MASTER

WIND POWER
OREGON STATE UNIVERSITY
DEPARTMENT OF ATMOSPHERIC SCIENCES

REPORT NO. BPA 80-5

OCTOBER 1980

EXECUTIVE SUMMARY

ON RESEARCH ON

NETWORK WIND POWER OVER THE PACIFIC NORTHWEST

PROGRESS REPORT, OCTOBER 1979 - SEPTEMBER 1980

PREPARED BY

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PRINCIPAL INVESTIGATORS

SUBMITTED TO THE
BONNEVILLE POWER ADMINISTRATION
PORTLAND, OREGON

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*Dr. Barber is now a professor in the Department of Meteorology at North Carolina State University.

Introduction

In 1975 the Bonneville Power Administration (BPA) contracted with Oregon State University (OSU) to investigate the wind power potential in The Dalles area of the Columbia River Gorge. Since 1975 wind power assessment activities have expanded to include the rest of the BPA service area. Several promising high wind sites have been found and undoubtedly many more remain to be discovered. Site prospecting is an integral part of the research program. Previous BPA Reports 76-1, 77-2, 78-3, and 79-4 have documented the progress of this research.

This research in FY80 is composed of six primary tasks. These tasks include data collection and analysis, wind flow studies around an operational wind turbine generator (WTG), kite anemometer calibration, wind flow analysis and prediction, the Klickitat County small wind energy conversion system (SWECS) program, and network wind power analysis. The data collection and analysis task consists of four sections, three of which deal with wind flow site surveys and the fourth with collecting and analyzing wind data from existing data stations.

The rest of this report summarizes the work accomplished in each of the major research areas.

Wind Data Analysis

As of September 1980 the wind data network consisted of 70 sites throughout the BPA service area. A map showing the site locations is given in Figure 1, and pertinent site information is given in Table 1. During the past 12 months, 12 new locations were instrumented with anemometers. Also, wind data were acquired from six existing anemometer sites operated by other agencies. Hourly speed and direction data are available for 21 of the sites, four to six hourly data are available at nine of the sites, five of the sites provide wind speed frequency distribution data, and mean monthly wind speed data are collected at 35 of the sites.

FIGURE 1. Wind data site locations.

An analysis was made at several of the wind data sites and the long-term National Weather Service sites to determine if there were significant variations in the mean monthly wind speeds from the climatological normal. The results indicated that during the summer (June-August 1979) the mean monthly wind speeds were 10-25% stronger along the Oregon coast and in the Willamette Valley in June and July, but were near normal in the interior. During the fall, significantly stronger than normal winds were recorded at Portland, as east winds prevailed in October and November. The high pressure center over the interior that created the east flow resulted in lighter than normal winds in the interior and along the southern Oregon coast. During the winter, lighter than normal wind (10-20%) occurred over the interior, and 15-20% stronger prevailing east flow was recorded at Portland and Astoria in December and February. Near normal winds were recorded along the southern

TABLE 1 Anemometer site data.

	Station Elevation MSL (ft)	Anemometer Height (ft)	Period of Record	Remarks*		Station Elevation MSL (ft)	Anemometer Height	Period of Record	Remarks*
1. Gold Beach	720	40	8/76-current	4	19. Mt. Hood Meadows	6600	30	1975-current	6
2. Hill Top	600	8	1/79-current 1968-72	4	20. Washougal	50	30	2/79-current	4
3. Cape Blanco CGLS	200	20	10/76-11/79	3	21. Augspurger Mtn.	2880	60, 150 40 75	12/76-1/78 4/75-4/78 7/78-current	1 1 1
4. Cape Blanco BPA	200	40	10/76-current	1	22. Mosier	640	40	2/77-current	4, 5
5. Wahl Ranch	100	30	8/79-current	4	23. Spring Creek	80	30	6/79-current	4
6. Knapp Ranch	20	30	8/79-current	4	24. KCIV	3120	45	6/74-current	1
7. Langlois Mtn.	1200	30	10/76-current	4	25. John Day Dam	200	40	6/78-current	1
8. Prairie Mtn.	3200	100	10/77-current	1	26. Sevenmile Hill	1840	40	3/77-current	4, 5
9. Race Rocks (BC)	100	30	1969-1976	1	27. Sevenmile Tower	1880	50, 150	10/78-current	1
10. King's Valley	400	30	9/78-current	4	28. Sauter RR	800	30	6/79-current	4
11. Bunker Hill	900	30	7/79-current	4	29. Sauter Ranch	1360	30	4/77-current	5
12. Newberg Ridge	1530	60	8/77-current	4	30. Goodnoe BPA Tower	2600	50, 195	4/80-current	1
13. Columbia River Jetty	15	40	12/77-9/79	7	31. Goodnoe 30 ft.	2600	30	11/79-8/80	1
14. Pioneer Airport	250	40	4/78-current	1	32. Goodnoe Hills	2565	45	4/76-current	1
15. Queets Hill	300	30	8/79-current	4	33. Juniper Point	3100	100	8/78-current	1
16. Cheeka Peak	1200	30	8/79-current	4	34. Roosevelt	1706	75	10/78-current	1
17. Friday Harbor	100	30	11/79-current	1	35. Wasco	1800	30	9/76-current	4
18. Sheridan	500	30	11/78-9/79	4	36. Shutler Flats	1200	40	9/76-12/79	4

