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OREGON STATE UNIVERSITY
DEPARTMENT OF ATMOSPHERIC SCIENCES

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REPORT NO. BPA 80-5

OCTOBER 1980

NETWORK WIND POWER OVER THE PACIFIC NORTHWEST
PROGRESS REPORT, OCTOBER 1979 - SEPTEMBER 1980

PREPARED BY

ROBERT W. BAKER and E. WENDELL HEWSON
PRINCIPAL INVESTIGATORS

SUBMITTED TO THE
BONNEVILLE POWER ADMINISTRATION
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*Dr. Barber is now a professor at North Carolina State University,
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1.0 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 the 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.

The 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.

This report also includes an appendix (Appendix 1). This appendix contains mean monthly wind speed data summaries, wind spectrum summaries, time series analysis plots, and high wind summaries.

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

2.0 WIND DATA ANALYSIS

2.1 WIND DATA NETWORK

2.2 CLIMATOLOGICAL WIND ANALYSIS FOR THE PERIOD JUNE 1979 - MAY 1980

2.3 WIND STATISTICS AT SELECTED WIND POWER DATA SITES

2.1 WIND DATA NETWORK

The wind data network as of September 1980 consisted of 70 sites throughout the Pacific Northwest. The site locations are shown in Figure 2.1.1 and pertinent station data such as station elevation, anemometer height, period of record, and type of wind recorder are displayed in Tables 2.1.1a and 2.1.1b.

FIGURE 2.1.1 Wind data site locations.

Twelve new locations were instrumented with anemometers during the past 12 months. Two of the sites are in the Kittitas Valley in central Washington (Sites 37 and 38); four anemometers were installed in the Snake River Valley in Southern Idaho (Sites 62, 66, 70 and 71); five systems were installed in the Columbia River Gorge (Sites 20, 23, 28, 30, and 31) ; and a wind-run anemometer was installed on a ridge just east of John Day, Oregon (Site 51).

TABLE 2.1.1a 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.

TABLE 2.1.1b 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.

Also wind data were acquired from six existing anemometer sites. These locations include Sites 9, 17, 25, 53, 54, and 60. The latter three are fire weather lookouts on the Yakima Indian Reservation where summer wind data are available (one to two observations per day).

Hourly speed and direction data are available for 21 of the sites; four to six hourly data are available at 9 of the sites; five of the sites provide wind speed frequency distribution data; and mean monthly wind speed data are collected at 36 of the sites.

2.2 CLIMATOLOGICAL WIND ANALYSIS FOR THE PERIOD JUNE 1979 - MAY 1980

Wind speed and direction data were gathered from several National Weather Service stations throughout the Pacific Northwest for the 12-month period beginning in June 1979 and ending in May 1980. The mean monthly wind speeds were compared to the long-term, usually 30-year, monthly averages to determine any significant (i.e., greater than 10%) departures from the climatological norm. The prevailing wind direction was also investigated to determine wind flow changes. The mean monthly wind speed data for these stations, along with data from several wind power data stations, are summarized in Table 2.2.1. The data station locations are shown in Figure 2.2.1.

FIGURE 2.2.1 Wind power data stations (solid stars) and the nearest long-term data stations (open stars).

TABLE 2.2.1 Mean monthly wind speeds (mph) at several long-term data stations and wind power data stations for the period June 1979 to May 1980. Long-term averages are also given.

<u>Station</u>	<u>Jun</u>	<u>Jul</u>	<u>Aug</u>	<u>Sep</u>	<u>Cct</u>	<u>Nov</u>	<u>Dec</u>	<u>Jan</u>	<u>Feb</u>	<u>Mar</u>	<u>Apr</u>	<u>May</u>	<u>Avg.</u>
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 ¹
Cape Blanco CGLS	17.4	M	14.1	M	14.5	14.3	System removed by the Coast Guard - - - - -						
Cape Blanco CGLS 1968-1972	14.7	16.0	14.9	13.7	14.8	16.9	20.9	19.9	17.8	18.5	17.6	15.5	16.8
Astoria	10.0	9.7	8.5	8.7	8.0	7.9	11.1	8.6	10.5	9.5	10.0	8.9	9.3
Astoria 1941-70	8.3	8.4	7.8	7.4	7.5	8.4	9.1	9.5	8.9	8.9	8.6	8.4	8.4
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	10.7 ¹	13.5 ¹
Eugene	8.1	9.0	7.4	8.3	7.4	6.2	6.8	7.8	6.7	7.4	7.7	6.4	7.4
Eugene 1941-70	7.4	8.0	7.5	7.4	6.6	7.1	7.7	8.3	7.9	8.6	7.7	7.4	7.8
Portland	8.7	8.4	7.2	7.8	7.8	11.2	11.3	10.9	11.0	8.0	8.4	7.2	9.0
Portland 1941-70	6.9	7.4	7.0	6.4	6.4	8.4	9.6	10.1	8.8	8.3	7.2	6.9	7.8
Augspurger Mtn.	22.0	22.9	21.7	17.8	17.1	17.7 ¹	System inoperative - - - - -						20.2 ¹
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	19.7	15.0 ¹
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
Pendleton	11.2	10.1	8.5	8.1	7.4	5.6	8.4	7.2	6.5	10.8	8.9	7.6	8.4
Pendleton 1941-70	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
Pequop Summit	14.6 ¹	System inoperative			17.1 ¹	17.3	15.3	19.2	15.2	20.3	14.3 ¹	12.4	16.2 ¹
Elko	6.7	6.1	6.0	5.1	4.7	4.8	4.1	5.5	5.2	6.2	6.7	5.8	5.6
Elko 1941-70	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

¹Data recovery less than 85%

M - Missing data

It should be noted that this comparison gives only a gross estimate of any basic flow changes from normal at the lower-elevation, long-term stations. The monthly departures from normal and the similarities with the normal do follow definite trends at most of the long-term stations. However, until longer-term data, say five years, are gathered from the wind power stations, determining the monthly velocity deviations from normal at these high wind sites based on the National Weather Service station records is difficult because of the spatial variations among stations. This is particularly true for the wind power sites in the Columbia River Gorge and in the Wells area shown in Figure 2.2.1. The Coast Guard station at Cape Blanco is adjacent to the BPA wind power station, so monthly comparisons are meaningful there. Comparisons of mean monthly wind speeds using three years of data from the BPA site to five years of data from the CGLS site revealed that the BPA and CGLS means were approximately the same in January through May. From June through August, the BPA site means were 15% higher, and from September through November they were 20% higher than the CGLS means. The reason for this is better anemometer exposure. Since the CGLS station was closed in December 1979, the above relationships are used to estimate departures from normal where CGLS data are not available.

The prevailing north flow along the Oregon Coast and in the Willamette Valley was generally 10-25% stronger than normal in June and July, as noted by the winds recorded at Cape Blanco CGLS, Astoria, Portland, and Eugene. The wind power sites in the Columbia Gorge recorded strong west winds during the summer as the monthly mean wind speeds varied from 17-23 mph, and the BPA site at Cape Blanco recorded mean monthly wind speeds from 15-22 mph. There were no significant departures from normal recorded at Pendleton or Elko during the summer months. Although limited data were available from the Pequop Summit site during the summer, the mean monthly wind speeds probably averaged between 12-14 mph in July, based on previous summer data and the wind-run data from the Radar Hill site. The August wind speeds at Pequop Summit probably averaged 15-20 mph, since the winds at Wells West and Radar Hill averaged 17-19 mph respectively. In August the mean monthly wind speed at the Cape Blanco BPA site appeared to be about 15% below normal.

During September the prevailing flow at Astoria was about 18% stronger than normal, near normal at Cape Blanco, 22% stronger than normal at Portland, and about 12% above the average at Eugene. The predominant wind direction was north at all of these locations. In October and November the mean monthly wind speeds agreed quite closely with the normal at Astoria as southeast winds prevailed. However, the Cape Blanco CGLS station recorded a 15% decrease from normal in November as south winds prevailed. The 17 mph mean wind speed recorded by the BPA anemometer appears to be lower than normal, as wind speeds during this month have averaged nearly 20 mph in the previous three years of record. The prevailing east flow at Portland out of the Columbia Gorge was 20-30% stronger than normal during October and November. In contrast, the mean monthly wind speed at Eugene was about 12% stronger than normal in October, but 13% below the average in November.

The fall winds at Pendleton and Elko were about 10% lighter than the climatological normal in September and October. In November, near normal winds were recorded at Elko, but there was about a 30% decrease in the mean monthly wind speed at Pendleton as north winds prevailed instead of the normal southeast flow. The Kennewick wind power site recorded about a 9 mph mean monthly wind speed in November as east flow prevailed. This appears to be much lower than normal, as previous data collected at Kennewick indicate a mean monthly wind speed in the 15-20 mph range with southwest winds predominant.

The mean monthly wind speeds at Astoria were over 20% stronger than normal in December and near-normal conditions appeared to prevail at Cape Blanco. Strong south-southeast winds prevailed. In the Willamette Valley the mean monthly wind speeds at Eugene were about 12% lighter than normal, but they were 18% stronger than average at Portland, as the east Gorge winds prevailed. Normal flow was recorded at Pendleton in December, and about 20%-lighter-than-normal wind conditions prevailed at Elko.

In January, the coast winds were 10-20% below normal. Although a full month of data were not available from the Cape Blanco BPA site, the near 18 mph mean speed is well below the expected 20 mph speed. In the interior, Pendleton recorded a 15% below-normal mean speed.

In February, Astoria and Portland had mean monthly wind speeds 18-25% higher than normal, as southeast to east flow prevailed. South winds prevailed at Cape Blanco and they appeared to be near normal. Fifteen percent lighter than normal wind speeds were recorded at Eugene, while 12 to 28% lighter than normal mean monthly wind speeds were recorded at Elko and Pendleton respectively. The dominant high pressure ridge over the interior resulted in lighter winds being recorded at the wind power sites at Goodnoe Hills and Kennewick in the Columbia Gorge.

In the spring, the mean monthly wind speeds were generally lower than normal at Cape Blanco, Pendleton, Elko, and Eugene, and higher than normal at Portland and Astoria. North flow prevailed along the Oregon Coast as the Astoria climatological differences varied from 6-16%. However, the mean monthly wind speeds recorded at the Cape Blanco BPA site were significantly lower than expected. The March mean monthly wind speed was 22% below normal, and the May winds were 12% below average. Eugene recorded about 15% lighter than normal winds in March and May, while little differences from normal were noted at Portland during these two months. However, in April, the mean monthly wind speeds were over 17% above average at Portland. In April and May, the prevailing west winds at Pendleton were 16-25% lighter than normal. About 16% lighter than normal winds were recorded at Elko in May.

In summary, during the summer the mean monthly speeds were 10-25% stronger along the Oregon coast and Willamette Valley in June and July, and 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 winds (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 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.

2.3 WIND STATISTICS AT SELECTED WIND POWER DATA SITES

Introduction

The hourly wind data collected at nine BPA wind power data sites were analyzed for the period June 1979-May 1980. The site locations are shown in Figure 2.3.1. The wind speed and direction are plotted every six hours on a monthly basis at selected paired sites. Every sixth hour was plotted for clarity. These plots are contained in Appendix 1. There is also a monthly and 12-month period wind statistics summary where all of the data were analyzed. This summary gives the site anemometer height, number of hourly observations available, mean wind speed, site power density, percent of winds in the 10-45 mph range, number of hours where the mean hourly wind speed equalled or exceeded 50 mph, the most frequent direction when the mean hourly wind speed was at least 10 mph, and the correlation coefficient between the two paired sites. The site pairings included Goodnoe Hills/Juniper Pt, Augspurger Mtn/Kennewick, Sevenmile Hill 50 ft/Sevenmile Hill 150 ft, KCIV/Roosevelt, Cape Blanco/Pequop Summit and Wanapum Dam/Kittitas. Wind speed duration curves, diurnal curves and wind rose plots are also given that further define the site wind power resource for the 12-month period.

Goodnoe Hills/Juniper Point

The wind statistics at these two sites showed good wind power potential during most of the period, as shown in Table 2.3.1. There was 73% data recovery at Goodnoe Hills and 82% at Juniper Pt. The mean wind speed at Goodnoe Hills was 15.0 mph and the power density was 440 watts/m² compared to a 20.2 mph mean wind speed and over 900 watts/m² at Juniper Pt. Some of the differences between the two sites are due to the increased anemometer height at Juniper Pt. However, a major reason for higher wind speeds is better exposure to the wind flow from all directions. This is particularly true during the winter months from November--March. The correlation between the two sites was good as the correlation coefficients varied from .71 to .97 and the average was .93 for the period. Hourly average wind speeds equalled or exceeded 50 mph 143 times at Juniper Pt. compared to 10 such occurrences at Goodnoe Hills.

