pole and Tethered Aerodynamically Lifting Anemometers (TALA kites) to obtain wind profiles up to 100 m. At some sites, 48 hr of continuous measurements

were made. A ranking of the 16 sites was established for each of these three techniques. The average of the scores produced an overall score used to assist in the final selection of sites for evaluation phase anemometry.

Nine anemometers with strip chart recorders were installed at the 10-m level. Two anemometers that also record wind direction were installed at sites with overall rankings of 1, 2, 3, 4, 5, 7, 8, 9 and 14. Site 7, with a ranking of 6, was dropped because of its proximity to candidate site 4. Site 9, with a ranking of 14, was chosen to cover an area that otherwise would have been void of measurements. Data collection began in early June. Every two weeks an AeroVironment field team visited the Tehachapi Region to take TALA kite measurements of winds aloft and to log vegetation indicators of wind patterns. Meteorological summaries of weather activity in the Tehachapi Region are obtained daily from the National Weather Service's stations at Sandberg and Bakersfield.

Expected Progress During Next Reporting Period:

Field measurements will terminate in November 1979. A final report will be prepared that assesses the effectiveness and cost of the methods and instruments used in this project in their application to the evaluation of the wind resource at a potential WECS cluster site.

Reports and Publications:

None.

4.1.3a Assessing the Local Wind Field with Instrumentation (C1c)

Contract No.: B-23453-A-H

Physical Science Laboratory
Box 3-PSL
Las Cruces, NM 88003

Principal Investigators:

Kenneth M. Barnett (505)522-4400

Ralph D. Reynolds (505)522-4400

Contract Monitor:

Thomas R. Hiester (509)942-4129

Objective:

To demonstrate and evaluate, in the field, a concept represented by an equipment system and a methodology to assess wind characteristics of an area that may become the site for an array of large wind energy conversion systems (LWECS).

Program Status:

The program began in December 1978 and will conclude in March 1980.

Progress During Reporting Period:

Six wind measuring systems have been installed on top of Sierra Grande, a nearly symmetrical mountain in northeastern New Mexico about halfway between Raton and Clayton. The summit of this mountain is 2659 m (8720 ft MSL) and stands above a mesa that is approximately 1829 m (6000 ft MSL) (see Figure 4.6). Two of the systems have sensors exposed on a tower at the peak, one at 10 m and the other at 20 m above the surface. These were put into operation on May 17, 1979. The other four are on posts at 10 m above the surface and ~250 m to the north, east, south and west of the peak. Two were started on May 29, one on May 30 and the last on June 6, 1979. The systems will be operated for approximately five months.

Each wind sensing system consists of a cup anemometer, vane and a data logger. The data logger is set to record wind speed, wind direction, time and header information once every 6 min on a

FIGURE 4.6. 1:24,000 Topographic Map of Sierra Grande Showing Four Tower Locations

cassette tape. The recorded wind speed is a 6-min average but the wind direction is an instantaneous sample of the wind direction from an 8-point compass. The tape and the lithium batteries ("D"-cell size) that power the system are replaced during each monthly visit. The tape with data is brought to the Physical Science Laboratory and read into an IBM "360" computer for data printout and processing.

This array of six sensors provides measurements of horizontal, vertical and time variations of wind speed and direction.

Expected Progress During Next Reporting Period:

A final report will be prepared that assesses the effectiveness and cost of the methods and instruments used in this project in their application to the evaluation of the wind resource at a potential WECS cluster site.

Reports and Publications:

None.

4.1.4 Climatological Adjustment of Short-Term Wind Statistics (Cld)

Pacific Northwest Laboratory
Richland, WA 99352

Principal Investigator:

J. Van Ramsdell (509)942-4825

Objective:

To develop techniques for improving estimates of climatological wind statistics derived from short-term measurements.

Program Status:

Work was initiated in FY 1979 and is to continue through FY 1980.

Progress During Reporting Period:

The work has been divided into two areas: 1) the evaluation of the effect of measurement strategies on the accuracy of climatological estimates, and 2) the improvement of estimates by comparison of the short-term measurements with data taken at a nearby reference location.

In the first area, work has centered around analysis of data from 37 sites throughout the United States. Various measurement strategies have been simulated, and the effects of the strategies on the accuracy of estimates of long-term mean wind speed have been determined. If the normal continuous-measurement strategy is followed, the estimate of the long-term mean is likely to be biased, i.e., systematically high or low, unless a full year's data are collected. If, on the other hand, measurements are made during 3 or 4 one-month-long measurement periods equally spaced throughout the year, the estimates will be unbiased.

Increasing the number of measurements made increases the accuracy of the estimates of the long-term mean, but the relationship between the two is not linear. Table 4.2 gives the relative uncertainty (inaccuracy) of various possible measurement strategies. The relative uncertainty of a single monthly average speed is 1.0 by definition. Those strategies with less than 12 months of data collection

per year are called intermittent strategies and the data collection periods are assumed to be equally spaced throughout the year. Figure 4.7 shows relative uncertainty of the long-term average wind speed to percent error. The results of this portion of the work have been prepared for publication in the Wind Technology Journal.

TABLE 4.2. Relative Uncertainties of Measurement Strategies

Months of Data Collection Per Year	1	2	Years 3	4	5
2*	0.58	0.46	0.39	0.35	0.31
3	0.48	0.35	0.30	0.28	0.24
4	0.42	0.31	0.27	0.24	0.20
6	0.39	0.27	0.24	0.22	0.18
12	0.35	0.25	0.23	0.20	0.16

*Strategy shows tendency to be biased.

In the second area, work has begun on a mathematical wind-speed model. The model incorporates both systematic and random variations in wind speed. These variations are related to physically real atmospheric processes. Predictions of a simplified version of the model compare favorably with the results of the work in the first area.

Expected Progress During Next Reporting Period:

Model development will be completed, and model predictions of climatological statistics will be compared with observed values. If the comparison is favorable, the model will be used to explore advanced techniques for adjusting estimates of climatological statistics based on short data records. Corotis and Justus (Tasks B3c and B3e, FY 1978) have reported on the limitations of straight statistical methods of adjusting climatological statistics.

FIGURE 4.7. Relationship Between Relative Uncertainty and Percent Error in Estimates of the Long-Term Mean

Reports and Publications:

Ramsdell, J. V., S. Houston and H. L. Wegley. 1980. "Measurement Strategies for Estimating Long-Term Average Wind Speeds." PNL-SA-7399, Pacific Northwest Laboratory, Richland, WA 99352. (To be published in Solar Energy)

4.1.5 Wind Shear in the Nocturnal Boundary Layer (Cle)

Contract No.: B-77751-A-E

Argonne National Laboratory
Argonne, IL 60439

Principal Investigators:

Bruce B. Hicks (312)972-5836

Douglas L. Sisterson (312)972-5836

Contract Monitor:

William T. Pennell (509)942-4620

Objective:

To determine the frequency of occurrence of nocturnal, low-level wind maxima over the Midwest and Great Plains, to identify geographical regions and seasons of the year that favor their formation and to formulate the principal processes that control the onset, duration, strength and altitude of these phenomena.

Program Status:

This program began during the last quarter of FY 1978. A report documenting statistics of wind maximum events should be forthcoming in FY 1980.

Progress During Reporting Period:

Field experiments conducted by this laboratory have provided detailed observations of wind profiles under conditions of strongly stratified flow, in which air motions are effectively "decoupled" from the constraints imposed by the usual frictional contact with the surface. In decoupled flow, air is free to accelerate in response to gravitational, inertial and geostrophic forces, with the result that velocities at heights of the order of 100 m are much greater than would be indicated by the application of a simple power law to near-surface winds. Since there are no available data on wind profiles to heights of several hundred meters in the Great Plains and midwestern states, considerable emphasis has been associated with the need to develop better methods for inferring wind profile shapes from low-level data.

A study of Wangara wind profiles has indicated that a power law exponent $p = 0.4$ can be used to signal the presence of sufficiently stable stratification that stability-decoupling can be expected near the surface. The value $p = 0.4$ has, therefore, been used to determine the frequency of occurrence of strongly stratified flow at Argonne; these are the conditions that are conducive to the formation of low-level wind maxima.

A four-year period of wind data obtained by use of a 45-m meteorological tower at Argonne has been reanalyzed to yield the median power law exponents illustrated in Figure 4.8. A comparison between the data shown for the months of February (F), May (M), August (A) and November (N) shows a strong diurnal cycle in every case but that high values of p are associated with summer months. Figure 4.9 illustrates the probability of occurrence of a power law exponent greater than 0.4 as a function of the time of day for the same selected months. In summer, the data indicate that low-level wind maxima might occur on more than 40% of occasions. In winter, the frequency of possible occurrence decreases to about 15%.

The procedures developed for application to the Argonne data set can be applied in any circumstance in which simple wind gradients relatively close to the surface are available. However, these procedures are untested. In order to test them and to extend the analysis to other better-documented circumstances, considerable effort has been spent on the reduction, error-checking and analysis of meteorological data obtained at the 488-m WKY-TV tower in Oklahoma. A copy of the complete data set has been obtained on more than 30 magnetic tapes. The data on these tapes has been scrutinized thoroughly, and a new master-set of three more densely packed tapes has been produced. This time-consuming process has been completed and the data are now ready for incorporation into the present studies of the occurrence of strong wind shears and wind maxima.

FIGURE 4.8. Median Power-Law Exponent as a Function of the Time of Day for the Months of February (F), May (M), August (A) and November (N)

FIGURE 4.9. Probability of Occurrence of the Power-Law Exponent $p = 0.4$ as a Function of the Time of Day for the Months of February (F), May (M), August (A) and November (N). The power-law exponent $p = 0.4$ is taken to signal decoupled conditions when nocturnal wind maxima are strongest.

It is proposed to make copies of the revised data tapes available to the wind energy research community, once testing is completed and permission is obtained from the originating institution.

Expected Progress During the Next Reporting Period:

Nocturnal wind maxima, as related to wind-energy resource assessment, will be studied. This program proceeds to apply the methods developed from studies of the Argonne and Oklahoma tower data, as augmented by the results of dedicated field experiments conducted under collaborating DOE programs. A simple diagnostic test of National Weather Service (NWS) data will be developed into nomograms that will relate simple meteorological parameters to the probability of occurrence of specific power-law exponents during stable nighttime hours over typical Great Plains and midwestern terrain. These procedures will be applied to existing NWS data in order to develop an improved assessment of the wind power potential in these areas.

Reports and Publications:

Sisterson, D. L., and P. Frenzen. 1978. "Nocturnal Boundary-Layer Wind Maxima and the Problem of Wind Power Assessment." Environ. Sci. and Technol., 12:218-221.

Sisterson, D. L., and B. B. Hicks. 1979. "Application of Power Laws for Wind Energy Assessment." Paper presented at the Conference and Workshop on Wind Characteristics and Wind Energy Siting 1979, June 19-21, 1979, Portland, Oregon.

4.1.6 Coordinate and Interpret Model Verification (C2a)

Pacific Northwest Laboratory
Richland, WA 99352

Principal Investigator:

Thomas R. Hiester (509)942-4129

Objective:

To evaluate the accuracy of numerical site-screening techniques.

Program Status:

All data sets have been selected and the modeling of them continues.

The program will conclude in 1980.

Progress During Reporting Period:

The NOABL and SIGMET codes developed by Science Applications, Inc. (SAI) (see 4.1.8) and the MATHEW code of Lawrence Livermore Laboratory (LLL) (see 4.1.7) were run on the Oahu data set. The SAI model verification results were reported. Because of the death of the LLL principal investigator, it was impossible to compile the MATHEW model verification results before the end of the reporting period.

A data set from the Nevada Test Site is to be the second and final data set used in this program. LLL will not participate in model verification efforts using these data. The Nevada Test Site data set consists of 28 cases. Each case consists of approximately 20 wind speed and direction observations from anemometers distributed throughout the Nevada Test Site. Each observation is a one-hour average at either 00Z or 12Z, therefore, coinciding with the upper-air observations made from a station within the test site. The 28 cases are representative of the conditions observed from October 1970 through March 1971. The methods of initializing the model runs are discussed under Task C2c.

Expected Progress During Next Reporting Period:

NOABL will be made operational on PNL computer systems where supplementary numerical experimentation will take place. SAI verification

efforts on the Nevada data set, performed under Task C2c, will be completed.

A final report summarizing the results of comparing simulated and observed wind fields will be prepared. The report will discuss the special problems of modeling flow over complex terrain, the attributes as well as the limitations of various models, and the options for future research and development.

Reports and Publications:

None.

4.1.7 Numerical Model Verification (C2b)

Contract No.: UCRL-50034-76

Lawrence Livermore Laboratory
University of California
Livermore, CA 94550

Principal Investigators:

Christine A. Sherman

John J. Walton (415)422-1100

Contract Monitor:

William T. Pennell (509)942-4620

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. As of the end of the reporting period, the future of this contract is uncertain due to the sudden death of Christine A. Sherman.

