Regional Wind Energy Assessment Progress Report

June 1986 - May 1987

Bonneville
POWER ADMINISTRATION

January 1988

DOE/BP/63406--5

DE90 009379

OREGON STATE UNIVERSITY
DEPARTMENT OF MECHANICAL ENGINEERING
WIND RESOURCES ASSESSMENT LABORATORY

REPORT NO. BPA 88-27

JANUARY 1988

REGIONAL WIND ENERGY ASSESSMENT
PROGRESS REPORT
JUNE 1986-MAY 1987

FINAL REPORT

Prepared by

J.E. Wade, Stel Walker, and S.Y. Kenagy

Submitted to the

Bonneville Power Administration
Division of Resource Management
Portland, Oregon

Contract No. DEAI79-86BP63406

OREGON STATE UNIVERSITY
DEPARTMENT OF MECHANICAL ENGINEERING
WIND RESOURCES ASSESSMENT LABORATORY

REPORT NO. BPA 88-27 JANUARY 1988

REGIONAL WIND ENERGY ASSESSMENT
PROGRESS REPORT
JUNE 1986-MAY 1987

FINAL REPORT

Prepared by

J.E. Wade, Stel Walker, and S.Y. Kenagy

Submitted to the

Bonneville Power Administration
Division of Resource Management
Portland, Oregon

Contract No. DEAI79-86BP63406

TABLE OF CONTENTS

ACKNOWLEDGEMENTS

This research was funded under Bonneville Power Administration contract DEAI79-86BP63406. We would like to acknowledge the substantial contributions of Nicholas Butler, electrical engineer and Contract Officer from BPA's Division of Resource Management. Max Holder, BPA instrument craftsman, deserves credit for keeping the equipment in the field operating and calibrated. We are also indebted to Laurie Dockendorf and Peggy Offutt for their secretarial support and Linda Hubbard who provided the administrative support.

SUMMARY

This report summarizes data from 14 locations in the Pacific Northwest for the period June 1986 through May 1987. The data are being collected as part of Bonneville Power Administration's Regional Wind Energy Assessment Program (Wind REAP) that has been continuing since 1981. The report documents the status of each site, relates this years winds to those of previous years, provides an analysis of each sites turbulence characteristics, examines the errors of using standard air density in calculation of wind energy, appraises the state of the wind industry and provides an updated appraisal of the economics of wind energy in the Pacific Northwest.

The major conclusions are:

- Fourteen sites were active during this last year. Four sites were instrumented at more than one level.
- The data recovery rate was 77% during the past year. At two of the sites data recovery was low because they were only instrumented for part of the year.
- All but one site collected temperature data and all but two sites had pressure data.
- Turbulence Intensity and the power law coefficient were found to vary widely with direction at most sites.
- It was found that for most cases that an assumption of standard atmosphere in density calculations results in little error in energy estimates. This was particularly true for monthly estimate and less true for hourly estimates.
- Inland locations were more sensitive temperature and pressure variation and had larger energy errors using an assumption of a standard atmosphere to calculate air density.
- The wind industry can now build a wind turbine for $1,000 to $1,200 per installed kilowatt of capacity.
- Unexpected performance degradations have been noted due to blade fouling by bugs. The performance losses have been up to 10%.
- Higher than expected operation costs and performance losses due to array effects have also plagued the industry. Array losses due to wake effects of upwind turbine have reduced wind farm performance at some facilities by as much as 20%.
- The cost of wind energy was examined at 12 Pacific Northwest wind survey sites. The costs varied from 0.05 to 0.55 $/kWh.
- If the installed cost of wind turbines were to drop to half the present value wind energy would be economically feasible at most Pacific Northwest wind energy development sites.

LIST OF FIGURES

FIGURE		PAGE

LIST OF TABLES

1.0 INTRODUCTION

This report is a summary of wind statistics collected for the period June 1986 through May 1987. The data were gathered at 14 locations throughout the Pacific Northwest. Data are being collected as part of Bonneville Power Administration's Regional Wind Energy Assessment Program (Wind REAP) that has been continuing since 1981. The data collection sites are shown in Figure 1-1 and the status of the equipment is listed in Table 1-1.

The main objectives in this report are to:

- Summarize data collected during the past year
- Document the status of each site including any equipment problems and quality assurance
- Discuss the relationship of this year's winds to those of previous years in the context of the climate experienced in the Pacific Northwest
- Present analysis of wind characteristics at each site that will provide potential developers with necessary information to assess the quality and quantity of the wind resource
- Evaluate the current cost feasibility of wind energy in the Pacific Northwest

Section 2.0 is a climatological discussion of the wind and climate of the past year in the Pacific Northwest. The Wind REAP site winds are compared to previous years and in relation to apparent departures from "normal" of climate at the several nearby National Weather Service locations shown in Figure 1-1. In this report the term "normal" will refer to the National Weather Service definition which is the previous 30 year period prior to this decade. The "normal" period at present is defined as 1941-1970. In 1990 the normal period will advance to 1951-1980.

In Section 3.0, wind characteristics and the status of data collection during the past year are discussed. At one site, Cape Blanco, there will be a discussion of the difference in the winds at two sites less than 100 yards from each other and at Goodnoe Hills and Pequop Summit an analysis of possible systematic errors that resulted in the winds at one site being corrected. The turbulence characteristics of each site are described as well as shear if the site has anemometers at more than one level.

Table 1-1. Pacific Northwest wind energy site status.

UPDATE STATUS REPORT
(PERIOD: 1 APRIL 1987 - 30 JUNE 1987)

SITE NAME	START	STOP	PRESENT STATUS ACTIVE	PRESENT STATUS INACTIVE
OREGON				
Cape Blanco M/W	1 Apr 1987	11 Jun 1987	X	
Cape Blanco Radio	1 Apr 1987	30 Jun 1987	X	
Hampton Butte	1 Apr 1987	18 Jun 1987	X	
Seven Mile Hill 50'	1 Apr 1987	30 Jun 1987	X	
Seven Mile Hill 150'	1 Apr 1987	30 Jun 1987	X	
Upper Pyle	1 Apr 1987	19 Jun 1987	X	
WASHINGTON				
Goodnoe Hills 50'	1 Apr 1987	30 Jun 1987	X	
Goodnoe Hills 195'	1 Apr 1987	30 Jun 1987	X	
Kennewick	1 Apr 1987	30 Jun 1987	X	
Kittitas	1 Apr 1987	30 Jun 1987	X	
Spring Creek	1 Apr 1987	30 Jun 1987	X	
NEVADA				
Pequop Summit	1 Apr 1987	30 Jun 1987	X	
Pequop Tower 50'	1 Apr 1987	30 Jun 1987	X	
Pequop Tower 150'	1 Apr 1987	30 Jun 1987	X	
MONTANA				
Browning Depot 40'	1 Jan 1987	30 Jun 1987	X	
Browning Depot 80'	1 Jan 1987	30 Jun 1987	X	
IDAHO				
Albion Butte	1 Apr 1987	30 Jun 1987	X	
Duncan Mtn	1 Apr 1987	30 Jun 1987	X	

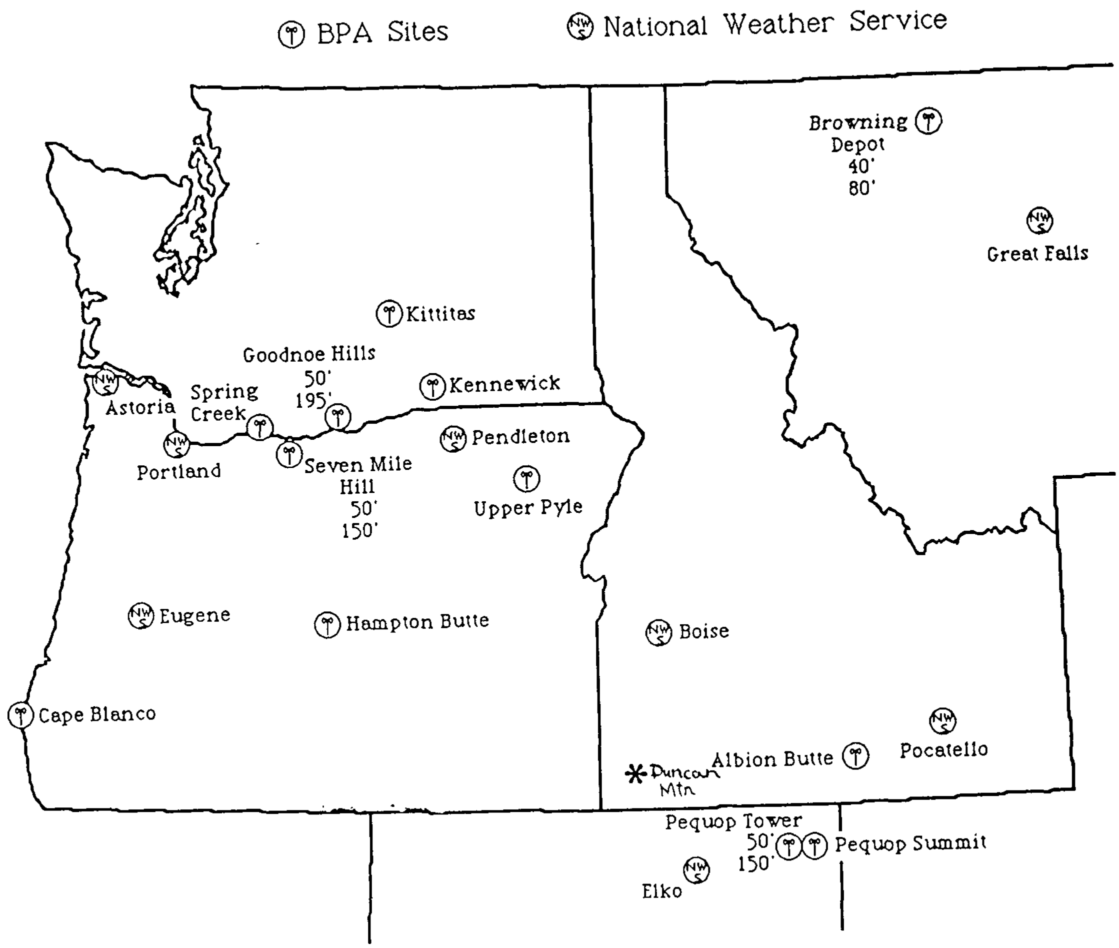

Figure 1-1. Map showing locations of Wind REAP sites and National Weather Service sites used in this report.

Section 4.0 will present analysis of the possible error associated with using a standard density correction as opposed to using measured temperature and pressure.

In Section 5.0 a wind turbine economics appraisal will be presented that will show that the economic feasibility of wind energy, while improving, is not yet cost effective in the Pacific Northwest.

2.0 CLIMATOLOGICAL ANALYSIS

2.1 Introduction

The climatological analysis has two purposes. One goal is to determine the extent the winds during the past year deviated from prior years and the second motivation is that we can evaluate the degree to which the past year can be considered typical. The value of this exercise is that it puts in perspective the winds measured at any site in the vicinity of the Wind REAP sites during the past year. In addition any significant trends in the wind caused by anemometer malfunction or changes in surface roughness are readily identified in such analysis.

The approach used in this analysis is to calculate departures from the mean at four widely dispersed wind energy survey sites in the Pacific Northwest. These sites have in common a long record of wind measurement. To amplify the analysis we also examine departures from "normal" (1941-1970 mean) for eight National Weather Service (NWS) sites scattered throughout BPA's service territory.

To further support the wind climate analysis we will examine the temperature and precipitation departures from "normal".

2.1 Results

Figure 2-1 displays a bar graph of departure from the long-term mean of the winds at four Pacific Northwest wind survey sites. In general the winds were below mean. Kennewick was the only site that had above average winds for the period June 1986 - May 1987 (+ 2.6%). In Table 2-1 the wind statistics are summarized. Cape Blanco had above normal winds in December and January but during most of the period was below average. Goodnoe Hills and Pequop were also consistently below average in most months.

These departures from the long-term means are also presented for NWS sites in Table 2-1 and Figures 2-2 and 2-3. East of the Cascades the trend is more uniform with all sites indicating below "normal" winds for the period. West of the Cascades only Astoria had stronger winds than "normal" during the period 6/86-5/87. Eugene and Portland were slightly below "normal".

Table 2-1. Mean speeds for the period June 1986 through May 1987 as well as departures from the mean. The mean period for NWS sites is 1941-1970. All speeds are in miles per hour.

STATION		JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	ANNUAL
ASTORIA	41-70	8.3	8.5	8.0	7.5	7.5	8.8	9.3	9.4	8.9	8.9	8.7	8.5	8.5
	86-87	10.6	10.8	9.8	8.4	8.8	10.1	9.5	10.1	8.9	9.9	9.6	10.7	9.8
	% DEP	27.7	27.1	22.5	12.0	17.3	14.8	2.2	7.4	.0	11.2	10.3	25.9	14.6
EUGENE	41-70	7.4	8.0	7.5	7.4	6.5	7.4	7.9	8.1	8.0	8.6	7.7	7.4	7.7
	86-87	7.9	7.5	7.8	7.9	5.6	7.5	6.5	7.8	7.3	7.5	7.5	7.6	7.4
	% DEP	6.8	(6.3)	4.0	6.8	(13.8)	1.4	(17.7)	(3.7)	(8.8)	(12.8)	(2.6)	2.7	(3.8)
PORTLAND	41-70	6.9	7.4	7.0	6.4	6.1	8.7	9.8	9.8	8.8	8.2	7.3	6.9	7.8
	86-87	7.2	6.3	6.3	6.3	5.5	7.3	10.4	9.9	8.0	8.0	6.7	7.1	7.4
	% DEP	4.3	(14.9)	(10.0)	(1.6)	(9.8)	(16.1)	6.1	1.0	(9.1)	(2.4)	(8.2)	2.9	(4.6)
PENDLETON	41-70	10.5	9.5	9.1	8.9	8.1	7.9	8.4	8.5	9.0	10.0	10.6	10.2	9.2
	86-87	7.1	8.0		6.1	4.9	6.7	4.5	5.9	6.0	7.2	6.6	6.0	6.3
	% DEP	(2.4)	14.2		(1.5)	(9.5)	14.8	(16.4)	(.6)	(3.3)	2.0	(7.7)	(11.2)	(2.0)
ELKO	41-70	6.7	6.2	6.0	5.5	5.2	5.1	5.1	5.4	5.9	6.7	7.2	6.9	6.0
	86-87	6.1	5.9		5.8	4.8	5.0	3.3	5.1					5.1
	% DEP	(9.0)	(4.8)		5.5	(7.7)	(2.0)	(35.3)	(5.6)					(14.2)
BOISE	41-70	9.1	8.5	8.2	8.3	8.5	8.5	8.4	8.3	9.2	10.2	10.2	9.6	8.9
	86-87	8.8	8.1	7.8	7.1	6.3	7.5	4.8	7.5	7.3	9.9	9.1	8.0	7.7
	% DEP	(3.3)	(4.7)	(4.9)	(14.5)	(25.9)	(11.8)	(42.9)	(9.6)	(20.7)	(2.9)	(10.8)	(16.7)	(13.8)
POCATELLO	41-70	10.3	9.2	9.0	9.1	9.2	10.2	10.2	11.2	10.9	11.6	11.8	10.6	10.3
	86-87	9.7	10.7	8.2	9.1	7.7	12.0	5.7	8.8	9.4	11.2	10.9	10.0	9.5
	% DEP	(5.8)	16.3	(8.9)	.0	(16.3)	17.6	(44.1)	(21.4)	(13.8)	(3.4)	(7.6)	(5.7)	(8.0)
GREAT FALLS	41-70	11.2	10.2	10.3	11.4	13.3	14.6	15.6	15.2	14.5	13.1	12.9	11.5	12.8
	86-87	10.1	10.8	10.1	11.6	11.0	14.1	15.0	15.2	12.2	10.7	12.7	11.7	12.1
	% DEP	(9.8)	5.9	(1.9)	1.8	(17.3)	(3.4)	(3.8)	.0	(15.9)	(18.3)	(1.6)	1.7	(5.6)
CAPE BLANCO	76-86	18.5	20.0	16.2	16.7	17.4	20.4	20.0	20.5	24.1	20.5	18.0	17.7	19.2
	86-87	19.1	21.3	12.1	13.0	11.4	16.5	25.6	27.4	17.2	18.0	13.1	16.7	17.6
	% DEP	3.2	6.5	25.3)	(22.2)	(34.5)	(19.1)	28.0	33.7	(28.6)	(12.2)	(27.2)	(5.6)	(8.1)
GOODNOE HILLS	80-86	17.1	16.7	16.0	14.3	12.9	12.7	11.1	13.2	13.4	14.2	16.6	17.7	14.7
	86-87	17.1	17.5	14.6	13.7	9.0	13.1	7.3	8.2	11.7	12.1	15.0	16.5	13.0
	% DEP	.0	4.8	(8.8)	(4.2)	(30.2)	3.1	(34.2)	(37.9)	(12.7)	(14.8)	(9.6)	(6.8)	(11.4)
KENNEWICK	76-86	16.0	15.2	13.9	13.7	14.3	17.6	15.3	14.4	15.8	16.7	16.6	16.8	15.5
	86-87	13.4	16.4	12.8	17.1	11.5	21.0	11.9	16.6	16.8	18.7	17.8	17.1	15.9
	% DEP	(16.3)	7.9	(7.9)	24.8	(19.6)	19.3	(22.2)	15.3	6.3	12.0	7.2	1.8	2.6
PEQUOP SUMMIT	76-86	15.7	14.2	13.4	13.1	13.6	15.9	18.3	16.4	17.7	18.3	17.0	16.4	15.7
	86-87	15.1	16.3	12.5	11.6	13.5	20.1	10.1	16.6	11.0	16.7	15.6	10.9	14.2
	% DEP	(3.8)	14.8	(6.7)	(11.5)	(.7)	26.4	(44.8)	1.2	(37.9)	(8.7)	(8.2)	(33.5)	(9.8)