The six hourly plots of speed and direction shown in Appendix 1 indicate the occasional variability in the flow pattern over the Goodnoe Hills-Juniper Pt area, especially when analyzing months where most or all of the data were available from both sites. In general, when moderate-to-strong west winds (those exceeding 15 mph) occur, the speeds are strongest at Juniper Pt and are more northwesterly in direction than at Goodnoe Hills. However, during December 1979 and January and February 1980 there were a few periods when the wind directions were noticeably different under strong winds. From December 22-23 the 15-25 mph wind speeds were fairly similar at both sites but the wind direction was 90 degrees at Juniper Pt and 180° at Goodnoe Hills. Between January 25-28 under 15-30 mph winds the directions again varied by about 90 degrees as northwest winds blew at Goodnoe Hills and northeast winds prevailed at Juniper Pt. From 15-25 February there were several wind-flow differences in both speed and direction. This was also the month of the lowest correlation coefficient, .71.

FIGURE 2.3.1 Selected wind power site locations.

Augspurger Mountain/Kennewick

The wind statistics for these two sites are given in Table 2.3.2. There were no data available at Augspurger Mountain past 8 November 1979 because of instrument failure. The data recovery was only 44% for the 12-month period. However, the limited wind data collected do indicate strong and persistent westerly flow as the mean wind speed was 20.2 mph and 88% of the time the speed was between 10 and 45 mph. The power density average over 650 watts/m² for the 5-month period.

In contrast, 86% of the data were collected at Kennewick from June 79-May 80. The mean wind speed averaged 16.2 mph and the average power density was 615 watts/m². Nearly 67% of the time the wind speeds were in the 10-45 mph range.

There was a fairly good correlation between the wind speeds at the two Gorge sites from June to October as the correlation coefficient averaged 0.83. The monthly six hourly speed and direction plots given in Figures 14-25 indicate that when strong west winds occurred in the Gorge there was about an 8-12-hour lag in the maximum wind occurrence at Kennewick as compared to Augspurger Mtn which is located about 150 miles to the west.

Sevenmile Hill Meteorological Tower

The Sevenmile Hill meteorological tower recorded persistent, moderate-to-strong west winds from June through October 1979 and March through May 1980, as noted in Table 2.3.3. The mean monthly wind speed at the 150-ft level averaged from 14.7-26.5 mph. During the winter the mean monthly speeds decreased to 10-14 mph. Over the 12-month period 76% of the data were recovered at the 50-ft level and 79% at the 150-ft level. The mean wind speeds for the period indicate 17.3 mph at the 50-ft level and 17.7 mph at the 150-ft level. However, since the data gaps are not coincident at both levels the .4 mph difference between the two levels does not indicate the actual speed difference. Upon further inspection when coincident speed data were available like in June, September, December, April, and May, it appears that the 50-ft level winds are about 88% as strong as the 150-ft level flow. If it is assumed that the 150-ft level data (i.e. the 17.7 mph

mean speed) are representative for the 12-month period then the adjusted 50-ft level mean wind speed is 15.6 mph.

As expected, the correlation coefficient was high at 0.99. The wind speed and direction tracked closely at both levels as noted in the monthly six hourly plots (see Appendix 1). For wind speeds exceeding 15 mph the wind direction difference between both levels was generally about 10 degrees. The largest speed differences between the two levels were about 5 mph and usually occurred under strong west flow, as noted in the monthly plots.

KCIV/Roosevelt

The wind data from these two sites in the Columbia River Gorge indicated that the most persistent and strongest winds occurred from June through August and March through May, as shown in Table 2.3.4. When similar periods of data were available at both sites there was fairly good correlation between the hourly data as the monthly correlation coefficients varied from 0.74-0.96. There was 96% data recovery at Roosevelt and only 73% at KCIV. The 12-month period mean annual winds speeds were 14.1 for KCIV and 14.0 for Roosevelt. However, the mean power density values differed by over 100 watts/m² as the value at Roosevelt was 345 watts/m² compared to 233 watts/m² at KCIV. Both sites showed good persistence values for wind speeds from 10-45 mph as these winds occurred 76% of the time at KCIV and 63% of the time at Roosevelt.

The monthly speed and direction plots, given in Appendix 1, indicated that the wind speeds at both sites tracked quite closely with each other with respect to the oscillations. However, there were occasional periods in the fall where the winds were out of phase as noted by the October and November plots (13-14 October and 9-10 November 1979).

Cape Blanco/Pequop Summit

The wind statistics for these two widely separated sites indicated good wind power potential during most of the 12-month period as shown in Table 2.3.5. The mean power density was 685 watts/m² at Cape Blanco and 460 watts/m² at Pequop Summit. There was 83% data recovery at Cape Blanco and

64% at Pequop Summit. The wind speed was in the 10-45 mph range 71% of the time at the Cape and 68% of the time at Pequop Summit. High winds, those greater or equal to 50 mph, were fairly common at Cape Blanco as there were 112 such observations compared to 39 at Pequop Summit.

The diversity in the wind flow between the sites resulted in correlation coefficients of 0.55-0.77. The monthly velocity plots in Appendix 1 indicate that quite often the speeds are out of phase (i.e.: when the speeds are low at one site they are high at the other). In February and March, when there was a full month of data for both sites, there were infrequent short periods where the wind speed at either or both sites was below 15 mph.

Wanapum Dam/Kittitas Microwave

A limited comparison is available between these two wind data stations in the Kittitas Valley as the Kittitas Microwave anemometer was installed in the latter part of March 1980. The wind data from Wanapum Dam indicate that moderate to strong flow occurred from June through August 1979 and March through May 1980 as shown in Table 2.3.6. There is a fair correlation between the winds at these two locations. In April the mean wind speed at the Kittitas Microwave was 13.9 mph compared to 12.0 mph at Wanapum Dam although the power density values were about the same. In May the mean speeds were nearly identical but the mean power density was much greater, 527 watts/m² compared to 339 watts/m² at Kittitas. In contrast, the percent of winds in the 10-45 mph range was significantly greater at the Kittitas Microwave. These data suggest that when the prevailing west winds are strong in the Kittitas Valley there are occasions when the speeds at Wanapum Dam are significantly higher than those at the Kittitas Microwave. The monthly speed and direction plots in Appendix 1 verify this. When considering the power density is a function of the cube of the wind speed a 30% increase in wind speed results in a doubling of the power density value. Also it should be remembered that the Wanapum Dam data are hourly (i.e., 1-5 min values) observations whereas the Kittitas Microwave data is a hourly mean speed taken from a strip chart. This sampling difference could also significantly contribute to the speed differences.

TABLE 2.3.1. Wind statistics for Goodnoe Hills and Juniper Point for Jun 79-May 80.

MONTH	YEAR	STATION	ANEMOMETER HEIGHT (FT)	NUMBER OF HOURLY OBSERVATIONS	MEAN WIND SPEED (MPH)	POWER DENSITY (WATTS/M ²)	PERCENTAGE FOR 10 ≤ V ≤ 45	NUMBER OF HOURS V ≥ 50 (MPH)	MOST FREQ. DIRECTION V ≥ 10 (MPH)	CORRELATION COEFFICIENT
JUNE	1979	GOODNOE HILLS	45	530	20.7	785.2	83.8	6	290	.93
		JUNIPER POINT	100	449	25.2	1384.1	81.3	20	300	
JULY	1979	GOODNOE HILLS	45	349	20.6	804.2	80.2	2	270	.98
		JUNIPER POINT	100	368	23.6	1106.8	85.6	8	300	
AUGUST	1979	GOODNOE HILLS	45	0	0.0	0.0	0.0	0	0	0.00
		JUNIPER POINT	100	713	20.1	873.7	77.4	7	300	
SEPTEMBER	1979	GOODNOE HILLS	45	228	15.3	436.2	68.4	0	330	0.00
		JUNIPER POINT	100	80	19.3	607.5	93.8	1	290	
OCTOBER	1979	GOODNOE HILLS	45	333	12.2	222.8	56.5	0	290	.94
		JUNIPER POINT	100	538	17.9	523.3	77.1	0	210	
NOVEMBER	1979	GOODNOE HILLS	45	719	8.5	103.7	34.8	0	290	.93
		JUNIPER POINT	100	706	13.8	394.1	63.0	3	90	
DECEMBER	1979	GOODNOE HILLS	45	674	14.8	428.7	60.2	0	290	.94
		JUNIPER POINT	100	737	21.2	1030.7	78.0	19	290	
JANUARY	1980	GOODNOE HILLS	45	744	10.9	241.7	43.8	0	290	.93
		JUNIPER POINT	100	744	17.1	730.0	69.1	16	110	
FEBRUARY	1980	GOODNOE HILLS	45	480	9.1	125.8	40.6	0	270	.71
		JUNIPER POINT	100	612	15.3	471.5	67.2	1	90	
MARCH	1980	GOODNOE HILLS	45	743	18.6	637.7	75.9	2	270	.96
		JUNIPER POINT	100	744	25.7	1474.1	78.8	35	280	
APRIL	1980	GOODNOE HILLS	45	720	16.0	484.3	70.3	0	280	.94
		JUNIPER POINT	100	716	20.0	846.3	80.4	15	310	
MAY	1980	GOODNOE HILLS	45	744	19.7	649.8	84.0	0	280	.97
		JUNIPER POINT	100	744	24.7	1268.3	84.5	18	310	
OVERALL		GOODNOE HILLS	45	6429	15.0	439.7	62.9	10	280	.93
		JUNIPER POINT	100	7151	20.2	908.6	76.3	143	300	

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TABLE 2.3.2 Wind statistics for Augspurger Mtn and Kennewick for Jun 79-May 80.

MONTH	YEAR	STATION	ANEMOMETER HEIGHT (FT)	NUMBER OF HOURLY OBSERVATIONS	MEAN WIND SPEED (MPH)	POWER DENSITY (WATTS/M ²)	PERCENTAGE FOR 10 ≤ V ≤ 45	NUMBER OF HOURS V ≥ 50 (MPH)	MOST FREQ. DIRECTION V ≥ 10 (MPH)	CORRELATION COEFFICIENT
JUNE	1979	AUGSPURGER MT. KENNEWICK	50 105	720 703	22.0 17.4	718.8 677.7	93.9 70.1	0 0	260 210	.83
JULY	1979	AUGSPURGER MT. KENNEWICK	50 105	744 689	22.9 22.4	987.4 1249.7	90.1 81.7	3 37	260 200	.89
AUGUST	1979	AUGSPURGER MT. KENNEWICK	50 105	741 711	21.7 17.7	768.5 808.3	88.4 69.8	0 21	270 200	.83
SEPTEMBER	1979	AUGSPURGER MT. KENNEWICK	50 105	719 156	17.8 17.1	465.0 516.4	84.3 74.4	0 0	270 210	.82
OCTOBER	1979	AUGSPURGER MT. KENNEWICK	50 105	744 610	17.1 16.2	414.3 498.0	83.9 74.4	0 0	260 270	.76
NOVEMBER	1979	AUGSPURGER MT. KENNEWICK	50 105	203 685	17.7 8.7	569.4 126.0	85.7 41.2	3 0	60 290	.85
DECEMBER	1979	AUGSPURGER MT. KENNEWICK	50 105	0 663	0.0 18.6	0.0 752.1	0.0 74.2	0 8	0 270	0.00
JANUARY	1980	AUGSPURGER MT. KENNEWICK	50 105	0 744	0.0 12.9	0.0 476.2	0.0 49.1	0 15	0 270	0.00
FEBRUARY	1980	AUGSPURGER MT. KENNEWICK	50 105	0 695	0.0 12.2	0.0 294.6	0.0 53.7	0 0	0 190	0.00
MARCH	1980	AUGSPURGER MT. KENNEWICK	50 105	0 744	0.0 19.5	0.0 753.1	0.0 78.0	0 1	0 280	0.00
APRIL	1980	AUGSPURGER MT. KENNEWICK	50 105	0 680	0.0 16.8	0.0 625.1	0.0 69.4	0 2	0 190	0.00
MAY	1980	AUGSPURGER MT. KENNEWICK	50 105	0 427	0.0 16.0	0.0 458.5	0.0 71.7	0 0	0 190	0.00
OVERALL		AUGSPURGER MT. KENNEWICK	50 105	3871 7507	20.2 16.2	666.4 615.7	88.0 66.5	6 84	260 200	.83

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TABLE 2.3.3 Wind statistics for the Sevenmile Hill meteorological tower for June 79-May 80.