Progress During the Reporting Period:

Oahu Data Base: The analysis of the surface wind data from Oahu from the period of August 1976 to July 1978 has been completed. A two-year data base consisting of hourly average wind speed and direction for up to 21 sites covering the island of Oahu is now available upon request. In addition, a report is available that gives a brief description of the Oahu data base, including audits of data availability for all stations. There is also a description of the statistical package for the data. This package makes up the bulk of the report and consists of monthly data summaries for each site for the reporting period. Figure 4.10 is a sample of such a summary.

AVERAGE HOURLY WIND SPEED (M/S)
FOR NOVEMBER 1977 AT LT
(30.5/26.0)**0.140 LAW SPEED SCALING

DAILY AVERAGE WIND SPEED (M/S)
FOR NOVEMBER 1977 AT LT
(30.5/26.0)**0.140 LAW SPEED SCALING
MONTHLY MEAN 4.7 (+/-) 2.7

AVERAGE HOURLY WIND DIRECTION (DEG)
FOR NOVEMBER 1977 AT LT

DAILY AVERAGE WIND DIRECTION (DEG)
FOR NOVEMBER 1977 AT LT
MONTHLY MEAN 130.0 (+/-) 21.1

DATA (*), WEIBULL FIT -
STATION LT NOVEMBER 1977
ANEMOMETER HEIGHT 26.0 SCALED TO 30.5
WITH A 0.140 POWER LAW

FREQUENCY OF OCCURANCE
STATION LT NOVEMBER 1977
ANEMOMETER HEIGHT 26.0 SCALED TO 30.5
WITH A 0.140 POWER LAW

FIGURE 4.10. An Example of the Statistics Presented
for Each Station and Each Month Included
in the Oahu Surface Wind Network Data
Summary (Shinn et al. 1979)

MATHEW Model Verification: The first year's computations were completed early this year, but much of the final analysis is still to be done. Figure 4.11 illustrates one of the elements of this analysis. It is a scatter plot of predicted versus observed wind speed for the Kahuku Hill site for a series of MATHEW runs. Figure 4.12 is a frequency of occurrence plot for the Kahuku site. In this figure, the MATHEW predictions (solid line) are compared with data (dashed line). This kind of plot gives information not only on MATHEW performance but also on the statistical characteristics of the site screening methodology. Other information produced by MATHEW includes isotachs for different wind regimes, e.g., trade winds (Figure 4.13) and winter storm conditions (Figure 4.14). MATHEW also predicts vertical profiles (Figure 4.15). Data that can be derived from MATHEW results consist of wind speed distribution curves at specific sites and annual-average power fields for the island. The MATHEW verification studies are not expected to continue.

Site Screening Methodology: Figure 4.16 illustrates the concept of the site selection methodology being tested. MATHEW, driven by climatological data, is used first to give a preliminary location for potential wind sites. Then Principal Components Analysis (PCA) is used to identify a statistical representative set of days for the year. These typical days provide inputs to MATHEW so that winds at sites where observations are not available may be predicted. From these predictions, wind statistics can be derived to provide wind-power-potential estimates for the sites.

All typical days for the first year's data have been run through MATHEW. Eight sites were held out for verification. From the MATHEW predictions, wind speed duration curves have been produced and from them the mean and median wind speeds derived. The PCA portion of the analysis seems to be giving good representation.

FIGURE 4.11. MATHEW Model Results. Predicted versus observed winds at the Kahuku Hill site

FIGURE 4.12. Kahuku Hill Annual Wind-Speed-Frequency Distribution

FIGURE 4.13. Oahu Trade Wind Conditions. Isotachs of the adjusted wind speed 120 m above topography during 1700 on August 12, 1976. The contour interval is 5.0 m/sec.

FIGURE 4.14. Oahu Winter Storm Conditions. Isotachs of the adjusted wind speed 120 m above topography during 0100 on November 24, 1976. The contour interval is 5.0 m/sec.

When actual data for the 12 typical days selected by PCA were used, mean winds were predicted slightly high (approximately 20%) as can be seen in Figure 4.17. This is a result consistent with the way in which PCA functions, i.e., strong wind conditions tend to be emphasized. Inclusion of the secondary patterns reduced the approximate means by about 5%.

The situation becomes more complicated when the predictions from MATHEW are treated in a similar manner. As can be seen in Figure 4.18, when annual-average power is computed using MATHEW predictions, reasonable kinds of distributions are obtained. Yet, if we look simply at annual mean wind-speed predictions for specific sites, a flattening is seen in the distribution. It is believed that this phenomenon arises from two sources. The first was the initial interpolation of the original data. This had a very strong tendency to flatten out this original guess, and since MATHEW attempts a minimal adjustment to achieve nondivergence, the resulting field will clearly reflect this. A new idea related to this initial interpolation will be tested. The second problem was the way in which velocities were defined in the code. This problem has been rectified in a new version of the code. Both of these problems lie properly under MATHEW verification rather than site screening methodology, which will in no way be altered by the improvements being made in the MATHEW analysis.

Reports and Publications:

Hardy, D. M., and J. J. Walton. 1978. "Principal Components Analysis of Vector Wind Measurements," J. Appl. Meteor., 17(8):1153-1162.

Knox, J. B. 1978. "LLL Wind Energy Studies (Oahu)." Paper presented at the Wind Energy - Here and New Symposium, December 19-20, 1978, Honolulu, Hawaii.

Shinn, J. H., C. A. Sherman, J. J. Walton, K. L. Hill, B. R. Clegg and D. Whisler. 1979. Oahu Surface Wind Network Summary of Data, August 1976 through July 1978. Lawrence Livermore Laboratory Report UCID-18232, Livermore, CA 94550.

FIGURE 4.15. Example of Wind Profiles Produced by MATHEW showing the Sensitivity to Input Data from the Station KH.

FIGURE 4.16. The LLL Site Screening Methodology

FIGURE 4.17. Mean Wind Speeds at Several Sites (Computed from the Set of Days Selected as "Typical" by the Principal Components Analysis) Versus the Mean Wind Speeds (Determined from the Full 365-Day Data Set).

FIGURE 4.18. Average Annual Power (W/m^2) at 50 m Derived from the LLL Site Screening Methodology

Walton, J. J. 1978. Structure and Function of the Principal Components Analysis (PCA) Code. Lawrence Livermore Laboratory Report UCID-17827, Livermore, CA 94550.

Walton, J. J., and D. M. Hardy. 1978. Principal Components Analysis and Its Application to Wind Field Pattern Recognition. Lawrence Livermore Laboratory Report UCRL-52488, Livermore, CA 94550.

Walton, J. J., and C. A. Sherman. 1978. "Objective Wind Field Pattern Characterization." Paper presented at the 9th International Technical Meeting on Air Pollution Modeling and Its Application, August 28-31, 1978, Toronto, Canada.

4.1.8 Numerical Model Verification (C2c)

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

Science Applications, Inc.
Post Office Box 2351
1200 Prospect Street
La Jolla, CA 92038

Principal Investigator:

Richard M. Traci (714)459-0211

Contract Monitor:

William T. Pennell (509)942-4620

Objective:

To develop, verify and demonstrate a WECS siting methodology for complex terrain. The methodology utilizes mathematical wind-field models to define the wind characteristics of sites within a region based on available meteorological data. Two wind-field models are used in complementary fashion: NOABL, an objective analysis model, and SIGMET, a primitive equation model.

Program Status:

The program is in the final model verification phase of a multi-year effort which began in May 1975 and is scheduled for completion in February 1980.

Progress During the Reporting Period:

Work during the reporting period concentrated on the first phase of the wind-field model verification program involving model simulations and comparison with wind data for Oahu, Hawaii. Figures 4.19a and 4.19b show Oahu topography at the resolution used in the simulations and the locations of the Oahu Wind Data Network (OWDN) stations. A 24-"event" simulation matrix, consisting of two times (0200 and 1400 LST) on each of 12 days, was selected from the extension OWDN data set during the yearly period August 1976 to July 1977.

FIGURE 4.19a. Oahu Topographic Schematic with Oahu Wind Data Network Locations

FIGURE 4.19b. Oahu Terrain Perspectives (1.6 km resolution)

Simulations were performed for the entire 24-event matrix, so the effect of initialization station density on NOABL model results could be studied. Three initialization approaches were used:

- Simulation I: OWDN surface data at WR, BP, KM, KO, KK, KP plus Lihue, Kauai, upper-air data.
- Simulation II: OWDN surface data at WR, BP, KM plus Lihue, Kauai, upper-air data.
- Simulation III: Lihue, Kauai, upper-air data only.

Simulation I was chosen as representative of a "rich" data density; Simulation II represents a typical prospecting study; and Simulation III represents somewhat of a "worst case" or generic flow application.

In addition, SIGMET simulations were performed for a typical trade wind flow, August 2, 1976, at 1400 LST and a typical Kona flow case, January 12, 1977, at 14 LST. Simulated results for the near-surface flow are illustrated in Figure 4.20 for the Kona flow simulation.

Typical results of the comparison of NOABL results with the OWDN station data are shown in Table 4.3 and Figures 4.21 and 4.22. Table 4.3 presents various statistical measures of the accuracy of the simulations and shows that an expected error in wind speed is 2.5 to 3 m/sec. Figure 4.21 compares the calculated and observed mean wind speed at the various stations and Figure 4.22 compares the calculated mean wind speed contours, based on Simulation II results with the observed mean wind speed at each of the OWDN stations.

The potential utility of NOABL as a wind-energy site-screening tool has been demonstrated in the relatively simple terrain and methodology of Oahu. NOABL's applicability in more general and more complex environments has yet to be established.

Expected Progress During Next Reporting Period:

The wind-field model verification program will be completed during the next reporting period. A program of wind-field simulations and detailed comparisons of model results with available field test data

FIGURE 4.20. Near Surface (~ 30 m AGL) Wind-Field Vectors and Speed Contours (m/sec): SIGMET Simulation of Oahu "Kona" Flow, 1/12/77 at 1500 LST (one-hour simulation time)

TABLE 4.3. Station Windspeed Results Correlation Quantities:
24 Event Oahu Verification Matrix, Oahu Wind Data
Network

Simulation Description (Events used in Analysis)	Least Squares Linear Fit Parameters		Root Mean Square Error RMSE, σ_q (m/sec)	Mean Bias $\bar{b}_q$ (m/sec)	Mean Deviation $\bar{d}_q$, m/sec	Linear Correlation Coefficient r
	a_0	a_1				
Simulation I : 6 surface & upper air						
● 0200 events	2.3	0.63	3.3	-0.01	2.4	0.63
● 1400 events	1.9	0.79	3.4	0.34	2.7	0.64
● all 24 sets	2.1	0.72	3.4	0.17	2.5	0.65
Simulation II : 3 surface & upper air						
● 0200 events	3.4	.43	4.2	-0.11	2.8	0.43
● 1400 events	3.2	.69	4.1	0.78	3.0	0.53
● all 24 events	3.2	.59	4.1	0.33	2.9	0.51
Simulation III: upper air only						
● 0200 events	3.5	.48	3.7	0.24	2.8	0.51
● 1400 events	2.4	.53	3.6	-1.27	2.9	0.54
● all 24 events	3.1	.48	3.6	-0.51	2.8	0.52

$$q_{\text{calc}} = a_0 + a_1 q_{\text{obs}}$$

$$\bar{b}_q = \frac{1}{N} \sum (q_{\text{calc}} - q_{\text{obs}}) = \text{mean bias}$$

$$\bar{d}_q = \frac{1}{N} \sum |q_{\text{calc}} - q_{\text{obs}}| = \text{mean deviation}$$

$$\sigma_q = \text{RMSE} = \left\{ \frac{1}{N} \sum (q_{\text{calc}} - q_{\text{obs}})^2 \right\}^{\frac{1}{2}} = \text{root mean square error}$$

FIGURE 4.21. Comparison of Calculated to Observed Mean Windspeed Based upon 24 Oahu Simulation Events (NOABL Simulation II: WR, BP, KM plus Lihue, Kauai, upper-air data)

FIGURE 4.22. Comparison of Predicted Near Surface (~ 15 m AGL) Mean Windspeed Contours, $\langle V \rangle$ m/sec, with Oahu Wind Network Data: NOABL Simulation of 24 "Event" Matrix of Oahu Windfields (Simulation II: stations WR, BP, KM, and Lihue, Kauai, upper-air data used in initialization).

sets from the Nevada Test Site will be performed. The program is similar in approach and extent to the study for Oahu, Hawaii, just described, although the terrain and meteorology are more complex.