*Remarks

1. Hourly average velocities taken from strip charts.
2. Five-minute average velocity observations taken hourly.
3. Velocity observations taken every four hours.
4. Monthly average speed data (wind-run anemometer).
5. Wind spectrum analyzer data.
6. Six-hour average velocities taken from strip charts.
7. Instantaneous hourly value.

*New

TABLE 1 (Cont.) Anemometer site data.

	Station Elevation MSL (ft)	Anemometer Height	Period of Record	Remarks*		Station Elevation MSL (ft)	Anemometer Height	Period of Record	Remarks*
37. Kittitas MW	2650	110	4/80-current	1	54. Signal Peak	5111	50	1977-1979	8
38. Boylston Mtn.	2400	20	4/80-current	1	55. Burns Butte	5307	35	12/76-5/79	4
39. Irrigon	300	30	2/78-current	4	56. Juniper Ranch	4200	30	6/78-11/79	4, 5
40. Kennewick	2050	105	6/76-current	1	57. Prineville Airport	3246	30	3/78-5/79	1
41. Sunnyside	3000	45	4/76-3/78 5/78-current	1 4	58. Coyote Hills	6700	35	9/76-3/79	4
42. Wanapum Dam	520	40	6/74-current	2	59. Adel	6571	50	8/76-4/78 4/78-3/79	4 1
43. Vantage Farms	890	30	4/78-current	4	60. Satus Lookout	4111	50	1977-1979	8
44. Mission Ridge	6730	30	1968-current	6	61. Valmy Tower	4700	33, 330	10/76-11/78	1
45. Stevens Pass	5100	30	1968-current	6	62. Mountain Home	3200	38	7/80-current	4
46. Crystal Mtn.	6870	40	1968-current	6	63. Wells West	6400	35	3/77-current	4
47. Mt. Baker	5040	30	1967-current	6	64. Radar Hill	5800	30	6/78-current	4
48. Bridger Bowl	8650	20	1968-current	6	65. Pequop Summit	7538	40	4/76-current	1
49. Jackson Hole	10,300	30	1968-current	6	66. Albion Butte	7000	38	7/80-current	4
50. Sun Valley	9100	20	1968-current	6	67. Hot Lakes	4400	30	9/78-current	4
51. John Day Ridge	5000	30	3/79-current	4	68. Pumpkin Ridge	3200	30	10/78-current	4
52. La Grande (Andrews)	3149	50	10/77-current	4	69. Cedar Butte	5000	38	10/80-current	4
53. Sopolia Lookout	4600	50	1977-1979	8	70. Menan Butte	5000	38	10/80-current	4

*Remarks

1. Hourly average velocities taken from strip charts.
2. Five-minute average velocity observations taken hourly.
3. Velocity observations taken every four hours.
4. Monthly average speed data (wind-run anemometer).
5. Wind spectrum analyzer data.
6. Six-hour average velocities taken from strip charts.
7. Instantaneous hourly value.