MONTH	YEAR	STATION	ANEMOMETER HEIGHT (FT)	NUMBER OF HOURLY OBSERVATIONS	MEAN WIND SPEED (MPH)	POWER DENSITY (WATTS/M ²)	PERCENTAGE FOR 10 ≤ V ≤ 45	NUMBER OF HOURS V ≥ 50 (MPH)	MOST FREQ. DIRECTION V ≥ 10 (MPH)	CORRELATION COEFFICIENT
JUNE	1979	SEVEN MILE 50	50	201	21.6	937.6	81.1	0	310	1.00
		SEVEN MILE 150	100	201	24.5	1321.7	82.1	7	300	
JULY	1979	SEVEN MILE 50	50	743	22.6	997.1	86.7	0	300	1.00
		SEVEN MILE 150	100	661	25.1	1383.2	83.2	8	300	
AUGUST	1979	SEVEN MILE 50	50	742	21.6	819.2	87.9	0	300	.99
		SEVEN MILE 150	100	107	23.6	1077.5	89.7	0	290	
SEPTEMBER	1979	SEVEN MILE 50	50	720	15.8	512.2	68.5	0	300	.99
		SEVEN MILE 150	100	719	17.7	717.5	71.1	0	300	
OCTOBER	1979	SEVEN MILE 50	50	744	13.5	306.2	63.7	0	300	.99
		SEVEN MILE 150	100	655	14.7	390.6	69.0	0	300	
NOVEMBER	1979	SEVEN MILE 50	50	720	10.7	162.4	53.8	0	110	.99
		SEVEN MILE 150	100	252	14.9	337.5	71.0	0	110	
DECEMBER	1979	SEVEN MILE 50	50	731	12.4	345.1	53.2	3	300	.99
		SEVEN MILE 150	100	744	14.0	506.1	60.5	5	300	
JANUARY	1980	SEVEN MILE 50	50	0	0.0	0.0	0.0	0	0	0.00
		SEVEN MILE 150	100	725	11.3	264.6	55.4	4	90	
FEBRUARY	1980	SEVEN MILE 50	50	0	0.0	0.0	0.0	0	0	0.00
		SEVEN MILE 150	100	696	10.3	155.0	53.9	0	110	
MARCH	1980	SEVEN MILE 50	50	634	19.7	751.6	79.3	3	310	.99
		SEVEN MILE 150	100	744	20.7	1013.5	74.9	12	290	
APRIL	1980	SEVEN MILE 50	50	716	15.7	425.8	71.6	0	300	.99
		SEVEN MILE 150	100	709	17.5	635.5	72.6	0	290	
MAY	1980	SEVEN MILE 50	50	743	22.8	888.3	91.5	0	300	1.00
		SEVEN MILE 150	100	737	26.5	1366.6	91.7	0	290	
OVERALL		SEVEN MILE 50	50	6694	17.3	589.2	73.2	6	300	.99
		SEVEN MILE 150	150	6950	17.7	725.2	70.9	36	300	

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TABLE 2.3.4 Wind statistics for KCIV and Roosevelt for Jun 79-May 80.

MONTH	YEAR	STATION	ANEMOMETER HEIGHT (FT)	NUMBER OF HOURLY OBSERVATIONS	MEAN WIND SPEED (MPH)	POWER DENSITY (WATTS/M ²)	PERCENTAGE FOR 10 ≤ V ≤ 45	NUMBER OF HOURS V ≥ 50 (MPH)	MOST FREQ. DIRECTION V ≥ 10 (MPH)	CORRELATION COEFFICIENT
JUNE	1979	KCIV	45	542	15.4	275.2	79.5	0	290	.96
		ROOSEVELT	70	614	18.1	561.7	79.0	0	270	
JULY	1979	KCIV	45	575	15.2	290.9	80.2	0	300	.95
		ROOSEVELT	70	672	16.9	468.3	74.3	1	290	
AUGUST	1979	KCIV	45	695	13.8	198.5	75.0	0	330	.93
		ROOSEVELT	70	707	13.7	286.4	63.4	0	280	
SEPTEMBER	1979	KCIV	45	720	12.6	160.9	70.7	0	330	.88
		ROOSEVELT	70	720	12.1	257.9	54.7	0	280	
OCTOBER	1979	KCIV	45	734	13.4	182.8	75.7	0	330	.80
		ROOSEVELT	70	743	11.1	175.9	54.4	0	270	
NOVEMBER	1979	KCIV	45	674	11.6	123.3	68.2	0	160	.84
		ROOSEVELT	70	706	8.8	106.7	40.4	0	270	
DECEMBER	1979	KCIV	45	269	13.5	219.5	68.8	0	180	.85
		ROOSEVELT	70	685	14.1	382.2	64.4	0	270	
JANUARY	1980	KCIV	45	434	14.2	291.2	74.2	2	180	.74
		ROOSEVELT	70	682	11.3	255.6	44.7	0	60	
FEBRUARY	1980	KCIV	45	159	14.5	234.8	81.8	0	300	.86
		ROOSEVELT	70	685	10.6	174.4	46.7	0	50	
MARCH	1980	KCIV	45	346	18.9	509.8	87.9	0	330	.94
		ROOSEVELT	70	744	19.4	673.7	80.5	3	280	
APRIL	1980	KCIV	45	472	13.3	200.1	70.3	0	330	.92
		ROOSEVELT	70	718	15.3	410.7	68.9	0	270	
MAY	1980	KCIV	45	744	15.8	274.9	84.1	0	330	.94
		ROOSEVELT	70	741	16.9	409.1	80.6	0	270	
OVERALL		KCIV	45	6364	14.1	233.4	76.0	2	330	.89
		ROOSEVELT	70	8417	14.0	345.6	62.6	4	270	

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TABLE 2.3.5 Wind statistics for Cape Blanco and Pequop Summit for Jun 79-May 80.

MONTH	YEAR	STATION	ANEMOMETER HEIGHT (FT)	NUMBER OF HOURLY OBSERVATIONS	MEAN WIND SPEED (MPH)	POWER DENSITY (WATTS/M ²)	PERCENTAGE FOR 10 ≤ V ≤ 45	NUMBER OF HOURS V ≥ 50 (MPH)	MOST FREQ. DIRECTION V ≥ 10 (MPH)	CORRELATION COEFFICIENT
JUNE	1979	C BLANCO BPA	40	719	18.1	490.2	82.1	0	20	.72
		PEQUOP SUMMIT	40	481	14.6	295.0	66.9	0	270	
JULY	1979	C BLANCO BPA	40	483	22.4	933.2	91.7	3	20	0.00
		PEQUOP SUMMIT	40	0	0.0	0.0	0.0	0	0	
AUGUST	1979	C BLANCO BPA	40	603	14.6	337.7	66.3	0	20	0.00
		PEQUOP SUMMIT	40	0	0.0	0.0	0.0	0	0	
SEPTEMBER	1979	C BLANCO BPA	40	720	16.2	463.0	75.1	0	20	0.00
		PEQUOP SUMMIT	40	0	0.0	0.0	0.0	0	0	
OCTOBER	1979	C BLANCO BPA	40	696	16.1	936.1	57.0	24	20	.55
		PEQUOP SUMMIT	40	184	17.1	507.7	69.6	0	300	
NOVEMBER	1979	C BLANCO BPA	40	706	17.3	871.9	65.4	21	190	.64
		PEQUOP SUMMIT	40	720	17.3	573.4	66.2	9	290	
DECEMBER	1979	C BLANCO BPA	40	411	22.4	1705.1	64.5	45	190	.63
		PEQUOP SUMMIT	40	744	15.3	429.5	62.8	9	290	
JANUARY	1980	C BLANCO BPA	40	207	17.7	624.8	79.2	0	360	.77
		PEQUOP SUMMIT	40	744	19.2	701.7	73.0	19	300	
FEBRUARY	1980	C BLANCO BPA	40	695	18.2	926.1	61.6	13	170	.63
		PEQUOP SUMMIT	40	695	15.2	426.6	63.9	1	290	
MARCH	1980	C BLANCO BPA	40	731	14.5	367.3	72.8	3	20	.77
		PEQUOP SUMMIT	40	743	20.3	634.6	85.6	1	290	
APRIL	1980	C BLANCO BPA	40	692	17.4	670.3	72.0	3	360	.66
		PEQUOP SUMMIT	40	549	14.3	293.5	65.2	0	140	
MAY	1980	C BLANCO BPA	40	586	13.6	264.1	68.1	0	360	.72
		PEQUOP SUMMIT	40	739	12.4	218.3	57.2	0	290	
OVERALL		C BLANCO BPA	40	7249	17.1	685.3	70.8	112	20	.67
		PEQUOP SUMMIT	40	5599	16.2	460.8	67.8	39	290	

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TABLE 2.3.6. Wind statistics for Wanapum Dam and Kittitas Microwave for June 1979-May 1980.

MONTH	YEAR	STATION	ANEMOMETER HEIGHT (FT)	NUMBER OF HOURLY OBSERVATIONS	MEAN WIND SPEED (MPH)	POWER DENSITY (WATTS/M ²)	PERCENTAGE FOR 10 ≤ V ≤ 45	NUMBER OF HOURS V ≥ 50 (MPH)	MOST FREQ. DIRECTION V ≥ 10 (MPH)	CORRELATION COEFFICIENT
JUNE	1979	WANAPUM DAM	40	720	17.3	692.0	65.7	8	270	0.00
		KITTITAS MW	110	0	0.0	0.0	0.0	0	0	
JULY	1979	WANAPUM DAM	40	724	15.6	612.0	58.4	3	270	0.00
		KITTITAS MW	110	0	0.0	0.0	0.0	0	0	
AUGUST	1979	WANAPUM DAM	40	357	14.9	480.2	59.1	0	270	0.00
		KITTITAS MW	110	0	0.0	0.0	0.0	0	0	
SEPTEMBER	1979	WANAPUM DAM	40	717	10.5	259.0	40.7	1	270	0.00
		KITTITAS MW	110	0	0.0	0.0	0.0	0	0	
OCTOBER	1979	WANAPUM DAM	40	725	8.8	153.7	38.6	0	280	0.00
		KITTITAS MW	110	0	0.0	0.0	0.0	0	0	
NOVEMBER	1979	WANAPUM DAM	40	714	7.1	51.3	33.9	0	280	0.00
		KITTITAS MW	110	0	0.0	0.0	0.0	0	0	
DECEMBER	1979	WANAPUM DAM	40	719	9.8	240.2	35.5	0	0	0.00
		KITTITAS MW	110	0	0.0	0.0	0.0	0	0	
JANUARY	1980	WANAPUM DAM	40	734	8.7	94.3	40.5	0	0	0.00
		KITTITAS MW	110	0	0.0	0.0	0.0	0	0	
FEBRUARY	1980	WANAPUM DAM	40	691	6.6	41.7	23.5	0	0	0.00
		KITTITAS MW	110	0	0.0	0.0	0.0	0	0	
MARCH	1980	WANAPUM DAM	40	710	13.1	420.1	50.7	2	0	.88
		KITTITAS MW	110	156	16.8	450.7	81.4	1	270	
APRIL	1980	WANAPUM DAM	40	703	12.0	360.5	44.8	0	270	.86
		KITTITAS MW	110	708	13.9	347.5	60.2	0	270	
MAY	1980	WANAPUM DAM	40	728	15.0	526.8	58.1	0	270	.89
		KITTITAS MW	110	667	14.7	339.0	70.2	0	270	
OVERALL		WANAPUM DAM	40	8262	11.5	322.5	45.3	14	270	.88
		KITTITAS MW	110	1531	14.5	354.3	66.7	1	270	

EOI ENCOUNTERED.

FIGURE 2.3.2a-c Speed duration curves for six wind power data sites for the period June 79-May 80. The Augspurger Mtn data are for June--November 79.

a

b

FIGURE 2.3.3a-b

Speed duration curves for four wind power data sites for the period June 79--May 80.

Diurnal Wind Analysis

The hourly wind data for ten sites of the 11 were processed to determine the monthly diurnal variations in the wind speed. Due to the short period of record the Kittitas Microwave data were not analyzed. The analysis revealed that at most of the sites the diurnal speed variations were greatest during the summer and least during the winter. A graphical analysis of these seasonal variations is given in Figures 2.3.4a-f and 2.3.5a-d. Only the summer or winter months where there was at least 90% data available were used. In the case of Augspurger Mountain there was no winter data so the October 1979 data were analyzed.

Figure 2.3.4a-f show six sites in the Columbia Gorge with Augspurger being the farthest west and Roosevelt being the farthest east of the six. The summer diurnal variations in the wind speed were very evident but the Sevenmile Hill and Juniper Point plots showed the most pronounced variations. At the six Gorge sites the lowest speeds occurred during the mid-morning. However, the speed maximums occurred progressively later in the late afternoon and early evening from Augspurger east to Roosevelt as shown in Figure 2.3.4a-f.

The July tower data from Sevenmile Hill (Figure 2.3.3b) show an interesting pattern as the wind shear, the difference between the wind speed at the two levels, is most pronounced at night and nearly disappears during the midafternoon. These patterns are due to changes in low level stability as very stable conditions prevail on clear summer nights which promote shear. In contrast, during the daylight hours surface heating mixes the lower atmosphere and thus reduces wind shear.

The summer diurnal variations in the wind speed at the four sites shown in Figure 2.3.5a-d show some different diurnal patterns than the six Gorge sites. Kennewick, which is considered as a Gorge site, shows very little diurnal variation during August as a relative minimum occurs during the midafternoon and the strongest winds persist after dark till just before sunrise (see Figure 2.3.5a). The July 1979 data for Wanapum Dam displayed in Figure 2.3.5b showed a very pronounced daily cycle as the mean wind speed more than doubled between midafternoon and late evening.

The coastal Cape Blanco site showed a daily wind speed maximum from midmorning to midafternoon. This pattern also prevailed at Pequop Summit in June 1979 (see Figure 2.3.5c and d)

During the winter months the diurnal variations were very small to nonexistent at most of the ten sites. The Sevenmile Hill tower speed data showed a very weak diurnal cycle as a relative speed maximum occurred during early afternoon in December 1979 (see Figure 2.3.4b). Also, the speed differences between both levels were very uniform throughout the day and night although there appears to be a slight tendency for the speed differences to be most pronounced during the midafternoon.