Reports and Publications:

Traci, R. M., G. T Phillips and K. C. Rock. 1979. "The Utility and Verification of Mathematical Windfield Models for Wind Energy Regional Screening and Site Selection." Paper presented at the Conference and Workshop on Wind Characteristics and Wind Energy Siting 1979, June 19-21, 1979, Portland, Oregon.

4.1.9 Small-Scale Terrain Effects (C3a)

Contract No.: DE-AC06-76ET20242

FWG Associates, Inc.
R.R. 2, Box 271-A Lakewood Drive
Tullahoma, TN 37388

Principal Investigator:

F. Walter Frost (615)455-1982

Contract Monitor:

William T. Pennell (509)942-4620

Objectives:

1. To develop the technology for siting wind energy conversion systems (WECS) relative to small-scale features contained within a region selected for wind-energy use.
2. Evaluate kite anemometers as a viable instrument for WECS site prospecting.

Program Status:

The third year of the Objective 1 program is in progress with the final report due October 1979. The program began August 1976.

Objective 2 is a one-year effort (October 1978 to October 1979).

Progress During the Reporting Period:

Objective 1: A draft report considering three-dimensional, small-scale terrain features has been prepared. This report provides organized material from existing literature that supports the wind prospector in choosing the best wind turbine location relative to small-scale terrain features. Information about the influence of various surface features on the local wind conditions is given. Such information can be used to take maximum advantage of local terrain conditions and to avoid extremely detrimental wind regions.

In this report information has been obtained from the literature for flow over natural and man-made protrusions (i.e., hills, cliffs, buildings) and depressions (i.e., valleys, canyons). Most of the information relates to idealized (i.e., laboratory or analytical) flow conditions and geometries; however, limited data from field studies is also reported. Unlike the previous report, "Guidelines for Siting Wind Turbine Generators Relative to Two-Dimensional, Small-Scale Terrain Features," which presents detailed engineering graphs, no attempt is made to format the information as a handbook or manual. Many problems are associated with quantitatively applying the available information to the actual siting of WECS in natural terrain. For example, well-defined or isolated terrain features, for which information concerning the flow field is available, cannot be easily identified on complex terrain. It is necessary, in these cases, to provide certain guidelines that make it possible to associate features within complex terrain with model features that have been tested or mathematically analyzed. In almost all cases the model features are highly idealized, thus requiring gross simplifications of the real features into idealized generic shapes. To simplify the discussion in this regard, terrain features considered have been categorized as protrusions (hills, bluffs, trees, shelterbelts), depressions (valleys, canyons, internal corners) and complex terrain.

The approach calls for qualitative selection of sites on the basis of principles and knowledge acquired from a thorough review of the theoretical and experimental results of fluid mechanics studies of a variety of geometric configurations. The report, therefore, provides a summary of the flow features for well-defined geometries that have been studied both experimentally and analytically. The information is quantitatively documented to the extent possible.

Three specific areas have been selected for example analysis of wind-site-selection techniques. One area represents relatively complex terrain for which a number of hilltop locations may be good sites. A second area representing a semi-isolated hill for which

experimental data is available has been compared with the prediction techniques and site selection criteria provided in the reports. Finally, a valley site has been selected and topographical maps obtained.

Objective 2: An equilibrium model of the kite and tether has been developed and a computer program is operational. The model confirms experimental calibration data provided by the kite anemometer manufacturer. A dynamic model has been developed and is operational but has not yet been applied specifically to the kite and tether system. Experimental testing of the kite is being carried out.

Expected Progress During Next Reporting Period:

Objective 1: The next year's report will present applications of these data and concepts to a number of example site-selection problems for a variety of different terrain conditions. Regions will be prescribed where sites can be selected and contour maps and photographs of the terrain are available. A step-by-step discussion of the reasoning used in the selection of the sites will serve to demonstrate the site-selection procedures and will provide convenient guides for use of wind-energy prospectors.

Objective 2: An analytical model of the kite, the tether and the sensor system will be developed. The model will: (1) allow evaluation of different kite configurations and tether systems, (2) provide insight into data acquisition, processing and interpretation and (3) give an understanding of the physical mechanism of the system. The results will delineate the proper use of kites in WECS system siting and ultimately, when verified by experiment, produce design criteria for development of future kite anemometer systems. Both equilibrium and dynamic analysis will be carried out.

An experiment program will consist of a field study to compare kite measurements with tower measurements and to verify the analytical model developed.

Reports and Publications:

None.

4.1.10 Update Small WECS Handbook (C3b)

Pacific Northwest Laboratory
Richland, WA 99352

Principal Investigator:

Harry L. Wegley (509)942-4627

Objective:

To revise A Siting Handbook for Small Wind Energy Conversion Systems in order to provide the general public with effective and inexpensive siting methods.

Program Status:

Review comments on the last edition were received and are being incorporated into a new edition.

Expected Progress During Reporting Period:

A revised edition is nearly completed. Slight organizational changes were made that include the addition of a new chapter on measurements and instrumentation. The aesthetic appeal of the handbook is enhanced with improved graphics and typesetting.

Progress During Next Reporting Period:

The revised manual will be completed and published for UC-60 distribution. There will be negotiations to determine means for wider dissemination of the handbook to the general public.

Reports and Publications:

None.

4.1.11 Large WECS Handbook (C3c)

Pacific Northwest Laboratory
Richland, WA 99352

Principal Investigators:

William T. Pennell (509)942-4620

Thomas R. Hiester (509)942-4129

Objective:

To provide siting strategies, critical evaluation of available siting techniques and other meteorological information that can be used to site single units or clusters of large WECS.

Program Status:

A new approach to the large WECS handbook has been taken on the current draft.

Progress During Reporting Period:

Criticism of the previous handbook, A Compendium of Siting Considerations for Large Wind Energy Systems, indicated that the technical information was useful, but the volume was poorly organized and did not address the audiences that are most likely to use it. The current revision, therefore, takes a substantially different approach. The Meteorological Aspects of Siting Large Wind Turbines, as the revision is titled, serves two major functions.

The first two chapters define the siting problem and the means to solve it. In Chapter 1, utility executives who must organize and execute a wind-energy site selection and development program will find an overview of the wind-energy problem that describes the data one must collect to document a resource. Of special significance are the discussions on the limitations of certain wind data because of wind variability from site to site or from one level to higher levels. Chapter 2 introduces the specific techniques that can be used for site screening. Since each technique has its limitations, Chapter 2 provides a strategy for using the techniques at the various stages of a site selection program.

The remainder of the document provides specific technical information. This information is especially useful to the utility technical staff who are closely involved with the actual siting work, either directly or through consultants. Information on numerical and physical modeling techniques is presented that advises the consumer of the strengths, limitations, and applications of the variety of modeling approaches available. The techniques using topographical, biological, geomorphological, and social/cultural indicators of wind-power potential are summarized. The state of the art for determining the arrangements of wind turbines in large clusters is reviewed. A chapter on measurements and instrumentation is followed by a discussion of meteorological hazards to large wind turbines. Finally, the appendices contain information on the regional resource assessments and a discussion of background meteorological theory pertinent to the siting problem.

Expected Progress During Next Reporting Period:

A draft of the handbook will be completed, reviewed, revised according to review comments and published for UC-60 distribution.

Reports and Publications:

None.

•

•

•

•

•

•

•

•

•

•

•

•

5.0 WIND CHARACTERISTICS FOR WECS OPERATIONS

During FY 1979, the main activities in this program area have been the production of wind forecasts by different techniques. The forecasts were used to evaluate accuracy and suitability of the techniques for satisfying the operational needs of utility companies. The most objective wind forecasting technique employed was one produced by Model Output Statistics (MOS, see 5.1.1). A subjective technique was also used to produce twice daily 24-hr wind forecasts for three of the DOE candidate sites. Using historical wind data from the three sites, the technique was developed and used to produce forecasts for the historical period for subsequent comparison and analysis (see 5.1.3). Five contracts were established to provide operational real-time wind forecasts at several DOE candidate sites (see 5.1.2). The results from this effort will allow evaluation of commercially available wind forecasts. A task was also established to verify forecast wind data against measured wind data to determine the reliability of various wind forecast techniques (see 5.1.4). The Wind Characteristics Program Element has, during this reporting period, participated in the international wind-forecasting verification program conducted by the International Energy Agency (see 5.1.5).

5.1 PROGRESS IN TECHNICAL TASKS

5.1.1 Wind Forecasts for WECS Operations by MOS (D2a)

Contract No.: B-23451-A-P

Techniques Development Laboratory
National Weather Service - NOAA
Silver Springs, MD 20910

Principal Investigator:

David B. Gilhousen (301)427-7768

Contract Monitor:

Harry L. Wegley (509)942-4627

Objective:

To examine the reliability and accuracy of wind forecasts produced by the Model Output Statistics (MOS) approach for nine wind turbine generator (WTG) sites.

Program Status:

The project was initiated in June 1979 and will continue through June 1980. An interim report is due in December 1979, and a final report is due in June 1980.

Progress During Reporting Period:

Deterministic forecasts for wind speed and direction were produced through several trial regressions. In particular, wind speed and direction forecasts for 12 hr and 21 hr (after 0000 GMT) were produced and verified on a year of dependent data. The predictors were various forecast fields from the Limited-Area Fine Mesh (LFM) numerical model. Regression equations were produced at each of the nine WTG sites shown in Figure 5.1.

Figure 5.2 shows the mean absolute error of the wind speed forecasts at the nine sites. The mean observed speed is plotted over each station circle to facilitate comparison among sites. With the exception of San Geronio Pass, most of the sites have similar

forecast errors. San Gorgonio Pass' errors are considerably larger because of their higher mean-wind speed.

FIGURE 5.1. The Nine Wind Turbine Generator Sites for Which Objective Wind Forecasts were Produced

Figure 5.3 shows the mean absolute error of the wind direction forecasts. Forecasts of wind direction exhibit the least error for the four eastern United States sites, while forecasts for the two stations in the Great Plains (Kingsley Dam, Nebraska, and Russell, Kansas) have the most error. Forecasts for San Gorgonio Pass valid at 2100 GMT exhibit a large error because of the presence of local mountain-valley circulations that are quite variable. The performance of the forecasts valid at 1200 GMT is quite good.

Expected Progress During Next Reporting Period:

Single station regression equations will be developed for all the sites for seven forecast projection times. These equations will forecast wind speed and direction, as well as the probability of certain ranges of wind speed. All forecasts will be verified on a year of independent data. This verification will help researchers decide whether the objective forecasts appear useful for WTG operations.

Reports and Publications:

None.

FIGURE 5.2. The Mean Absolute Error of Objective Wind Speed Forecasts

FIGURE 5.3. The Mean Absolute Error of Objective Wind Direction Forecasts

5.1.2 Real-Time Subjective Wind Forecasts (D2b)

Contract No.: B-87040-A-P

Murray and Trettel, Inc.
414 West Frontage Road
Northfield, IL 60093

Contract No.: B-87038-A-P

General Weather Center
910 Fisher Building
Detroit, MI 48202

Contract No.: B-23098-A-P

ACCU-Weather
619 W. College Avenue
State College, PA 16801

Contract No.: B-87039-A-P

Global Weather Services
P.O. Box 6053
Leawood, KS 66206

Contract No.: B-87037-A-P

Freese-Notis Weather
1453 N.E. 66th Avenue
Des Moines, IA 50313

Principal Investigators:

John P. Murray (M&T) (312)446-7800
Lyle E. Brosche (GWC) (313)871-3511
Joel N. Meyers (A-W) (814)237-5801
Victor E. Cook (GWS) (913)642-7373
Charles Notis (F-NW) (515)289-1314

Contract Monitor:

Harry L. Wegley (509)942-4627

Objective:

To produce subjective wind forecasts using real-time data typically available to the operational forecaster.

Program Status:

A survey was made of all organizations in the private sector that produce operational weather forecasts. A Request for Quotations (RFQ) was sent to interested organizations to produce real-time 24-hr hourly average wind speed and direction forecasts for eleven DOE candidate wind turbine sites for a 6-mo period. Five contractors were selected (three to forecast for each site), and the forecasting work began May 1, 1979. Wind forecasts have been received from each contractor for a 5-mo period (May through September 1979). One month of forecasting remains to be completed in October 1979.

Progress During Reporting Period:

The forecasters became familiar with the sites by studying site descriptions and 12 mo of wind climatology provided by PNL. Observed site winds were provided (as they became available) to correct any systematic forecast errors. However, the initial 2-mo delay in getting feedback to the forecasters resulted in some rather large errors during the early part of the contract period. In July, the Hanford meteorological station was added to the forecast program as a measure of wind forecasting accuracy when both real-time feedback and a high degree of site familiarity exist. At the close of this reporting period, 5 mo of wind forecasts (three for Hanford) have been received and prepared for entry into computer verification programs.