*New

Oregon coast. In the spring, the mean monthly wind speeds were generally lower than normal at all of the referenced sites, except higher than normal mean monthly speeds were recorded at Portland and Astoria.

The wind speeds measured at several of the wind power data sites indicated at least a 13 mph mean wind speed for the 12-month period June 79 - May 80 (reference Table 2). At the 25 sites that had winds measured for the entire period, 13 had mean speeds ≥ 13 mph. Partial data were available for this period at 29 sites. Of these sites, nine had at least a 13 mph mean wind speed. The mean period wind speed was ≥ 15 mph at eight sites which included Cape Blanco BPA, Langlois Mountain, Sevenmile Bell, Sevenmile Hill, Juniper Point, Goodnoe Hills, Kennewick, and Pequop Summit. Where only partial data were available, ≥ 15 mph mean speeds were recorded at Cheeka Peak, Augspurgen Mountain, Crystal Mountain, Bridger Bowl, and Jackson Hole.

Calibration of the Kite Anemometer

Kite anemometers have been extensively used by OSU scientists during the past two years to assist in defining the wind resource characteristics at several locations in the BPA service area. These portable anemometers have given valuable information on wind velocity change with height (wind profiles), turbulence levels, and the spatial variation of the wind flow in the lowest 400 feet of the atmosphere.

To describe the accuracy and precision of the handheld kite anemometer, several tests were made flying the sled-type kite next to tower-mounted anemometers and also next to each other. Thirty-eight calibration tests were made against nine tower-mounted anemometers. The calibration results indicated very good agreement with the tower anemometers, as the root mean square (RMS) error was .521 mph, the mean bias was +.008 mph, and the average error was 2.1%. The tests were made for wind speeds from 11-44 mph.

On several occasions the kite anemometers were flown next to each other in order to detect any significant differences which may be due to reading bias or systematic errors between kites. The mean speed differences ranged from 0.4-6.9% and averaged about 3%. The turbulence levels measured by the kites were also in good agreement.

Table 2. Mean monthly wind speeds (mph) at several of the wind power sites for the period June 1979 - May 1980

Station		1979							1980					
No.	Name	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Average
1	Gold Beach	10.9	6.9	M	15.6	16.4	13.3	16.1	13.2	10.5	14.5	15.5	12.2	13.2
2	Hill Top	M	10.8	M	6.6	10.8	11.2	17.9	10.0	14.5	10.0	14.6	M	11.8
4	Cape Blanco BPA	18.1	22.4 ¹	14.6	16.2	16.1	17.3	22.4	17.7 ¹	18.2	14.5	17.4	13.6 ¹	17.1
3	Cape Blanco CGLS	17.4	M	14.1	M	14.5	14.3	System removed						
5	Wahl Ranch				11.6	9.7	12.7	16.0	13.7	14.3	11.2	10.8	10.4	12.3
6	Knapp Ranch				M	10.2	M	System inoperative						
7	Langlois Mtn.	15.4	16.6	M	8.8	15.6	13.5	22.2	M	M	13.9	13.2	M	
8	Prairie Mtn.	10.8	9.4 ¹	M	15.3 ¹	13.7 ¹	15.3 ¹	12.7 ¹	15.1 ¹	17.6 ¹	M	10.2 ¹	11.7 ¹	13.5 ¹
10	Kings Valley	5.8	4.9	4.0	3.6	4.0	System removed							
18	Sheridan	9.4	5.8	6.9	M	5.8	System removed							
13	Col. River Jetty	11.2 ¹	11.6 ¹	M	13.2	M	System removed							
15	Queets				7.7	9.0	14.9	14.4	16.1	System inoperative				8.0
16	Cheeka Peak				18.9	15.1	21.5	System inoperative						
17	Friday Harbor						5.9	9.1	6.7	System inoperative				11.4 ¹
12	Newberg Ridge	6.6	7.0	5.6	9.6	11.4	M	11.2	11.9	12.7	8.9	9.4	7.1	9.2
14	Pioneer AP	12.8 ¹	9.3	11.6 ¹	7.5 ¹	6.4	5.7	6.5	5.9 ¹	M	7.0 ¹	7.9	7.1	7.6 ¹
11	Bunker Hill	11.2	13.0	10.3	8.1	7.8	6.9	7.4	11.9	10.3	7.4	9.2	6.7	9.2
20	Washougal								13.6	M	M	M	2.9	
21	Augspurger Mtn.	22.0	22.9	21.7	17.8	17.1	17.7 ¹	System inoperative						
23	Spring Creek	20.2	13.6	14.6	14.3	9.4	8.7	8.5	7.2	6.5	6.5	13.9	21.5	12.1
22	Mosier	15.0	16.0	15.2	10.0	7.6	6.2	9.0	5.7	5.1	10.7	9.7	14.2	10.4
26	Sevenmile Bell	23.3	22.9	22.6	16.1	13.8	10.4	9.2	9.6	6.7	15.6	15.3	20.5	15.5
27	Sevenmile Hill 50'	21.6 ¹	22.6	21.6	15.8	13.5	10.7	12.4	M	M	19.7	15.7	22.8	17.3 ¹
27	Sevenmile Hill 150'	24.5 ¹	25.1	23.6 ¹	17.7	14.7	14.9 ¹	14.0	11.3	10.3	20.7	17.5	26.5	17.7 ¹
28	Sauter RR	19.2	20.8	21.7	13.9	9.4	3.8	4.3	3.8	2.2	11.4	12.1	15.9	11.5
24	KCIV	15.4 ¹	15.2	13.8	12.6	13.4	11.6	13.5 ¹	14.2 ¹	14.5 ¹	18.9 ¹	13.3 ¹	15.8	14.1 ¹
35	Wasco	17.5	15.5	14.7	11.0	9.7	7.5	10.7	8.8	6.6	13.2	11.2	14.4	11.7
33	Juniper Point	25.2 ¹	23.6 ¹	20.1	19.3 ¹	17.9 ¹	13.8	21.6	17.0	15.3	25.7	20.0	24.7	20.3 ¹