The January data for Juniper Point, Goodnoe Hills, and Roosevelt indicated a relative wind speed minimum around noon as shown in Figure 2.3.4d-f. The Kennewick plot, Figure 2.3.5a, also indicated a similar tendency.

It is apparent that thermally-produced temperature (pressure) gradients that create the very noticeable daily wind speed variations at the wind power sites in the Columbia Gorge, along the Oregon Coast and in northeast Nevada are very weak during the winter as large scale (synoptic) pressure patterns created by storm fronts are the dominant driving force for the winds. The movement of storms (and wind) through the Northwest appears to occur in a random fashion during the day and night.

Wind Rose Analysis

The distribution of wind direction (by 16 compass points) and wind speed are plotted for the 12-month period for each of the ten sites in Figures 2.3.6a-f and 2.3.7a-d. The percent frequency and the mean wind speed is plotted for each direction. The analysis for the six Gorge sites from Augspurger Mountain to Roosevelt indicate that most of the strong winds, those where the mean speed exceeds 12 mph, are from the west to northwest direction. It should be noted that the Augspurger data are incomplete for the period as only June-November 1979 data are available. Most of these six sites show a secondary maximum direction frequency from the east, a wind flow that occurs frequently during the winter months. The better exposure of Juniper Pt to the wind flow in all directions compared to Goodnoe

Hills is very apparent in Figures 2.3.6d and e. The direction frequency plots are similar but the mean wind speed from most directions equals or exceeds 12 mph at Juniper Pt.

The Kennewick plot indicates that most of the power-producing winds come from the south-southwest or west as shown in Figure 2.3.7a. A similar bi-modal distribution is shown at Cape Blanco where persistent strong winds are common from both the north and the south.

The data from Pequop Summit indicate that most of the strong flow comes from the southwest through north. The most persistent strong winds come from the west to northwest directions.

Augspurgen Mtn.

a

Sevenmile Hill Tower

b

KCIV

c

Juniper Point

d

Goodnoe Hills

e

Roosevelt

f

FIGURE 2.3.4a-f Diurnal speed variation plots for six wind power data sites in the Columbia Gorge.

a

b

c

d

FIGURE 2.3.5a-d Diurnal speed variation plots for four wind power data sites.

FIGURE 2.3.6a-f Wind rose analysis plots for six wind power data sites in the Columbia Gorge for the period June 79--May 80. The Augspurger Mtn. data are for June--November 79.

a

b

c

d

FIGURE 2.3.7a-d

Wind rose analysis plots for four wind power data sites for the period June 79--May 80.

3.0 CALIBRATION OF THE KITE ANEMOMETER

3.0 CALIBRATION OF THE KITE ANEMOMETER.

Introduction

Kite anemometers have been extensively used by OSU 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 speed change with height (wind profiles), turbulence levels, and spatial variation of the wind flow. They have also been used to check tower wind speed measurements, and in three instances the tower anemometers were found to be significantly out of calibration.

During last year's work several different Tethered Aerodynamic Lifting Anemometer (TALA) units were calibrated against tower anemometers (reference BPA Report 79-4). The accuracy of the four models tested ranged from .3 to 12.6%. Three of the models were strain gauge systems, and the fourth (Model 150) was a spring scale unit. The strain gauge systems have not proven to be field reliable due to electronic problems. The handheld spring scale unit that is read visually has proven to be very useful, as there have been minimum maintenance problems.

To further describe the accuracy and precision of the handheld Model 150 TALA unit, several tests were made flying the kite anemometers next to tower-mounted anemometers and also next to each other. Wind speed measurements were taken over a 10- to 15-minute period. When a 10-minute sampling period was used, the 'eyeball' average wind speed for 5 seconds was determined every 15 seconds. For a 15-minute data run, the 5-second 'eyeball' average was taken every 20 seconds. From the family of data points, a mean and standard deviation of the wind speed was determined. A turbulence indicator, called Turbulence Intensity (I), was calculated by dividing the standard deviation by the mean speed. A mean wind speed from the tower strip chart recorder was calculated for the 10-15 minute period and compared to the TALA average speeds.

Tower Calibrations

During FY 80, 38 calibration tests were made against 9 tower-mounted anemometers. Of the 38 tests, 9 were 10-minute samples. The anemometer

heights varied from 45-300 feet. Table 3.1.1 summarizes the tower site location, sample number, and anemometer height. The data from Altamont Pass was provided courtesy of Pacific Gas and Electric Co., San Francisco, CA, and Pacific Wind Energy, Corvallis, OR.

The calibration results indicated very good agreement with the tower anemometers. The root mean square (RMS) error of the 38 samples was .521 mph and the mean bias was +.008 mph (see Table 2). The average error was 2.1%. The wind speeds ranged from 11-44 mph. A graphic depiction of the agreement is given in Figure 3.1.1. There appears to be little difference noted between the 10- and 15-minute samples.

FIGURE 3.1.1 Comparison of kite anemometer and tower anemometer speed measurements.

TABLE 3.1.1 Kite anemometer calibration station data.

<u>Station Name</u>	<u>Sample No.</u>	<u>Anemometer Height (Feet)</u>
Goodnoe Hills	19	45
Goodnoe Hills BPA	1	50
Goodnoe Hills BPA	5	195
Juniper Point	4	100
KCIV	2	45
Cape Blanco BPA	1	40
Langlois Mountain	1	20
Altamont Pass (CA)	2	200
Altamont Pass (CA)	3	300

TABLE 3.1.2 Kite anemometer/tower anemometer calibration summary.
 Nine 10-minute samples and twenty-nine 15-minute
 samples were taken from December 1979 - July 1980 at
 seven different locations.

<u>Sample No.</u>	<u>RMS Error (mph)¹</u>	<u>Abs. Error (mph)²</u>	<u>Mean Bias (mph)³</u>	<u>Average Error (%)⁴</u>
38	.521	.582	+.008	2.1

1 $RMS = \left| \frac{1}{N} \sum (V_T - V_K)^2 \right|^{\frac{1}{2}}$ where V_T = tower speed, V_K = kite speed,
 N = sample size

2 $Absolute\ Error = \frac{1}{N} \sum |V_T - V_K|$

3 $Mean\ Bias = \frac{1}{N} \sum (V_T - V_K)$

4 $Average\ Error = \left(\frac{1}{N} \sum \left| \frac{V_T - V_K}{V_T} \right| \right) \times 100\%$

Kite Anemometer Precision Measurements

Since the spring scale units are read visually, kite anemometers were flown next to each other to detect any significant difference which may be due to reading bias or systematic errors between different kites. The heights ranged from 45-200 feet. For a 45-foot test the kites were about 100 feet apart, and for a 200-foot test they were about 300-400 feet apart. Comparison of mean wind speed and turbulence intensity values are given in Tables 3.1.3 and 3.1.4 for 12 tests under varying wind speed and turbulence levels. The sampling time ranged from 5-15 minutes, although the majority of the tests were for 15 minutes. Data were taken every 15 seconds for the 5- and 10-minute tests, and every 20 seconds for the 15-minute tests.

The wind speed was within 3% agreement between the sensors, as noted in Table 3.1.3. The differences ranged from 0.4-6.9%. The largest difference, 6.9%, was detected under light and gusty flow. Also, the measurement period was only 5 minutes.

The turbulence intensities were also in good agreement between the sensors. The average difference was about .02, as noted in Table 3.1.4. The largest difference, .07, occurred under light and gusty flow at Cape Blanco.

From these tests it appears that there is no significant inherent error in reading the fluctuating spring. Perhaps the 5-second 'eyeball' average every 15-20 seconds tends to smooth out observer bias. Much of the error between kite measurements may be due to the spatial variation in the wind field. The data indicate that there is better agreement between kites for a longer sampling period. The limited data indicate an average error of 3.9% for 5-minute periods, 2.9% for 10-minute periods, and 2.3% for 15-minute sampling intervals.

TABLE 3.1.3 Comparison of mean wind speeds recorded by kite anemometers flown next to each other.

Location	Sampling Time (Min.)	Height (Feet)	TALA Number								Difference [*] (%)
			2	3	4	5	6	7	8	9	
Goodnoe Hills	10	45					32.9	33.6			2.1
Goodnoe Hills	15	200		20.9			20.3	20.1			4.0
Goodnoe Hills	15	200		21.5				20.9			2.9
Goodnoe Hills	15	200	29.7				30.2	29.0			4.1
Goodnoe Hills	15	200				20.0			20.5	20.1	2.5
Goodnoe Hills	15	200								22.1	.5
Juniper Point	15	100			27.5		27.6	27.6			.4
Juniper Point	15	100	26.8			26.5		26.2			2.2
Juniper Point	10	100			25.7	26.1		25.3			3.1
Cape Blanco	5	200				14.6	14.4	15.4			6.9
Cape Blanco	5	200				24.2	24.0				.8
Langlois Mountain	10	200				22.7	23.0	22.1			3.9
AVERAGE											2.8

* % Difference = $\frac{\bar{V} \text{ (high)} - \bar{V} \text{ (low)}}{\bar{V} \text{ (low)}} \times 100$

TABLE 3.1.4 Comparison of turbulence intensities (I) recorded by kite anemometers flown next to each other.

Location	Sampling Time (Min.)	Height (Feet)	TALA Number								Difference*
			<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>	<u>6</u>	<u>7</u>	<u>8</u>	<u>9</u>	
Goodnoe Hills	10	45					.08	.09			.01
Goodnoe Hills	15	200		.11			.11	.10			.01
Goodnoe Hills	15	200		.09				.09			.00
Goodnoe Hills	15	200	.13				.12	.13			.01
Goodnoe Hills	15	200				.16			.18	.18	.02
Goodnoe Hills	15	200							.14	.13	.01
Juniper Point	15	100			.12			.10	.12		.02
Juniper Point	15	100	.10			.09		.10			.01
Juniper Point	10	100		.11	.11		.14				.03
Cape Blanco	5	200		.17	.10	.15					.07
Cape Blanco	5	200		.15	.18						.03
Langlois Mountain	10	200		.15	.15	.10					.05
AVERAGE											.02

* Difference - I (high) - I (low)

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4.0 WIND PROFILE MEASUREMENTS

4.1 WIND PROFILE MEASUREMENTS AT THE GOODNOE HILLS MOD-2 SITES

4.2 WIND PROFILE MEASUREMENTS AT JUNIPER POINT

4.3 WIND PROFILE MEASUREMENTS IN THE CAPE BLANCO AREA

4.0 WIND PROFILE MEASUREMENTS

Wind profiles were taken in the Goodnoe Hills, Juniper Point, and Cape Blanco area using the kite anemometer. Simultaneous measurements were taken for 10-15 minute periods at the 50-, 200-, and 350-ft levels. Speed readings were taken every 15-20 seconds and the wind directions were taken once per minute. The mean and the standard deviation of the velocity data were calculated to determine the wind speed and direction change with height and the Turbulence Intensity at each level. The Turbulence Intensity (I) is defined as the standard deviation of the speed divided by the mean speed. Values less than 0.10 indicate smooth flow; values between 0.10 and 0.20 indicate moderate turbulence levels; and high turbulence levels are defined by values exceeding 0.20.

The Goodnoe Hills and Juniper Point areas are west/east oriented ridges that are mostly grass-covered or barren. A topography map showing both areas is given in Figure 4.0.1. The Goodnoe Hills WTG sites are indicated by Sites 1-3 while Sites A-C are anemometer locations (See Figure 4.0.1a). The Juniper Point anemometer site is shown in Figure 4.0.1b. The prevailing power producing wind direction is southwest through northwest with the west winds being the most persistent.

FIGURE 4.0.1 Goodnoe Hills and Juniper Point area topography maps.
a) Goodnoe Hills WTG area showing the locations of WTG 1, 2, and 3. The lettered sites are anemometer locations.
b) Juniper Point anemometer site.

4.1 WIND PROFILE MEASUREMENTS AT THE GOODNOE HILLS MOD-2 SITES

Introduction

Kite anemometers were flown simultaneously at the three MOD-2 sites at Goodnoe Hills to measure the change in wind speed with height. During the past year 16 profiles have been taken at the WTG 1 and WTG 2 sites, and 19 profiles were made at the WTG 3 site. Wind data were taken at three levels (50, 200, and 350 feet) for most of the profiles. A few of the measurements were limited to the 50- and 200-foot levels. The sampling period varied from 5-15 minutes, although 44 of the 51 profiles were 15-minute runs.

The data are summarized for each site in graphical and tabular form. The date, time, and mean wind speed (in mph) are given for each level as well as the turbulence intensity, I, and the mean direction at the 200-foot level. The power law exponent, α , from the simple power law¹ was also calculated for the 50- to 200-foot level.

At each site the profiles were plotted by directions: southwest (220-235°), west-southwest (245-255°), west (260-275°), and west-northwest (280-300°). This was done in order to see if there were significant changes in the wind profile by direction. Also, the mean direction at the 200-foot level was used to categorize the flow. Below each plot the pertinent wind data are given.