NOTE: VALUES IN PARENTHESIS REPRESENT NEGATIVE PERCENT DEPARTURES FROM NORMAL PEQUOP SUMMIT SPEEDS ESTIMATED AFTER 9/86 FROM NEARBY PEQUOP TOWER

CAPE BLANCO NOV 86 AND FEB 87 ESTIMATED FROM NEARBY CAPE BLANCO RADIO % DEPARTURE FROM MEAN

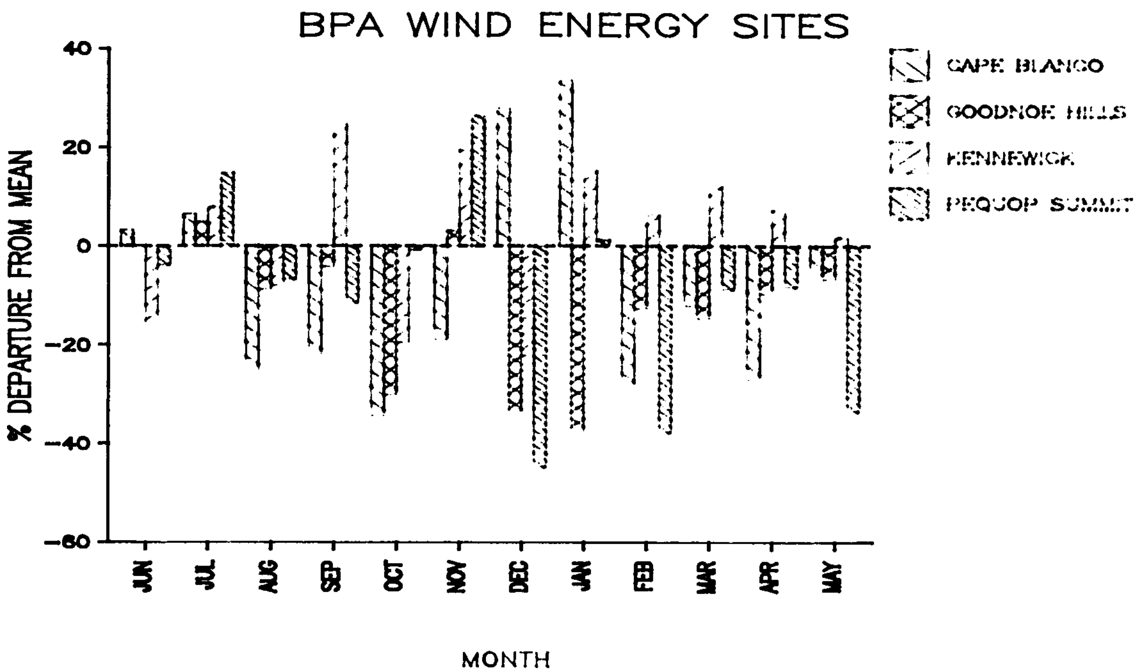

Figure 2-1. Departures from the long-term mean wind speed at four Pacific Northwest wind survey sites.

The period June 1986 through May 1987 was warmer than "normal" throughout the region. This is particularly true east of the Cascades and from January to May 1987 (see Figures 2-4 and 2-5 and Table 2-2). Most sites were about 5% warmer than "normal" for the entire period. In general warm dry weather winters in the Pacific Northwest have been associated with El Niño events. A weak El Niño occurred during the winter through spring of 1987 and was accompanied by a serious drought in the Pacific Northwest.

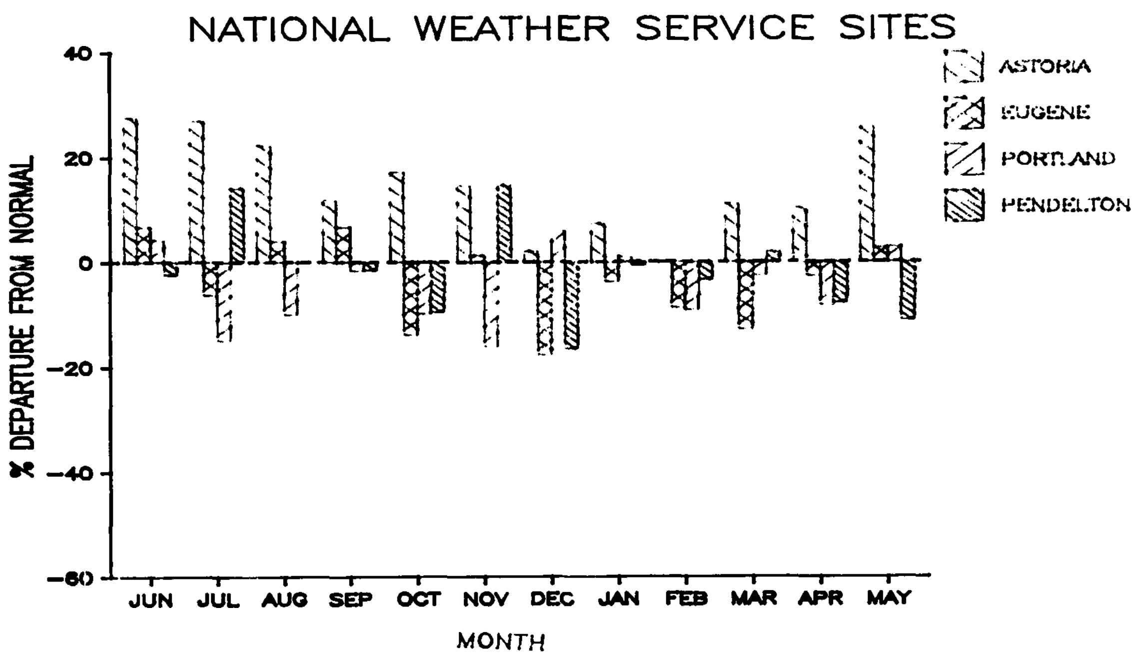

Figure 2-2. Departures from normal of windspeed at four Oregon National Weather Service sites in Oregon

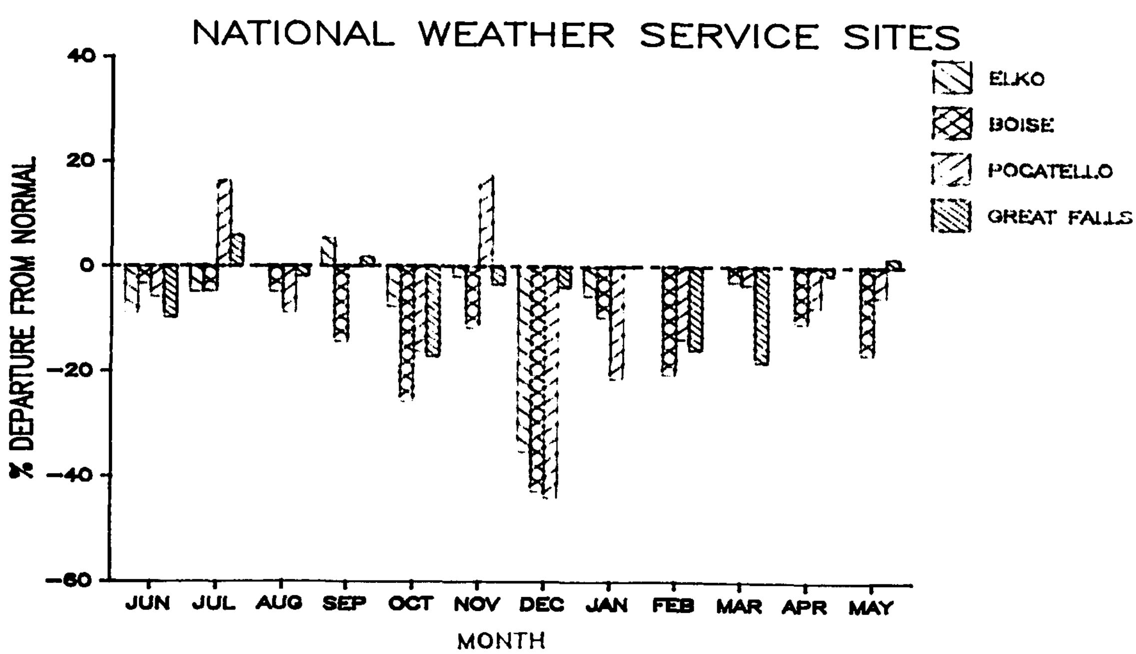

Figure 2-3. Departures from normal of windspeed at four National Weather Service sites in the Pacific Northwest.

Table 2-2. Temperature means and departures from "normal" for eight selected NWS sites in the Pacific Northwest. Temperatures are given in degrees Fahrenheit.

STATION		JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	ANNUAL
ASTORIA	41-70	56.6	60.1	60.6	58.5	52.9	46.6	43.1	41.1	43.9	44.4	47.6	52.2	50.6
	86-87 DEP	1.8	(1.4)	.5	(2.8)	2.0	1.3	1.3	2.6	2.4	3.6	2.8	2.8	1.4
	86-87	58.4	58.7	61.1	55.7	54.9	47.9	44.4	43.7	46.3	48.0	50.4	55.0	52.0
	% DEP	3.2	(2.3)	.8	(4.8)	3.8	2.8	3.0	6.3	5.5	8.1	5.9	5.4	3.1
EUGENE	41-70	61.1	66.8	66.2	62.1	53.3	45.3	41.3	40.1	43.5	45.8	49.6	55.1	52.5
	86-87 DEP	2.5	(3.7)	3.7	(3.3)	1.1	1.2	(1.4)	(.5)	.2	1.5	2.8	2.8	.6
	86-87	63.6	63.1	69.9	58.8	54.4	46.5	39.9	39.6	43.7	47.3	52.4	57.9	53.1
	% DEP	4.1	(5.5)	5.6	(5.3)	2.1	2.6	(3.4)	(1.2)	.5	3.3	5.6	5.1	1.1
PORTLAND	41-70	62.5	67.7	67.3	62.7	54.3	45.5	40.9	38.9	43.2	45.9	58.4	56.7	53.7
	86-87 DEP	3.8	(2.4)	5.0	(1.2)	2.7	2.2	(.3)	.7	2.0	2.8	3.8	3.7	1.9
	86-87	66.3	65.3	72.3	61.5	57.0	47.7	40.6	39.6	45.2	48.7	62.2	60.4	55.6
	% DEP	6.1	(3.5)	7.4	(1.9)	5.0	4.8	(.7)	1.8	4.6	6.1	6.5	6.5	3.6
PENDLETON	41-70	66.2	73.8	71.7	63.8	52.5	41.1	36.0	32.8	39.4	43.9	50.3	58.4	52.5
	86-87 DEP	3.8	(6.2)	4.1	(4.9)	1.5	1.1	(4.5)	(2.4)	(.3)	2.5	3.6	1.3	.0
	86-87	70.0	67.6	75.8	58.9	54.0	42.2	31.5	30.4	39.1	46.4	53.9	59.7	52.5
	% DEP	5.7	(8.4)	5.7	(7.7)	2.9	2.7	(12.5)	(7.3)	(.8)	5.7	7.2	2.2	(.4)
ELKO	41-70	61.2	70.1	67.6	58.4	47.5	35.3	26.1	25.0	31.0	36.0	43.4	52.4	46.2
	86-87 DEP	4.5	(3.1)	2.9	(5.4)	(1.5)	(1.3)	(1.2)	(3.5)	.1	1.5	6.1	3.2	.2
	86-87	65.7	67.0	70.5	53.0	46.0	34.0	24.9	21.5	31.1	37.5	49.5	55.6	46.4
	% DEP	7.4	(4.4)	4.3	(9.2)	(3.2)	(3.7)	(4.6)	(14.0)	.3	4.2	14.1	6.1	(.2)
BOISE	41-70	65.8	74.6	72.0	63.2	51.9	39.7	32.0	29.9	36.1	41.4	48.6	57.4	51.1
	86-87 DEP	6.2	(5.0)	3.9	(5.8)	.7	.7	(4.0)	(2.1)	1.5	2.8	7.4	4.8	.9
	86-87	72.0	69.6	75.9	57.4	52.6	40.4	28.0	27.8	37.6	44.2	56.0	62.2	52.0
	% DEP	9.4	(6.7)	5.4	(9.2)	1.3	1.8	(12.5)	(7.0)	4.2	6.8	15.2	8.4	1.4
POCATELLO	41-70	62.5	71.2	68.9	59.2	48.1	35.2	26.6	23.8	29.5	35.5	44.6	54.0	46.6
	86-87 DEP	4.9	(4.1)	1.6	(5.1)	(.1)	.8	(2.1)	(4.6)	4.1	3.8	6.9	3.7	.8
	86-87	67.4	67.1	70.5	54.1	48.0	36.0	24.5	19.2	33.6	39.3	51.5	57.7	47.4
	% DEP	7.8	(5.8)	2.3	(8.6)	(.2)	2.3	(7.9)	(19.3)	13.9	10.7	15.5	6.9	1.5
GREAT FALLS	41-70	61.9	69.3	67.5	57.4	47.9	34.0	25.7	18.7	26.7	31.4	42.7	53.2	44.7
	86-87 DEP	4.1	(4.4)	1.5	(5.9)	1.7	(2.3)	7.5	13.7	9.3	4.8	10.1	4.6	3.7
	86-87	66.0	64.9	69.0	51.5	49.6	31.7	33.2	32.4	36.0	36.2	52.8	57.8	48.4
	% DEP	6.6	(6.3)	2.2	(10.3)	3.5	(6.8)	29.2	73.3	34.8	15.3	23.7	8.6	14.5

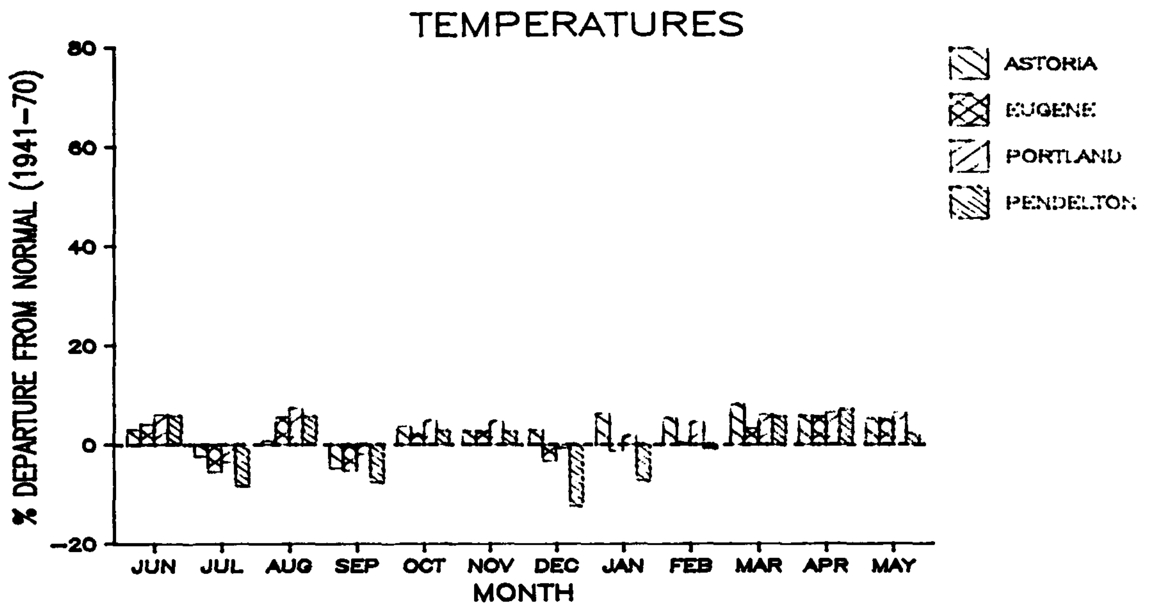

Figure 2-4. Temperature departures from "normal" (in deg. f) at four Oregon NWS sites.

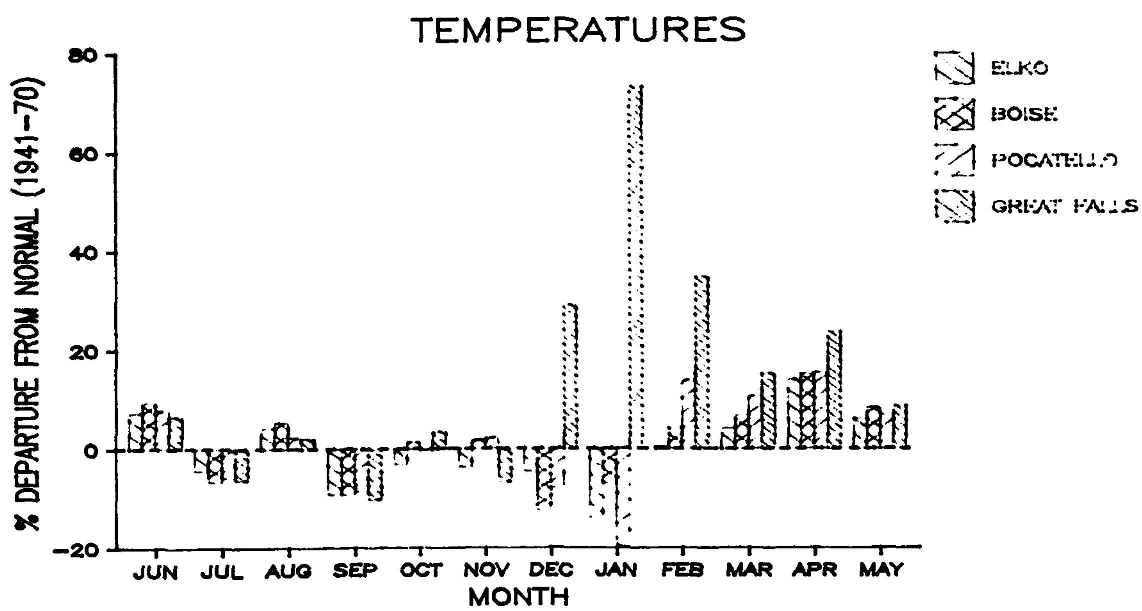

Figure 2-5. Temperature departures from "normal" (in deg. f) at four Pacific Northwest NWS sites.