M - Missing data 1 <85% recovery

Table 2. (Continued)

Station No.	Name	1979								1980					Average
		Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May		
25	John Day Dam	14.7	14.2	14.4	9.8	7.4	6.1	7.0	5.5	4.2	11.5	12.0	M	9.7	
32	Goodnoe Hills	20.3	21.2 ¹	M	15.3 ¹	12.2 ¹	8.5	14.8	10.9	10.3	18.6	16.0	20.0	15.0 ¹	
31	Goodnoe 30'						8.6 ¹	11.5 ¹	9.2	9.8 ¹	16.6 ¹	12.6	M		
30	Goodnoe BPA 50'												14.8 ¹		
30	Goodnoe BPA 195'												18.1 ¹		
34	Roosevelt	18.1	16.9	13.7	12.1	11.1	8.8	14.1	11.3	10.6	19.4	15.3	16.9	14.0	
36	Shutler Flat	12.8	14.3	System inoperative				7.8	System inoperative						
39	Irrigon	9.5	8.2	7.9	5.9	5.6	System inoperative								
40	Kennewick	17.4	22.4	17.7	17.1 ¹	16.2	8.7	18.6	12.9	12.2	19.5	16.8	16.0 ¹	16.2	
41	Sunnyside	M	15.0	13.5	12.0	12.0	9.9	9.9							
42	Wanapum Dam	17.3	15.6	14.9 ¹	10.5	8.8	7.1	9.8	8.7	6.6	13.1	12.0	15.0	11.5	
37	Kittitas MN										16.8 ¹	13.9	14.7		
38	Boylston Mtn.												15.7 ¹		
43	Vantage Farms		System inoperative												
68	Pumpkin Ridge	4.0	4.7	3.4	2.7	4.0	5.2	12.1	8.3	7.3	5.5	System removed		5.7	
52	La Grande (Andrews)	9.6	10.1	8.5	7.4	9.2	11.0	16.8	12.1	11.6	11.4	13.0	11.8	11.0	
67	Hot Lakes	M	10.9	7.2	System removed										
51	John Day Ridge									9.4	7.8	7.2			
56	Juniper Ranch	M	M	M	M	M	3.2	System inoperative							
47	Mt. Baker									5.7	7.8				
44	Mission Ridge							9.2	12.7	9.3	10.5				
45	Stevens Pass						6.6	8.2	8.2	8.1	7.8				
46	Crystal Mtn.							17.7	18.6	18.0	16.3				
19	Mt. Hood Meadows								12.0	M	15.2				
48	Bridger Bowl									15.2	15.6				
49	Jackson Hole							18.4	18.3	16.9	18.4				
50	Sun Valley								11.1	9.5	12.3				
65	Pequop Summit	14.6 ¹	M	M	M	17.1 ¹	17.3	15.3	19.2	15.2	20.3	14.3 ¹	12.4	16.2 ¹	
63	Wells West	M	M	17.2	12.7	7.7	14.9	9.6	14.7	14.3	15.2	14.1	9.6	13.3	
64	Radio Hill	11.6	11.2	19.2	13.4	17.7	14.5	6.7	M	15.3	10.8	8.1	M	12.9	