Wind direction readings were also taken at the 50-, 200-, and 350-foot levels once per minute during most of the profiles. In general, the direction differences averaged about 10° between the 50- and 200-foot levels at all of the WTG sites. Between the 200- and 350-foot level the direction differences averaged about 7° at WTG 1 and 3 and 10° at WTG 2. Also, the directional turbulence was greatest at the 50-foot level, as the average variation from the mean was about $\pm 20^\circ$ compared to $\pm 10^\circ$ degrees at the 200- and 350-foot levels.

$$1 \quad \alpha = \frac{\ln \frac{V_{200}}{V_{50}}}{\ln \frac{200}{50}}$$

Wind Profiles Taken at the WTG 1 Site

The 18 wind profiles taken at WTG 1 are shown in Figures 4.1.1-4.1.4. The two profiles taken under 220° flow were noticeably different, as one indicated no significant change in wind speed with height and the other a modest change with height (see Figure 1).

The profiles under west-southwest wind were very similar for wind speeds exceeding 14 mph, as noted in Figure 4.1.2. The shear was not great, as the α values varied from .07-.12. The wind profile taken under wind speeds of 10-11 mph indicated a slightly negative shear under the gusty flow.

Wind profiles were taken in five west wind situations. The profiles plotted in Figure 3 indicated a similar shape, especially profiles 12, 14, and 16 that were taken in June and August. The two winter profiles, 2 and 4, indicated more shear and a similar shape.

The profiles taken under west northwest flow were in fairly good agreement, as noted in Figure 4.1.4. The change in wind speed with height was most pronounced in the lowest 200 feet and the α values varied from .05-.12.

No.	Date	Time(PST)	50'	200'	350'	$\alpha(50-200')$	I(200')	DIR(200')
3	12/13/79	1054-1109	17.6	21.1	24.1	.13	.08	220°
7	4/10/80	1321-1336	19.5	19.7	19.6	.01	.14	220°

FIGURE 4.1.1 Wind profiles at WTG 1 for direction 220°.

No.	Date	Time(PST)	50'	200'	350'	$\alpha(50-200')$	I(200')	DIR(200')
6	3/19/80	1146-1156	21.7	24.0		.07	.07	250°
10	6/18/80	1217-1232	11.0	10.5	11.0	-.03	.21	245°
11	6/18/80	1715-1730	14.2	16.6	17.5	.11	.13	255°
13	6/26/80	1910-1925	20.3	23.9	25.8	.12	.08	255°

FIGURE 4.1.2 Wind profiles at WTG 1 for directions 245-255°.

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

No.	Date	Time(PST)	50'	200'	350'	$\alpha(50-200')$	I(200')	DIR(200')
5	3/18/80	1237-1247	22.7	24.2		.05	.08	300°
8	4/29/80	1719-1734	26.4	29.7	31.8	.08	.21	280°
9	5/22/80	1330-1345	21.8	26.0	27.4	.13	.12	280°
15	7/16/80	1724-1739	25.2	29.7	30.6	.12	.12	295°

FIGURE 4.1.4 Wind profiles at WTG 1 for directions 280-300°.

Wind Profiles Taken at the WTG 2 Site

There were noticeable differences in the wind shear measured under southwest flow as noted in Figure 4.1.5. The most pronounced shear was measured during the winter morning profile, as the α value was .21. The spring and summer measurements taken during the afternoon indicated little shear.

Figure 4.1.6 shows that the largest wind shear sampled under west-southwest flow was during the early evening hours in June. The α value was .16. The other two profiles indicated little shear, as the α value varied from .05-.07.

The wind profiles shown in Figure 4.1.7 are for west flow. It appears that the wind shear increases with wind speed, as noted by the progressive increase in the 200-foot-level wind speed. This shear may also be due to an increase in stability, as profile 1 was taken during a cold winter afternoon and profile 7 was taken just before sunset in March.

The effects of stability on the shape of the wind profile under west-northwest flow can be seen in Figure 4.1.8. The most shear was measured during the summer just before sunset and shortly after sunrise, as the α values varied from .16-.19 in profiles 15 and 16. The other three profiles taken during the afternoon showed a slight wind shear.

No.	Date	Time(PST)	50'	200'	350'	$\alpha(50-200')$	I(200')	DIR(200')
2	12/13/79	1013-1028	16.9	22.7	24.6	.21	.08	220°
6	4/10/80	1358-1413	18.2	18.5	19.4	.01	.16	225°
9	6/18/80	1301-1316	11.0	10.5	11.9	-.03	.24	235°

FIGURE 4.1.5 Wind profiles at WTG 2 for directions 220-235°.

No.	Date	Time(PST)	50'	200'	350'	$\alpha(50-200')$	I(200')	DIR(200')
3	1/17/80	1355-1410	19.5	21.6	21.9	.07	.16	250°
11	6/26/80	1109-1124	21.8	23.5	25.0	.05	.10	250°
12	6/26/80	1830-1845	20.6	25.7	28.1	.16	.13	255°

FIGURE 4.1.6 Wind profiles at WTG 2 for directions 250-255°.

No.	Date	Time(PST)	50'	200'	350'	$\alpha(50-200')$	I(200')	DIR(200')
1	12/ 5/79	1358-1413	21.6	26.3		.14	.15	260°
5	3/19/80	1218-1228	18.5	19.8		.05	.17	275°
7	4/29/80	1756-1811	26.4	32.7	34.3	.15	.09	275°
8	5/22/80	1240-1255	21.4	22.4	23.3	.03	.16	275°
13	6/27/80	1108-1123	20.8	23.3	23.9	.08	.15	260°

FIGURE 4.1.7 Wind profiles at WTG 2 for directions 260-275°.

No.	Date	Time(PST)	50'	200'	350'	$\alpha(50-200')$	I(200')	DIR(200')
4	3/18/80	1344-1349	23.4	25.4		.06	.15	290°
10	6/18/80	1745-1800	15.4	16.8	19.5	.06	.13	280°
14	7/16/80	1644-1659	24.3	26.7	28.1	.07	.10	305°
15	8/ 5/80	0734-0749	21.3	27.8	31.9	.19	.16	280°
16	8/ 5/80	1925-1940	19.8	24.6	28.1	.16	.11	285°

FIGURE 4.1.8 Wind profiles at WTG 2 for directions 280-300°.

Wind Profiles Taken at the WTG 3 Site

Under southwest flow three of the profiles shown in Figure 4.1.9 indicate little change of wind speed with height. The most noticeable shear measured under this wind direction occurred during a winter morning.

The profiles measured under west-southwest winds showed fairly good agreement, as a slight change of wind speed with height was recorded, as noted in Figure 4.1.10. Also, the turbulence level for all of the runs was high, as turbulence intensity values ranged from .16-.30.

In general, a slight increase in wind speed with height was measured under west flow at the WTG 3 site (see Figure 4.1.11). Profile 9 indicated a slightly negative shear. A noticeable wind shear was measured during the early evening hours under west-northwest flow (see Figure 4.1.12). Profiles 8, 18, and 19 show an increase in wind shear with stability and speed. At this time the low level stability was increasing, as the sun was setting. Profiles 5 and 16 were taken during the mid-day and show little change in wind speed with height.

No.	Date	Time(PST)	50'	200'	350'	$\alpha(50-200')$	I(200')	DIR(200')
3	12/13/79	0932-0947	13.1	17.4	19.7	.20	.08	220°
7	4/10/80	1203-1218	20.4	20.6	20.7	.01	.13	230°
10	6/18/80	1350-1405	11.5	12.4	13.0	.05	.16	235°
12	6/18/80	1745-1800	18.1	19.0	20.9	.04	.11	235°

FIGURE 4.1.9 Wind profiles at WTG 3 for directions 220-235°.

No.	Date	Time(PST)	50'	200'	350'	$\alpha(50-200')$	I(200')	DIR(200')
4	1/17/80	1315-1330	16.1	18.5	19.1	.10	.21	250°
11	6/18/80	1715-1730	14.2	14.9	16.4	.03	.30	250°
14	6/26/80	1754-1809	25.4	27.6	29.5	.06	.16	245°
17	8/ 5/80	0642-0657	21.8	25.6	27.1	.12	.19	255°

FIGURE 4.1.10 Wind profiles at WTG 3 for directions 245-255°.

No.	Date	Time(PST)	50'	200'	350'	$\alpha(50-200')$	I(200')	DIR(200')
1	6/ 6/79	1030-1100	20.6	22.9	25.7	.08	.15	260°
2	12/ 5/79	1419-1434	22.1	24.9		.09	.11	260°
6	3/19/80	1109-1119	22.1	23.1		.03	.09	265°
9	5/22/80	1105-1120	20.8	20.5	22.7	-.01	.12	260°
13	6/26/80	0940-0955	16.2	19.8	20.4	.14	.19	275°
15	6/27/80	0900-0915	19.6	21.7	21.8	.07	.15	265°

FIGURE 4.1.11 Wind profiles at WTG 3 for directions 260-275°.

No.	Date	Time(PST)	50'	200'	350'	$\alpha(50-200')$	I(200')	DIR(200')
5	3/18/80	1440-1450	25.2	28.4		.09	.10	290°
8	4/29/80	1821-1836	23.7	33.8	36.2	.26	.06	280°
16	7/16/80	1615-1630	24.9	27.5	28.7	.07	.11	295°
18	8/ 5/80	2120-2135	16.2	22.2	21.5	.23	.07	280°
19	8/ 5/80	1925-1940	18.4	25.1	27.7	.22	.09	285°

FIGURE 4.1.12 Wind profiles at WTG 3 for directions 280-300°.

Conclusions

The wind profiles measured at the three MOD-2 sites indicated, in general, a slight change in wind speed with height. The average α value for the 50-200 foot level for the three sites ranged from .08 at WTG 1 to .10 at WTG 3. The highest shear values (high α) were measured at WTG 2 and 3. At these two sites the daytime shear appears to be higher in the winter than in the summer and noticeably higher during the late evening to early morning hours, especially for west-northwest flow. The high shears measured are probably associated with an increase in low-level stability.

The directional shear between the 50- and 200-foot levels at all three sites was about 10°. The 200- to 350-foot directions varied by about 7° at WTG 1 and 3 and 10° at WTG 2. 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.

4.2 WIND PROFILES TAKEN AT JUNIPER POINT

Kite anemometers were flown next to the 100 ft Juniper Point meteorological tower on five occasions during the past year to determine the change of wind speed with height. The profile data are graphically depicted and listed in Figures 4.2.1a-b. The measurements were made under moderate to strong west-southwest to northwest flow which is the prevailing power producing wind quadrant. The 100 ft data are from the tower anemometer and the 50, 200, and 350 ft data are from the kite anemometers.

Most of the profiles indicate little shear between the 50 and 200 ft level. These profiles agree with those taken last year and documented in BPA Report 79-4. The only profile that showed much shear was profile 5 where there was a modest wind speed increase in the lowest 100 ft. This run was made shortly after sunrise so the wind shear could be due to early morning low level stability.

No.	Date	Time (PST)	50'	100'	200'	350'	α (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

* α (50-200').

FIGURE 4.2.1a Wind profiles at Juniper Point.

No.	Date	Time(PST)	50'	100'	200'	350'	α (100-200')	I (200')	DIR (200')
4	3/27/80	0945-0955		21.5	22.0	20.9	.02	.16	250
5	5/23/80	0736-0751	22.6	26.0	25.1	25.1	.08*	.07	290

* α (50-200')

FIGURE 4.2.1b Wind profiles at Juniper Point.

4.3 WIND PROFILES TAKEN IN THE CAPE BLANCO AREA

During the past year wind profiles were taken at six locations in the Cape Blanco area. The site locations are shown in Figure 4.3.1. Sites 1-5 are over the headland of the Cape at around 200 feet MSL; and Site 6 is at Langlois Mountain, which is at 1200 feet MSL. Fixed-place anemometers are located at Site 6, Site 2, and at Site 5, the Cape Blanco BPA Station.

CONTOUR INTERVAL 200 FEET
WITH SUPPLEMENTARY CONTOURS AT 100 FOOT INTERVALS

FIGURE 4.3.1 Cape Blanco wind profile locations.

The profiles are plotted along with the profile data in Figures 4.3.2a-b. Most of the measurements were made under south flow. In general, most of the measurements indicated little wind speed increase with height, as the α values varied from 0.01-0.13. All of the locations except Site 3 in the lowland were well exposed to south winds with little obstructions to the flow. However, Site 3 was a small open area surrounded by trees (40-60 feet in height). The winds in the lowest 100 feet were so erratic and turbulent that it was impossible to fly the kite anemometer. The resulting shear was large, as noted in Figure 4.3.2b, and the α value was estimated as 0.63. This large shear was similar to that measured in previous studies under south flow at the Cape Blanco Airport, where α values exceeding 0.40 were measured over the dense tree canopy (reference BPA Report 79-4).

Site No.	Date	Time (PST)	50	200	350	I (200)	DIR (200)	α (50-200')
4	12/19/79	0834-0849	20.9	25.0	25.2	.11	180-200°	.13
4	2/20/80	1411-1426	16.2	16.4	16.4	.17	180-190°	.01
5	2/20/80	1243-1304	14.4*	15.6	16.1	.05	150°	.05
6	2/21/80	1515-1530	22.6	23.2	24.4	.12	190°	.02

*40-foot data.

FIGURE 4.3.2a Wind profiles taken in the Cape Blanco area.