Precipitation departures from "normal" were found to provide a reasonably good indication of the strength of the fall and winter wind resource in the Pacific Northwest (see Wade, et al., 1986). Table 2-3 and Figures 2-6 and 2-7 display the monthly departures from the 1941 through 1970 period "normal". The drought experienced in the Pacific Northwest is evident. September was the only consistently above average month in the whole region. December was a much drier than "normal" month and is associated with winds that are abnormally weak (see Figures 2-6 to 2-7).

Table 2-3. Precipitation departures from "normal" in inches at eight NWS sites in the Pacific Northwest.

STATION		JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	ANNUAL
ASTORIA	41-70	2.4	1.0	1.6	3.1	6.2	9.9	11.6	11.3	7.8	7.3	4.6	2.8	69.6
	86-87 DEP	(1.5)	.7	(1.4)	.5	(.8)	1.5	(4.2)	(.9)	(2.7)	1.3	(1.6)	1.1	(8.0)
	86-87	.9	1.7	.1	3.6	5.5	11.4	7.3	10.4	5.1	8.5	3.0	4.0	61.6
	% DEP	(61.3)	62.5	(91.0)	16.4	(12.2)	15.6	(36.6)	(8.1)	(35.0)	17.4	(34.3)	39.8	
EUGENE	41-70	1.2	.3	1.0	1.5	3.5	6.8	8.5	8.4	5.1	5.1	2.8	2.0	46.0
	86-87 DEP	(.9)	.2	(.9)	3.2	(1.0)	4.2	(5.2)	1.3	(.7)	(2.3)	(.7)	.0	(2.8)
	86-87	.3	.4	.0	4.7	2.5	11.0	3.3	9.7	4.5	2.8	2.0	2.0	43.2
	% DEP	(73.4)	55.6	(95.8)	220.7	(29.1)	61.9	(61.1)	15.1	(12.7)	(45.0)	(26.1)	1.5	
PORTLAND	41-70	1.5	.5	1.1	1.6	3.1	5.2	6.4	6.2	3.9	3.6	2.3	2.1	37.4
	86-87 DEP	(1.2)	.7	(1.0)	2.7	(1.1)	1.1	(2.1)	.8	(1.5)	1.3	(.4)	(.5)	(1.2)
	86-87	.2	1.2	.1	4.3	2.0	6.3	4.3	6.9	2.5	4.9	1.9	1.6	36.2
	% DEP	(84.4)	160.9	(91.2)	167.1	(34.8)	21.1	(32.9)	12.5	(37.7)	36.0	(16.0)	(21.6)	
PENDLETON	41-70	.7	.3	.6	.6	1.0	1.5	1.7	1.7	1.1	1.1	1.0	.7	11.8
	86-87 DEP	(.7)	.2	(.5)	.7	(.2)	.6	(.8)	(.3)	(.5)	.3	(.5)	(.2)	(1.8)
	86-87	.0	.5	.0	1.3	.8	2.1	.8	1.5	.6	1.4	.5	.5	10.0
	% DEP	(95.7)	60.0	(96.4)	120.7	(15.8)	43.2	(50.6)	(14.5)	(42.3)	31.1	(52.5)	(34.3)	
ELKO	41-70	.9	.3	.6	.5	.6	.8	1.0	1.2	.8	.9	.8	1.0	9.3
	86-87 DEP	(.5)	(.2)	(.6)	.3	(.5)	(.7)	(1.2)	(.9)	(.6)	(.1)	.3	(.5)	.8
	86-87	.4	.1	.0	.8	.0	.1	(.2)	.3	.2	.7	1.1	.5	4.0
	% DEP	(57.1)	(63.6)	(96.6)	72.3	(92.9)	(84.3)	(122.4)	(76.7)	(76.5)	(15.3)	35.4	(51.5)	
BOISE	41-70	1.0	.3	.4	.6	.8	1.3	1.3	1.6	1.1	1.0	1.2	1.2	11.7
	86-87 DEP	(.6)	(.1)	(.3)	2.4	(.4)	(.3)	(1.2)	(.9)	.2	1.0	(.8)	(.5)	(1.7)
	86-87	.4	.2	.1	2.9	.3	1.0	.1	.7	1.2	2.0	.4	.7	10.0
	% DEP	(63.2)	(34.6)	(82.5)	405.2	(56.0)	(22.5)	(91.0)	(55.5)	15.9	95.1	(68.1)	(43.3)	
POCATELLO	41-70	1.1	.5	.6	.7	.9	.9	1.0	1.1	.9	.9	1.2	1.2	10.9
	86-87 DEP	(.7)	(.4)	(.5)	.7	(.5)	.0	(.8)	(.1)	(.2)	(.1)	(.7)	.8	(2.4)
	86-87	.3	.1	.1	1.3	.4	.9	.2	1.0	.7	.8	.5	2.0	8.5
	% DEP	(68.9)	(74.5)	(76.7)	104.6	(57.6)	(2.2)	(79.2)	(8.8)	(17.4)	(10.6)	(59.5)	68.3	
GREAT	41-70	2.8	1.1	1.3	1.0	.8	.7	.8	1.0	.8	.9	1.5	2.5	15.2
FALLS	86-87 DEP	(1.0)	.6	(.5)	.5	.1	(.3)	(.5)	(1.0)	(.5)	.9	(.9)	.1	(2.5)
	86-87	1.7	1.7	.8	1.5	.9	.5	.3	.1	.2	1.8	.6	2.6	12.7
	% DEP	(37.5)	51.8	(38.2)	47.6	9.8	(39.2)	(66.3)	(95.0)	(68.0)	94.6	(57.0)	4.4	

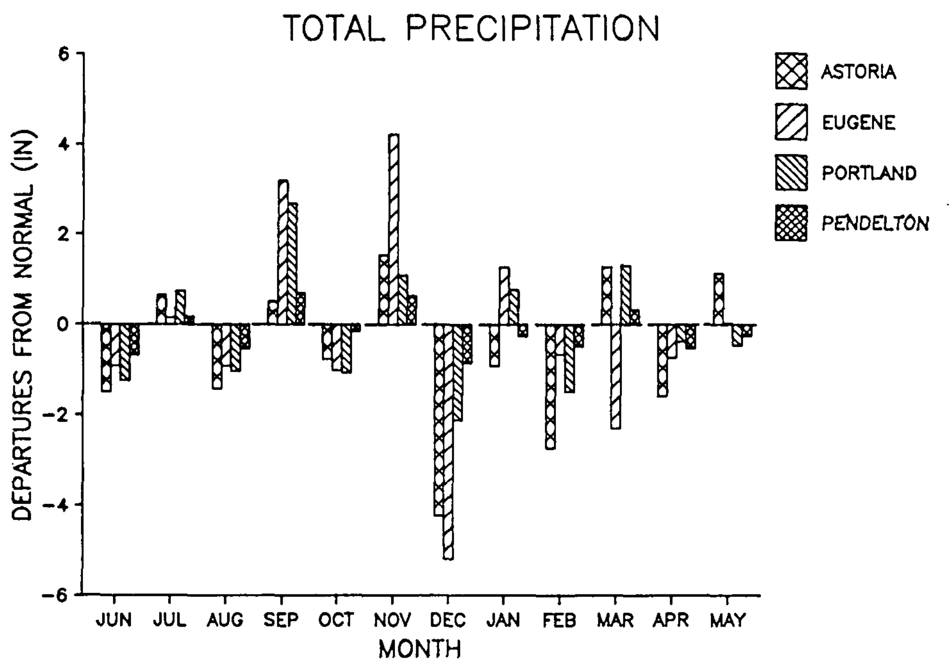

Figure 2-6. Departures from normal of precipitation in inches at four Oregon National Weather Service Sites.

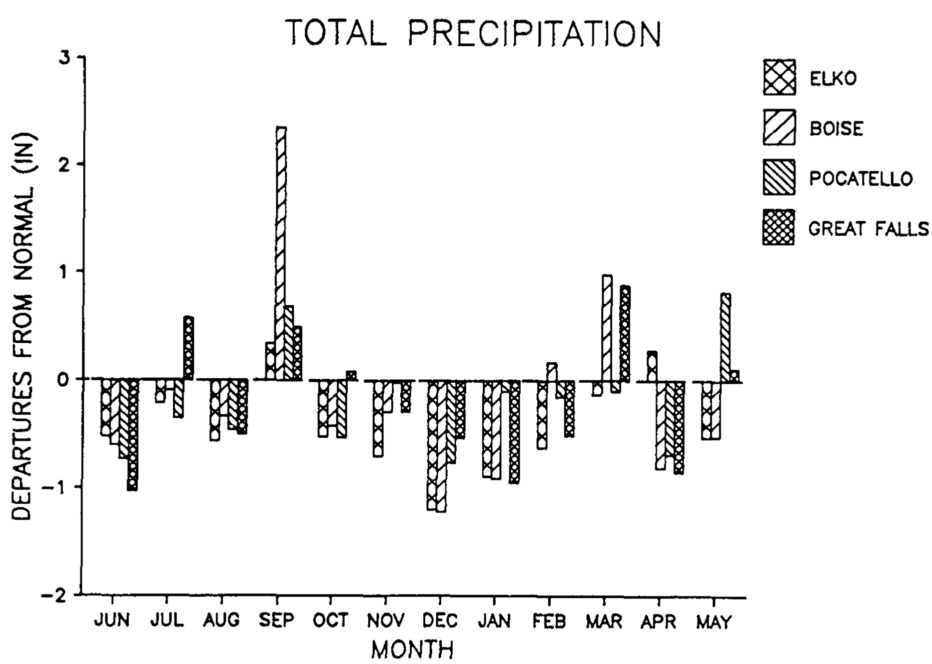

Figure 2-7. Departures from normal of precipitation in inches at four Pacific Northwest National Weather Service sites.

Figure 2-8 shows the seasonal variation of temperature at the four long-term wind data sites in Pacific Northwest. Note the large seasonal temperature variation at all the sites except Cape Blanco where the temperature is moderated by the ocean's relative warmth. The importance of temperature in wind energy is that it effects the density of the air and thus the available energy. In Section Four there will be a discussion of possible error in power and energy calculations due to temperature and pressure variations.

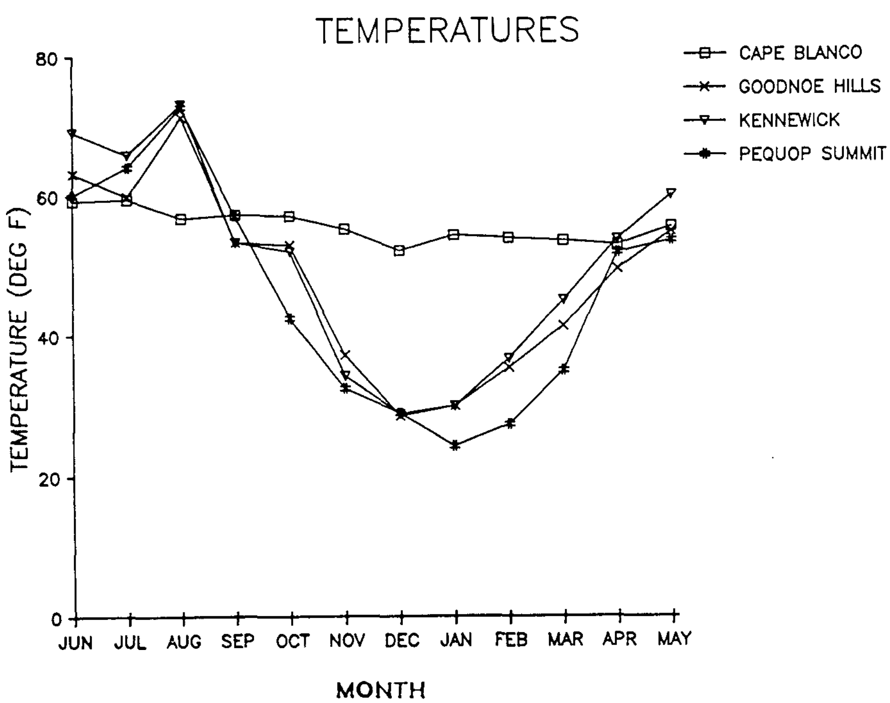

Figure 2-8. Seasonal temperature variations at four Pacific Northwest wind energy sites. Temperatures are in degrees Fahrenheit.

3.0 WIND SITE DATA SUMMARY

3.1 Introduction

Wind data have been collected at high wind sites throughout the BPA area since 1976. In this section we will examine the statistics at each active wind energy survey site during the period 1 June 1986 through 31 May 1987. The statistics for this period for all the current sites are summarized in Table 3.1. The statistics include mean monthly speed in mph, number of hours of data, power density in watts per square meter, mean monthly temperature, mean monthly pressure in inches of mercury and the most frequent direction.

In previous reports a discussion of the statistics at each site included analysis of the seasonal and diurnal wind variation (see references for previous annual wind energy assessments). In this report emphasis will be on discussion of turbulence and vertical wind variation at the active sites. For each site, a statistical summary is presented that provides information on anemometer height, data recovery rate, peak hourly average wind speed, peak gust and time, energy statistics, and the Weibull fit shape and scale parameters.

The energy statistics provided for each site include available energy and power density as well as estimated gross annual energy output for five selected wind turbines at that site. These gross annual energy estimates should not be confused with the energy that could be produced at a site. The net power produced at a site would include losses due to turbine down time, array effects, electrical line losses, blade fouling performance penalties, turbulence effects or any other factor that may effect machine performance.

At sites that have anemometers at more than one height there will be a discussion of the vertical wind variation as a function of wind direction. At most of the sites statistics are available to discuss the downwind and crosswind components of Turbulence Intensity. Crosswind turbulence was shown in Baker, et al. (1986) to have a significant effect on wind turbine performance. Downwind turbulence intensity is likely to most impact near the cut-in and cut-out speeds of wind turbines. High turbulence would result a greater number of on off cycles. It is important to note that these turbulence statistics are only computed for the speed range 10 to 97 mph.

Table 3.1. Wind statistics at active BPA wind survey sites in the Pacific Northwest. Annual averages are not provided for sites with low data recovery.

SITE NAME (ANEM. HT (FT)/ ELEV. (FT)		JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	ANNUAL AVG
ALBION BUTTE	V(MPH)	12.5	13.1	11.4	12.2	11.0								
IDAHO	N	720.0	744.0	744.0	720.0	540.0								
21/7110	PD(W/M**2	457.0	394.0	305.0	317.0	224.0								
	TEMP(DEG F)	65.0	63.0	70.0	47.0	43.0								
	PRES.(IN)	24.2	24.2	24.2	24.1	24.1								
	PREV. DIR.	WNW	WNW	WNW	WNW	WNW								
BROWNING	V(MPH)	12.3	14.0	10.5	11.9	14.7	21.6	22.8	24.5	17.4	15.2	16.5	14.4	16.3
DEPOT	N	665.0	717.0	731.0	690.0	737.0	720.0	693.0	737.0	667.0	676.0	715.0	744.0	8492.0
MONTANA	PD(W/M**2	248.0	330.0	192.0	285.0	372.0	1001.0	1132.0	1129.0	521.0	597.0	520.0	333.0	555.0
80/4500	TEMP(DEG	60.0	59.0	64.0	45.0	47.0	28.0	30.0	30.0	32.0	31.0	47.0	52.0	43.8
	PRES.(IN)													
	PREV. DIR.				SW	SW	SW	SW	SW	SW	SW	SW	SW	SW
CAPE BLANCO	V(MPH)	19.1	21.3	12.1	13.0	11.4		25.6	27.4	29.2	34.4	22.8	19.4	
MW	N	696.0	717.0	744.0	614.0	557.0		559.0	742.0	106.0	173.0	30.0	742.0	
OREGON	PD(W/M**2	1003.0	902.0	287.0	308.0	594.0		1975.0	1596.0	1072.0	3159.0	1164.0	995.0	
50/217	TEMP(DEG F)		(SEE CAPE BLANCO RS)											
	PRES.(IN)													
	PREV. DIR	NNE	NNE	NNE	NE	NE		S	S	S	S	S	N	
CAPE BLANCO	V(MPH)					13.3	16.5	18.1	19.8	17.2	18.0	13.1	16.7	
RS	N					387.0	708.0	710.0	698.0	672.0	744.0	720.0	744.0	
OREGON	PD(W/M**2)					640.0	823.0	991.0	1208.0	768.0	1254.0	664.0	946.0	
50/200	TEMP(DEG F)	59.0	59.0	57.0	57.0	57.0	55.0	52.0	54.0			53.0	55.0	
	PRES.(IN)	30.0	30.0	29.9	29.8	29.9	30.0	29.9	29.9	29.8	29.8	29.9	29.9	
	PREV. DIR.					S	S	S	SSW	NNW	N	NNW	WSW	
DUNCAN MTN.	V(MPH)							10.4	14.8	13.2	14.6	13.4	10.6	
IDAHO	N							38.0	744.0	672.0	744.0	720.0	708.0	
80/6240	PD(W/M**2)							138.0	311.0	303.0	293.0	297.0	131.0	
	TEMP(DEG F)				(NO TEMPERATURE, PRESSURE OR DIRECTION DATA)									
	PRES.(IN)													
	PREV. DIR.													
GOODNOE	V(MPH)	13.5	12.8	11.2	10.3	6.8	11.3	6.5	7.0	10.4	11.0	10.9	10.8	10.2
HILLS	N	714.0	744.0	744.0	720.0	744.0	720.0	545.0	740.0	671.0	744.0	696.0	741.0	8523.0
WASHINTON	PD(W/M**2	356.0	247.0	220.0	193.0	156.0	424.0	263.0	196.0	383.0	260.0	281.0	266.0	270.4
50/2540	TEMP(DEG F)	63.0	60.0	71.0	53.0	53.0	37.0	29.0	30.0	35.0	41.0	49.0	55.0	48.0
	PRES.(IN)	27.2	27.2	27.2	27.1	27.3	27.3	27.3	27.2	27.1	27.2	27.2	27.2	27.2
	PREV. DIR	W	W	W	W	W	W	W	W	W	W	W	W	W
HAMPTON	V(MPH)	12.8	14.2	11.8	12.3	12.5	17.6	14.3	17.2	17.0	19.5		14.2	14.9
BUTTE	N	494.0	590.0	695.0	650.0	598.0	685.0	652.0	683.0	658.0	589.0		290.0	6584.0
OREGON	PD(W/M**2	304.0	310.0	232.0	250.0	278.0	511.0	275.0	498.0	432.0	580.0		356.0	366.0
34/6343	TEMP(DEG F)	64.0	64.0	72.0	52.0	53.0	38.0	34.0	31.0	34.0	36.0		46.0	47.6
	PRES.(IN)	24.6	24.7	24.7	24.5	24.6	24.6	24.6	24.6	24.4	24.4		24.5	24.6
	PREV. DIR	N	NNW	N	NW	NNE	WSW	S	S	S	S		N	S
KENNEWICK MW	V(MPH)	13.4	16.4	12.8	17.1	11.5	21.0	11.9	16.6	16.8	18.7	17.8	17.1	15.9
WASHINGTON	N	649.0	670.0	685.0	648.0	744.0	720.0	601.0	729.0	669.0	743.0	720.0	744.0	8322.0
105/2200	PD(W/M**2	693.0	585.0	300.0	783.0	569.0	1448.0	1001.0	1123.0	977.0	800.0	846.0	741.0	822.2
	TEMP(DEG F)	69.0	66.0	73.0	53.0	52.0	34.0	29.0	30.0	37.0	45.0	54.0	60.0	50.2
	PRES.(IN)	28.0	28.1	28.1	28.0	28.2	28.1	28.2	28.1	28.1	28.0	28.1	28.0	28.1
	PREV. DIR	S	S	N	S	N	S	N	SSW	SW	SW	SW	SSW	SSW
KITTITAS MW	V(MPH)	13.6	14.7	11.4	11.9	8.6	11.3	6.2	7.5	10.8	11.2	13.8	13.2	11.2
WASHINGTON	N	720.0	744.0	744.0	681.0	63.0	720.0	728.0	744.0	672.0	744.0	719.0	726.0	8005.0
110/2660	PD(W/M**2	479.0	571.0	323.0	384.0	285.0	456.0	281.0	343.0	437.0	443.0	547.0	549.0	424.8
	TEMP(DEG F)	68.0	65.0	72.0	56.0	55.0	39.0	32.0	31.0	38.0	45.0	54.0	60.0	51.3
	PRES.(IN)	27.5	27.6	27.6	27.5	27.6	27.6	27.7	27.6	27.6	27.5	27.5	27.5	27.6
	PREV. DIR	WNW	WNW	WNW	WNW	E	WNW	ESE	WNW	WNW	WNW	WNW	WNW	WNW