Expected Progress During Next Reporting Period:

Visits to each contractor are planned for October 1979 to discuss the preliminary results of forecast verification and to discuss preparation of the contractor's final report. Pertinent information from the final reports and from the wind forecast verification will be incorporated into a topical report on wind forecasting reliability to be written by PNL in mid-FY 1980.

Reports and Publications:

None.

5.1.3 Historical Subjective Wind Forecasts (D2c)

Contract No.: B-23451-A-P

Weather Services Corporation
Bedford, MA 01730

Principal Investigator:

James J. Serna (617)275-8860

Contract Monitor:

Harry L. Wegley (509)942-4627

Objective:

To determine the accuracy and potential usefulness of wind forecasts for any of the proposed wind turbine generator (WTG) sites. Specifically, three sites were used for this study: Block Island, Rhode Island; Boone, North Carolina; and Russell, Kansas. The period of study covered December 1977 through December 1978.

Program Status:

Nearly all of the study-period forecasts have been completed. Only October 1978 and November 1978 are incomplete. It is expected that these last two months of forecasts will be completed on or before September 15, 1979.

Progress During Reporting Period:

The initial work centered around each of the sites so that their characteristics could be studied in relation to the wind under various weather patterns. One characteristic, topography, is of prime importance to the wind field, and its effects can be inserted into the forecast procedure. The topographic maps showing the location of each WECS site were examined, and some of the verified winds were studied in order to get a feel for any local effects.

Block Island: Being surrounded by water, Block Island is subject to sea breezes during the spring, summer and autumn. Frequently, a southerly to southwesterly sea breeze developed at Block Island regardless of the prevailing pressure gradient. However, the strength

of the sea breeze depended on the gradient. Under a northwest gradient, the sea breeze developed as a southwesterly wind at roughly the same speed as the gradient would support, but under a prevailing southwest gradient, a south-southwest sea breeze developed at speeds nearly double to what the gradient would support. During the spring, summer and autumn, a prevailing northwest gradient was altered during daylight hours by differential heating. In effect, surface pressures over mainland southern New England were lowered because of heating, while pressures over the water remained relatively high. As a result, artificial troughing took place over land, turning the prevailing gradient southwesterly over water. This example should not be confused with a true sea breeze. Under sea breeze conditions, the overall large-scale pressure gradient is unaffected.

Boone: Boone's elevation (>4,000 ft) and the orientation of the mountain ridges near it are of great importance to a wind forecaster. It was decided that the 850-mb surface (roughly 5,000 ft) would be more representative of Boone than the surface analysis and this was indeed true. An accurate forecast of the 850-mb level gave a more accurate wind forecast for Boone than using a surface prognostic chart. At the 850-mb level, wind direction is much more conservative than at the surface. Only when the center of the 850-mb high-pressure ridge was nearby did the winds become light and variable. The presence of the essentially west-east mountain ridge just west of the Boone location apparently did have an effect on the winds. It appears that under a prevailing west-northwest to northwest flow at 850 mb, the winds are channeled and the speed enhanced by this range of mountains, resulting in super-gradient speeds. Comparison of actual wind observations at the 850-mb level with the verified winds from the Boone location showed that under the northwest flow situations, the Boone winds were frequently 30 to 40% higher than winds observed at Greensboro, North Carolina, and in a few instances, were nearly double the Greensboro winds. This would not be expected over flat terrain.

Russell: The individual hourly winds at the Russell location appear to be much less affected by topography than either Boone or Block Island. Russell is located in essentially flat, open terrain, and its winds are much more reliable relative to the surface gradient. However, in terms of forecasting a surface weather pattern, Russell is a very interesting location. With the Rocky Mountains to the west, all surface features moving west to east must come out of the mountains. Attempting to locate a surface feature in the mountains is quite difficult, and at times impossible, because of the effect of the mountains on surface observations.

Developing a Forecast Procedure: The format for this project calls for a 24-hr forecast of winds for each of the locations twice daily, 06Z and 18Z; therefore, the solution calls for the development of a 24-hr prognostic chart upon which the individual wind forecasts would be based. One immediate and simple tool for developing a prognostic chart is called "persistence." Extending the persistence method to its logical conclusion, a forecaster would continue moving systems along with no change in intensity, or in direction and speed, for days on end. This would lead to some rather large forecast errors. This is where the use of the upper-level charts becomes important and where the computer-derived forecasts can be of great value.

The Forecast Procedure: Using the microfilmed surface- and upper-air charts, a 24-hr prognostic chart (24-hr prog) was developed. Every attempt was made to simulate as closely as possible the real-time conditions. Hypothetically, an 18Z forecast of March 3 was assumed. The first input to the 24-hr prog was a review of the previous day's set of surface charts. The position, strength and motion of all weather features were observed up through and including the 15Z analysis of March 3 (under real-time conditions, the 15Z chart would be available at about 17Z). This provided the "persistence" and was the initial step in building the 24-hr prog. The upper-level charts were then considered. The data from 12Z March 2, 00Z March 3, and

12Z March 3 were reviewed with emphasis again placed on motion and strength of all important features, especially on changes of motion or strength. Subjective interpretation of the upper-level charts was used in determining what effect upper-level features would have on surface features; based on persistence and subjective analysis of upper-level features, the final 24-hr prog was developed. Several hours of the verified wind data just prior to forecast time were reviewed to provide the initial conditions, and based solely on the 24-hr prog, each forecast was completed.

Reports and Publications:

None.

5.1.4 Wind Forecast Verification (D2d)

Pacific Northwest Laboratory
Richland, WA 99352

Principal Investigators:

Alan H. Miller (509)942-4122
Harry L. Wegley (509)942-4627

Objective:

Forecasts of wind as required by utilities employing WTGs are not standard in the general meteorological community. Therefore, new and different techniques need to be developed, and a need exists to verify the quality of forecasts and provide feedback.

Program Status:

A computer program to merge forecasted and observed data and to perform an analysis has been generated and run on monthly data for three sets of forecasts and eleven sites for the months of May through August 1979.

Progress During Reporting Period:

In this reporting period, the variables needed to describe the quality of a forecast were defined and incorporated into a computer program called WINSUM. WINSUM produces graphic displays of forecasted and observed data pairs and their differences in a time series format. At the same time it stores the data in an array for processing in a statistical program that computes values of the forecasted and observed data, as well as their differences.

The product of this program has been well accepted by the forecast community, since it provides the needed feedback for developing the forecast methods specific to a site.

Expected Progress During Next Reporting Period:

A complete analysis of the forecasts done by both subjective and objective methods will be performed as data becomes available.

Reports and Publications:

None.

5.1.5 International Wind-Forecasting Verification Program (D3b)

Pacific Northwest Laboratory
Richland, Washington 99352

Principal Investigator:

Harry L. Wegley (509)942-4627

Objective:

To define criteria for an international wind-forecasting verification scheme and to provide wind forecasts and observations to determine the reliability of wind forecasts for WECS operations.

Program Status:

This program was established in 1976 by the International Energy Agency (IEA). Work began in May 1979 with the first meeting of technical experts from participating nations. This study will continue at least through July 1980, when a final report on wind-forecasting reliability will be issued. If the IEA determines that a need exists for further research in this area, the program may be extended beyond 1980.

Progress During Reporting Period:

In May 1979 the required wind forecasting verification statistics were identified by consulting with representatives of participating nations. At this meeting an accelerated work schedule was also approved. The United States began three studies in 1979 to provide input into the international wind-forecasting verification program.

These studies were to use:

- 1) objective wind-forecasting data produced by the National Weather Service using model output statistics at nine DOE candidate wind turbine generator (WTG) sites,
- 2) subjective wind-forecasting data using historical data for three DOE candidate WTG sites, and
- 3) real-time subjective wind-forecasting data produced for eleven DOE candidate sites.

Expected Progress During Next Reporting Period:

All wind-forecasting data available by January 1980 will be placed on magnetic tape and sent to the operating agent for this task (Sweden) for verification. The results of the forecast verification will be reviewed as they become available. In mid 1980 a second technical meeting will be held to outline the final report to be published by July 1980. Because of the acceleration of work in this task, the IEA may recommend refining and upgrading the wind-forecasting techniques to better meet the needs of WECS users. Such a decision would extend this effort beyond FY 1980.

Reports and Publications:

None.

6.0 SPECIAL STUDIES

This activity was established to initiate work on new topics that could then be transferred into the appropriate program area. During this reporting period, two efforts were conducted. The first involved establishing a reliability/accuracy testing program for commercially available wind measurement equipment (see 6.1.1). The second effort was the development of a short course for siting small wind turbines (see 6.1.2). Early versions of the short course were presented on two occasions. The comments and criticism from these presentations will be incorporated into the short course being prepared for wide distribution.

6.1 PROGRESS IN TECHNICAL TASKS

6.1.1 Prototype Program for Reliability/Accuracy Testing of Meteorological Instrumentation (E2a)

Pacific Northwest Laboratory
Richland, WA 99352

Principal Investigator:

J. Van Ramsdell (509)942-4825

Objective:

To identify, test and evaluate inexpensive meteorological instrumentation for potential use in siting small wind energy conversion systems (SWECS).

Program Status:

Work began in FY 1979 and will continue in FY 1980.

Progress During Reporting Period:

The initial step in evaluating the wind instruments was to prepare an adequately documented laboratory test facility. A 2-ft-dia wind tunnel has been calibrated for this use. The wind tunnel is capable of generating wind speeds between 2 and 20 mph for determination of the accuracy and linearity of instrument output.

Initial wind-tunnel tests have been completed on two anemometers systems: a Natural Power A30-101 Wind Speed Compiler and a Weather Measure W224 Recording Wind System.

Equipment has been ordered for the outdoor test facility. When initial wind-tunnel tests on an instrument are completed, this facility will be used to test and evaluate the performance of wind sensors in the natural environment.

Expected Progress During Next Reporting Period:

Wind tunnel testing of anemometers will continue. The outdoor test facility will be completed and environmental tests will begin.

Reports and Publications:

None.

6.1 PROGRESS IN TECHNICAL TASKS

6.1.1 Prototype Program for Reliability/Accuracy Testing of Meteorological Instrumentation (E2a)

Pacific Northwest Laboratory
Richland, WA 99352

Principal Investigator:

J. Van Ramsdell (509)942-4825

Objective:

To identify, test and evaluate inexpensive meteorological instrumentation for potential use in siting small wind energy conversion systems (SWECS).

Program Status:

Work began in FY 1979 and will continue in FY 1980.

Progress During Reporting Period:

The initial step in evaluating the wind instruments was to prepare an adequately documented laboratory test facility. A 2-ft-dia wind tunnel has been calibrated for this use. The wind tunnel is capable of generating wind speeds between 2 and 20 mph for determination of the accuracy and linearity of instrument output.

Initial wind-tunnel tests have been completed on two anemometers systems: a Natural Power A30-101 Wind Speed Compiler and a Weather Measure W224 Recording Wind System.

Equipment has been ordered for the outdoor test facility. When initial wind-tunnel tests on an instrument are completed, this facility will be used to test and evaluate the performance of wind sensors in the natural environment.

Expected Progress During Next Reporting Period:

Wind tunnel testing of anemometers will continue. The outdoor test facility will be completed and environmental tests will begin.

Reports and Publications:

None.

6.1.2 Siting Short Course for Small WECS (E2b)

Pacific Northwest Laboratory
Richland, WA 99352

Principal Investigator:

J. Van Ramsdell (509)942-4825

Objective:

To develop a short course on the meteorological aspects of small WECS siting for agricultural extension agents and WECS dealers.

Program Status:

Work began in October 1978, and preliminary versions of the course were presented in April and May 1979. Revision of the course is continuing into FY 1980.

Progress During Reporting Period:

The initial short course was presented on April 19 and 20, 1979, following the American Wind Energy Association meeting in San Francisco, California. The second presentation was given May 1 and 2, 1979, at Rocky Flats, Colorado. Each presentation consisted of approximately 12 hr of lecture and discussion. Topics included: the siting scenario and site evaluation process, description of the wind resource, estimation of wind power, selection of the location for WECS, meteorological hazards to WECS and wind measurement.

Expected Progress During Next Reporting Period:

Material presented in the short course is being revised based on comments received following the initial presentations. As revisions are completed, the material will be given to the Solar Energy Research Institute, which will put the short course in its final form.

Reports and Publications:

None.

6.1.2 Siting Short Course for Small WECS (E2b)

Pacific Northwest Laboratory
Richland, WA 99352

Principal Investigator:

J. Van Ramsdell (509)942-4825

Objective:

To develop a short course on the meteorological aspects of small WECS siting for agricultural extension agents and WECS dealers.

Program Status:

Work began in October 1978, and preliminary versions of the course were presented in April and May 1979. Revision of the course is continuing into FY 1980.