M - Missing data

¹ < 85% data recovery

Spatial Comparison of the Wind Flow in the Goodnoe Hills and Cape Blanco Area

Simultaneous kite anemometer measurements were taken at several locations in the Goodnoe Hills and Cape Blanco areas to determine the spatial variation in the wind flow. The 45-minute samples of wind velocity taken at the 50-, 200-, and 350-foot levels were compared to the wind velocity measured by in-place, base station anemometers. Measurements were taken several times during the 12-month period under moderate to strong prevailing wind flow conditions.

The spatial measurements made within three miles of the MOD-2 WTG area indicated noticeable differences on a seasonal basis. A map showing the measurement site locations is given in Figure 2. During the winter the winds were stronger east of the WTG area, whereas in the spring and summer the differences were not as noticeable. No data were taken in the fall. In most of the cases the coincident winds measured by the Juniper Point anemometer, about 10 miles west of Goodnoe Hills, were significantly stronger than those measured at Goodnoe. Also, the winds measured on the ridgetop sites at Juniper Point and Goodnoe Hills were generally much higher than those measured on the Columbia River at the John Day Dam. These differences were most noticeable during the winter.

Simultaneous wind velocity measurements were taken at several locations shown in Figure 2 in a 20-square-mile area on the ridgetop and slopes of Juniper Point. In contrast to the variation in the relationships between the wind speeds measured near the Goodnoe Hills WTG area, the gradient of the wind speed over the Juniper Point area appeared to be fairly uniform for the limited amount of data taken. For the most part, the ridge crest locations surveyed agreed quite closely with the Juniper Point anemometer measurements. All of the slope locations showed a 15-20% decrease in the wind speed compared to the base station Juniper Point anemometer on the top of the ridge. There was about a 25% decrease in the wind speed measured on the valley floor compared to the Juniper Point location.

Simultaneous wind velocity measurements were taken at the three MOD-2 sites on several occasions under moderate to strong westerly flow. The site locations are shown in Figure 2. Measurements were made with the kite anemometer at the 50-, 200-, and 350-foot levels. The average differences between the speeds measured at the three sites were small ($\leq 5\%$). However, on

CONTOUR INTERVAL 200 FEET
WITH SUPPLEMENTARY CONTOURS AT 100 FOOT INTERVALS
TRANSVERSE MERCATOR PROJECTION

FIGURE 2. Spatial wind measurement stations in the Goodnoe Hills/Juniper Point area. Fixed-place anemometers are located at Sites A, B, and C (Goodnoe Hills) and at Site D (Juniper Point) and at Site E (John Day Dam). The MOD-2 WTG locations are Sites 19, 20, and 24.

an individual sample basis, the differences ranged from -15% to +20%.

The wind flow measured at the three MOD-2 sites was compared to the winds measured at the 45-foot level at the long-term Goodnoe Hills anemometer site (Site A, .3 miles south of the WTG area) and the 50-foot level wind data from BPA meteorological tower, Site C, which is situated between WTG 2 and 3. The relationship of the flow measured in the WTG area to that measured at Site A varied by direction. For southwest winds, the WTG site and Site A speeds were in good agreement, under west flow the WTG site speeds were slightly less, and for west-northwest winds the wind speed was only 75-85% as strong at the BPA tower as that measured at Site A.