Table 3.1. (Continued)

SITE NAME (ANEM. HT (FT)/ ELEV. (FT)		JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	ANNUAL AVG
ALBION BUTTE	PREV. DIR	1003.0	744.0	744.0	744.0	737.0	1001.0	1132.0	1129.0	1072.0	3159.0	1164.0	744.0	8492.0
PEQUOP	U(MPH)	15.1	16.3	12.5	11.6									
SUMMIT	N	710.0	703.0	719.0	277.0									
NEVADA	PD(W/M**2	233.0	377.0	184.0	159.0									
	TEMP(DEG F)			73.0		42.0	32.0	29.0	24.0	27.0	35.0	52.0	53.0	
	PRES.(IN)			23.7		23.7	23.6	23.6	23.5	23.5	23.6	23.7	23.7	
	PREV. DIR.	SSW	SSW	SSW	W									
PEQUOP TOWER	V(MPH)	15.3	15.5	13.1	10.7	13.5	20.1	10.1	16.6	11.0	16.7	15.6	10.9	14.1
NEVADA	N	701.0	744.0	742.0	174.0	668.0	720.0	743.0	623.0	298.0	612.0	720.0	576.0	7321.0
50/7540	PD(W/M**2	461.0	410.0	249.0	152.0	402.0	679.0	241.0	598.0	316.0	661.0	514.0	186.0	405.8
	TEMP(DEG F)		(NO TEMPERATURE OR PRESSURE DATA)											
	PRES.(IN)													
	PREV. DIR.	SSE	W	W	W	W	W	W	W	SW	SW	W	W	W
SEVENMILE	V(MPH)	19.8	21.1	18.2	13.6	8.1	10.5	6.4	8.4	8.9	12.1	15.3	17.5	13.3
HILL	N	720.0	369.0	715.0	720.0	744.0	720.0	378.0	306.0	672.0	744.0	720.0	744.0	7552.0
OREGON	PD(W/M**2	844.0	951.0	762.0	485.0	331.0	503.0	158.0	175.0	366.0	526.0	746.0	837.0	557.0
50/1880	TEMP(DEG F)	63.0	61.0	70.0	55.0	53.0	41.0	33.0	34.0	38.0	42.0	49.0	54.0	49.4
	PRES.(IN)	28.3	28.4	28.3	28.2	28.4	28.4	28.4	28.3	28.3	28.2	28.3	28.3	28.3
	PREV. DIR.	WNW	WNW	WNW	WNW	WNW	WNW	E	E	WNW	WNW	WNW	WNW	WNW
SPRING CREEK	V(MPH)	17.4	17.6	14.8	13.2	9.4	5.2	5.9	5.4	6.0	6.7	10.0	12.1	10.3
WASHINGTON	N	170.0	561.0	268.0	260.0	196.0	291.0	743.0	739.0	636.0	728.0	719.0	729.0	6040.0
76/97	PD(W/M**2	674.0	575.0	613.0	440.0	552.0	197.0	123.0	161.0	234.0	235.0	283.0	438.0	377.1
	TEMP(DEG F)	73.0	70.0	75.0	60.0	61.0	44.0	34.0	34.0	41.0	46.0	56.0	62.0	54.7
	PRES.(IN)	29.8	30.0	29.9	29.8	30.0	30.0	30.1	30.1	29.9	29.9	29.9	29.8	29.9
	PREV. DIR.	W	W	SW	WNW	SW	W	E	E	E	W	W	W	W
UPPER PYLE	V(MPH)	8.3	15.2	13.6	12.1	11.7	14.0	12.8	16.7	13.1	15.9	14.3	9.6	13.1
OREGON	N	69.0	545.0	744.0	720.0	744.0	720.0	744.0	744.0	672.0	744.0	720.0	110.0	7276.0
50/3660	PD(W/M**2	219.0	287.0	255.0	321.0	406.0	703.0	487.0	695.0	503.0	744.0	452.0	175.0	437.3
	TEMP(DEG F)	74.0	65.0	71.0	52.0	48.0	34.0	27.0	24.0	32.0	37.0	48.0	51.0	46.9
	PRES.(IN)	26.5	26.7	26.7	26.6	26.8	26.7	26.8	26.7	26.7	26.6	26.7	26.7	26.7
	PREV. DIR.	N	N	N	N	N	N	S	N	N	N	N	N	N

3.2 Site Discussions

Albion Butte

The Albion Butte site characteristics have been described in detail in BPA report 85-19. During past year data were lost due to a severe ice and wind storm that destroyed the anemometer. Data were lost from November 1986 through May 1987. The mean speed measured during the period of record was 12 mph however the strongest wind speeds occur in the winter months at this site and a typical mean speed for a year would be closer to 16 mph.

Turbulence Intensities for Albion Butte as function of direction are presented in Figure 3.1. Cross wind Turbulence Intensity (Iv) and Downwind (Iu) are in the moderate category for most directions except north which has high Turbulence Intensity. The high Turbulence Intensity for NW-NE flow is perhaps induced by roughness when the wind flows parallel to the ridge. The least slope of this ridge is quite steep.

Wind statistics for Albion Butte are presented in Table 3-2. Data recovery was only 40% so the statistics should be viewed with caution. Although energy statistics are normalized to a full year, the strongest wind season was not included in the record.

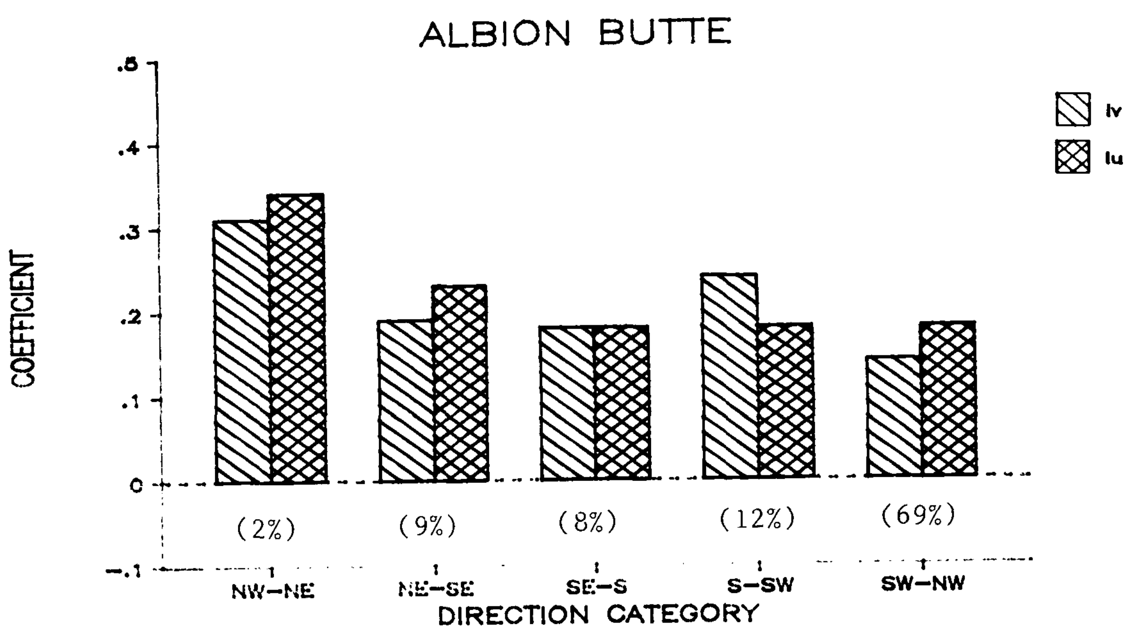

Figure 3-1. **Crosswind (Iv) and Downwind (Iu) Turbulence Intensity Coefficient at Albion Butte (21 ft) as a function of wind direction. Percent of winds from each direction is enclosed in parentheses.**

Table 3-2. Annual Summary for Albion Butte.

ALBION BUTTE

Data Period: Jun. 1986 - May 1987 Site Elevation: 7110 ft

Wind Statistics

Anemometer Level:	21 ft	Data Recovery Rate:	39.6%
Average Speed:	12.1 mph	Power Density:	202 W/M**2
Available Energy:	1770 KWh/M**2	% Time (Speed 12.0-60.0):	44.6%
Maximum (1 Hr Avg):	60.3 mph	Maximum Gust:	80.5 mph
Date: 7/4 - 1600		Date: 7/4 - during hour 1400	
Shape Factor:	1.57	Scale Factor:	13.5 mph
Standard Deviation of Hourly Wind Speeds:			7.96

Estimated Turbine Energy Output (Normalized to period of record)

Turbine Type:	NORDTANK 65 KW	ENERTECH 300 KW	FLO-190 300 KW	USWP 56 100 KW
Hub Height	75 ft	100 ft	57 ft	60 ft
Swept Area:	201 M**2	730 M**2	347 M**2	229 M**2
Est Total Energy*:	112446 kWh	493725 kWh	223248 kWh	140732 kWh
Capacity Factor*:	0.194	0.188	0.085	0.161
Efficiency Factor**:	0.216	0.239	0.269	0.254
Alpha Factor Used:	0.100	0.100	0.100	0.100

Turbine Type	DYNERGY 180 KW
Hub Height:	160 ft
Swept Area:	308 M**2
Est Total Energy*:	220916 kWh
Capacity Factor*:	0.123
Efficiency Factor**:	0.220
Alpha Factor Used:	0.100

* Assuming 100% availability

** Estimated monthly energy, KWh/(Available energy, KWh/M**2)(Swept area, M**2)

Browning Depot

At the Browning Depot the mean wind speed averaged 16.3 mph for the 86-87 period. Data recovery was 97% for the year. The data in Table 3-3 indicates a maximum gust of 92 mph was measured in April. Table 3.1 shows that strong winter winds averaging over 20 mph were experienced at this site in western Montana. The annual available energy at 80 ft was nearly 3300 kWh/m^2. Figure 3-2 displays the variation of Turbulence Intensity and the power law coefficient (a). For the prevailing southwest winds the Turbulence Intensity is low to moderate and the shear or vertical wind variation is small. In general Crosswind Turbulence Intensity is less than Downwind for most directions at this site.

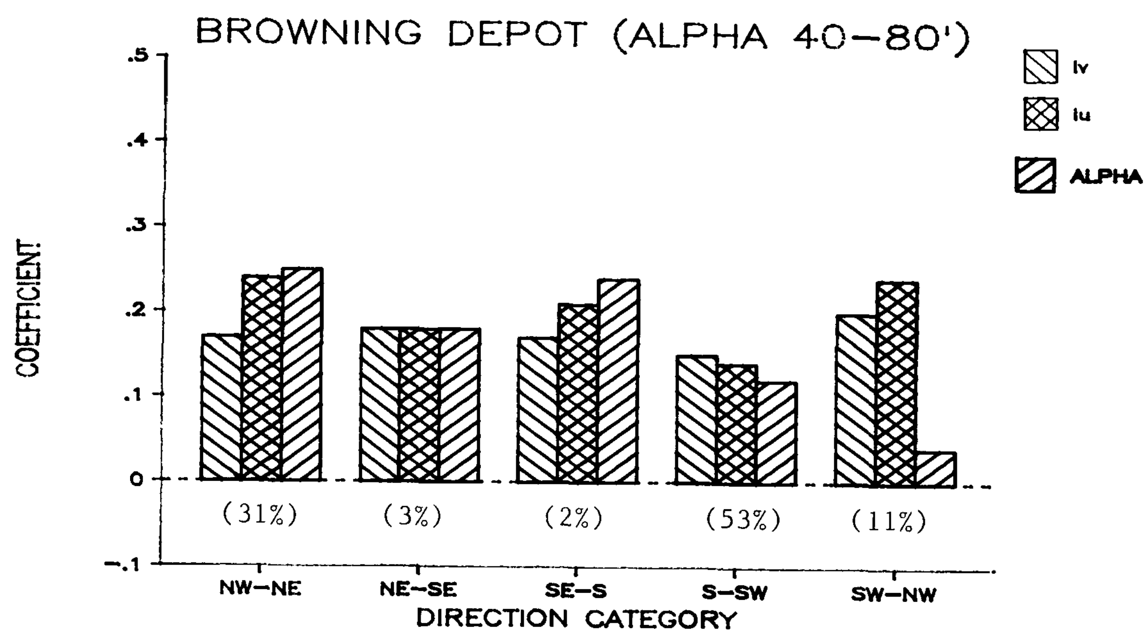

Figure 3-2. **Crosswind (Iv) and Downwind (Iu) Turbulence Intensity Coefficient at Browning Depot (80 ft) as a function of wind direction. Percent of winds from each direction is enclosed in parentheses.**

Table 3-3. Annual Summary Statistics for Browning Depot.

BROWNING DEPOT

Data Period: Jun. 1986 - May 1987 | Site Elevation: 4500 ft

Wind Statistics

Anemometer Level:	40 ft	Data Recovery Rate:	96.6%
Average Speed:	15.1 mph	Power Density:	375 W/M**2
Available Energy:	3289 KWh/M**2	% Time (Speed 12.0-60.0):	57.6%
Maximum (1 Hr Avg):	58.7 mph	Maximum Gust:	92.3 mph
Date: 11/23-1600		Date: 4/16 - during hour 1300	
Shape Factor:	1.74	Scale Factor:	17.0 mph
Standard Deviation of Hourly Wind Speeds:			9.06

Wind Statistics

Anemometer Level:	80 ft	Data Recovery Rate:	97.0%
Average Speed:	16.3 mph	Power Density:	453 W/M**2
Available Energy:	3965 KWh/M**2	% Time (Speed 12.0-60.0)	63.2%
Maximum (1 Hr Avg)	62.8 mph	Maximum Gust:	86.5 mph
Date: 4/16-1300		Date: 11/23 - during hour 1300	
Shape Factor:	1.81	Scale Factor:	18.4 mph
Standard Deviation of Hourly Wind Speeds:			9.48

Alpha Value (40 ft - 80 ft): 0.114

Estimated Turbine Energy Output (Normalized to period of record)

Turbine Type:	NORDTANK 65 KW	ENERTECH 300 KW	FLO-190 300 KW	USWP 56 100 KW
Hub Height:	75 ft	100 ft	57 ft	60 ft
Swept Area:	201 M**2	730 M**2	347 M**2	229 M**2
Est Total Energy*:	164557 kWh	730236 kWh	343202 kWh	209236 kWh
Capacity Factor*:	0.285	0.278	0.131	0.239
Efficiency Factor**:	0.211	0.234	0.280	0.254
Alpha Factor Used:	0.114	0.114	0.114	0.114

Turbine Type:	DYNERGY 180 KW
Hub Height:	160 ft
Swept Area:	308 M**2
Est Total Energy*:	336638 kWh
Capacity Factor*:	0.188
Efficiency Factor**:	0.217
Alpha Factor Used:	0.114

* Assuming 100% availability

** Estimated monthly energy, KWh/(Available energy, KWh/M**2)(Swept area, M**2)

Cape Blanco

There are two anemometer sites at Cape Blanco within 200 yards of each other. The newest site, called Cape Blanco Radio Site was installed as possible replacement location for the historical site called, Cape Blanco Microwave. The Cape Radio site was installed in October 1986 and information is retrieved by telephone modem connection. The data recovery for the year was only 62%, but over the period of time the anemometer has been installed the data recovery has been 92%. Numerous data recovery problems were encountered this past year at the microwave site that included failure of anemometers and problems with data collection on the CR-21. Most of the recorder problems were due to cassette tapes being improperly installed. Statistical data for both locations are given in Tables 3-4 and 3-5.