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 4.3.2b Wind profiles taken in the Cape Blanco area.

More profile data have to be collected over the well exposed headland in both south and north flow to determine the wind shear in likely WTG development areas. Also, one or two 200-300 foot meteorological towers instrumented at several levels are needed to record continuous data. From the limited data collected, the wind shear does not appear to be great where areas have a well exposed, smooth fetch. Considerable shear can be expected in the forested area which prevails in the Cape area lowland. The exposure at Langlois Mountain appears to be very good, as the smooth grassy slopes accelerate the flow as it passes over the ridge, thus decreasing the low level shear.

5.0 SPATIAL COMPARISON OF THE WIND FLOW
IN THE GOODNOE HILLS AND CAPE BLANCO AREA

- 5.1 COINCIDENT WIND VELOCITY MEASUREMENTS AT SEVERAL LOCATIONS IN THE
GOODNOE HILLS/JUNIPER PT AREA
- 5.2 COMPARISON OF THE WIND FLOW AT THE MOD-2 SITES WITH THAT AT THE
LONG-TERM GOODNOE HILLS ANEMOMETER SITE AND THE BPA 195-FT
METEOROLOGICAL TOWER
- 5.3 COMPARISON OF SIMULTANEOUS WIND MEASUREMENTS AT THE THREE MOD-2 SITES
- 5.4 COINCIDENT WIND VELOCITY MEASUREMENTS AT SEVERAL LOCATIONS IN THE
CAPE BLANCO AREA

5.1 COINCIDENT WIND VELOCITY MEASUREMENTS AT SEVERAL LOCATIONS IN THE GOODNOE HILLS/JUNIPER POINT AREA

Introduction

Simultaneous kite anemometer measurements were taken at several locations in the Goodnoe Hills/Juniper Point area on several occasions during the past year. The measurement locations are shown in Figure 5.1.1. There are fixed-place anemometers recording continuous speed and direction on strip chart recorders at five of the locations noted A-E in Figure 5.1.1. The anemometer heights vary from 30-200 feet, as noted in Table 5.1.1. Kite anemometer data were taken at the 23 numbered locations in Figure 5.1.1 at the 50, 200, and 350-foot levels for a 15-minute period. The wind speed and direction at the three levels were then averaged over the 45-minute sampling time for comparison purposes.

TABLE 5.1.1 Fixed-place anemometer locations in the Goodnoe Hills/Juniper Point study area.

<u>Site</u>	<u>Location</u>	<u>Elevation (ft. MSL)</u>	<u>Anemometer Height (ft.)</u>
A	Goodnoe Hills	2565	45
B	Goodnoe Hills	2600	30
C	Goodnoe Hills	2600	50, 195
D	Juniper Point	3100	100
E	John Day Dam	200	40

The coincident measurements were made in two sub-areas in Figure 5.1.1. The first sub-area was in the vicinity of the Goodnoe Hills WTG site, which included Sites 17-22. All of the anemometer data were referenced for comparison purposes to the Site A anemometer data (the long-term data site). The other sub-area was along the slopes of Juniper Point, Sites 1-16 in Figure 5.1.1. The wind data from these sites were compared to the coincident wind data from the Site D anemometer. A description of what was measured in the two sub-areas follows. More data have to be taken to draw any conclusions, as the data base is not large.

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

FIGURE 5.1.1 Spatial measurement site locations.
The sites noted by dots and numerically coded are where kite anemometer measurements were taken.
The lettered sites indicate where fixed-place anemometers are located (reference Table 1).

Goodnoe Hills WTG Area

Coincident wind measurements were made on 12 occasions west and east of the MOD-2 area. A summary of the wind speed and direction data are given in Table 5.1.2. Wind speed data from the Goodnoe Hills BPA tower, Site C, were not available until April 1980. Due to instrument malfunction, much of the Site B data are missing. To note the differences between the wind flow on the 2500-3000 foot ridge north of the Columbia River and that on the river, the data from the John Day Dam, Site E, were analyzed. The data from all of the sites were referenced to the coincident Site A anemometer data. This is the long-term anemometer site that has been in operation since 1976; the mean annual wind speed is about 16.5 mph. Since the wind can quickly vary in time, only relative differences of greater than 10% are considered significant.

The measurements taken under moderate-to-strong flow during the winter (i.e., December-February) indicated that under southwest winds the flow was stronger at the WTG area and east of the area than at Site A, or west of Site A, as noted in Table 5.1.2. Under more westerly flow, the winds were stronger east of the WTG area at Sites 21 and 22. Measurements at Sites 17 and 18 indicated a 10-40% decrease in the speeds noted at Site A.

The speed differences between Sites A, D, and E were most pronounced during the winter, as the wind speed at Site D, Juniper Point, was often 2-4 times as strong as that measured at Site A. Conversely, the winds measured at the John Day Dam were much lighter than those recorded at all of the ridgetop sites due to the exposure of the higher elevation sites to the prevailing upper-air southwest flow and the effect of the persistent winter inversion over the lower elevations that inhibits strong winds.

In the April measurements under strong west-to-southwest flow, Sites 17 and 21 recorded the most differences, as the wind speeds were considerably stronger at these two sites than at Site A. Also, the Juniper Point anemometer recorded 35-40% higher speeds than those at Site A. The wind flow along the river was similar to that measured in the WTG area.

The measurements taken in May under west northwest flow indicated the winds in the WTG area were 15-30% lighter than those measured at Site A, and the flow was 10-20% lighter east of the WTG area. The Juniper Point winds were about 20% stronger than those measured at Site A.

TABLE 5.1.2 Coincident wind speeds at several locations in the Goodnoe Hills area. The data from Sites A-E are from fixed-place anemometers, and those from Sites 17-23 are from portable kite anemometers where the wind velocities were averaged over the 50-350 foot level. Wind directions are given in parentheses (i.e., 21 = 210° true).

<u>Date</u>	<u>Time (PST)</u>	<u>A</u>	<u>B</u>	<u>C</u>	<u>D</u>	<u>E</u>	<u>17</u>	<u>18</u>	<u>19</u>	<u>20</u>	<u>21</u>	<u>22</u>	<u>23</u>
12/13/79	1230-1325	9.0(21)	13.0(22)		35.0(27)	2.0(18)	7.0(23)					16.8(24)	16.9(23)
12/13/79	1340-1440	16.7(26)	15.1(25)		29.0(27)	4.0(18)		11.5(23)			24.5(27)		20.7(26)
1/17/80	1545-1640	26.0(20)	18.3(27)		30.0(31)	18.0(18)	23.9(27)					21.5(29)	21.6(28)
2/6/80	1540-1635	25.7(28)	19.5(29)		42.0(28)	11.0(20)	23.3(28)					27.1(28)	27.3(26)
2/6/80	1650-1745	21.0(27)	15.5(27)		42.0(29)	15.0(20)		11.2(26)			21.9(25)		21.9(26)
4/29/80	1445-1540	26.7(24)	23.0(28)	23.0*(28)	37.0(20)	30.0(21)		27.5(28)		26.5(27)	32.9(24)		
4/29/80	1555-1650	29.0(27)	26.3(29)	24.7*(28)	39.0(30)	30.0(20)	33.6(27)			29.4(27)		28.6(25)	
5/22/80	1540-1635	33.7(28)		26.0(29)	41.0(30)					29.0(27)	29.9(27)	26.2(28)	
5/22/80	1710-1805	33.3(29)		26.7(30)	40.0(31)		32.6(27)	30.5(29)		28.2(28)			
6/18/80	1530-1625	13.3(23)		14.3(24)	15.0(25)		12.7(24)	12.6(21)		12.3(23)	13.5(25)	12.6(25)	
8/5/80	1055-1110	19.7(25)		19.7(27)	22.0(28)		21.3(28)	20.3(27)	20.0(28)	21.6(27)	21.4(26)	18.4(26)	

*50-foot-level (otherwise, the data are from the 195-foot-level anemometer).

However, in June and August the measurements made indicated no significant differences in the winds measured near the WTG area. The Juniper Point winds were slightly stronger, about 12-13%.

Juniper Point Area

Eleven measurement surveys were made from March-August in the Juniper Point area. The data are summarized in Table 5.1.3. The wind data were compared to the coincident wind data from the 100-foot Juniper Point meteorological tower, Site D in Figure 5.1.1. The anemometer has been in operation since August of 1978, and the annual mean speed is about 20 mph. Because of rapid variations in the wind field, only wind speed differences greater than 10% are considered significant for comparison purposes.

In contrast to the wide variations in the relationships between the speeds at the various sites measured in the Goodnoe Hills WTG area, the distribution of 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 (12, 6, 7, 8, 15, and 16) agreed quite closely with the Juniper Point anemometer measurements. Only Sites 9 and 10 along the ridge crest showed about an average 10-12% decrease in mean wind speed. All of the slope locations showed a 15-20% decrease in wind speed. Site 4 on the valley floor recorded the most difference, as an average 25% decrease was measured.

Although the relationships from this limited data look encouraging, more measurements must be taken, especially during the winter months. Also, many more locations need to be surveyed. Because of the large survey area, it is anticipated that the measurement method will be changed to measure only the 200-foot level winds at each location for a 30-60 minute period in order to get more accurate relationships established. This change will be needed because of the temporal variation in the wind field.

TABLE 5.1.3

Coincident wind speeds at several locations in the Juniper Point area. The data from Sites A-E are from fixed-place anemometers, and those from Sites 1-16 are from kite anemometers where the wind velocities were averaged over the 50-350 foot level. Wind directions are given in parentheses (i.e., 25 = 250° true).

Date	Time (PST)	A	C	D	E	1	2	3	4	5	6	7
3/27/80	1100-1135	23.0(25)		21.8(25)	20.0(20)		17.4(26)					16.7(26)
3/27/80	1205-1240	24.0(24)		18.5(26)				19.9(27)			22.1(27)	
4/29/80	0800-0855	24.0(24)	20.0*(28)	26.3(27)	18.0(20)		21.1(30)					23.3(29)
4/29/80	0910-1005	26.0(23)	20.0*(28)	28.0(28)	17.0(20)			22.6(25)			23.8(28)	
5/23/80	0935-1030	22.0(22)	20.0(25)	20.0(27)			17.6(27)					
5/23/80	1100-1155	23.0(22)	22.0(23)	22.6(26)			19.1(28)			20.6(28)	21.3(27)	
5/23/80	1215-1310	25.0(22)	20.0(27)	26.3(27)				20.8(27)				26.1(27)
6/27/80	1530-1625	22.0(27)	18.0(29)	25.7(30)		19.7(30)		18.6(28)				
6/27/80	1650-1745	25.0(28)	18.0(20)	26.3(31)					16.7(32)			22.7(32)
8/5/80	1540-1635	26.0(26)	32.0(27)	30.3(29)					25.0(28)	25.7(29)		27.2(28)
8/5/80	1415-1510	25.0(24)	31.0(27)	29.3(28)		25.5(29)		26.0(29)			28.3(26)	

Date	Time (PST)	A	C	D	E	8	9	10	11	12	13	14	15	16
3/27/80	1100-1135	23.0(25)		21.8(25)	20.0(20)			18.0(28)						
3/27/80	1205-1240	24.0(24)		18.5(26)									16.0(28)	
4/29/80	0800-0855	24.0(24)	20.0*(28)	26.3(27)	18.0(20)								26.9(29)	
4/29/80	0910-1005	26.0(23)	20.0*(28)	28.0(28)	17.0(20)		25.0(28)							
5/23/80	0935-1030	22.0(22)	20.0(25)	20.0(27)			17.7(28)	17.7(28)						
5/23/80	1100-1155	23.0(22)	22.0(23)	22.0(26)										
5/23/80	1215-1310	25.0(22)	20.0(27)	26.3(27)						31.4(28)				
6/27/80	1530-1625	22.0(27)	18.0(29)	25.7(30)				25.3(28)				19.3(30)		24.8(31)
6/27/80	1650-1745	25.0(28)	18.0(20)	26.3(31)		23.7(34)			21.3(28)	23.7(32)				
8/5/80	1540-1635	26.0(26)	32.0(27)	30.3(29)		29.1(28)			25.9(29)	28.0(28)				
8/5/80	1415-1510	25.0(24)	31.0(27)	29.3(28)							27.7(30)	25.8(28)		26.9(29)

*50-foot level data (otherwise, it is 200-foot-level data).

5.2 COMPARISON OF THE WIND FLOW AT THE MOD-2 SITES TO THAT AT THE LONG-TERM GOODNOE HILLS ANEMOMETER SITE AND THE BPA 195-FT METEOROLOGICAL TOWER

During the past year several measurements of the wind speed have been made at the three MOD-2 sites at the 50-, 200-, and 350-foot levels. The measurements made with kite anemometers varied from 10-15 minutes in length with the majority being for a 15-minute period. The mean wind speeds at the three levels are compared to the coincident mean wind speeds measured by the 45-foot-level anemometer at the long-term Goodnoe Hills data station, Site A.

The wind speeds are analyzed by direction to determine if there are any significant differences between the flow patterns from a nominal "southwest" (220-250°), "west" (260-270°), and "west-northwest" (280-300°) direction as measured by the Site A anemometer. These are the most prevalent power-producing wind directions, as noted in Table 5.2.1. Three years of data indicate that the wind speed equals or exceeds 15 mph about 52% of the time.