Progress During Reporting Period:

The initial short course was presented on April 19 and 20, 1979, following the American Wind Energy Association meeting in San Francisco, California. The second presentation was given May 1 and 2, 1979, at Rocky Flats, Colorado. Each presentation consisted of approximately 12 hr of lecture and discussion. Topics included: the siting scenario and site evaluation process, description of the wind resource, estimation of wind power, selection of the location for WECS, meteorological hazards to WECS and wind measurement.

Expected Progress During Next Reporting Period:

Material presented in the short course is being revised based on comments received following the initial presentations. As revisions are completed, the material will be given to the Solar Energy Research Institute, which will put the short course in its final form.

Reports and Publications:

None.

7.0 METEOROLOGICAL VALIDATION OF PHASE I CANDIDATE SITES

As part of the Meteorological Validation Program, work in this area during FY 1979 focused on collecting, analyzing and reducing meteorological data collected at U.S. Department of Energy (DOE) candidate sites. During this reporting period, cassette data loggers replaced the analog strip chart recorders, thus providing digitized data at 14 candidate sites.

A major effort during FY 1979 was providing support to DOE for selecting candidate sites for receiving future wind turbines for field testing. These sites will receive meteorological measurement equipment. As of the end of FY 1979, DOE had selected seven MOD-2 candidate sites with 15 to 20 additional sites to be selected in FY 1980.

7.1 PROGRESS IN TECHNICAL TASKS

7.1.1 Support to DOE's Selection and Evaluation of Candidate Sites (Phase I) (A1)

Pacific Northwest Laboratory
Richland, WA 99352

Principal Investigator:

David S. Renné (509)942-4623

Objective:

To select a set of sites, proposed by interested electric service organizations, to receive meteorological measurement equipment for additional wind-energy evaluation. From time to time, installation sites will be selected from these candidate sites to receive large wind turbines for field testing and operation in an electric utility grid.

Program Status:

The U.S. Department of Energy (DOE) released a Program Opportunity Notice (PON) on July 4, 1979, to interested electric service organizations. The PON requested proposals for: 1) a site to be a candidate for immediate installation of up to three MOD-2 wind turbines and 2) sites to receive meteorological measurement equipment for additional wind-energy documentation. From the successful proposals in this second category, sites will be selected for receiving future wind turbine systems for field testing. A second PON was issued on July 29, 1979, to organizations responding to the first category to propose the MOD-2 installation site.

Progress During Reporting Period:

By the end of the reporting period, DOE had selected seven MOD-2 candidate sites and from these chose the Goodnoe Hills, Washington, site (proposed by the Bonneville Power Administration) as the site to receive three MOD-2 wind turbine generators. PNL provided assistance in the selection by reviewing and analyzing the wind data submitted in these proposals.

Expected Progress During Next Reporting Period:

DOE will select approximately 15 to 20 additional candidate sites to receive meteorological measuring equipment. PNL and its subcontractor will arrange to have the equipment installed on these sites and to have the data analyzed and equipment maintained at all candidate sites.

Reports and Publications:

None.

7.1.2 Application of Refined Techniques for Estimating
Wind Characteristics at Candidate Sites (A2)

Contract No.: B-23149-A-E

SRI International
333 Ravenswood Avenue
Menlo Park, CA 94025

Principal Investigator:

Chandrakant M. Bhumralkar (415)326-6200

Contract Monitor:

David S. Renné (509)942-4623

Objectives:

The objectives of this study are to apply refined computer techniques (developed in an earlier study) to:

- estimate wind speeds at sites where measurements are not available,
- improve the techniques further by introducing meteorological factors not previously included,
- test the techniques against wind observations collected during 1977 and 1978 by DOE and NASA.

The refinements to the basic technique will include use of digitized terrain data, use of variable heights of the boundary layer, use of variable vertical wind profiles, and formulation of improved computational methods.

The locations of interest in regard to wind energy cover a broad range of weather conditions and terrain including coastal areas, plains, and mountains. The sites are:

- Block Island, Rhode Island
- Oahu, Hawaii
- Boone, North Carolina
- Clayton, New Mexico
- Ludington, Michigan

- San Geronio Pass, California
- Holyoke, Massachusetts
- Huron, South Dakota

The costs for further application of the method to other sites will be determined.

Program Status:

The SRI method for estimating wind characteristics at a potential generator site uses a mass-consistent wind flow model to interpolate between those few stations where wind measurements are made. The model simulates the effects of terrain on the flow. This methodology has been described by Bhumralkar, Ludwig and Mancuso (1978). It requires terrain heights for the region and wind measurements made at nearby National Weather Service stations. To make it feasible to use a long series of wind measurements, the wind data are transformed into a small set of representative patterns (eigenvectors). Also, a time series of coefficients of the eigenvectors is obtained. The wind speed and direction at the potential site are determined for each eigenvector using the wind-flow model. Then 3-hourly winds at the site are computed from the appropriate model solutions and the coefficients. Simulated wind statistics at the site, including means and run durations, are calculated. These procedures proved to be reasonably accurate in preliminary tests.

Progress During Reporting Period:

During the present contract, the procedures have been improved in regard to accuracy and efficiency. One improvement involves the automatic selection of terrain heights from digital terrain data provided by the U.S. Geological Survey. The format of the data is such that it is efficient to decode height values at latitude increments of approximately 0.005° and then to average six of these values to obtain the desired values, as shown in Figure 7.1. Figure 7.2 is a computer plot of the height values for the area from 33° to 34°N , 116° to 117°W . Each symbol represents the average height value for a 0.01° area: A printed "1" represents a height of 0 to

7-7

FIGURE 7.2. Computer-Printer Plot of Terrain Heights for a 1° Latitude/Longitude Region. Symbols, in numerical and alphabetical order, represent height increases of 200 ft.

A second improvement to the programs provides greater efficiency in processing the meteorological data. A third improvement eliminates the need for an assumption (such as a power law) concerning the shape of the vertical wind profile. Instead, the geostrophic wind is used as the condition for motion at the top of the boundary layer. Wind values between the surface (10 m) and the top are interpolated logarithmically to give the initial conditions for the wind-flow model. This has the additional advantage of giving a geostrophic wind (computed from sea-level pressure data that accompany the surface wind observations) that corresponds to each 3-hourly set of wind reports.

A fourth improvement to the programs increases the vertical resolution of the computations to ensure accurate results at the hub height. This involves use of both a coarse grid and a fine grid for each site. Computations are made first for the coarse grid and the results are used as initial conditions for the fine grid. The two grids, each having 10 vertical levels, are shown in Figure 7.3.

A fifth improvement involves the introduction of a sloping boundary-layer top (as indicated in Figure 7.3) lying at a specified average height above the terrain. (For the United States, the average height of the boundary-layer top is given in Holzworth 1972). After specifying this height and a slope factor k , the boundary-layer height at each grid point is computed using a simple formula. If k is set equal to zero, the boundary layer top is flat; if k equals 1, the top slopes exactly with the terrain. Values between 0 and 1 give intermediate slopes. This formulation seems to be simple, yet realistic.

FIGURE 7.3. Coarse and Fine Grid Levels in the Sigma System

Expected Progress During Next Reporting Period:

Computer runs will be used to test the accuracy of the improved procedures by comparing the computer simulations with wind measurements made at eight sites in the United States. The wind measurements for 1977 are being furnished by PNL for this purpose. The research also includes making an estimate of the cost of applying this methodology to any other potential generator site.

Reports and Publications:

None.

7.1.3 Meteorological Validation Program (A3)

Contract No.: B-23454-A-E

Environmental Systems Corporation
1212 Pierce Parkway
P.O. Box 2525
Knoxville, TN 37901

Principal Investigator:

Thomas B. Carlson (615)637-4741

Contract Monitor:

William F. Sandusky (509)942-4823

Objectives:

The objectives of this program are: a) to conduct meteorological measurements at potential and actual wind turbine sites selected by DOE, b) to provide reduced meteorological data acquired at these sites to PNL, and c) to provide meteorological data acquisition systems for 20 new candidate sites.

Program Status:

The contract period began September 1, 1978, and continued through September 30, 1979.

Progress During Reporting Period:

During the month of October 1978, cassette data loggers were installed at fourteen (14) candidate sites replacing the analog strip chart recorders. This marked the beginning of the acquisition of digital data at the candidate sites. In addition, elevator systems were added to 12 towers and more sensitive wind instruments were installed at the turbine sites at Block Island, Rhode Island; Clayton, New Mexico; and Culebra, Puerto Rico. During the installation of the new wind sensors, the cassette data loggers were expanded to acquire four channels of wind turbine parameter data for performance studies.

Routine maintenance at the fourteen (14) sites was performed on a 72-hr response basis. From January through July 1979, more than 35

contracted maintenance actions and numerous additional quick-response maintenance actions were performed to restore the sites to operation and to maintain a 90% data recovery rate. In addition to routine maintenance, quarterly calibrations were performed at each site to ensure data validity.

All installations, maintenance actions, calibrations, and data reduction activities were conducted under a rigorous quality assurance program tailored for this project. Narrative reports describing the conduct of this project were provided monthly and summarized quarterly.

Each month a composite data tape was produced from the individual cassettes received from the sites. Cassette data tapes were changed periodically by the utility representatives and sent to the Environmental Systems Corporation (ESC) for processing. These data tapes were processed, edited, and compiled into a composite 9-track data tape for transmission to PNL.

Under this contract, ESC was also required to provide equipment for installation at 20 new candidate sites for Phase II of the Meteorological Validation Program. The equipment procured includes towers and elevators, sensor systems, ESC cassette data loggers, and all peripheral equipment necessary to complete a stand-alone data acquisition system.

Expected Progress During Next Reporting Period:

These services will continue as needed. The equipment will be installed at the new sites following selection.

Reports and Publications:

None.

7.1.4 Data Analysis and Reporting (A4)

Pacific Northwest Laboratory
Richland, WA 99352

Principal Investigator:

William F. Sandusky (509)942-4823

Objective:

To document, on a monthly basis, the pertinent wind data collected from the meteorological measurement equipment installed at each of DOE's candidate wind turbine sites.

Program Status:

PNL assumed the responsibility of this program in July 1978 and selected Environmental Systems Corporation of Knoxville, Tennessee, as its subcontractor to collect and reduce the data at each site and maintain the meteorological equipment. PNL prepares a monthly data report from the reduced data tape provided by ESC.

Progress During Reporting Period:

PNL began preparing monthly data reports for each site beginning with the data from November 1978. In addition, PNL arranged to have Western Scientific Services, Inc. of Fort Collins, Colorado, reduce the strip charts at all sites for October 1978 (digital data loggers were installed at all sites in November 1978, replacing the strip chart recorders) so that a continuous series of monthly data reports could be maintained from the inception of the program (December 1976). By the end of this reporting period, reports were being prepared within a month after receiving the data tape.

Expected Progress During Next Reporting Period:

Monthly data reports will continue to be prepared for existing sites, as well as for new candidate sites once the equipment is installed on these sites (spring of 1980). In addition, an annual data summary for all the sites will be prepared for general distribution during the winter of 1980.

Reports and Publications:

Renné, D. S., and W. F. Sandusky. 1979. "Meteorological Measurements of DOE's Candidate Wind Turbine Sites." Paper presented at the International Expert Meeting, September 26-27, 1979, Boone, North Carolina.

Monthly data reports have been or are being prepared for each candidate site beginning in 1976 and continuing.

8.0 PHASE II TURBINE SITE METEOROLOGICAL VALIDATION ACTIVITIES

During FY 1979, PNL provided support to DOE's selection and evaluation of installation sites for large wind energy conversion systems. As part of this effort, PNL assisted in the analysis of wind data for proposed sites to receive three MOD-2 wind turbines. In conjunction with this effort, PNL is developing a data base for DOE's large-wind-turbine sites so that machine performance can be compared to the free-stream meteorological environment. Machine output parameters, such as alternator power output and yaw error, are being recorded and monthly reports using these data will be published for each wind turbine site.

8.1 PROGRESS IN TECHNICAL TASKS

8.1.1 Evaluation of Phase II Turbine Sites (B1)

Pacific Northwest Laboratory
Richland, WA 99352

Principal Investigator:

William F. Sandusky (509)942-4823

Objective:

To develop a data base from information collected at DOE's large wind-turbine field testing sites so that performance of the machines can be compared to the "free stream" meteorological environment.

Program Status:

Machine output parameters (alternator power output, yaw error, nacelle wind speed and direction) are currently being recorded simultaneously with the meteorological tower parameters at the MOD-0A sites in Clayton, New Mexico; Block Island, Rhode Island; and Culebra, Puerto Rico.