Both sites recorded winds over 100 mph during the past year. The microwave recorded a 105 mph gust and the radio site recorded a 100.2 mph gust. Strongest hourly speeds were 82.4 and 59.6 mph respectively.

The mean wind speed for the period was 19.5 mph for the microwave and 16.8 mph for the radio site. When 3,090 matched hours were compared for speeds greater than 10 mph the mean speed for the radio site was 23.8 and 28.8 mph for the microwave. Figure 3-3 presents a bivariate distribution of the ratio the microwave site to the new radio location. The results suggest that for southerly flow there is a large difference in wind speed at these two sites. For easterly flow the two sites have similar ratios.

Figure 3-4 presents the variation of Turbulence Intensity with wind direction at the microwave location. Most notable is the low turbulence for southerly flow. There is a greater variation of the crosswind component of Turbulence Intensity at this site. This may be due to the site's location which is on a bluff. In general when the crosswind component exceeds the downwind it is due to upwind obstructions or extreme terrain variations. Most often the crosswind Turbulence Intensity is about 75% of the value of the downwind Turbulence Intensity.

Table 3-4. Annual Summary Statistics for Cape Blanco Microwave.

CAPE BLANCO M/W

Date Period: Jun. 1986 - May 1987 Site Elevation: 217 ft

Wind Statistics

Anemometer Level:	50 ft	Data Recovery Rate:	64.8%
Average Speed:	19.5 mph	Power Density:	1185 W/M**2
Available Energy:	10379 KWh/M**2	% Time (Speed 12.0-60.0):	64.1%
Maximum (1 Hr Avg):	82.4 mph	Maximum Gust:	105.1 mph
Date: 2/ 1 - 100		Date: 12/22 - during hour 200	
Shape Factor:	1.43	Scale Factor:	21.4 mph
Standard Deviation of Hourly Wind Speeds:			13.97

Estimated Turbine Energy Output (Normalized to period of record)

Turbine Type:	NORDTANK 65 KW	ENERTECH 300 KW	FLO-190 300 KW	USWP 56 100 KW
Hub Height:	75 ft	100 ft	57 ft	60 ft
Swept Area:	201 M**2	730 M**2	347 M**2	229 M**2
Est Total Energy*:	233111 kWh	990841 kWh	622831 kWh	275035 kWh
Capacity Factor*:	0.403	0.377	0.237	0.314
Efficiency Factor**:	0.112	0.131	0.173	0.116
Alpha Factor Used:	0.000	0.000	0.000	0.000

Turbine Type:	DYNERGY 180 KW
Hub Height:	160 ft
Swept Area:	308 M**2
Est Total Energy*:	405877 kWh
Capacity Factor*:	0.226
Efficiency Factor**:	0.127
Alpha Factor Used:	0.000

* Assuming 100% availability

** Estimated monthly energy, KWh/(Available energy, KWh/M**2)(Swept area, M**2)

Table 3-5. Annual Summary Statistics for Cape Blanco Radio.

CAPE BLANCO RADIO

Data Period: June 1986 - May 1987 Site Elevation: 217 ft

Wind Statistics

Anemometer Level:	50 ft	Data Recovery Rate:	61.5%
Average Speed:	16.8 mph	Power Density:	668 W/M**2
Available Energy:	5852 KWh/M**2	% Time (Speed 12.0-60.0):	60.2%
Maximum (1 Hr Avg):	59.6 mph	Maximum Gust:	100.2 mph
Date: 3/ 2 - 2200		Date: 1/31 - during hour 2300	
Shape Factor:	1.51	Scale Factor:	18.6 mph
Standard Deviation of Hourly Wind Speeds:			11.46

Estimated Turbine Energy Output (Normalized to period of record)

Turbine Type:	NORDTANK 65 KW	ENERTECH 300 KW	FLO-190 300 KW	SWP 56 100 KW
Hub Height:	75 ft	100 ft	57 ft	60 ft
Swept Area:	201 M**2	730 M**2	347 M**2	229 M**2
Est Total Energy*:	210610 kWh	889257 kWh	527785 kWh	270321 kWh
Capacity Factor*:	0.364	0.338	0.201	0.309
Efficiency Factor**:	0.179	0.208	0.260	0.202
Alpha Factor Used:	0.000	0.000	0.000	0.000

Turbine Type:	DYNERGY 180 KW
Hub Height:	160 ft
Swept Area:	308 M**2
Est Total Energy*:	383818 kWh
Capacity Factor*:	0.214
Efficiency Factor**:	0.213
Alpha Factor Used:	0.000

* Assuming 100% availability

** Estimated monthly energy, KWh/(Available energy, KWh/M**2)(Swept area, M**2)

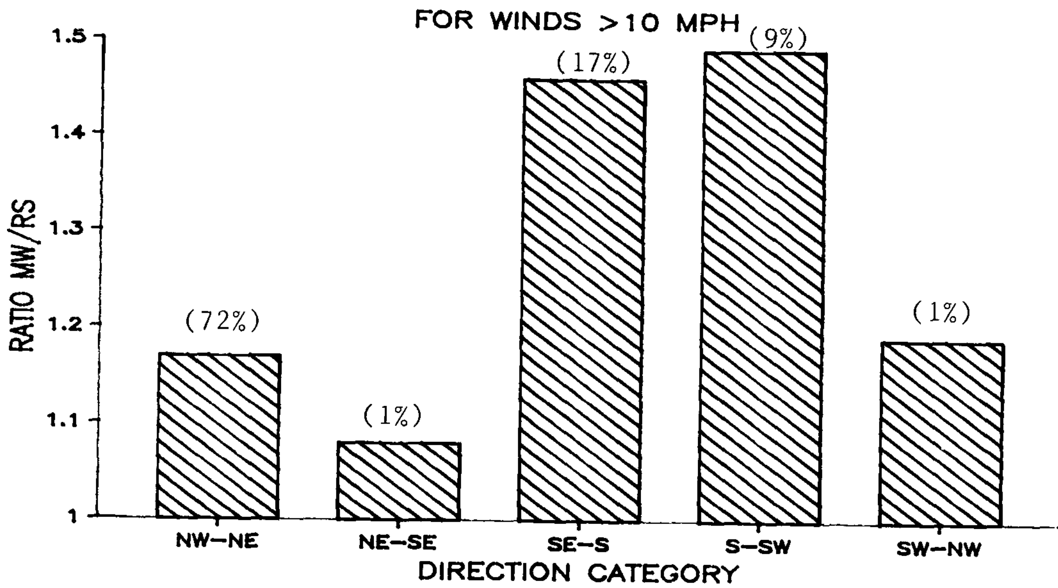

Figure 3-3. The variation of the ratio of Cape Blanco MW to the Radio site for various wind direction sectors. Percent of winds from each direction is enclosed in parentheses.

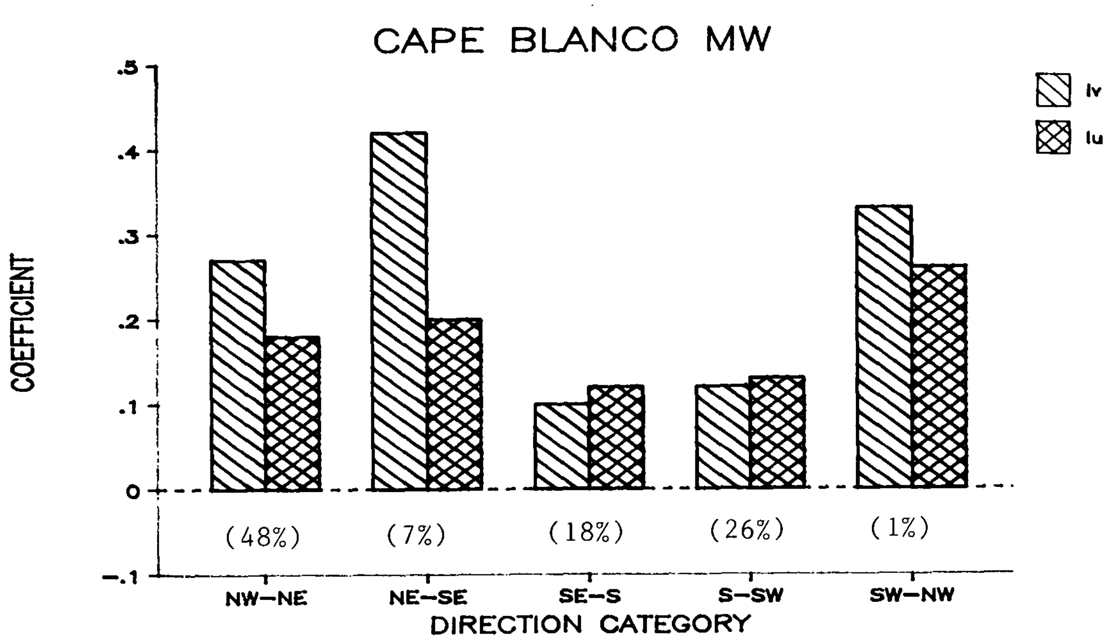

Figure 3-4. Crosswind (Iv) and Downwind (Iu) Turbulence Intensity Coefficient at Cape Blanco MW (50 ft) as a function of wind direction. Percent of winds from each direction is enclosed in parentheses.

Duncan Mountain

On-Site Energy (OSE), of Portland ,Oregon, has installed an anemometer at Duncan Mountain, a location previously monitored by BPA. Two wind turbines are being tested to determine the feasibility of using wind power at remote communication facilities. OSU has obtained permission to collect this data using a modem from the OSE data logger. Wind speed and peak gust are available along with information on the performance of wind turbines and solar collectors. The statistics are summarized in Table 3-6. The mean wind speed measured at the site was 13.3 mph at 80 ft. Data recovery was excellent since collection began in late December 1986.

Table 3-6. Annual Summary Statistics for Duncan Mtn.

DUNCAN MTN

Data Period: Jun. 1986 - May 1987 Site Elevation: 6240 ft

Wind Statistics

Anemometer Level:	80 ft	Data Recovery Rate:	41.4%
Average Speed:	13.3 mph	Power Density:	191 W/M**2
Available Energy:	1675 KWh/M**2	% Time (Speed 12.0 - 60.0):	54.4%
Maximum (1 Hr Avg):	42.1 mph	Maximum Gust:	64.3 mph
Date: 1/25 - 1200		Date: 2/ 1 - during hour 1700	
Shape Factor:	2.21	Scale Factor:	15.0 mph
Standard Deviation of Hourly Wind Speeds:			6.40

Estimated Turbine Energy Output (Normalized to period of record)

Turbine Type:	NORDTANK 65 KW	ENERTECH 300 KW	FLO-190 300 KW	USWP 56 100 KW
Hub Height:	75 ft	100 ft	57 ft	60 ft
Swept Area:	201 M**2	730 M**2	347 M**2	229 M**2
Est Total Energy*:	90674 kWh	374209 kWh	163314 kWh	109794 kWh
Capacity Factor*:	0.157	0.142	0.062	0.125
Efficiency Factor**:	0.269	0.306	0.281	0.286
Alpha Factor Used:	0.000	0.000	0.000	0.000

Turbine Type:	DYNERGY 180 KW
Hub Height:	160 ft
Swept Area:	308 M**2
Est Total Energy*:	133662 kWh
Capacity Factor*:	0.075
Efficiency Factor**:	0.259
Alpha Factor Used:	0.000

* Assuming 100% availability
** Estimated monthly energy, KWh/(Available energy, KWh/M**2)(Swept area, M**2)

Goodnoe Hills

Wind data have been collected at the BPA tower since May of 1980. During the past year data recovery was 97% at this location. The site statistics are presented in Table 3-7. Figure 3-5 presents an analysis of the variation in Turbulence Intensity and the power law coefficient alpha at the Goodnoe Hills tower. The results suggest little spatial variation in either component of Turbulence Intensity. However, for southeast through south winds the crosswind (Iv) component is larger than the downwind (Iu) indicating rougher terrain or more obstructions to the flow from that sector.

The change in alpha with wind direction at Goodnoe Hills is pronounced with moderate shear for NW-SE flow, low shear for SE-SW and strong shear for the most common wind direction sector, SW-NW. The winds from the other sectors are most likely to be strong during the day when mixing is good. Flow from the SW-NW may occur at speeds greater than 10 mph throughout the day, and since shear is larger at night (see Persson 1984), the mean will be larger.

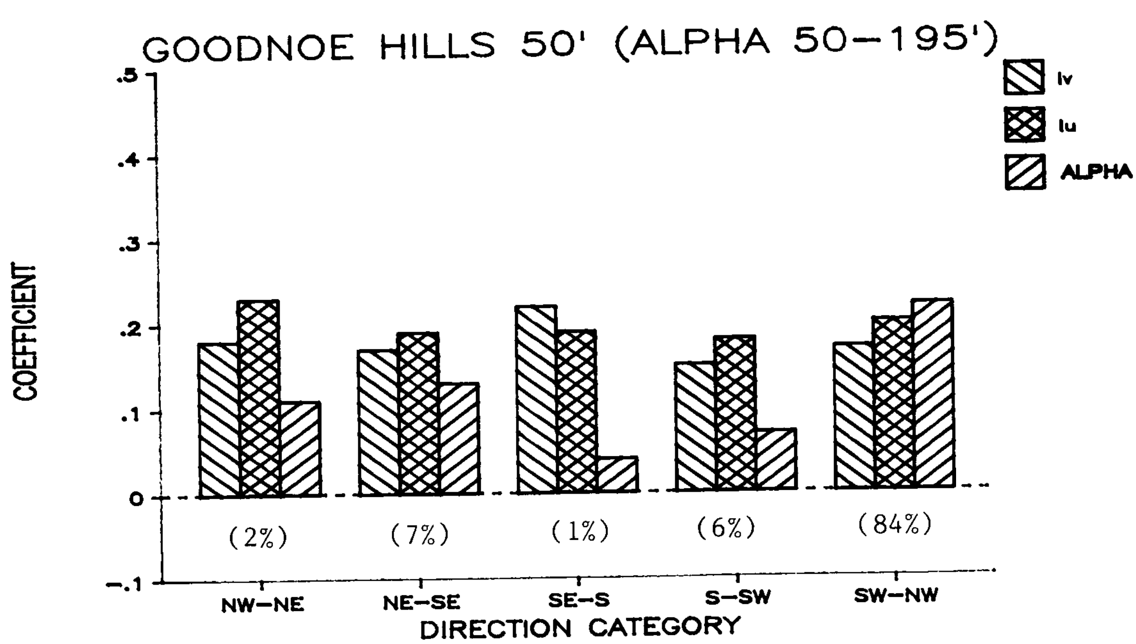

Figure 3-5. Crosswind (Iv), Downwind (Iu) Turbulence Intensity and power law coefficient at Goodnoe Hills (50 ft) as a function of wind direction. Percent of winds from each direction is enclosed in parentheses.

Table 3-7. Annual Summary Statistics for Goodnoe Hills.

GOODNOE HILLS

Data Period: Jun. 1986 - May 1987 Site Elevation: 2640 ft

Wind Statistics

Anemometer Level:	50 ft	Data Recovery Rate:	97.3%
Average Speed:	10.3 mph	Power Density:	136 W/M**2
Available Energy:	1194 KWh/M**2	% Time (Speed 12.0 - 60.0):	37.7%
Maximum (1 Hr Avg):	40.2 mph	Maximum Gust:	58.4 mph
Date: 2/24 - 000		Date: 2/24 - during hour 1000	
Shape Factor:	1.57	Scale Factor:	11.4 mph
Standard Deviation of Hourly Wind Speeds:			6.78

Wind Statistics

Anemometer Level:	195 ft	Data Recovery Rate:	86.7%
Average Speed:	13.2 mph	Power Density:	299 W/M**2
Available Energy:	2618 KWh/M**2	% Time (Speed 12.0 - 60.0):	49.6%
Maximum (1 Hr Avg):	45.4 mph	Maximum Gust:	60.3 mph
Date: 2/24 - 000		Date: 2/23 - during hour 2200	
Shape Factor:	1.52	Scale Factor:	14.7 mph
Standard Deviation of Hourly Wind Speeds:			9.01

Alpha Value (50 ft - 195 ft): 0.185

Estimated Turbine Energy Output (Normalized to period of record)

Turbine Type:	NORDTANK 65 KW	ENERTECH 300 KW	FLO-190 300 KW	USWP 56 100 KW
Hub Height:	75 ft	100 ft	57 ft	60 ft
Swept Area:	201 M**2	730 M**2	347 M**2	229 M**2
Est Total Energy*:	45853 kWh	226306 kWh	54813 kWh	40946 kWh
Capacity Factor*:	0.079	0.086	0.021	0.047
Efficiency Factor**:	0.289	0.335	0.233	0.257
Alpha Factor Used:	0.185	0.185	0.185	0.185

Turbine Type:	DYNERGY 180 KW
Hub Height:	160 ft
Swept Area:	308 M**2
Est Total Energy*:	100689 kWh
Capacity Factor*:	0.056
Efficiency Factor**:	0.272
Alpha Factor Used:	0.185

* Assuming 100% availability

** Estimated monthly energy, KWh/(Available energy, KWh/M**2)(Swept area, M**2)

Hampton Butte

Data recovery at Hampton Butte was much better this year at Hampton Butte. This was the first year data had were collected in January, February and March when access to the site is poor. However problems still occurred and the data recovery rate was only 75%. The winds during the first three months of the year are strong as had been anticipated averaging about 18 mph. The site experienced no gusts above 70 mph, but as Figure 3-6 shows the site has moderately turbulent winds from all directions.