When there are power-producing winds, they occur about 13% of the time from the "southwest" direction, 17% of the time from the "west" direction, and about 47% of the time from the "west-northwest" direction. The wind flow is strongest out of the "west-northwest."

The comparisons are made by taking the ratio of the wind speed measured at each WTG site to those measured at Site A. This was done for the 50-, 200-, and 350-foot level speeds. The comparison data are summarized in Table 5.2.2. Next to each ratio the number of samples is given.

Under "southwest" flow the wind speeds were in good agreement at the 50-foot level at Site A and the three MOD-2 sites, as noted in Table 5.2.2. The 200-foot-level flow was slightly stronger at the WTG sites than that measured at Site A, and the 350-foot winds were about 15-25% stronger.

Under "west" winds the 50-foot level winds were slightly weaker than those recorded at Site A. The 200-foot wind speeds measured at the MOD-2 sites were fairly close to those measured at Site A, and the 350-foot-level winds were 12-15% stronger.

However, when the wind direction was from 280-300°, the wind speed was only about 75-85% as strong at the 50-foot level at the MOD-2 sites as that measured at Site A. At the 200-foot level the winds are about 10% lower, and at the 350-foot level the wind speeds are in fair agreement with those measured at Site A.

TABLE 5.2.1 Frequency of power-producing winds when the Site A wind speed $\geq$ 15 mph (1976-1979 data).
Other wind directions have occurrences of significantly less than 1%.

Direction	220	230	240	250	260	270	280	290	300	310	320	330	340	040	050	060	070
Frequency (%)	.7	2.2	4.2	5.8	8.2	8.7	19.6	18.2	9.5	4.1	4.5	1.8	1.4	1.0	1.4	1.2	.9
Mean speed (mph)	21.8	21.4	22.3	23.1	23.3	24.2	27.3	27.0	25.7	26.1	28.4	24.2	26.3	20.3	20.8	18.9	17.9

TABLE 5.2.2 Comparison of the 50-, 200-, and 350-foot level winds ($\bar{V}_1$, $\bar{V}_2$, $\bar{V}_3$) measured at the MOD-2 sites to those measured by the anemometer at Site A for selected directions. The number of observations is given in parentheses.

<u>SITE A DIRECTION</u>	<u>220-250°</u>	<u>260-270°</u>	<u>280-300°</u>	<u>WEIGHTED AVERAGE</u>
<u>50-Foot Level</u>				
$\bar{V}_1/\bar{V}_A$	.97 (18)	.91 (6)	.83 (18)	.91 (42)
$\bar{V}_2/\bar{V}_A$	1.01 (14)	.97 (9)	.77 (10)	.93 (33)
$\bar{V}_3/\bar{V}_A$	1.01 (15)	.95 (11)	.74 (12)	.91 (38)
<u>200-Foot Level</u>				
$\bar{V}_1/\bar{V}_A$	1.00 (16)	1.00 (9)	.91 (16)	1.01 (41)
$\bar{V}_2/\bar{V}_A$	1.04 (11)	1.10 (11)	.89 (10)	1.01 (32)
$\bar{V}_3/\bar{V}_A$	1.07 (10)	1.02 (12)	.90 (13)	1.01 (35)
<u>350-Foot Level</u>				
$\bar{V}_1/\bar{V}_A$	1.14 (12)	1.12 (8)	1.00 (12)	1.08 (32)
$\bar{V}_2/\bar{V}_A$	1.18 (9)	1.15 (11)	.97 (6)	1.13 (26)
$\bar{V}_3/\bar{V}_A$	1.26 (9)	1.13 (11)	.94 (9)	1.11 (29)

BPA installed a 195-ft meteorological tower in April about halfway between WTG 2 and 3. The tower is instrumented with strip chart recording anemometers at the 50 and 195-ft level. A comparison of the coincident winds measured for a 15-minute period at the 50 and 200-ft levels at each of the three WTG sites is given in Table 5.2.3. The sample number ranged from 12-21 periods. The sampling was made in April through August under southwest-to-northwest winds at speeds of 11-34 mph. The limited data taken indicated that the 50-ft level winds speeds measured at WTG 1 and 2 were 8-9% stronger than those measured at the BPA tower. The difference at WTG 3 averaged about 4%. At the 200-ft level it appears that the winds are about 7% higher than those measured at the tower. Although the accuracy of the kite anemometers is on the order of $\pm 3\%$, there appears to be no systematic error in the measurement system as reported in Section 3.0. Therefore, the differences between the meteorological tower and the MOD-2 sites are most likely due to spatial variations in the wind flow under moderate-to-strong westerly winds.

TABLE 5.2.3 Comparison of 15-minute kite anemometer measurements at the three WTG sites to those at the 195-ft BPA meteorological tower. The ratio is the WTG site speed/tower speed. The measurements were made under south-to-northwest flow from 11-34 mph.

<u>Level</u> <u>(ft)</u>		<u>WTG-1</u>	<u>WTG-2</u>	<u>WTG-3</u>
50	No. of Obs	21	13	18
	Avg Ratio	1.08	1.09	1.04
	σ	.078	.060	.082
	Range	.96-1.21	.96-1.21	.95-1.21
200	No. of Obs	18	12	16
	Avg Ratio	1.07	1.06	1.07
	σ	.083	.071	.061
	Range	.79-1.15	.95-1.15	.96-1.17

The coincident hourly average wind speeds were compared between the 45-ft level anemometer at Site A and the 50- and 195-ft level winds from the BPA tower, Site C. The period of record was 8 May to 27 August 1980. There were 2574 coincident paired observations at the 50-ft level and 2570 at the 195-ft level where the ratio of the Site A wind speeds to those at Site C were made. The analysis was done by wind direction and speed class where Site C was the independent variable (i.e.: For a given wind direction and speed at Site C the corresponding speed at Site A was used to calculate the ratio V_A/V_C). The relationships are summarized in Table 5.2.4 where only directions with at least 50 observations were noted. Fifty observations are approximately 2% of the data base used. As noted in Table 5.2.4, the vast majority of the observations were for wind directions 270-300° with 280° being the most frequent. From the long-term data taken at Site A this quadrant appears to be where most of the power producing winds come from, as noted in Table 5.2.1. Also 280° is the most frequent direction.

The analysis of the 45- and 50-ft level winds indicate that the westerly flow is considerably stronger at Site A as noted in Table 5.2.4. The mean wind speed for the period was 19.5 mph at Site A compared to 13.7 mph at the 50-ft level anemometer at Site C. When considering the wind flow in excess of 12 mph the most pronounced variations are for directions 270-300°, as the ratios are often in the 1.30-1.50 range. In general, as the wind speed increased the ratio decreased. For wind directions 230-260° and speeds ≥ 12 mph the wind flow is about 10-20% stronger at Site A than at the 50-ft level at Site C.

The 195-ft level winds at the BPA meteorological tower averaged about 10% lower than those at Site A as the mean wind speed for the period was 17.4 mph at the tower compared to 19.5 mph at Site A (See Table 5.2.4). The largest differences between the wind speeds at both sites appear to occur under 10-30 mph flow from directions 280-300°. At wind speeds above 30 mph there is little difference between the measured flow for directions 270-280° and about a 10-20% difference for directions 290-300°. As the wind speed increased the ratios decreased. For wind directions 230-270° and speeds ≥ 12 mph the strength of the wind at the 195-ft level at Site C was similar to that measured at the 45-ft level at Site A.

TABLE 5.2.4 Ratio of the wind speed at the Goodnoe Hills 45-ft level Site A anemometer (V2) to the 50 and 195-ft levels of the BPA Site C meteorological tower (V1). The period of record was from 5/8 - 8/27/80 (2574 obs at 50 ft and 2570 at 195 ft). Only directions where at least 50 observations were available are noted. The ratio given is V2/V1.

Direction		No	Speed Class (mph)													
(VI)	Obs		1-4	5-9	10-12	13-15	16-18	19-21	22-24	25-27	28-30	31-33	34-36	37-39	40-42	43-45
$\bar{V}_{45}/\bar{V}_{50}$	230	109	1.25	1.14	1.06	1.08	1.13	1.15								
	240	151	1.44	1.24	1.13	1.12	1.16	1.16	1.08							
	250	68	1.50	1.20	1.18	1.20	1.22	1.20								
	260	93	1.38	1.12	1.27	1.20	1.19	1.22	.96	1.00						
	270	308	1.64	1.29	1.46	1.35	1.32	1.35	1.12	1.08	1.06					
	280	698	1.33	1.66	1.63	1.55	1.50	1.46	1.31	1.28	1.13		1.14			
	290	459	1.58	1.82	1.72	1.58	1.57	1.51	1.44	1.50	1.41	1.47	1.23			
	300	240	1.79	1.90	1.71	1.45	1.47	1.54	1.46	1.43	1.41					
Total Obs. Used		2126														
$\bar{V}_{45}/\bar{V}_{195}$	230	108	1.13	1.06	.96	1.00	.98	1.04								
	240	128	1.43	1.10	1.06	1.03	1.03	1.03	1.00	1.00						
	250	78		1.15	.94	1.10	1.11	1.07	1.00	.74						
	260	113	1.38	1.30	.99	1.09	1.09	1.02	1.00	.83		.94				
	270	248	1.10	1.16	1.05	1.10	1.03	1.08	1.00	.98	.88	.92	.82			
	280	745	2.13	1.21	1.23	1.14	1.14	1.09	1.13	1.13	1.10	1.08	1.02	1.20	1.17	.88
	290	491	2.00	1.32	1.29	1.27	1.19	1.15	1.15	1.18	1.14	1.08	1.13	1.25		
	300	179	3.00	1.48	1.33	1.26	1.19	1.13	1.20	1.16	1.22	1.08	1.24		1.20	
Total Obs. Used		2090														

$$\bar{V}_{45} = 19.5$$

$$\bar{V}_{50} = 13.7$$

$$\bar{V}_{45} = 19.5$$

$$\bar{V}_{195} = 17.4$$

It should be remembered that only four months of data were used in this analysis of the speed differences between Sites A and C. At least a year of data are needed to note seasonal fluctuations in the flow pattern. However, these preliminary results indicate significant differences, especially at the 50-ft level, between the winds measured at both sites as the wind speed at Site A is much stronger, especially for wind directions 270-300°. These flow differences between two anemometer sites located about .5 mi apart on a ridge crest reveal the need for a comprehensive wind measurement program in complex terrain in order to accurately assess the spatial variation in the wind power potential.

5.3 COMPARISON OF SIMULTANEOUS WIND MEASUREMENTS AT THE THREE MOD-2 SITES

Several simultaneous kite anemometer measurements were taken at the 50- and 200-foot or the 50-, 200-, and 350-foot levels at the three WTG sites. Ten- to 15-minute samples were taken at each level. Thirteen such measurements were made simultaneously at WTG 1 and WTG 2, and 17 runs were made at WTG 1 and WTG 3. The wind speeds were averaged over the two to three levels and compared against each other.

The average of the differences between the speeds measured at the three MOD-2 sites, as noted in Table 5.3.1, were small. It appears that the wind speeds at WTG 2 are slightly stronger than those at WTG 1, and about 5% stronger than those at WTG 3.

TABLE 5.3.1 Comparison of simultaneous wind speed measurements taken at the three MOD-2 sites.

	<u>NO. OF SAMPLES</u>	<u>AVERAGE RATIO</u>	<u>RATIO RANGE</u>	<u>NO. OF SAMPLES (50,200,350')</u>	<u>NO. OF SAMPLES (50,200')</u>
$\bar{V}_2/\bar{V}_1$	13	1.02	.93-1.22	8	5
$\bar{V}_3/\bar{V}_1$	17	.97	.83-1.15	10	7

$\bar{V}_1$ = average speed measured at WTG 1

$\bar{V}_2$ = average speed measured at WTG 2

$\bar{V}_3$ = average speed measured at WTG 3

However, on an individual sample basis there were significant flow differences, as indicated by the range of the ratios. These individual differences are due to the spatial variations in the wind field over the MOD-2 area. From the limited data taken, it appears that these fluctuations may balance out, so that the overall wind speed differences between the three WTG sites are slight.

(For further analysis of the flow patterns over the MOD-2 area, refer to Appendix 1, where wind directions and speed are plotted for each measurement period.)

5.4 COINCIDENT WIND VELOCITY MEASUREMENTS AT SEVERAL LOCATIONS IN THE CAPE BLANCO AREA

Introduction

Spatial variations of winds in the Cape Blanco area were investigated during three field trips over the winter and early spring months of this contract period. These investigations involved comparing the winds at several locations along east-west and north-south transects. BPA has recorded wind data at Cape Blanco for nearly four years and during this time this site has had a mean annual wind speed of about 18 mph which distinguishes it as an area of excellent wind power potential. The objective of these spatial comparisons was to determine the extent along the shoreline and inland of the strong winds. Three separate wind surveys were conducted: 18 and 19 December 1979, 20 and 22 February 1980, and 13 and 14 March 1980. The results of these field surveys are described below.