Progress During Reporting Period:

Appropriate signal conditioning of the Clayton, Block Island, and Culebra MOD-0A sites was developed to allow machine parameters to be recorded on the data logger simultaneously with the tower meteorological parameters. Software packages were developed to relate machine performance characteristics with free-stream wind conditions.

Expected Progress During Next Reporting Period:

Plans are under way to have similar data-collection programs developed for the Hawaii MOD-0A, Boone MOD-1 and Goodnoe Hills MOD-2 sites.

Reports and Publications:

None.

8.1.2 Support to DOE's Site Selection Process (B2)

Pacific Northwest Laboratory
Richland, WA 99352

Principal Investigator:

David S. Renné (509)942-4623

Objective:

To assist DOE in the analysis of meteorological data from the existing candidate sites so that it can select the most advantageous sites for installation and field testing of large wind turbines.

Program Status:

Four MOD-0A sites and one MOD-1 site have currently been selected by DOE from the original 17 candidate sites selected in 1976.

Progress During Reporting Period:

During the reporting period, PNL assisted DOE in the analysis of wind data submitted in proposals from utilities responding to the PONs issued in July 1979 (see 7.1.1). From these and other analyses, DOE selected the Goodnoe Hills, Washington, site (proposed by the Bonneville Power Administration) for installation of three MOD-2 wind turbines.

Expected Progress During Next Reporting Period:

PNL will continue to refine data analysis techniques to assist DOE in the site-selection process.

Reports and Publications:

None.

8.1.3 Special Instrumentation and Data Collection

Procedures at Phase II Sites (B3)

Contract No.: B-23454-A-E

Environmental Systems Corporation
1212 Pierce Parkway
P.O. Box 2525
Knoxville, TN 37901

Principal Investigator:

Thomas B. Carlson (615)637-4741

Contract Monitor:

William F. Sandusky (509)942-4823

Objective:

To provide PNL with the appropriate electronic interface assistance to ensure that machine output parameters at wind turbine installation sites are recorded on the digital data loggers simultaneously with meteorological parameters (see 8.1.1).

Program Status:

Machine output parameters (alternator power output, yaw error, nacelle wind speed and direction) are currently being recorded simultaneously with the meteorological tower parameters at the MOD-0A sites in Clayton, New Mexico; Block Island, Rhode Island; and Culebra, Puerto Rico.

Progress During Reporting Period:

Appropriate signal conditioning of the Clayton, Block Island, and Culebra MOD-0A sites was developed to allow machine parameters to be recorded on the data logger simultaneously with the tower meteorological parameters. Software packages were developed to relate machine performance characteristics with free-stream wind conditions.

Expected Progress During Next Reporting Period:

PNL's subcontractor will provide assistance to ensure that proper electronic interfacing between machine output parameters and the

next tower digital data logger is established at the Hawaii MOD-0A site, the Boone MOD-1 site, and the Goodnoe Hills MOD-2 site.

Reports and Publications:

None.

8.1.4 Turbine Installation (Phase II) Site Data
Analysis and Reporting (B4)

Pacific Northwest Laboratory
Richland, WA 99352

Principal Investigator:

William F. Sandusky (509)942-4823

Objective:

To present graphical displays relating machine turbine parameters to meteorological data collected from the tower.

Program Status:

This reporting is currently under way for the Clayton, New Mexico, MOD-OA site.

Progress During Reporting Period:

Several software routines have been developed by PNL to allow the data to be presented in a format useful for machine performance analyses. Basically, these programs are set up to evaluate the theoretical power performance curve of a MOD-OA based on hourly data.

Expected Progress During Next Reporting Period:

Since data are available for a sampling rate of one sample every 2 min, analysis programs addressing machine-performance characteristics for much higher detail than hourly averages will be investigated. These programs will be extended to the other installation sites as the data are made available.

Reports and Publications:

None.

8.1.5 Anemometer/Microprocessor Test Program (C2)

Pacific Northwest Laboratory
Richland, WA 99352

Principal Investigator:

David S. Renné (509)942-4623

Objective:

To identify commercially viable, inexpensive anemometer units with microprocessing capabilities that can provide useful wind-energy statistics and to advance the state-of-the-art in these capabilities.

Program Status:

This program began in FY 1979 and will continue through FY 1981.

Progress During Reporting Period:

Several commercially available units were ordered so that their capabilities could be tested and compared. Most of these units were received at PNL by the end of the reporting period. A prototype PNL unit was also designed and built and will be used in the test program.

Expected Progress During Next Reporting Period:

All units will be bench-tested and compared, with the results and recommendations provided to the manufacturers. A report describing the PNL unit will also be produced.

Reports and Publications:

None.

9.0 REFERENCES

- Bhumralkar, C. M., F. L. Ludwig and R. L. Mancuso. 1978. Estimation of Wind Characteristics at Potential Wind Energy Conversion Sites. SRI International, 333 Ravenswood Avenue, Menlo Park, CA 94025.
- Cliff, W. C., C. G. Justus and C. E. Elderkin. 1978. Simulation of the Hourly Wind Speeds for Randomly Dispersed Sites. PNL-2523, Pacific Northwest Laboratory, Richland, WA 99352.
- Frost, W., B. H. Long and R. E. Turner. 1978. Engineering Handbook on the Atmospheric Guidelines for Use in Wind Turbine Generator Development. NASA Technical Paper 1359, National Aeronautics and Space Administration, Washington, DC 20546.
- Holzworth, G. C. 1972. Mixing Heights, Wind Speeds, and Potential for Urban Air Pollution Throughout the Contiguous United States. Report AP-11, Environmental Protection Agency, Office of Air Programs, Research Triangle Park, Raleigh, NC 27711.
- Hunt, J. C. R. 1978. "Wind Over Hills." Survey paper for NOAA-NSF Workshop, Boulder, CO 80302.
- Kaimal, J. C. 1978. "Horizontal Velocity Spectra in an Unstable Surface Layer." J. of the Atmos. Sci. 35(1):18-24.
- Lindley, C. A. 1979. "Electric Utility Application of WECS in an Island Location." In Proceedings of the Workshop on Economic and Operation Requirements and Status of Large Scale Wind Systems, eds. E. F. Clark and F. de Winter, pp. 171-187. Altas Corporation, Santa Cruz, CA 95060.
- U.S. Department of Energy, Division of Distribution of Solar Technology. 1978. Federal Wind Energy Program, Program Summary, January 1978. DOE/ET-002311. U.S. Government Printing Office, Washington, DC 20402. Stock No. 061-000-00050-0.

APPENDIX A

MANAGEMENT OVERVIEW OF THE
WIND CHARACTERISTICS PROGRAM ELEMENT

MANAGEMENT OVERVIEW

The Wind Characteristics Program Element (WCPE) involves both management and technical efforts. The management effort has three primary roles:

- Program Planning -- formulating and integrating plans for research tasks conducted by PNL and contractors of PNL and DOE.
- Contract Administration and Control of Research Tasks -- preparing procurements, such as RFPs, reviewing unsolicited proposals, preparing and awarding contracts, and monitoring technical progress, financial status and contractual commitments.
- Reports, Information Exchange and Liaison -- reporting research and development (R&D) results, relating R&D results to needs of other elements of the program and industry, and identifying areas needing new research.

To accomplish these management functions, PNL has organized the WCPE into four technical areas and four staff functions. These technical areas are: Finance, Subcontracts, Special Studies, and Schedule and Reports. (During this reporting period the Meteorological Validation Program has been managed independently of the WCPE). Technical work conducted by PNL is designed primarily to fill gaps between and to consolidate the results of contractor efforts.

A Program Development Plan (PDP) is prepared for DOE by the Program Manager and the Program Area Leaders. The PDP defines the program's research priorities and establishes tasks and milestones designed to produce the wind characteristics information needed by wind turbine designers, planners and potential users of wind turbines. Tasks conducted by contractors are monitored and the results assimilated under the direction of the Program Area Leaders. The Program Area Leaders also direct the PNL technical tasks, which help to focus contractor and PNL results on specific needs. The Program Area Leaders are also responsible for the publication of research results in a format and style appropriate to the needs of the user community. A comprehensive monthly progress report is prepared and submitted to DOE to allow detailed tracking of the program established in the PDP.

Funding

The funding history of the Wind Characteristics Program Element at PNL is shown in Table A-1. For the period shown, the funding averaged about 7% of the total budget of the Federal Wind Energy Program. The following sections contain financial information for the program during FY 1979, as prepared by James W. Bixler, the program's financial representative. This information includes subcontracts and budget outlay.

TABLE A-1. Funding History

	Thousands of Dollars					
	<u>FY 76</u>	<u>T Q(a)</u>	<u>FY 77</u>	<u>FY 78</u>	<u>FY 79</u>	<u>FY 80</u>
Wind Characteristics	700	699	1,900	2,320	2,700	4,559 ^(b)
Site Evaluation (MVP)				600	1,400	
Total	700	669	1,900	2,920	3,645	4,559

(a) Transition quarter

(b) Wind characteristics and site evaluation (MVP) combined in FY 80.

FY 1979 SUBCONTRACTS

During FY 1979 the following subcontracts were initiated within the Wind Characteristics Program Element:

<u>FIRM</u>	<u>AMOUNT (K's)</u>
FWG Associates (Project Task-A1b)	27
Western Scientific Services, Inc. (A1c)	24 ^(a)
Science Applications, Inc. (A1f)	31
Marlatt & Assoc. (B1b)	22
GEOMET (B1c)	90
Global Weather Consultants (B1e)	56
Development Planning & Research Associates, Inc. (B2f)	20
Aerovironment, Inc. (C1c)	89
Flow Industries (C1f)	29
Science Applications, Inc. (C2c)	45
FWG Associates (C3a)	51
ACCU-Weather, Inc. (D2b)	7
Freese-Notis Weather (D2b)	19
General Weather Center (D2b)	7
Global Weather Services, Inc. (D2b)	10
Murray & Trettel, Inc. (D2b)	10
Weather Services Corp. (D2c)	34
Simpson Weather Associates	13

<u>UNIVERSITY</u>	
Penn State University (A1c)	12
Virginia Polytechnic Institute & State University (A1h)	26
Desert Research Institute (A1h)	19
Oregon State University (A1i)	130
Oregon State University (A1j)	61
Colorado State University (A2a)	25 ^(b)
University of Alaska (B1g)	150

(a) Total subcontract for \$44K of which \$20K from FY 1979 capital equipment authorizations.

(b) Total subcontract for \$48K of which \$23K from FY 1979 capital equipment authorizations.

<u>UNIVERSITY (Con't.)</u>	<u>AMOUNT (K's)</u>
University of Hawaii (B11)	44
University of Virginia (B2d)	95
Colorado State University (C1a)	7
Oregon State University (C1b)	100
New Mexico State University (C1c)	106
<u>GOVERNMENT</u>	
NOAA/WPL (A1d)	80
NOAA (B1b)	40
Argonne National Lab (C1e)	25
NOAA/ERL (C1g)	50
Techniques Development Lab/NOAA (D2a)	40
<u>CONSULTING AGREEMENT</u>	
CB Winn	7
GH Fichtl	8
TRC-Denver	17
Development Planning & Research Associates, Inc.	7
Dr. Riley/Flow Industries	2
Dr. Lissaman/Aerovironment, Inc.	<u>1</u>
TOTAL	<u>\$1636</u>

The \$1636K in subcontracts within the WCPE were placed in the following categories:

<u>Category</u>	<u>No.</u>	<u>Amount (K's)</u>	<u>%</u>
Small Firm	15	\$419	26
Large Firm	3	165	10
University	12	775	47
Government	5	235	14
Consulting Agreement	<u>6</u>	<u>42</u>	<u>3</u>
TOTAL	<u>41</u>	<u>\$1636</u>	<u>100</u>

During FY 1979 the following subcontracts were initiated within the Meteorological Validation Program:

<u>FIRM</u>	<u>AMOUNT (K's)</u>
Environmental Systems Corp.	692 ^(a)
SRI, International	66
Western Scientific Services, Inc.	5
FWG Associates	5
Tri-Ex Tower Corp.	34
<u>CONSULTING AGREEMENT</u>	
Thomas BA Senior/University of Michigan	4
Dipak Sengupta/University of Michigan	3
Marjorie Greene/HARC	3
Michael Changery/NOAA	1
J. Donald Brown	5
Other Consulting Agreements	<u>5</u>
TOTAL	<u>\$823</u>

(a) Total subcontract for \$850K of which \$158K was cost incurred in FY 1978.

The \$823K in subcontracts with the MVP were placed in the following categories:

<u>Category</u>	<u>No.</u>	<u>Amount (K's)</u>	<u>%</u>
Small Firm	4	736	89
Large Firm	1	66	8
Consulting Agreement	<u>6</u>	<u>21</u>	<u>3</u>
TOTAL	<u>11</u>	<u>\$823</u>	<u>100</u>

FY 1979 BUDGET OUTLAY

Detail

In FY 1979 Pacific Northwest Laboratory had a total budget outlay for the Wind Characteristics Program Element of \$3750K. The WCPE was distributed \$2300K in budget outlay of the total. The Meteorological Validation Program was distributed \$1450K in budget outlay of the total.