Table 3-8 shows that the gross annual energy output for a US Windpower turbine would be about 190,000 kWh per year. The sites mean annual wind speed is 14.9 mph.

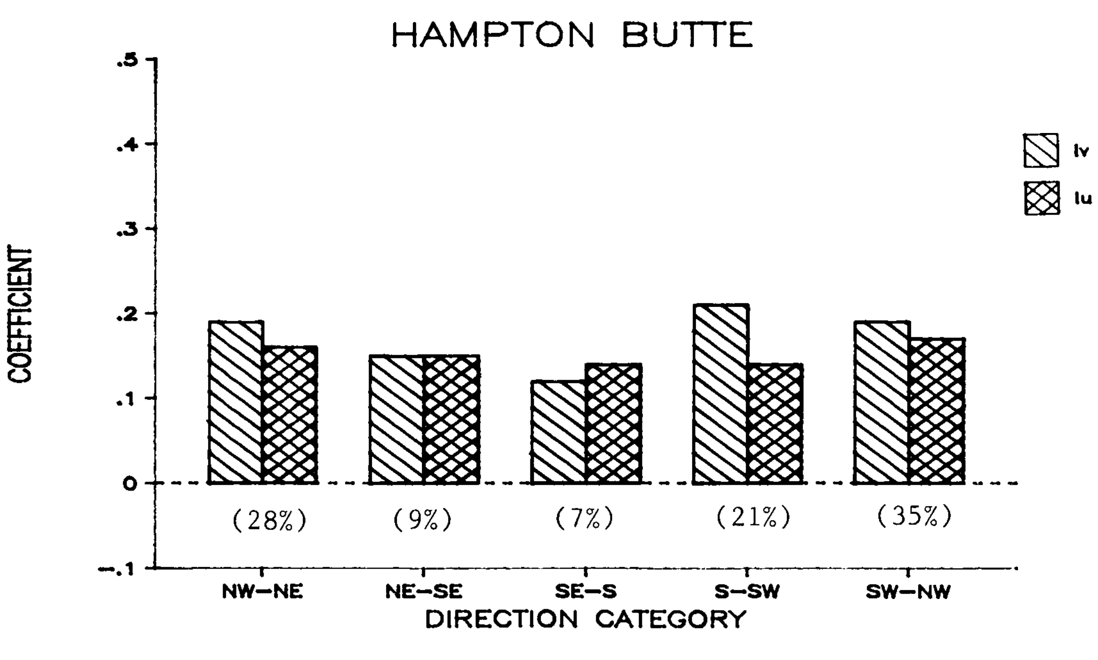

Figure 3-6. Crosswind (Iv) and Downwind (Iu) Turbulence Intensity Coefficient at Hampton Butte (34 ft) as a function of wind direction. Percent of winds from each direction is enclosed in parentheses.

Table 3-8. Annual Summary Statistics for Hampton Butte

HAMPTON BUTTE

Data Period: June 1986 - May 1987 Site Elevation: 6343 ft

Wind Statistics

Anemometer Level:	34 ft	Data Recovery Rate:	75.2%
Average Speed:	14.9 mph	Power Density:	278 W/M**2
Available Energy:	2434 KWh/M**2	% Time (Speed 12.0-60.0):	62.2%
Maximum (1 Hr Avg):	48.5 mph	Maximum Gust:	69.5 mph
Date: 3/ 4 - 1600		Date: 3/ 4 - during hour 1600	
Shape Factor:	2.09	Scale Factor:	16.8 mph
Standard Deviation of Hourly Wind Speeds:			7.57

Estimated Turbine Energy Output (Normalized to period of record)

Turbine Type:	NORDTANK 65 KW	ENERTECH 300 KW	FLO-190 300 KW	USWP 56 100 KW
Hub Height:	75 ft	100 ft	57 ft	60 ft
Swept Area:	201 M**2	730 M**2	347 M**2	229 M**2
Est Total Energy*:	150643 kWh	658240 kWh	295312 kWh	189641 kWh
Capacity Factor*:	0.261	0.250	0.112	0.216
Efficiency Factor**:	0.243	0.268	0.299	0.287
Alpha Factor Used:	0.100	0.100	0.100	0.100

Turbine Type:	DYNERGY 180 KW
Hub Height:	160 ft
Swept Area:	308 M**2
Est Total Energy*:	296224 kWh
Capacity Factor*:	0.165
Efficiency Factor**:	0.248
Alpha Factor Used:	0.100

* Assuming 100% availability
** Estimated monthly energy, KWh/(Available energy, KWh/M**2)(Swept area, M**2)

Kennewick

Data recovery was 95% at Kennewick this year. The mean speed measured was 16 mph at 105 ft and the available energy was nearly 5000 kWh/m^2 for the period (see Table 3-9).

Figure 3-7 compares the two components of Turbulence Intensity for several wind directions. The prevailing wind is south through south- southwest and for that direction sector turbulence is low. It should be kept in mind that the anemometer height is higher at this site than most others in this report.

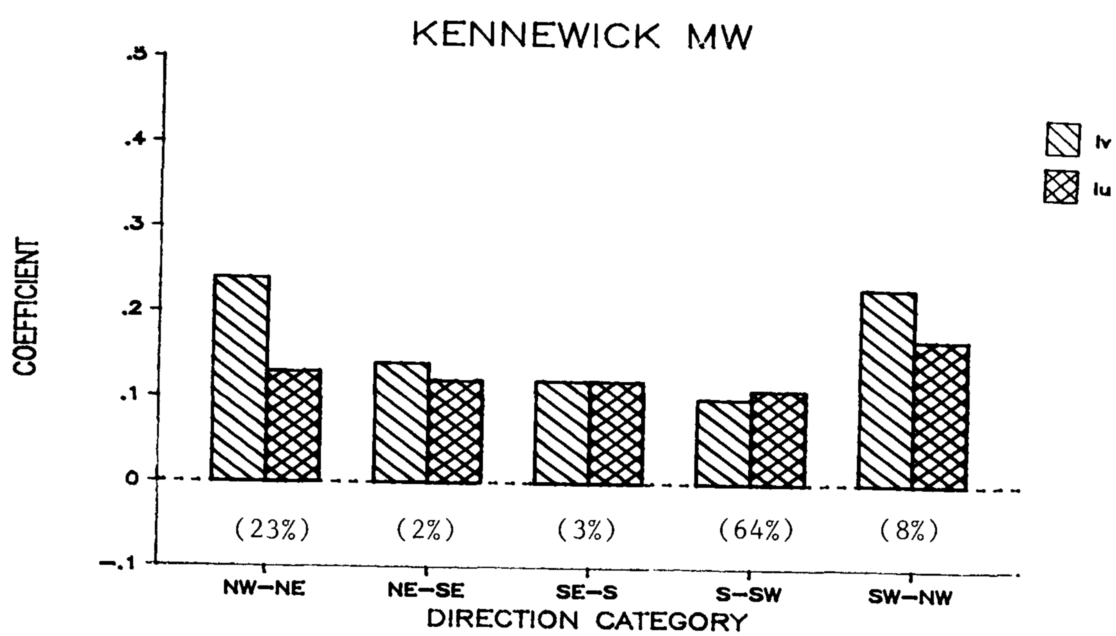

Figure 3-7. Crosswind (Iv) and Downwind (Iu) Turbulence Intensity Coefficient at Kennewick (105 ft) as a function of wind direction. Percent of winds from each direction is enclosed in parentheses.

Table 3-9. Annual Summary Statistics for Kennewick.

Kennewick 105

Data Period: Jun. 1986 - May 1987 Site Elevation: 2200 ft

Wind Statistics

Anemometer Level	105 ft	Data Recovery Rate:	95.0%
Average Speed:	16.0 mph	Power Density:	564 W/M**2
Available Energy:	4944 KWh/M**2	% Time (Speed 12.0-60.0):	54.5%
Maximum (1 Hr Avg):	65.4 mph	Maximum Gust:	76.1 mph
Date: 11/23 - 1400		Date: 11/23 - during hour 1400	
Shape Factor:	1.52	Scale Factor:	17.7 mph
Standard Deviation of Hourly Wind Speeds:			10.89

Estimated Turbine Energy Output (Normalized to period of record)

Turbine Type:	NORDTANK 65 KW	ENERTECH 300 KW	FLO-190 300 KW	USWP 56 100 KW
Hub Height:	75 ft	100 ft	57 ft	60 ft
Swept Area:	201 M**2	730 M**2	347 M**2	229 M**2
Est Total Energy*:	163950 kWh	728786 kWh	373988 kWh	211134 kWh
Capacity Factor*:	0.284	0.277	0.142	0.241
Efficiency Factor**:	0.182	0.205	0.262	0.221
Alpha Factor Used:	0.100	0.100	0.100	0.100

Turbine Type:	DYNERGY 180 KW
Hub Height:	160 ft
Swept Area:	308 M**2
Est Total Energy*:	339426 kWh
Capacity Factor*	0.189
Efficiency Factor**:	0.196
Alpha Factor Used:	0.100

* Assuming 100% availability

** Estimated monthly energy, KWh/(Available energy, KWh/M**2)(Swept area, M**2)

Kittitas Microwave

Data recovery at Kittitas was about 90% during the past year and the measured mean annual wind speed was 11.4 mph. The winds this year were about 12% weaker than normal. Statistics for the site are presented in Table 3-10 and a comparison of Turbulence Intensity coefficients for various wind directions are presented in Figure 3-8. The large crosswind Turbulence Intensity for the northwest - northeast sector indicates more friction or wind flow obstructions are present in that sector. Another possible reason for the enormous difference between the magnitudes of the two components of Turbulence Intensity could be due to a "dead band" problem in the direction potentiometer. This would result in occasional opens in the circuit when the wind was from "dead band" direction resulting in large Iv values.

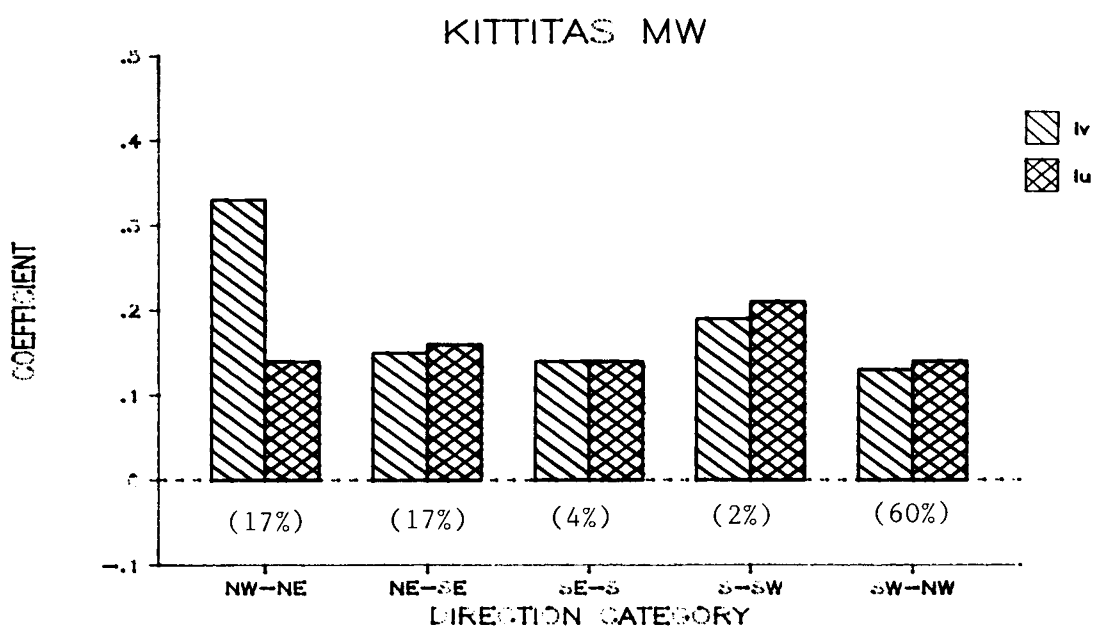

Figure 3-8. Crosswind (Iv) and Downwind (Iu) Turbulence Intensity Coefficient at Kittitas Microwave (110 ft) as a function of wind direction. Percent of winds from each direction is enclosed in parentheses.

Table 3-10. Annual Summary Statistics at Kittitas Microwave.

KITTITAS M/W

Data Period: Jun. 1986 - May 1987 Site Elevation: 2660 ft

Wind Statistics

Anemometer Level:	110 ft	Data Recovery Rate:	91.4%
Average Speed:	11.4 mph	Power Density:	223 W/M**2
Available Energy:	1952 KWh/M**2	% Time (Speed 12.0-60.0):	38.8%
Maximum (1 Hr Avg):	50.6 mph	Maximum Gust:	65.9 mph
Date: 3/26 - 100		Date 3/26 - during hour 100	
Shape Factor:	1.40	Scale Factor:	12.5 mph
Standard Deviation of Hourly Wind Speeds:			8.32

Estimated Turbine Energy Output (Normalized to period of record)

Turbine Type:	NORDTANK 65 KW	ENERTECH 300 KW	FLO-190 300 KW	USWP 56 100 KW
Hub Height:	75 ft	100 ft	57 ft	60 ft
Swept Area:	201 M**2	730 M**2	347 M**2	229 M**2
Est Total Energy *:	88229 kWh	386970 kWh	166018 kWh	106210 kWh
Capacity Factor*:	0.153	0.147	0.063	0.121
Efficiency Factor**:	0.252	0.280	0.298	0.285
Alpha Factor Used:	0.100	0.100	0.100	0.100

Turbine Type:	DYNERGY 180 KW
Hub Height:	160 ft
Swept Area:	308 M**2
Est Total Energy*:	170946 kWh
Capacity Factor*:	0.095
Efficiency Factor**:	0.254
Alpha Factor Used:	0.100

* Assuming 100% availability

** Estimated monthly energy, KWh/(Available energy, KWh/M**2)(Swept area, M**2)

Pequop Summit

The Pequop Summit site had poor data recovery during the period (50%). The data recording system failed at the site resulting in no data between November and May. The statistics are presented in Table 3-11.

These statistics should be used with caution because of the data is not representative of a whole year. The turbine energy outputs are normalized to a year, but when the strongest wind season is missing the normalization is ineffectual.

The wind speeds measured at Pequop Summit also appeared to be uncharacteristically weak. The wind speeds were compared to nearby Pequop Tower's 50 and 150 ft levels to rule out regional climatic variation. Based on that analysis a factor of 1.29 was used to adjust up the speeds at this site from May 1986 until the present anemometer is recalibrated. The statistics in Table 3-11 are corrected.

The variation of Turbulence Intensity is presented in Figure 3-9 for Pequop Summit. Note the large crosswind component Iv at this site. One reason for this is that the anemometer is only 30 feet above ground. It is important to note again that these turbulence statistics are only computed for the speed range 10 to 97 mph.

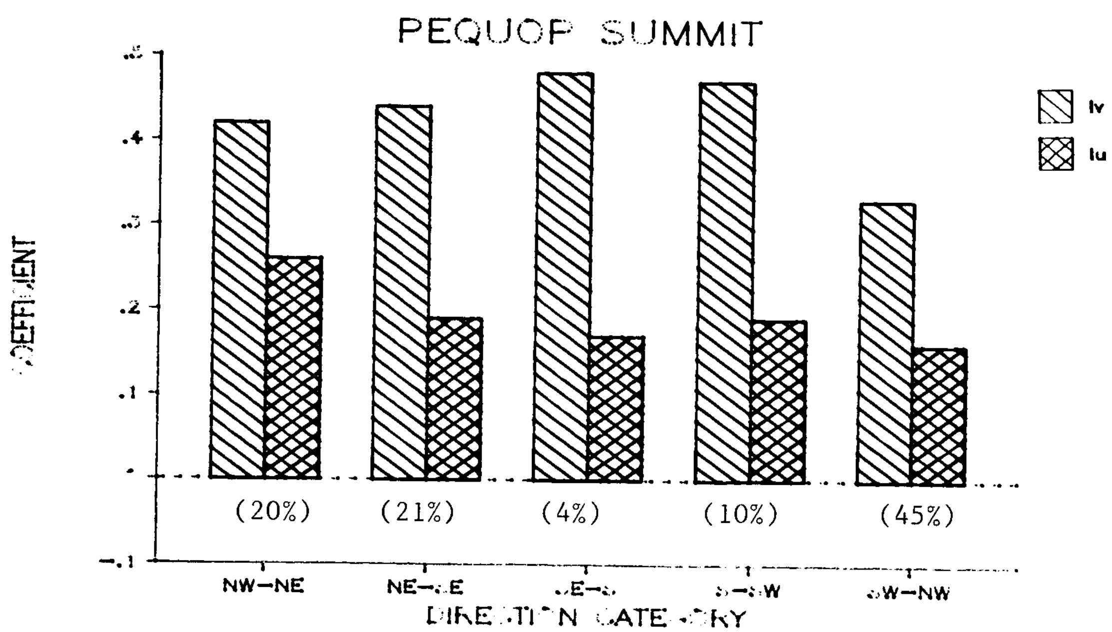

Figure 3-9. **Crosswind (Iv) and Downwind (Iu) Turbulence Intensity Coefficient at Pequop Summit (30 ft) as a function of wind direction. Percent of winds from each direction is enclosed in parentheses.**

Table 3-11. Annual Summary Statistics for Pequop Summit.