When comparing the coincident wind speeds measured at each WTG site to those at the BPA meteorological tower, the WTG site speeds averaged 4-9% stronger than the tower at the 50-foot level. At the 200-foot level the WTG site speeds averaged about 7% stronger.

The hourly wind data collected from May-August 1980 from the BPA tower were compared to the coincident hourly data from the Site A anemometer. The results indicated that at the 50-foot level the wind flow at Site A was 30-50% stronger for wind directions 270-300° and about 10-20% stronger for directions 230-260°. The wind flow at the 195-foot level from the BPA tower was fairly similar to that measured by the Site A 45-foot-level anemometer, as the speeds were about 10% lower at the BPA tower. The most noticeable differences occurred under wind flow directions 270-300°.

Simultaneous wind velocity measurements were taken at several locations in the Cape Blanco area. The measurement locations are shown in Figure 3. Measurements taken in a west-to-east direction indicated that under moderate to strong south-to-southwest winds, the wind speed decreased from the tip of the Cape inland in six of the eight runs made. Eleven north/south transects were made. In most of the runs under south winds the strength of the wind decreased from the tip of the Cape northward as the wind passed over the tree-covered Cape headland. Wind flow measurements made at Langlois Mountain (Site 2 in Figure 3), about 1000 feet above the headland, indicated stronger winds than over most of the Cape.

These limited measurements indicate that there appear to be significant flow variations in the Cape Blanco area. More field measurements are needed

FIGURE 3. Wind velocity measurement sites in the Cape Blanco area. In-place anemometers are located at Sites 1, 2, and 4.

using fixed-place meteorological towers and supplemental kite anemometer surveys to accurately assess the extent of the wind power potential in this high wind area.

Wind Profile Measurements

Several wind profiles were taken using kite anemometers at three promising wind power development areas: Goodnoe Hills, Juniper Point, and Cape Blanco. Measurements were made at the 50-, 200-, and 350-foot levels. Most of the effort was centered at the three Goodnoe Hills MOD-2 WTG sites.

The wind profiles measured in southwest to northwest flow at the three MOD-2 sites generally indicated a slight change in wind speed with height. The WTG site locations are given in Figure 2. The average power law exponent value, α , in the simple power law* varied from .08 at WTG 1 to .10 at WTG 3. The most noticeable differences between the winds measured at the 50- and 200-foot levels (i.e., wind shear) occurred at night. Also, daytime shear values appear to be higher in the winter than in the summer. The directional shear between the 50- and 200-levels was about 10° . The directional gustiness was the greatest at the 50-foot level, as the average variation off of the mean direction was $\pm 20^\circ$ compared to $\pm 10^\circ$ at the other two levels. An example of the profiles taken is given in Figure 4.

Several wind profiles were taken in moderate to strong westerly flow at Juniper Point. This site location is shown in Figure 2. Most of the profiles indicated little shear between the 50- and 200-foot levels as noted in Figure 5. The profiles were similar to those measured previously in last year's work.

Wind profiles were taken at six locations in the Cape Blanco area (see Figure 6). Five of these locations were over the well exposed headland and the other was at Langlois Mountain, which is about 12 miles northeast of the Cape and at 1200 feet MSL. In general, the measurements indicated slight to

$$* \quad \alpha = \frac{\ln \frac{V_{200}}{V_{50}}}{\ln \frac{200}{50}}$$

No.	Date	Time(PST)	50'	200'	350'	$\alpha(50-200')$	I(200')	DIR(200')
2	12/ 5/79	1329-1344	22.6	26.3		.11	.11	270°
4	1/17/80	1315-1330	19.4	23.7	24.8	.14	.06	270°
12	6/26/80	1200-1215	23.6	25.4	26.1	.05	.13	275°
14	6/27/80	1020-1035	17.8	20.1	21.3	.09	.14	265°
16	8/ 5/80	0813-0828	26.3	28.3	29.8	.05	.11	270°

FIGURE 4. Wind profiles at WTG 1 for directions 260-275°.

No.	Date	Time(PST)	50'	100'	200'	350'	I(100-200')	I(200')	DIR(200')
1	3/27/80	0930-0940		22.5	22.6	21.2	.00	.12	260
2	6/27/80	1409-1424	28.4	27.7	27.4	28.8	-.03*	.09	320
3	3/26/80	1639-1649		35.5	36.0	36.7	.01	.09	270

* $\alpha(50-200')$.