For the WCPE, FY 1979 costs were \$2348K. A detail of those costs is shown below.

<u>COSTS</u>	<u>AMOUNT (K's)</u>
PNL :	
Labor & Overheads	\$1277
Materials	34
Travel	55
Services (Computer, Duplicating, Graphics, Photography, Technical Editing)	<u>72</u>
PNL TOTAL	\$1438

SUBCONTRACTORS:

FIRM

FWG Associates	\$24
Western Scientific Services, Inc.	24
Science Applications, Inc. (A1f)	21
Marlatt & Associates	3
GEOMET	7
Global Weather Consultants	5
North American Weather Consultants	18
Development Planning & Research Assoc., Inc.	12
Aerovironment, Inc.	71
Flow Industries	29
Science Applications, Inc. (C2e)	48
Science Applications, Inc. (C2e)	22
FWG Associates	50
ACCU-Weather, Inc	7

<u>FIRM (Continued)</u>	<u>AMOUNT (K's)</u>
Freese-Notis Weather	16
General Weather Center	6
Global Weather Service, Inc.	8
Murray & Trettel, Inc.	8
Western Services Corp.	33
Simpson Weather Associates	7
 <u>UNIVERSITY</u>	
Penn State University	12
Virginia Polytechnic Institute & State University	26
Desert Research Institute	19
Oregon State University (A1i)	30
Oregon State University (A1j)	21
Colorado State University (A2a)	25
University of Alaska	15
University of Virginia	39
University of Texas	27
Colorado State University (C1a)	7
Oregon State University (C1b)	27
New Mexico State University	66
 <u>GOVERNMENT</u>	
NOAA/WPL	36
Argonne National Lab (A)	10
NOAA	15
Argonne National Lab (C1e)	25
NOAA/ERL	25
Techniques Development Lab/NOAA	25

<u>CONSULTING AGREEMENT</u>	<u>AMOUNT (K's)</u>
CB Winn	7
GH Fichtl	8
TRC-Denver	16
Development Planning & Research Assoc., Inc.	7
Dr. Riley/Flow Industries	2
Dr. Lissaman/Aerovironment, Inc.	<u>1</u>
SUBCONTRACTORS TOTAL	\$910
WCPE TOTAL	<u>\$2348</u>

A summary of FY 1979 WCPE costs by project task/area is shown below.

<u>AREA</u>	<u>PNL AMOUNT (K's)</u>	<u>NON-PNL AMOUNT (K's)</u>	<u>TOTAL</u>	<u>%</u>
<u>Technical</u>				
A. Wind Characteristics for Design & Performance Evaluation of WECS	\$346	\$263	\$609	26
B. Wind Resource Assessment	226	164	390	17
C. Siting Methodologies	206	373	579	25
D. Wind Characteristics for WECS Operations	90	110	200	9
E. Special Studies	<u>75</u>	<u>-0-</u>	<u>75</u>	<u>3</u>
TOTAL TECHNICAL	<u>\$943</u>	<u>\$910</u>	<u>\$1853</u>	<u>80</u>
F. <u>Administration</u>				
Project Management	\$249	-0-	\$249	10
Planning & Procurement	147	-0-	147	6
Contract Monitoring	51	-0-	51	2
Direct Assistance to WSB	26	-0-	26	1
Liaison	<u>22</u>	<u>-0-</u>	<u>26</u>	<u>1</u>
TOTAL ADMINISTRATION	<u>\$495</u>	<u>-0-</u>	<u>\$495</u>	<u>20</u>
TOTAL WCPE	<u>\$1438</u>	<u>\$910</u>	<u>\$2348</u>	<u>100</u>

For the MVP, FY 1979 costs were \$1297K. A detail of those costs is shown below.

<u>COSTS</u>	<u>AMOUNT (K's)</u>
PNL:	
Labor & Overheads	\$462
Materials	9
Travel	23
Services (Computer, Duplicating, Graphics, Photography, Technical Editing)	<u>46</u>
PNL TOTAL	<u>\$540</u>
SUBCONTRACTORS:	
<u>FIRM</u>	
Environmental Systems Corporation	\$683
SRI International	50
Western Scientific Services, Inc.	5
FWG Associates	4
<u>CONSULTING AGREEMENT</u>	
Thomas BA Senior/University of Michigan	2
Dipak Sengupta/University of Michigan	1
Marjorie Greene/HARC	1
Michael Changery/NOAA	1
J. Donald Brown	5
Other Consulting Agreements	<u>5</u>
SUBCONTRACTORS TOTAL	<u>\$757</u>
MVP TOTAL	<u><u>\$1297</u></u>

A summary of FY 1979 MVP costs by project task/area is shown below.

AREA	PNL AMOUNT (K's)	NON-PNL AMOUNT (K's)	TOTAL	%
A. Meteorological Validation of Phase I Candidate Sites	\$216	\$741	\$957	74
B. Phase II Turbine Site Meteorological Validation Activities	63	10	73	6
C. Prototype Siting Exercise	31	-0-	31	2
D. Program Management	<u>230</u>	<u>6</u>	<u>236</u>	<u>18</u>
TOTAL MVP	<u>\$540</u>	<u>\$757</u>	<u>\$1297</u>	<u>100</u>

Summary

Of the total FY 1979 PNL budget outlay of \$3750K, costs were \$3645K or 97.2%. A summary of those costs is shown below.

<u>COSTS</u>	<u>AMOUNT (K's)</u>
PNL:	
Labor & Overheads	\$1739
Materials	43
Travel	78
Services	<u>118</u>
PNL TOTAL	\$1978
SUBCONTRACTORS TOTAL	<u>\$1667</u>
WIND ENERGY TOTAL	<u><u>\$3645</u></u>

In addition to the PNL WCPE costs of \$3645K, another \$100K was costed in FY 1979 by Lawrence Livermore Laboratory. The LLL program was coordinated with PNL but funded directly from DOE Headquarters to LLL.

A summary of the total PNL WCPE (including LLL program) is shown below.

<u>CATEGORY</u>	<u>AMOUNT (K's)</u>	<u>%</u>
PNL	\$1978	53
Non-PNL	1531	41
Government	<u>236</u>	<u>6</u>
TOTAL	<u><u>\$3745</u></u>	<u><u>100</u></u>

APPENDIX B

PUBLISHED REPORTS

GIVEN UC-60 DISTRIBUTION

WIND CHARACTERISTICS PROGRAM ELEMENT (WCPE)

Reports given UC-60 distribution and available from:

National Technical Information Service
United States Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22151

Price: Printed Copy,* Microfiche \$3.00

<u>*Pages</u>	<u>NTIS Selling Price</u>
001-025	\$ 4.50
026-050	5.00
051-075	5.50
076-100	6.00
101-125	6.50
126-150	7.00
151-175	7.78
176-200	8.50
201-225	8.75
226-250	9.00
251-275	10.00
276-300	10.25

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

Pam R. Partch
WCPE Reports Schedule and Control Coordinator

Phone: FTS 444-4410
Commercial: (509) 942-4410

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/RAHN 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	Micro-fiche
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	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	RL0/2229-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	RL0/2438-76/1	Colorado State University Department of Civil Engineering Fort Collins, CO 80523	December 1976	68
Freeman, B. E. et al.	Development of a Wind Energy Site Selection Methodology	RL0/2440-76/4	Science Applications, Inc. P. O. Box 2351 La Jolla, CA 92037	December 1976	150
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	Pacific Northwest Laboratory P. O. Box 999 Richland, WA 99352	January 1977	49

Verholek, M. G.	Summary of Wind Data from Nuclear Power Plant Sites	BNWL-2220 WIND-4	Pacific Northwest Laboratory P. O. Box 999 Richland, WA 99352	March 1977	339
Orgill, M. M.	Survey of Wind Measurement Field Programs	BNWL-2220 WIND-3	Pacific Northwest Laboratory P. O. Box 999 Richland, WA 99352	May 1977	57
Justus, C. G. et al.	Wind Energy Statistics for Large Arrays of Wind Turbines (Great Lakes and Pacific Coast Regions)	RL0/2439-77/2	Georgia Institute of Technology School of Aerospace Engineering Atlanta, GA 30332	May 1977	114
Dochon, 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	72
Traci, R. M. et al.	Development of a Wind Energy Site Selection Methodology	RL0/2440-77/11	Science Applications, Inc. P. O. Box 2351 La Jolla, CA 92038	June 1977	205
Hewson, E. W. et al.	Vegetation as an Indicator of High Wind Velocity	RL0-2227-T24-77/2	Oregon State University Department of Environmental Sciences Corvallis, OR 97331	July 1977	58
Elliot, D. L.	Synthesis of National Wind Energy Assessments	BNWL-2220 WIND-5	Pacific Northwest Laboratory P. O. Box 999 Richland, WA 99352	July 1977	58
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	Pacific Northwest Laboratory P. O. Box 999 Richland, WA 99352	July 1977	137
Changery, M. J. Hodge, W. T. Ramsdell, J. V. (PNL)	Index - Summarized Wind Data ^(a)	BNWL-2220 WIND-11	National Oceanic and Atmospheric Administration National Climatic Center Federal Building Asheville, NC 28801	September 1977	180
Corotis, R. B.	Stochastic Modeling of Site Wind Characteristics	RL0/2342-77/2	Northwestern University Department of Civil Engineering Evanston, IL 60201	September 1977	152
MacCready, P. B., Jr. Worden, J.	Assessing the Local Wind Field for Siting of Wind Power Systems	RL0/2441-76/16	AeroVironment Inc. 145 Vista Avenue Pasadena, CA 91107	September 1977	100
Kolm, K. E. Marrs, R. W.	Predicting the Surface Wind Characteristics of Southern Wyoming from Remote Sensing and Eolian Geomorphology	RL0/2343-78/1	University of Wyoming Department of Geology Laramie, WY 82071	September 1977 (In Printing)	122
Cliff, W. C.	The Effect of Generalized Wind Characteristics on Annual Power Estimates from Wind Turbine Generators	PNL-2436	Pacific Northwest Laboratory P. O. Box 999 Richland, WA 99352	October 1977	49

(a) Available from National Oceanic and Atmospheric Administration.

Doran, J. C. et al.	Accuracy of Wind Power Estimates	PNL-2442	Pacific Northwest Laboratory P. O. Box 999 Richland, WA 99352	October 1977	26
Elderkin, C. E. Wendell, L. L.	Summary of the Development Plan for the Wind Characteristics Program Element of the Federal Wind Energy Program	PNL-2501	Pacific Northwest Laboratory P. O. Box 999 Richland, WA 99352	October 1977	55
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	77
Vukovich, F. M. Clayton, C. A.	On a Technique to Determine Wind Statistics in Remote Locations	RL0-2445-78/1	Research Triangle Institute P. O. Box 12194 Research Triangle Park, NC 27709	December 1977	120
Agopian, K. G. Crow, S. C	The Effect of Atmospheric Density Stratification on Wind Turbine Siting	RL0/2444-78/1	Poseidon Research 11777 San Vicente Blvd. Suite 641 Los Angeles, CA 99049	January 1978	101
Elderkin, C. E. Wendell, L. L.	Semi-Annual Report of the Wind Characteristics Program Element for the Period July 1977 Through December 1977	PNL-2519	Pacific Northwest Laboratory P. O. Box 999 Richland, WA 99352	January 1978	95
Garstang, M. et al.	Coastal Zone Wind Energy Part I - Synthesis and Results	RL0-2344-76/77-5	University of Virginia Clark Hall Charlottesville, VA 22903	January 1978	60
Garstang, M. et al.	Coastal Zone Wind Energy Part II - Climatology	RL0-2344-76/77-6	University of Virginia Clark Hall Charlottesville, VA 22903	January 1978	182
Verholek, M. G.	A Measurement Program to Characterize the Wind at a Potential WECS Site	PNL-2516	Pacific Northwest Laboratory P. O. Box 999 Richland, WA 99352	March 1978	24
Ramsdell, J. V.	Estimates of the Number of Large Amplitude Gusts	PNL-2508	Pacific Northwest Laboratory P. O. Box 999 Richland, WA 99352	March 1978	53
Wendell, L. L. Wegley, H. L. Verholek, M. G.	Report from a Working Group Meeting on Wind Forecasts for WECS Operation	PNL-2513	Pacific Northwest Laboratory P. O. Box 999 Richland, WA 99352	March 1978	20
Ekstrom, P. A. Verholek, M. G.	A Wind Prospector's Instrument	PNL-2514	Pacific Northwest Laboratory P. O. Box 999 Richland, WA 99352	April 1978	14
Verholek, M. G. Ekstrom, P. A.	Remote Wind Measurements with a New Microprocessor-Based Accumulator Device	PNL-2515	Pacific Northwest Laboratory P. O. Box 999 Richland, WA 99352	April 1978	23
Verholek, M. G.	Preliminary Results of a Field Experiment to Characterize Wind Flow Through a Vertical Plane	PNL-2518	Pacific Northwest Laboratory P. O. Box 999 Richland, WA 99352	April 1978	42