PEQUOP SUMMIT

Data Period: Jun. 1986 - May 1987 | Site Elevation: 7530 ft

Wind Statistics

Anemometer Level:	30 ft	Data Recovery Rate:	50.3%
Average Speed:	15.6 mph	Power Density:	396 W/M**2
Available Energy:	3468 KWh/M**2	% Time (Speed 12.0 - 60.0)	59.6%
Maximum (1 Hr Avg):	57.0 mph	Maximum Gust:	58.4 mph
Date: 11/22 - 1200		Date: 6/ 5 - during hour 1600	
Shape Factor:	1.66	Scale Factor:	17.4 mph
Standard Deviation of Hourly Wind Speeds:			9.75

Estimated Turbine Energy Output (Normalized to period of record)

Turbine Type:	NORDTANK 65 KW	ENERTECH 300 KW	FLO-190 300 KW	USWP 56 100 KW
Hub Height:	75 ft	100 ft	57 ft	60 ft
Swept Area	201 M**2	730 M**2	347 M**2	229 M**2
Est Total Energy*:	35927 kWh	151823 kWh	64863 kWh	41719 kWh
Capacity Factor*:	0.062	0.058	0.025	0.048
Efficiency Factor**:	0.236	0.268	0.253	0.245
Alpha Factor Used:	0.030	0.030	0.030	0.030

Turbine Type:	DYNERGY 180 KW
Hub Height:	160 ft
Swept Area:	308 M**2
Est Total Energy*:	56999 kWh
Capacity Factor*:	0.032
Efficiency Factor**:	0.228
Alpha Factor Used:	0.030

* Assuming 100% availability

** Estimated monthly energy, KWh/(Available energy, KWh/M**2)(Swept area, M**2)

NOTE: Speed statistics have been adjusted by a factor of 1.29 to account for error in the anemometer measurements.

Pequop Tower

The Pequop Tower has been in operation since 1982. Data recovery this year was 84% and the mean 50 ft speed was 14.5 mph. The statistics for the site are presented in Table 3-12.

Figure 3-10 provides a graphic comparison of the Turbulence Intensity and power law coefficients for various wind directions. The data indicate that shear (represented by the power law coefficient alpha) is low and turbulence is moderate.

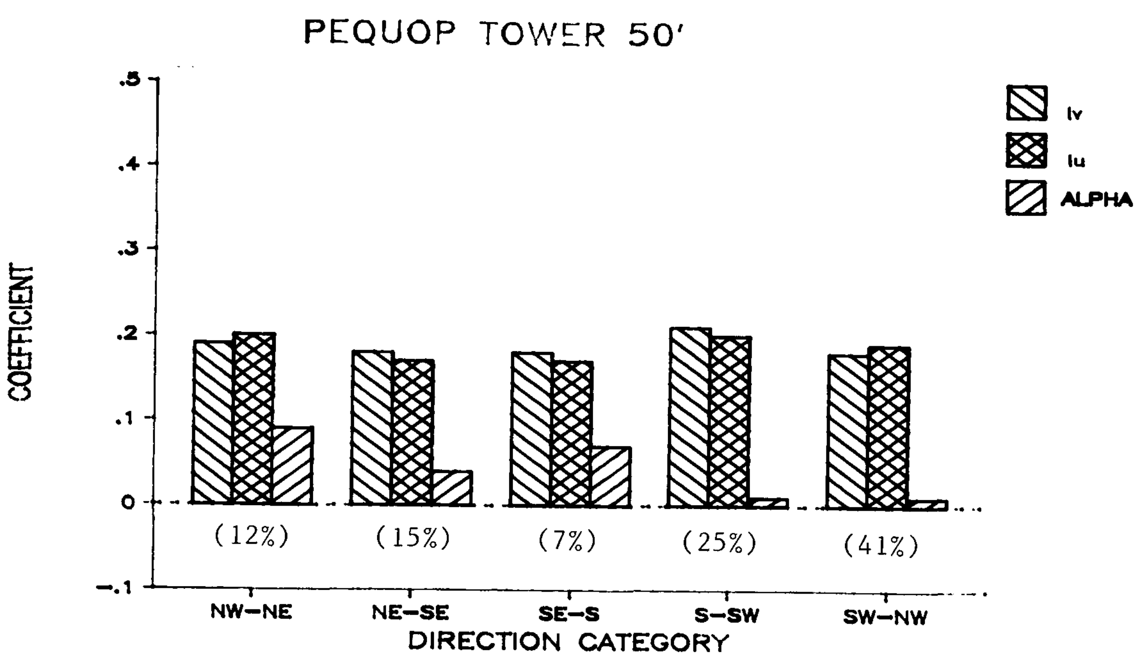

Figure 3-10. Crosswind (Iv), Downwind (Iu) Turbulence Intensity and power law coefficient alpha at Pequop Tower (50 ft) as a function of wind direction. Percent of winds from each direction is enclosed in parentheses.

Table 3-12. Annual Summary Statistics for Pequop Tower.

PEQUOP TOWER

Data Period: Jun. 1986 - May 1987 Site Elevation: 7540 ft

Wind Statistics

Anemometer Level:	50 ft	Data Recovery Rate:	83.6%
Average Speed:	14.5 mph	Power Density:	318 W/M**2
Available Energy:	2789 KWh/M**2	% Time (Speed 12.0 - 60.0):	54.1%
Maximum (1 Hr Avg):	67.0 mpa	Maximum Gust:	87.6 mph
Date: 7/ 4 - 1700		Date: 7/ 4 - during hour 1600	
Shape Factor:	1.69	Scale Factor:	16.3 mph
Standard Deviation of Hourly Wind Speeds:			8.92

Wind Statistics

Anemometer Level:	150 ft	Data Recovery Rate:	83.5%
Average Speed:	15.9 mph	Power Density:	375 W/M**2
Available Energy:	3284 KWh/M**2	% Time (Speed 12.0 - 60.0):	62.2%
Maximum (1 Hr Avg):	66.9 mph	Maximum Gust:	82.4 mph
Date: 7/ 4 - 1700		Date: 7/ 4 - during hour 1700	
Shape Factor:	1.85	Scale Factor:	17.9 mph
Standard Deviation of Hourly Wind Speeds:			9.02

Alpha Value (50 ft - 150 ft): 0.083

Estimated Turbine Energy Output (Normalized to period of record)

Turbine Type	NORDTANK 65 KW	ENERTECH 300 KW	FLO-190 300 KW	USWP 56 100 KW
Hub Height:	75 ft	100 ft	57 ft	60 ft
Swept Area:	201 M**2	730 M**2	347 M**2	229 M**2
Est Total Energy*:	102572 kWh	452030 kWh	201426 kWh	129152 kWh
Capacity Factor*:	0.177	0.172	0.077	0.147
Efficiency Factor**:	0.217	0.246	0.265	0.254
Alpha Factor Used:	0.083	0.083	0.083	0.083

Turbine Type:	DYNERGY 180 KW
Hub Height:	160 ft
Swept Area:	308 M**2
Est Total Energy*:	195017 kWh
Capacity Factor*:	0.109
Efficiency Factor**:	0.223
Alpha Factor Used:	0.083

* Assuming 100% availability

** Estimated monthly energy, KWh/(Available energy, KWh/M**2)(Swept area, M**2)

Seven Mile Hill Tower

Data have been collected at Seven Mile Hill, near The Dalles Oregon, since 1978. The tower has two anemometer levels at 50 and 150 ft. The 1986-87 statistics are presented in Table 3-13. The most notable statistic is the power law coefficient or alpha value of 0.03. This low value means that the terrain is smooth from the prevailing wind direction. Alpha values are low for other direction sectors (see Figure 3-11) at this site and even negative for the NW-NE sector. A negative shear coefficient is indicative of low level acceleration. However the were only 19 cases for that sector for 1986-87. For the entire period of record alpha for NW-NE was 0.03 (402 cases). Turbulence Intensity is low for the prevailing wind direction sector SW-NW. The high turbulence for wind flow with a southerly component indicates the roughness and more rugged terrain in that direction.

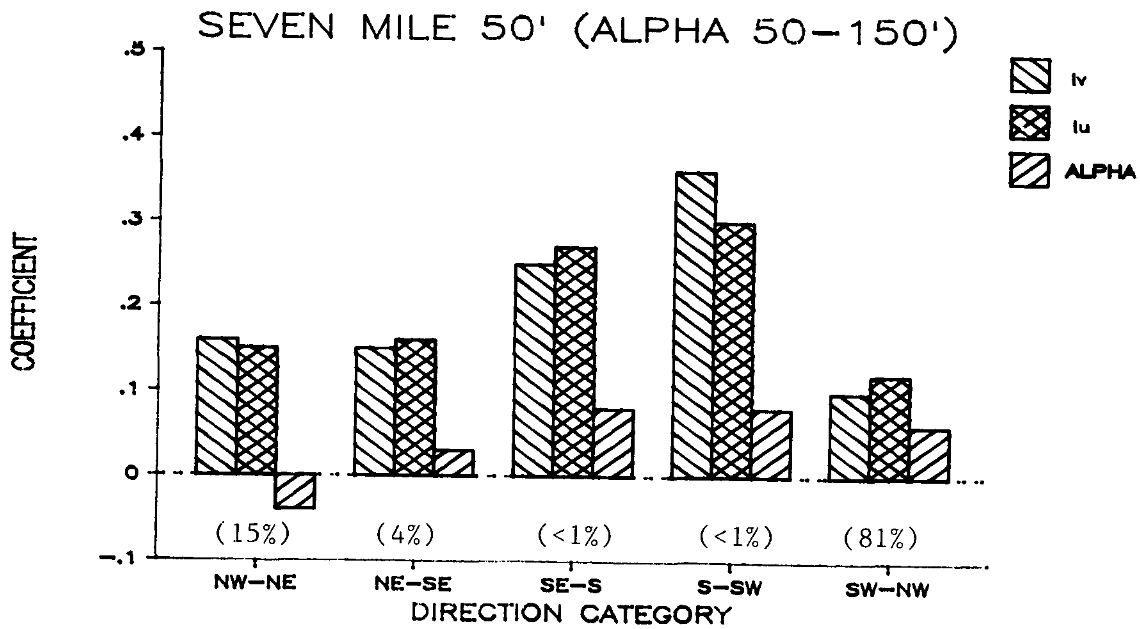

Figure 3-11. Crosswind (Iv), Downwind (Iu) Turbulence Intensity and power law coefficient alpha at Seven Mile Hill Tower (50 ft) as a function of wind direction. Percent of winds from each direction is enclosed in parentheses.

Table 3-13. Annual Summary Statistics for Seven Mile Hill Tower.

SEVEN MILE HILL

Data Period: Jun. 1986 - May 1987 | Site Elevation: 1880 ft

Wind Statistics

Anemometer Level:	50 ft	Data Recovery Rate:	86.2%
Average Speed:	13.6 mph	Power Density:	368 W/M**2
Available Energy:	3222 KWh/M**2	% Time (Speed 12.0 - 60.0):	49.0%
Maximum (1 Hr Avg):	45.2 mph	Maximum Gust:	61.2 mph
Date: 5/27 - 1500		Date: 11/18 - during hour 1900	
Shape Factor:	1.39	Scale Factor:	14.9 mph
Standard Deviation of Hourly Wind Speeds:			10.00

Wind Statistics

Anemometer Level:	150 ft	Data Recovery Rate:	89.9%
Average Speed:	14.0 mph	Power Density:	432 W/M**2
Available Energy:	3787 KWh/M**2	% Time (Speed 12.0 - 60.0):	49.3%
Maximum (1 Hr Avg):	48.2 mph	Maximum Gust:	61.3 mph
Date: 3/26 - 500		Date: 11/18 - during hour 1900	
Shape Factor:	1.33	Scale Factor:	15.2 mph
Standard Deviation of Hourly Wind Speeds:			10.79

Alpha Value (50 ft - 150 ft): 0.030

Estimated Turbine Energy Output (Normalized to period of record)

Turbine Type:	NORDTANK 65 KW	ENERTECH 300 KW	FLO-190 300 KW	USWP 56 100 KW
Hub Height:	75 ft	100 ft	57 ft	60 ft
Swept Area:	201 M**2	730 M**2	347 M**2	229 M**2
Est Total Energy*:	141225 kWh	591972 kWh	305717 kWh	188411 kWh
Capacity Factor*:	0.244	0.225	0.116	0.215
Efficiency Factor**:	0.242	0.272	0.311	0.289
Alpha Factor Used:	0.030	0.030	0.030	0.030

Turbine Type:	DYNERGY 180 KW
Hub Height:	160 ft
Swept Area:	308 M**2
Est Total Energy*:	254342 kWh
Capacity Factor*:	0.142
Efficiency Factor**:	0.265
Alpha Factor Used:	0.030

* Assuming 100% availability

** Estimated monthly energy, KWh/(Available energy, KWh/M**2)(Swept area, M**2)

Spring Creek Hatchery

An anemometer is located in Columbia River Gorge on a 76 ft pole at the Spring Creek Fish Hatchery. Statistics for the past year are presented in Table 3-14. The data recovery for this site only 69%. Most of the problem at this site was with the tape recorder for the data logger. Numerous problems were encountered reading tapes during the past year. The tape recorder was changed and the problems diminished but did not disappear. A better quality of cassette tape will be used in the future.

Because of the large seasonal wind speed variation (see Table 3-1) and low data recovery at this location, normalized energy statistics presented in Table 3.14 are subject to error in estimates of gross annual energy output.

The Turbulence Intensities for this site are moderate except for the rare case of northerly wind flow. The crosswind component Iv is less than the downwind Iu except for the NW-NE sector indicating a well exposed anemometer and few wind flow obstructions in the other direction sectors (see Figure 3-12).

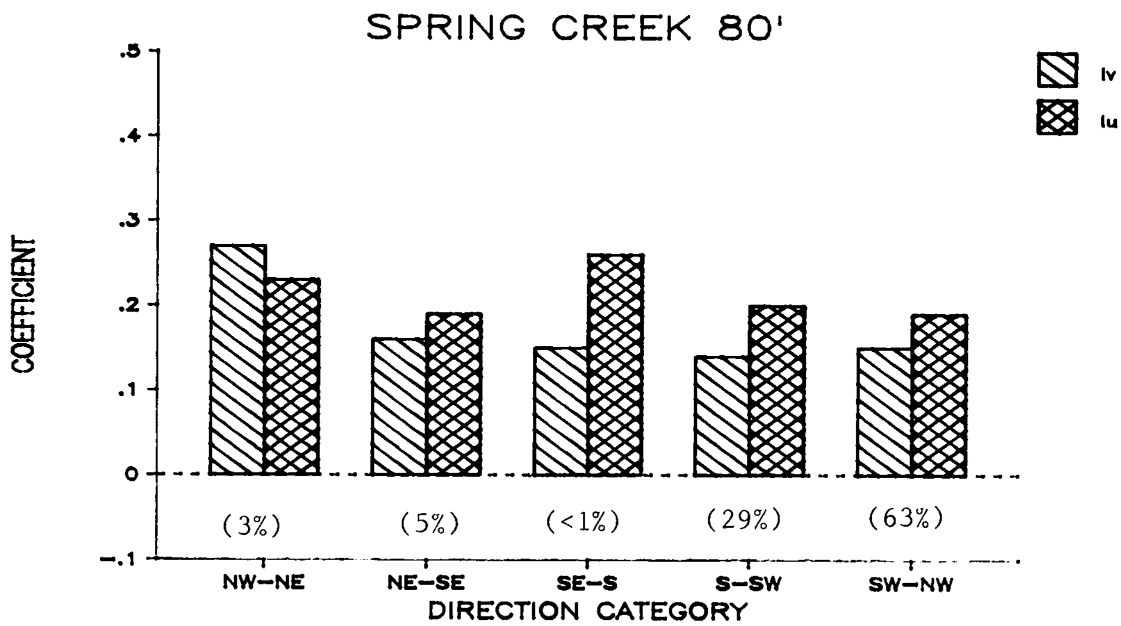

Figure 3-12. **Crosswind (Iv) and Downwind (Iu) Turbulence Intensity Coefficient at Spring Creek Hatchery (76 ft) as a function of wind direction. Percent of winds from each direction is enclosed in parentheses.**

Table 3-14. Annual Summary Statistics for Spring Creek Hatchery.

SPRING CREEK HATCHERY

Data Period: Jun. 1986 - May 1987 — Site Elevation: 37 ft

Wind Statistics

Anemometer Level:	76 ft	Data Recovery Rate:	69.0%
Average Speed:	9.4 mph	Power Density:	168 W/M**2
Available Energy:	1472 KWh/M**2	% Time (Speed 12.0 - 60.0):	33.8%
Maximum (1 Hr Avg):	41.8 mph	Maximum Gust:	67.0 mph
Date: 7/22 - 1200		Date: 6/28 - during hour 300	
Shape Factor:	1.18	Scale Factor:	9.9 mph
Standard Deviation of Hourly Wind Speeds:			8.07

Estimated Turbine Energy Output (Normalized to period of record)

Turbine Type:	NORDTANK 65 KW	ENERTECH 300 KW	FLO-190 300 KW	USWP 56 100 KW
Hub Height:	75 ft	100 ft	57 ft	60 ft
Swept Area:	201 M**2	730 M**2	347 M**2	229 M**2
Est Total Energy*:	85135 kWh	378019 kWh	149431 kWh	96601 kWh
Capacity Factor*:	0.147	0.144	0.057	0.110
Efficiency Factor**:	0.289	0.314	0.330	0.317
Alpha Factor Used:	0.140	0.140	0.140	0.140

Turbine Type:	DYNERGY 180 KW
Hub Height:	160 ft
Swept Area:	308 M**2
Est Total Energy*:	174835 kWh
Capacity Factor*:	0.098
Efficiency Factor**:	0.282
Alpha Factor Used:	0.140

* Assuming 100% availability

** Estimated monthly energy, KWh/(Available energy, KWh/M**2)(Swept area, M**2)

NOTE: **Low data recovery at this site may result in the estimated energy output having large error.**

Upper Pyle Canyon

Upper Pyle Canyon has had a data recovery rate of 83% during this past year. Early in the period there were some tape changing problems, but since then, data recovery has been excellent (see Table 3-1). The wind and energy statistics are presented in Table 3-15 and a turbulence analysis is graphically portrayed in Figure 3-13. The maximum gust at this site was 94.4 mph in February of 1987. The mean speed is 13.8 mph which is slightly stronger than the mean for this site for the period 3/84 - 5/86. The Turbulence Intensity is moderate for all directions (see Figure 3-13).