FIGURE 5. Wind profiles at Juniper Point.

modest wind shear in the lowest 200 feet at most of the sites, as the α values varied from .01-.13. However, very high shear was measured at one of the headland sites that was surrounded by tree cover (see Figure 7). Under south flow the wind speed increased from 7 to 17 mph from the 50- to 200-foot level (i.e., $\alpha = .63$).

FIGURE 6. Cape Blanco wind profile locations.

Site No.	Date	Time (PST)	50	200	350	I (200)	DIR (200)	α (50-200!)
1	3/13/80	1211-1235	17.9	20.2	26.5	.15	180°	.11
1	3/14/80	0859-0919	15.6	17.5	19.3	.13	250°	.10
2	3/13/80	1409-1434	16.1	16.9	17.5	.06	180°	.04
2	3/14/80	1344-1412	20.7	21.7	24.0	.08	270°	.04
3	3/13/80	1306-1316	7.0*	16.7	19.9	.11	170°	.63*

*Estimated.

FIGURE 7. Wind profiles taken in the Cape Blanco area.

Large Area Wind Power Prospecting Surveys

Aerial surveys using a BPA helicopter were made in the Columbia Gorge and Northeast Washington. Also, an extensive ground survey was made in the Kittitas Valley area in Central Washington to assess the wind power potential and locate potential anemometer sites.

The helicopter survey provided a rapid means of assessing a large area in a short amount of time. From the air wind-deformed trees, sand dunes, sand scours, or other wind stress features were easily observed. Also, terrain roughness, extent of tree cover, access, and the location of transmission lines were also assessed.

The Columbia Gorge aerial survey in The Dalles area covered approximately 1500 square miles in about six hours of flying time. Photographs from the air and on the ground were taken at 68 locations. Five sub-areas were identified where the wind-deformed trees indicated a mean annual wind speed in the 12-18 mph range.

The Northeast Washington aerial survey covered about 3500 square miles in five hours of flying time. Whereas numerous ground stops were made in the Columbia Gorge survey, only two ground stops were made in the Northeast Washington survey. Photographs were taken of the topography and wind-deformed vegetation at 36 locations. Three sub-areas were identified that had significant tree flagging that indicated mean annual wind speeds in the 12-18 mph range. Several other locations displayed wind-deformed trees, but due to dense forests and poor accessibility, the immediate development of these locations as wind power sites would probably be limited.

In December 1979 a three-day wind prospecting survey was made in the Kittitas Valley area to locate favorable wind sites to instrument. The survey was made for both BPA and the Water and Power Resources Service (WPRS). The survey revealed that there are many well exposed areas in the Kittitas Valley and surrounding ridges that probably experience good power-producing wind flow in the spring and summer. The wind-deformed vegetation in the region was very evident. The barren hilly area east of Ellensburg and the western end of the Kittitas Valley look particularly promising. The estimated mean annual wind speeds in these two areas is 12-14 mph. Two anemometers were subsequently located east of Ellensburg, and one wind sensor was located west of Ellensburg near Thorp.

Wind Flow Studies Around the Clayton 200 KW WTG

Preliminary wake studies were made around the 125-foot-diameter 200 KW MOD-OA WTG at Clayton, New Mexico in March 1980. Kite anemometers were used to take several coincident measurements of the hub height wind speed up and downwind of the operating and non-operating WTG. Measurements of the wake were also taken in a lateral direction. The results indicated that the wake velocity deficits were generally largest within 4 diameters (D) of the WTG. These deficits were on the order of 15-20%. At 5D downwind

the measured velocity deficits were about 10%. From 7-10D downwind the deficits were generally negligible, although under stable west flow a 20% deficit was measured at 7D downwind. The deficits are summarized in Figure 8. For the limited amount of data taken the deficits appear reasonable and approximate the wake model results of Aerovironment, Inc. (Walker, 1980).

FIGURE 8. Wake velocity deficits measured under four different wind directions at Clayton, New Mexico. The circles radiating from the WTG indicate diameter spacing from 2-9D.