Wegley, H. L.	A Siting Handbook for Small Wind Energy Conversion Systems	PNL-2521	Pacific Northwest Laboratory P. O. Box 999 Richland, WA 99352	May 1978	150
Justus, C. G. Mikhail, A. S.	Energy Statistics for Large Wind Turbine Arrays	RLO/2439-78/3	Georgia Institute of Technology School of Aerospace Engineering Atlanta, CA 30332	May 1978	115
Cliff, W. C. Justus, C. G. Elderkin, C. E.	Simulation of Hourly Wind Speeds for Randomly Dispersed Sites	PNL-2523	Pacific Northwest Laboratory P. O. Box 999 Richland, WA 99352	May 1978	43
Meroney, R. N., et al	Wind Characteristics over Complex Terrain: Laboratory Simulation and Field Measurement at Rakaia Gorge, New Zealand	RLO/2438-77/2	Colorado State University Department of Civil Engineering Fort Collins, CO 80523	May 1978 (In Printing)	220
Hewson, E. W. Wade, J. E.	Wind Power Potential in the Pacific Northwest Region	RLO/2227-T24-78/2	Oregon State University Department of Environmental Sciences Corvallis, OR 97331	June 1978 (In Printing)	80
Cliff, W. C. Fichtl, G. H.	Wind Velocity-Change (Gust Rise) Criteria for Wind Turbine Design	PNL-2526	Pacific Northwest Laboratory P. O. Box 999 Richland, WA 99352	July 1978	25
Marrs, R. W. Kopriva, S.	Regions of the Continental United States Susceptible to Eolian Action	RLO-2343-78/2	University of Wyoming Laramie, WY 82071	July 1978	10
Carlisle, W. J. Marrs, R. W.	Airflow Over Part of the Southern High Plains	RLO/2343-78/4	University of Wyoming Laramie, WY 82071	July 1978 (In Printing)	60
Kerrigan, T. C.	A Technique for Analyzing the Structure of Atmospheric Turbulence	PNL-2509	Pacific Northwest Laboratory P. O. Box 999 Richland, WA 99352	September 1978	55
Kerrigan, T. C.	A Verification Statistic for Numerical Wind Models	PNL-2510	Pacific Northwest Laboratory P. O. Box 999 Richland, WA 99352	September 1978	79
Kerrigan, T. C.	Spectral Estimates of a Wind Fluctuation Statistics Pertaining to Wind Energy Generators	PNL-2511	Pacific Northwest Laboratory P. O. Box 999 Richland, WA 99352	September 1978	36
Wendell, L. L. et al.	Annual Report of the Wind Characteristics Program Element for the Period July 1977 through July 1978	PNL-2545	Pacific Northwest Laboratory P. O. Box 999 Richland, WA 99352	December 1978	140
Cliff, W. C.	Wind Direction Change Criteria for Wind Turbine Design	PNL-2531	Pacific Northwest Laboratory P. O. Box 999 Richland, WA 99352	January 1979	26
Marwitz, J. D. Gilkey, K. B.	Catalog of Available Wind Data for Idaho, Montana and Wyoming	RLO/2343-79/1	University of Wyoming Laramie, WY 82071	February 1979 (In Printing)	30

Marlatt, W. E., et al.	Assessment of the Applicability of the National Fire Weather Data Library to Wind Energy Analyses	PNL-2538	Marlatt and Associates 3611 Richmond Drive Fort Collins, CO 80523	May 1979	98
Hewson, E. W. Wade, J. E. Baker, R. W.	A Handbook on the Use of Trees as Indicators of Wind Power Potential	RLO/2227-T24-79/3	Oregon State University Department of Environmental Sciences Corvallis, OR 97331	May 1979	22
Huang, C. H. Fichtl, G. H.	Gust-Rise Exceedance Statistics for Wind Turbine Design	PNL-2530	Pacific Northwest Laboratory P. O. Box 999 Richland, WA 99352	July 1979	35

DISTRIBUTION

No. of
Copies

No. of
Copies

OFFSITE

	A. A. Churm DOE Chicago Patent Group 9800 S. Cass Avenue Argonne, IL 60439	Ben Wolff American Wind Energy Association 1621 Connecticut Avenue, N.W. Fifth Floor Washington, DC 20009
3	C. I. Aspliden Department of Energy 600 E. Street, N.W. Washington, DC 20545	Richard Katzenberg American Wind Energy Association Natural Power, Inc. New Boston, NH 03070
3	G. P. Tennyson Department of Energy Albuquerque Operations Office 4501 Indian School Road N.E. Suite 151 Albuquerque, NM 87110	E. J. Warchol Bonneville Power Administration P.O. Box 3621 Portland, OR 97208
27	DOE Technical Information Center Peter Smeallie AWEA Windletter 1609 Connecticut Avenue N.W. Washington, DC 20009 T. G. Zambrano AeroVironment, Inc. 145 Vista Avenue Pasadena, CA 91107 Clarissa Quinlan Alaska State Energy Office 338 Denali Street Anchorage, AK 99501 Paul N. Vosburgh Alcoa Allied Products Aluminum Company of America Alcoa Center, PA 15069 Dr. K. C. Spengler American Meteorological Society 45 Beacon Street Boston, MA 02108	S. J. Hightower Bureau of Reclamation Denver Federal Center Building 67, Code 254 Denver, CO 80225 M. Ginosar/J. Lerner California Solar Energy Commission Energy Resources, Conservation and Development Commission 1111 Howe Avenue, Mail Stop 15 Sacramento, CA 95825 Ed Kennell Clean Energy Products Wind Power Systems and Components 3534 Bagley N. Seattle, WA 98103 Lawrence Lewin Department of Mechanical Engineering Colorado State University Fort Collins, CO 80523 Dr. R. N. Meroney Colorado State University Fort Collins, CO 80523

No. of
Copies

E. H. Gilmore
Department of Agriculture
Agriculture Research Service
Bushland, TX 79012

L. A. Liljedahl
Department of Agriculture
Agriculture Wind Energy Program
Building 001, Room 126 BARC-West
Beltsville, MD 20705

Jay Tappan
Department of Energy
State of Oregon
Labor and Industries Building
Room 111
Salem, OR 98310

Harry Moses
Carbon Dioxide and Climate
Research Program
Office of Health and Environ-
mental Research
U.S. Department of Energy
Mail Stop E-201 Germantown
Washington, DC 20545

Dr. Edgar Demeo
Electric Power Research Institute
3412 Hillview Avenue
Palo Alto, CA 94303

Dr. Olle Ljungstrom
FFA, The Aeronautical Research
Institute
Forskningsstationen i Stockholm
Drottning Kristinas Vag 47
S-114 29 Stockholm, Sweden

R. B. Lawford
Fisheries & Environment
25 St. Clair Avenue East
Toronto, Canada M4T 1M2

No. of
Copies

Dr. W. Frost
FWG Associates, Inc.
R.R. 3, Box 331
Tullahoma, TN 37388

R. J. Barchet/L. Krawitz
General Electric Company
P.O. Box 8555
Philadelphia, PA 19101

R. C. Koch
Geomet, Inc
15 First Field Road
Gainthersburg, MD 20760

Gerald T. Norman
Global Weather Consultants, Inc.
12 S. First St., Suite 701
San Jose, CA 95113

Dr. J. B. Knox
Lawrence Livermore Laboratory
University of California
P.O. Box 808
Livermore, CA 94550

Ms. Abbey Page
Maine Office of Energy Resources
55 Capital
Augusta, ME 04330

Marlatt and Associates
3611 Richmond Drive
Fort Collins, CO 80521

Frank R. Eldridge, Jr.
MITRE Corporation
1820 Dolley Madison Boulevard
McLean, VA 22102

V. F. Garrett
Montana Energy and MHD Research
and Development Institute, Inc.
P.O. Box 3809
Butte, MT 59701

No. of
Copies

J. Konigsberg
Montana Energy Office
Capital Station
Helena, MT 59601

Phillip French
NASA Scientific and Technical
Information Facility
P.O. Box 8757
Baltimore/Washington International
Airport
Baltimore, MD 21240

R. A. Wolf
NASA Scientific and Technical
Mail Stop 500-201
Cleveland, OH 44135

M. J. Changery
National Oceanic and Atmospheric
Administration
National Climatic Center
Federal Building
Asheville, NC 28801

R. J. Templin
National Research Council of
Canada
National Aeronautical
Establishment
M-2 Montreal Road
Ottawa, Ontario K1A 0R6

Ms. Peggy McDonald
N.E. Solar Energy Center
70 Memorial Drive
Cambridge, MA 02142

John L. Zimmerman
New England Wind Energy
Conversion Services
RDL Box 52E
Moretown, VT 05660

P. W. Blakely
New Zealand Electricity
Rutherford House
Lambton Quay
Wellington, New Zealand

No. of
Copies

2 F. W. Hewson/J. E. Wade
Oregon State University
Corvallis, OR 97331

Earl Davis
Pacific Gas and Electric Co.
215 Market St.
San Francisco, CA 94106

D. M. Tompkins
PRC Eng. Analysis Co.
7600 Old House Road
McLean, VA 22102

3 Charles Toftoy
Project Manager
Raytheon Service Co.
Century Building, Rm 826
234 Jefferson Davis Highway
Arlington, VA 22202

Terry J. Healy/C. Hansen
Rockwell International
Rocky Flats Plant
P.O. Box 464
Golden, CO 80401

E. Kadlec
Sandia Laboratories
Division 5443
P.O. Box 5800
Albuquerque, NM 87115

R. M. Traci
Science Applications, Inc.
P.O. Box 2351
La Jolla, CA 92038

I. Vas/Roger Taylor
Solar Energy Research Institute
1536 Cole Blvd.
Golden, CO 80401

Dr. C. M. Bhumralkar
Stanford Research
Institute, International
Menlo Park, CA 94025

No. of
Copies

Energy Coordinator Environmental
Resources Section
US Army Corps of Engineers
Seattle District
P.O. Box C 3755
Seattle, WA 98124

Bruce Bailey
Atmospheric Sciences Research
Center
SUNY Albany - ES 324
Albany, NY 12222

R. Crowder
Taylor Woodrow Construction,
Limited
Taywood House
345 Ruislip Road
Southhall
Middlesex UBI 2QX
England

Dr. P. Yen
University of Hawaii at Monoa
Holmes Hall 240
2540 Dole Street
Honolulu, HI 96822

Dr. N. K. Wagner
Dept. of Civil Engineering
University of Texas
Austin, TX 78712

Dr. M. Garstang
University of Virginia
Charlottesville, VA 22903

R. E. Akins
Department of Engineering
and Mechanics
Virginia Polytech Institute
Blacksburg, VA 24069

David Kapus
Washington State Division of
Engineering and Architecture
106 Maple Drive
Olympia, WA 98504

No. of
Copies

Ms. Susan Hosch
Washington State Energy Office
400 E. Union Avenue, 1st Floor
Olympia, WA 98504

John Young
Washington Public Power Supply
System
P.O. Box 968
Richland, WA 99352

S. R. Epur/G. D. Thomann
Wichita State University
P.O. Box 44
Wichita, KS 67208

Farrell Smith Seiler
Wind Energy Report
Box 14 - 104 X. Village Avenue
Rockville Centre, NY 11571

Paul Gipe
Wind Power Digest
P.O. Box 539
Harrisburg, PA 17108

Dr. V. Barros
28 De Julio 28
9120 Puerto Madryn
Chulret
R. Argentina

ONSITE

2 DOE Richland Operations Office
P.O. Box 550
Richland, WA 99352

H. E. Ransom
R. K. Stewart

No. of
Copies

43 Pacific Northwest Laboratory
Battelle Boulevard
Richland, WA 99352

W. R. Barchet
J. C. Barnard
R. L. Conley
J. R. Connell
J. C. Doran
R. L. Drake
K. Drumheller
C. E. Elderkin
D. L. Elliott
R. L. George
P. C. Hays
T. R. Hiester
T. C. Jameson
A. H. Miller
P. R. Partch
W. T. Pennell
E. H. Phinney
D. C. Powell
J. W. Ramsdell
H. L. Wegley
L. L. Wendell (15)
R. K. Woodruff
Technical Information - Library (5)
Publishing Coordination (2)