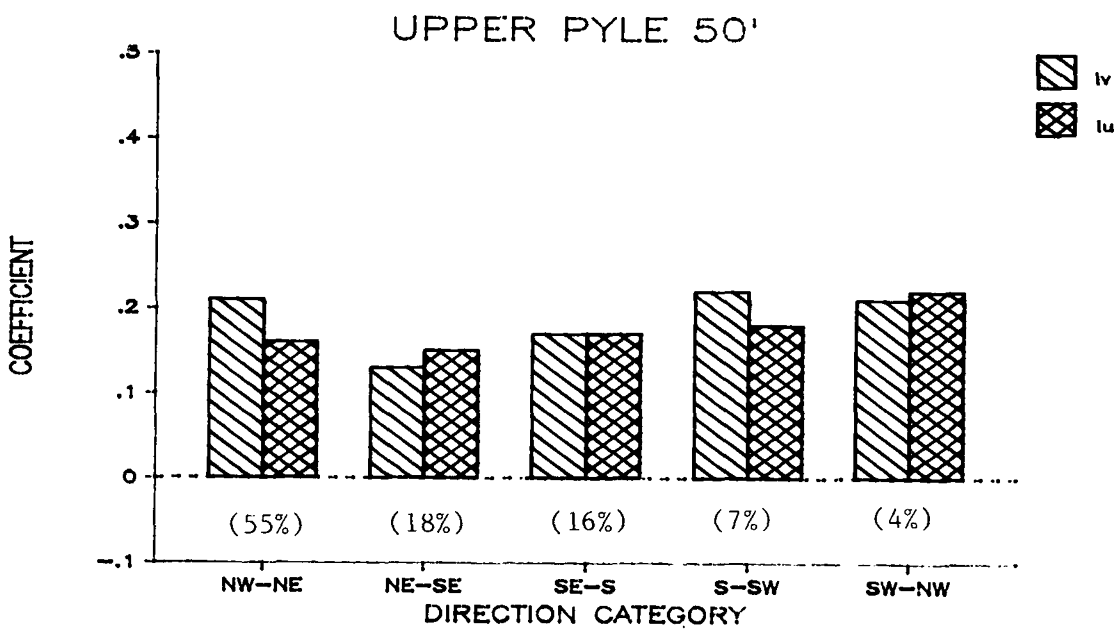

Figure 3-13. Crosswind (Iv), Downwind (Iu) Turbulence Intensity Coefficient at Upper Pyle Canyon (50 ft) as a function of wind direction. Percent of winds from each direction is enclosed in parentheses.

Table 3-15. Annual Summary Statistics for Upper Pyle Canyon.

UPPER PYLE CANYON

Data Period: Jun. 1986 - May 1987 | Site Elevation: 3660 ft

Wind Statistics

Anemometer Level:	50 ft	Data Recovery Rate:	83.1%
Average Speed:	13.8 mph	Power Density:	316 W/M**2
Available Energy:	2772 KWh/M**2	% Time (Speed 12.0 - 60.0):	54.4%
Maximum (1 Hr Avg):	61.8 mph	Maximum Gust:	94.4 mph
Date: 1/ 3 - 600		Date: 2/22 - during hour 1900	
Shape Factor:	1.61	Scale Factor:	15.4 mph
Standard Deviation of Hourly Wind Speeds:			8.90

Estimated Turbine Energy Output (Normalized to period of record)

Turbine Type:	NORDTANK 65 KW	ENERTECH 300 KW	FLO-190 300 KW	USWP 56 100 KW
Hub Height:	75 ft	100 ft	57 ft	60 ft
Swept Area:	201 M**2	730 M**2	347 M**2	229 M**2
Est Total Energy*:	139732 kWh	616834 kWh	284001 kWh	174818 kWh
Capacity Factor*:	0.242	0.235	0.108	0.200
Efficiency Factor**:	0.222	0.248	0.284	0.261
Alpha Factor Used:	0.100	0.100	0.100	0.100

Turbine Type:	DYNERGY 180 KW
Hub Height:	160 ft
Swept Area:	308 M**2
Est Total Energy*:	278331 kWh
Capacity Factor*:	0.155
Efficiency Factor**:	0.230
Alpha Factor Used:	0.100

* Assuming 100% availability
** Estimated monthly energy, KWh/(Available energy, KWh/M**2)(Swept area, M**2)

4.0 SENSITIVITY ANALYSIS OF POWER AND ENERGY CALCULATIONS TO TEMPERATURE AND PRESSURE VARIATIONS

Currently, the Wind Resource Assessment Laboratory programs use an elevation-based calculation to determine the air density at different sites. A more accurate calculation of air density is based on air temperature and pressure measurements using the ideal gas law. The present study compares these two methods of calculating air density, and their resulting effects on the calculation of wind power density and energy available. The elevation--based method uses the following polynomial to calculated air density [see Footnote 1]:

$$q = 1.1225 \sum_{i=0}^{8} (ai \cdot h^i)$$

where: q = air density in kg/m^3,

h = site elevation in feet,

a0 = 1,

a1 = -2.8639261 E-5,

a2 = -3.834012897 E-10,

a3 = 2.916875 E-13,

a4 = -6.022591146 E-17,

a5 = 6.817708334 E-21,

a6 = -4.332682292 E-25,

a7 = 1.450892857 E-29,

a8 = -1.995752728 E-34.

The more accurate temperature and pressure-based method calculates air density by assuming that air behaves as an ideal gas:

$$q = P/RT$$

where: q = air density (kg/m^3),

P = air absolute pressure (kg/m^2),

T = air absolute temperature (°K),

R = gas constant for air = 287.00 J/(kg°K).

The accuracy of the air density calculation affects the accuracy of both the wind power density and the energy available calculations because:

$$\textbf{Power density} = \textbf{Power/Area} = (q/2) \cdot V^3$$
$$\textbf{Energy Available} = \textbf{Power density} \cdot \textbf{Time} = (q/2) \cdot (V^3) \cdot \textbf{Time}$$

where: Power = the power in the wind,

Area = the area in the vertical plane perpendicular to the wind direction,

V = wind speed when the wind speed is between 12 and 60 mph,

V = 0 otherwise,

T = the amount of time that the wind speed is between 12 and 60 mph.

For any time period during which the wind speed is assumed constant (in our case one hour), the error percentage in the power density and energy available calculations will be exactly the same as the error percentage in the air density calculation [see Footnote 2]. Since wind speed varies and power and energy are proportional to the cube of the wind speed and only linearly with density, the air density percentage error will not generally be the same as the power and energy percentage error.

To determine the significance of these errors, 21 months of hourly wind and weather data at each of 3 sites were studied. The 3 sites, chosen for their differences in elevation and temperature variation, were: Albion Butte, at elevation 7110 ft, in the mountains of southern Idaho; Cape Blanco, at elevation 217 ft, on the southern Oregon coast; and Kennewick, at elevation 2200 ft, on the Columbia River in southern Washington.

Calculations of power density and energy available based on the 2 methods of calculating air density were compared on both an hourly and a monthly basis. For hours when temperature or pressure data were missing but velocity data was available, the elevation-based air density was assumed. The results are shown in Table 4-1, and summarized below.

The smallest monthly error was 1.53% and the largest was -5.83%. The average monthly error was -0.97% and the standard deviation was 1.64%. Errors were often positive in summer and negative in the winter.

Thus, over time, improving the air density calculation would improve the power and energy calculations by only about 1%. During the winter months at inland locations power is underestimated because the air is often cold and the density is larger. At coastal locations the ocean keeps air temperature closer to standard conditions (60°F).

Footnotes:

1. This polynomial was determined by Nick Butler of Bonneville Power Administration by curve-fitting an 8th-degree polynomial to Standard Atmosphere air density data.
2. Error refers to the accuracy of the elevation based calculations with respect to the temperature and pressure based calculations.

Table 4-1. **Calculation of energy errors from not accounting for temperature and pressure variations.**

SITE & MONTH	% VELOCITY DATA RECOVERY	% PRESS & TEMP DATA RECOVERY	MEAN HOURLY % ERROR	SIGMA HOURLY % ERROR	MONTHLY % ERROR
AL586	30.91	31.05	1.05	2.23	0.79
AL686	100.00	100.00	0.46	2.12	-0.48
AL786	100.00	100.00	0.46	1.89	-0.26
AL886	100.00	100.00	1.06	1.67	0.51
AL986	100.00	100.00	-1.86	2.19	-2.15
AL1086	72.58	72.45	-3.09	1.56	-2.95
AL687	41.94	41.94	0.38	2.03	-0.43
AL787	100.00	100.00	1.26	1.80	0.84
AL887	100.00	100.00	1.37	1.59	1.29
AL987	94.58	94.58	-0.03	2.16	-1.35
CB686	96.67	85.69	-0.73	0.82	-0.70
CB786	96.37	96.37	-1.01	0.76	-0.98
CB886	100.00	100.00	-1.20	0.67	-1.31
CB986	85.28	85.14	-0.55	0.80	-0.39
CB1086	74.87	97.18	-0.79	0.75	-0.10
CB1286	75.13	31.32	-0.18	0.70	-0.04
CB187	99.73	6.32	-0.06	0.30	-0.06
CB287	15.77	0.00	0.00	0.00	0.00
CB387	23.25	0.00	0.00	0.00	0.00
CB487	4.17	5.69	-1.24	0.55	-1.42
CB587	99.73	100.00	-1.68	0.87	-1.88
CB687	34.58	84.44	-1.50	0.74	-1.36
KN486	3.33	0.42	-0.37	0.76	-0.56
KN586	93.28	88.84	-1.13	2.11	-1.52
KN686	90.14	89.17	1.27	2.09	0.91
KN786	90.05	89.25	0.76	1.90	0.46
KN886	92.07	91.13	1.97	1.92	1.53
KN986	90.00	90.42	-1.38	1.59	-1.62
KN1086	100.00	100.00	-2.05	1.43	-2.47
KN1186	100.00	100.00	-4.95	1.67	-4.25
KN1286	80.78	98.79	-6.06	1.10	-5.83
KN187	97.98	99.60	-4.89	1.84	-4.71
KN287	99.55	99.40	-4.33	1.28	-3.84
KN387	99.87	99.87	-2.72	1.55	-2.39
KN487	100.00	100.00	-1.43	1.91	-1.72
KN587	100.00	100.00	-0.16	2.22	-0.96
KN687	100.00	100.00	0.63	2.36	-0.14
KN787	100.00	72.45	1.00	1.70	0.59
KN887	97.98	0.00	0.00	0.00	0.00
KN987	96.81	1.39	0.00	0.00	0.00
MEAN					-0.97
SIGMA					1.64

5.0 ECONOMIC UPDATE ON WIND ENERGY FEASIBILITY

5.1 Introduction

This section will examine the economics of wind energy in the Pacific Northwest. The intention is to provide an update of the analysis performed in BPA 86-20 Baker, et al. (1986). In this analysis some new assumptions will be made based on the current "state of the industry" in wind energy.

The cost of turbines has decreased moderately since 1986. The wind industry can now build and install turbines for $1,000 to $1,200 per kilowatt of capacity (see Lynette, 1987). There have been improvements in the performance and design but problems with performance have arisen that were not considered a few years ago. One serious problem is blade fouling by bugs or dust. Blade designers were aware that a rough blade would perform poorly. They assumed, however, that the blades would remain clean or be cleaned on a regular basis. In the last two years the industry has become acutely aware of this problem and taken measures to prevent losses of up to 10% or more.

Reliability has been a problem. Both operation and maintenance costs and downtime have cut into wind energy facility revenues. The cost of land resulted in an effort to pack turbines closer together and terms such as "dense pack" and "wind walls" were coined to describe the congested configurations of wind machines. In some cases the results were disastrous with many wind farm operators experiencing energy losses of up to 20% in tightly packed arrays.

The wind industry is no longer a collection of small investors and government funded test facilities. It now represents, in California alone, nearly $3,000,000,000 of installed equipment (Lynette, 1987). However the industry is not yet mature and is still learning from its mistakes rather than anticipating them.

In this section using up-to-date, but moderately conservative assumptions, the economics of wind energy in Pacific Northwest will be evaluated. The results show that economically wind turbines will not be cost competitive in this region, at even our best sites, unless the cost per installed kilowatt is less than $600.

5.2 Approach and Assumptions

The approach in this economic analysis was to compute energy output from the annual wind statistics at each site. When the site had less than a full year of data the statistics were normalized to a full year. Even the normalization process can not help if the data loss was too great. One site, Pequop Summit, was not included in the analysis because of only 50% data recovery.

The turbine used was the U S Windpower 100 kW wind system. The manufacturer's specifications for the sea level performance curve are corrected to the elevation of each of the Pacific Northwest wind energy sites.

To assess the cost of energy (COE) a simple economic model was used in which the levelized bus-bar cost of energy is given by the formula:

$$\mathbf{COE} = (((\mathbf{IC} \cdot \mathbf{FCR}) + \mathbf{LOM}) / (\mathbf{NAEOP})) \cdot (1 + \mathbf{LRR}) \qquad [1]$$

where:

COE = bus-bar cost of energy in $/kWh,
IC = installed cost (machine cost plus balance of plant, i.e. roads and, land and interconnect costs)
FCR = fixed charge rate,
LOM = levelized cost for operation and maintenance,
NAEOP = net annual energy output (defined below), and
LRR = land rent royalty.

The net annual energy output (NEOP) is given by:

$$\mathbf{NAEOP} = \mathbf{AEOP} \cdot \mathbf{SE} \cdot \mathbf{AF} \cdot \mathbf{AE} \cdot \mathbf{TE} \cdot \mathbf{BE} \qquad [2]$$

where:

AEOP = gross annual energy output in kWh/year,
SE = system efficiency which takes account of parasitic electrical losses and forced outages,
AF = availability factor (accounts for maintenance down time),
AE = array efficiency (accounts for turbine wake losses),
TE = turbulent wind capture efficiency, and

BE = blade performance efficiency factor (accounts for blade roughness caused performance losses should not be confused with the turbine energy capture efficiency which is accounted for in the factor AEOP).

The levelized operation and maintenance cost (LOM) are based on a formula by Lynette (1986) :

$$LOM = P_{rated} \cdot 315 \cdot RR^{-.75} \quad [3]$$

where:

P_{rated} = the rated power of the turbine (kW), and

RR = the rotor radius (ft).

The assumptions used in our model are listed in Table 5.1. These assumptions are not necessarily valid for each location in the Pacific Northwest because array losses will be negligible on ridges where only one row of turbines will be sited or in a location such as Browning, MT where the turbines could be widely spaced. Also some sites are more turbulent than others and coastal sites may have higher O&M costs because of corrosion than an inland site. Turbine availability and O&M costs will almost certainly be a function of the remoteness of the site. Cost will be higher and downtime longer at the most remote sites. Two sets of assumptions are used. One is what we feel represents typical numbers for the industry and the other is representative of the best of the industry.

5.3 Results

Table 5-2 presents the results of the economic analysis for 12 wind energy sites in the Pacific Northwest. These results indicate that the cost of energy given these 1987 assumptions is too high for economic feasibility here in this region. The cost of energy range from 5 to 55 cents per kWh. If the installed cost were to drop to half the value assumed in the typical case here the cost of energy at many sites would decrease to less than 50 mills/kWh. Also as improvements are made in turbine reliability and efficiency the cost of energy will decrease.

Table 5-1. Assumptions for the cost of energy model.

	PARAMETER	ASSUMED VALUE TYPICAL	ASSUMED VALUE BEST
LOM	levelized operation and maintenance costs	$100,000	$80,000
IC	installed cost	$100,000	$80,000
FCR	fixed charge rate	.15	.10
LOM	levelized operation and maintenance costs	$2,588	$2,588
LRR	land rent royalty	.05	.05
SE	system efficiency	.975	.975
AF	availability factor	.96	.98
AE	array efficiency	.90	.95
TE	turbulence efficiency	.98	.98
BE	blade efficiency	.95	.95
P_{rated}	rated power	100 kW	100 kW
RR	rotor radius	28 ft	28 ft
PERFORMANCE CHARACTERISTICS OF US WINDPOWER 100KW			

Table 5-2. Annual energy output and cost of energy at 12 Pacific Northwest wind survey sites.

SITE NAME	ANNUAL ENERGY OUTPUT (kWh)	COST OF ENERGY ($/kWh)	
		TYPICAL	BEST
ALBION BUTTE, ID	140732	.167	.093
BROWNING DEPOT, MT	209236	.113	.063
CAPE BLANCO, OR	275035	.086	.048
DUNCAN MTN, ID	109794	.214	.12
GOODNOE, WA	40946	.575	.321
HAMPTON BUTTE, OR	189641	.124	.069
KENNEWICK, WA	211134	.111	.062
KITTITAS, WA	106210	.222	.124
PEQUOP TOWER, NV	129152	.182	.102
SEVEN MILE, OR	188411	.125	.07
SPRING CREEK, WA	96601	.244	.136
UPPER PYLE, OR	174818	.135	.075

REFERENCES

Baker, R.W., J.E. Wade and S.N. Walker, 1986: Wind Turbine Performance and Array Spacing, BPA 86-20, Bonneville Power Administration, Portland, OR.

Baker, R.W. and J.E. Wade, 1985: Pacific Northwest Wind Regional Energy Assessment Program, Report BPA 85-19, Bonneville Power Administration, Portland, OR.

Lynette, R.L., 1986: The California Wind Farm Experience, Energy Technology Conference, Proceedings, March.

Lynette, R.L., 1987: Comments from Wind Energy Conference, Leeuwarden Netherlands, Reported in Wind Energy Weekly, November 29, 1987.

Persson, O.P., 1984: Wind Energy Assessment Studies in the Juniper Point Goodnoe-Hills Area, BPA Report 83-13, Bonneville Power Administration, Portland, OR.

Wade, J.E., R.W. Baker and K. Redmond: 1986: Regional Wind Energy Assessment Program Progress Report BPA 86-22. Bonneville Power Administration, Portland, Oregon.