Statistical Analysis of Wind Power and Wind Speed Data at BPA Sites and NWS Stations

Since most of the wind data taken at potential wind power data sites are for only a few years the long-term, usually 20-30 years, wind records from several National Weather Service (NWS) sites in the Pacific Northwest were investigated to see if the short-period wind power site data base could be enhanced to give a more accurate interpretation of climatological normals and extremes. The site locations are shown in Figure 9. From the reconstructed data base at the wind power sites, the wind power would be modeled and used as input to simulation programs designed to investigate the impact of a network of wind farms at these locations on regional energy potential.

FIGURE 9. Wind power sites (*) and NWS stations (x) included in study.

The probability distributions of wind power at the six network sites has a mixed distribution, with positive probabilities (of considerable magnitude) corresponding to values of power equal to zero and 2.5 MW and a continuous distribution over the range between the two extreme values. The shape of the continuous portion of the distribution is somewhat difficult to characterize, because fluctuations that may be due to certain biases in the wind speed data are present in the frequency polygons. Unlike the distributions for the individual sites, the distribution of wind power for the total system is essentially continuous. The only complication that arose was the necessity of replacing the numerous missing values with mean values for the individual sites to avoid a substantial reduction in sample size.

Largely because of the considerable distances between the NWS stations and the network sites and because of the high degree of variability in wind speeds over even small distances, statistical relationships between network sites and NWS station wind speeds are apparently quite weak. Comparisons of different periods of record for the NWS stations, nevertheless, do suggest that the short period of data available at the network sites may not be entirely representative of the long-term wind speed distributions. Specifically, considerably less variability in NWS station wind speeds is evident for the recent shorter time period.

Wind Flow Analysis and Prediction

This task was divided into three parts. The case study started last year was finished and an additional case was analyzed to include complex terrain of the Rocky Mountains. A new method for computing the surface horizontal pressure gradient force, termed modified pressure gradient force, was used and compared to the sea level surface pressure gradient force extracted from weather maps. The second phase of the research was to correlate the winds at several potential wind power sites to the pressure gradient force developed in the case study, to a measure of the low-level stability, and to the winds aloft. The last phase of the work was to develop a statistical scheme to predict the winds in the Columbia Gorge.

The results indicated that the modified pressure gradient force showed little improvement from using the sea level pressure gradient force. The

modified pressure gradient force analysis yielded better results than the sea level pressure analysis in mountainous regions while there was little difference over flat areas.

The correlation analysis indicated that when the pressure gradient force is west to east (i.e., west flow) there is a fair relationship with the observed winds and the pressure gradient force. Under east flow there is a poor relationship. There appears to be a reasonable correlation between the winds at Goodnoe Hills to the flow at the 850 mb level (about 4500 ft MSL). However, the Augpurger Mountain winds do not relate well to the 850 mb winds. The results of the stability/wind speed computations showed a similar pattern.

A model output statistics (MOS) approach was used to predict the winds at Goodnoe Hills. The results indicated that the accuracy of the forecast decreases rapidly with time, as the 12-hour forecast performed reasonably well but the 24- and 48-hour forecasts performed poorly.

Klickitat County SWECS Project

The BPA wind energy pilot project in Klickitat County commenced in 1980 in cooperation with the Klickitat County PUD. Several small wind energy conversion systems (SWECS) ranging from 2-10 KW output will be installed in the county by the end of 1981. The purpose of the SWECS project is to promote the use of small windmills for residential use, to test the efficiencies of different kinds of wind generators, and to investigate their interfacing with the utility.

A preliminary site prospecting survey was made in the fall of 1979 by OSU to locate possible SWECS candidate sites. From this survey, two 2.1 KW Enertech turbines were installed at two locations. A more intensive wind assessment survey was made during the winter and early spring, which included visiting nearly 100 residences who applied for participation in the pilot project. From these 100 applicants, 18 sites were chosen for instrumentation with wind sensors (see Figure 10). Some of these 18 sites will be chosen by BPA at a later date as windmill locations.

* - WINDMILL

• - SWECs APPLICANTS

★ - ANEMOMETER RECIPIENTS

FIGURE 10. SWECs applicant, anemometer, and windmill sites.