Results

Eight locations were examined in the Cape Blanco area using TALA kites. These locations shown in Figure 5.4.1 include:

Site

- 1 At the Coast Guard Light Station on the tip of Cape Blanco (anemometer site);
- 2 Langlois Mt (anemometer site);
- 3 State Park land
- 4 Wahl's (anemometer site);
- 5 West Langlois;
- 6 4-Mile Road;
- 7 Proposed DOE meteorological tower; and
- 8 Base station east of Cape Blanco.

The winds at each location were measured generally at the 50, 200, and 350-ft level and were averaged together in Table 5.4.1 except in cases 2-5. Sixteen spatial comparisons are presented. The velocity data from the 40-ft level anemometer at Site 1 was compared to the averaged flow at the other sites. Measurements taken in a west-to-east direction are shown in comparisons

FIGURE 5.4.1 Wind speed measurement sites in the Cape Blanco area. In-place anemometers are located at Sites 1, 2, and 4.

1, 3, 5, 6, 7, 8, 11, and 16. In all but cases 3 and 16 the winds decrease from the tip of the Cape inland. In case 3 the wind flow at 50 ft is similar at both locations. In case 16, west winds blowing up over the steep west face of the Cape were highly turbulent and were reduced considerably at the lower levels. In fact, it was impossible to obtain data at 50 feet due to the gusty flow.

A large number of south-to-north comparisons were made in this area. Cases 2, 3, 5, 6, and 9-15 all compare locations on a north-south transect. In 8 of the 10 cases the predominantly southerly winds decreased in strength as they flowed over the tree covered coastline. The weakest winds were always found at the northernmost location (Site 6). In the two cases in which the winds did not show a decrease from south to north, the location that disrupted the pattern was Site 5 which is close to the ocean and has good exposure to south winds.

Four cases involved Langlois Mt in the comparison. Langlois Mt is at elevation 1200 ft and in all four cases the winds at the high elevation location were stronger than the lower level locations further west. The furthest westerly location, Site 1, on the tip of Cape, has stronger winds than Langlois Mt. except perhaps under west flow.

The results noted in these three surveys are similar to those reported in BPA report 79-4 describing the wind field survey conducted June 12-14, 1979, in the Cape Blanco area. The winds during the June survey were north-westerly, but again the northernmost locations (Sites 5 and 6) had weaker winds. Under southerly flow one would expect frictional retardation of the winds as they flow from the southern Cape sites north. Under north winds one might expect the northernmost locations to have the strongest winds and at the southern locations the wind would be reduced due to the greater roughness length. Perhaps the observed strong winds in the southern part of the Cape under northerly flow are due to local acceleration because of the higher elevation on the southern end of the Cape. Under southerly flow the reduced winds at the northern end of the Cape are perhaps due not only to frictional retardation, but may also be the result of flow separation as the wind passes over the southern part of the Cape, which is at 200 ft MSL, and flows north over Sites 5 and 6 which are close to sea level.

TABLE 5.4.1 Spatial wind comparisons using the kite anemometer at Cape Blanco.
Wind speeds (V) are given in mph and direction (D) in degrees.
Turbulence intensity (I) values are also given.

	DATE M/D/YR	TIME (PST)	LEVELS (ft)		SITE NUMBERS							
					1	2	3	4	5	6	7	8
(1)	12/18/79	1245- 1320	50,200	V	50 ³			35.7				31.4
				I				.15				.12
				D	180 ³			150				160
(2)	"	1400- 1415	200	V	30 ³				31.6			37.2
				I					.17			.15
				D	180 ³				160			190
(3)	"	1420- 1435	50	V	30 ³				28.0			
				I					.19			
				D	180 ³				160			
(4)	"	1505- 1520	200	V	40 ³	39.9				18.4		
				I		.12				.21		
				D	180 ³	180				190		
(5)	"	1525- 1540	50	V	45 ³	35				9.5		
				I						.44		
				D	180 ³	180				180		
(6)	12/19/79	0945- 1020	50,200	V	33 ¹				17.0	11.0		27.2
				I					.25	.14		.15
				D	220 ¹				195	170		190
(7)	"	1100- 1135	50,200	V	35 ³	34.5	23.9					23.5
				I		.10	.18					.12
				D	190 ¹	190	175					180
(8)	2/21/80	1650- 1725	50,200 & 350	V	27.2	22.8	15.4					
				I	.06	.12	.16					
				D	185	180	190					
(9)	2/21/80	1805- 1900	50,200 & 350	V	30 ¹	16.5 ²	18.1		21.6	13.1		
				I		.14			.10	.20		
				D	180	160	170		187	177		
(10)	2/22/80	0930- 1025	50,200 & 350	V	23 ¹		26.3		28.9	25.5		
				I			.13		.12	.19		
				D	210 ¹		210		220	220		
(11)	2/22/80	1125- 1200	50,200 & 350	V	33.1	31.4	26.6					
				I	.09	.17	.13					
				D	230	223	240					
(12)	3/13/80	1655- 1735	50,150 & 350	V	30.0 ¹			34.8			32.9	
				I				.08			.12	
				D	180 ¹			185			190	
3)	3/14/80	1550- 1630	150 & 350	V	18.0 ¹			21.1			18.2	
				I				.10			.16	
				D	220 ¹			210			240	

TABLE 5.4.1 (Continued)

	DATE M/D/YR	TIME (PST)	LEVELS (ft)		SITE NUMBERS							
					1	2	3	4	5	6	7	8
(14)	3/14/80	1550- 1630	150 & 350	V	18 ¹			21.1			18.2	
				I				.10			.16	
				D	220 ¹			210			240	
(15)	3/14/80	1740- 1820	50,150 & 350	V	18 ¹			22.8			18.5	
				I				.13			.13	
				D	210 ¹			215			225	
(16)	3/14/80	1455- 1525	50,150 & 350	V	18 ¹		19.8	23.2				
				I			.16	.13				
				D	220		240	220				
(17)	3/14/80	1130- 1152	150 & 350	V	15.9		16.3					
				I	.38		.16					
				D	275		255					

¹Winds measured by anemometer at 40'.

²Winds measured by anemometer at 20'.

³Estimated winds at 40' based off of the available wind data from the Coast Guard anemometer at 20'.

⁴Estimated (from the 30' wind-run anemometer)

6.0 LARGE AREA WIND POWER PROSPECTING SURVEYS

6.1 AERIAL SURVEYS OF WIND POWER POTENTIAL IN THE BPA SERVICE AREA

6.2 KITTITAS VALLEY WIND POWER PROSPECTING TRIP

6.1 AERIAL SURVEYS OF WIND POWER POTENTIAL IN BPA SERVICE AREA

Introduction

An important requirement for the rapid implementation of wind turbine generators as a supplemental source of energy is the development of techniques for rapidly identifying sites with good wind power potential. As part of the FY80 OSU/BPA wind power study it was proposed to perform aerial wind surveys in three areas in the Pacific Northwest using a BPA helicopter. The areas selected are shown in Figure 6.1.1. However, due to the limited availability of BPA helicopters and budget constraints, Area 2 was not surveyed.

The objective of these aerial surveys was to rapidly identify, in a large area, locations with promising wind power potential based on the amount of wind deformation in trees. Research on the use of trees as an indicator of wind power potential has been conducted at OSU over the past four years for the federal Department of Energy (see Hewson, et al., 1977, 1978, 1979, and 1980). Each of the three areas which were selected for aerial surveys had a significant amount of tree cover. In addition, the Columbia Gorge survey area had a number of locations with anemometers which had been set up by BPA and DOE, that could serve as verification for the results of the initial aerial survey. This section will describe the procedures used and results obtained during each aerial survey. Finally, conclusions are discussed and sites are recommended which deserve further study.

Survey Procedure

BPA's four-passenger jet ranger helicopters were used for the aerial surveys (see Figure 6.1.2). Prior to each flight, 1:500,000 aeronautical maps were used to delineate topographic features which might enhance (accelerate) the wind flow, identify refueling stops, and assist in planning an efficient flight path.

In addition, all available wind data for the region were screened, including upper air data, which provides an indication of free air wind velocities at various altitudes above the surface. Table 6.1.1 presents mean annual wind speeds for upper air locations near the regions surveyed.

FIGURE 6.1.1 Proposed helicopter survey areas: (1) The Columbia River Gorge, (2) Central Washington, (3) Northeast Washington and Northern Idaho.

FIGURE 6.1.2 BPA helicopter used for the aerial surveys.

TABLE 6.1.1 Surface and upper air data in the region of the aerial surveys.

<u>LOCATION</u>	<u>LEVEL (FT. MSL)</u>	<u>SPEED (MPH)</u>	<u>DIRECTION (DEG.)</u>
Yakima, WA	1080 (SFC)	6.9	W
	3300	11.1	NW and SW
	4900	13.2	WNW
	6600	16.6	W
Spokane, WA	2670 (SFC)	8.3	SW
	3300	14.5	SW
	4900	17.5	SW
	6600	18.1	SW
Pendleton, OR	1480 (SFC)	9.2	SE
	3300	15.0	W
	4900	15.7	WSW
	6600	16.3	WSW

Surface and upper air data indicated that good wind power potential may be found in the Columbia Gorge area above 2000 feet and in the northeast Washington area above 4000 feet.

Other preflight planning included monitoring weather conditions so that the survey could be conducted during light winds and under clear skies. The precaution of flying during light winds is particularly important to avoid introduction of exaggerated tree flagging by the bending of the trees at the time of observation due to high winds. Flight safety and passenger comfort are also enhanced by flying in light winds, as the combination of low altitude and low air speed makes the aircraft more sensitive to turbulence.

In each aerial survey the survey team consisted of a pilot, a spotter to note direction and degree of flagging, a photographer to photograph locations and document the tree deformation, and a navigator who kept track of locations and noted degree and direction of flagging on a map. Photographs were taken primarily with a 35mm camera. An 80-210mm zoom lens was

also tested. Most of the photographs were taken from an oblique angle, however some vertical-angle shots were taken to test their value. Supposedly, the advantage of vertical photographs is that the direction and degree of flagging can be more accurately determined. Oblique photographs of flagged trees should be taken at right angles to the direction of maximum asymmetry. This requires flying around the stand of flagged trees to determine the direction of maximum asymmetry.

The spotter was also responsible for noting the species of wind-flagged trees. Trees of different species respond differently to the wind. However, Wade and Hewson (1980) have found that for species of the same genera the response to wind was sufficiently similar so that calibration of the indices of deformation could be developed by genus rather than by species. The relationships between mean annual wind speed and degree of wind deformation for five genera of trees noted in the aerial surveys are presented in Table 6.1.2. An example of the visual deformation classes is given in Figure 6.1.3.

Other natural features were noted in the aerial survey. These include topographic features which accelerate the winds or sand dunes which may be the result of strong winds. Although they are less quantifiable, they still provide evidence of wind strength. Blowdown of trees provides an indication of locations where severe winds might be a possible impediment to wind utilization. Such factors as the amount of land area, accessibility, proximity to power lines, and land-use conflicts are also readily identifiable in aerial surveys.

TABLE 6.1.2 The relationship between mean annual wind speed $\bar{V}$ (m/s) and two indices of tree deformation, Griggs-Putnam Index (G) and Barsch Index (B).

Fir (true)	$\bar{V} = 0.7 G + 6.0 \pm 1.9 \text{ m/s}$
Juniper	$\bar{V} = 0.6 G + 4.4 \pm 2.1 \text{ m/s}$
Pines	$\bar{V} = 0.7 G + 3.3 \pm 1.9 \text{ m/s}$
Douglas-fir	$\bar{V} = 0.8 G + 3.3 \pm 1.6 \text{ m/s}$
Oak	$\bar{V} = 1.1 B + 3.0 \pm 2.0 \text{ m/s}$

Conifer Trees
(G Index)

Broadleaf Trees
(B Index)

FIGURE 6.1.3 Griggs-Putnam (G) and Barsch (B) Index classes.

Columbia River Gorge Survey

The survey in the Columbia River Gorge area covered 1500 square miles in about 6 hours of flying time. The flight path and 68 locations where wind-deformed trees were noted are shown in Figure 6.1.4. Also noted in Figure 6.1.4 are the direction and degree of flagging.

Photographs were taken in this survey from both the oblique angle and vertical angle. The vertical angle photographs did not turn out well because of poor contrast. Oblique-angle photographs turned out well, particularly when a small stand of trees was well exposed to the wind. In closed or continuous canopy forest, few flagged trees were noted because winds are often displaced well above the top of the tree canopy. The degree and direction of flagging were noted by the spotter and simultaneous photographs were taken to document the flagging. Examples are shown in Figure 6.1.5 and 6.1.6. Later, when the photographs were processed, an independent evaluation was made of the degree of tree flagging from the prints. These two independent evaluations agreed quite closely.

We observed three dominant directions: southwest, west, and northwest. Southwest winds were found on the north and south ends of survey area above 4000 feet (see Five Mile Butte Sites 20-22 and Satus Ridge Sites 47-52). Both west and northwest winds were common at lower elevations. The upper level flow above this area is southwesterly, particularly in the winter months. West and northwest winds are the result of a summertime thermally-driven west-to-east flow and topographic channeling of both the prevailing southwest winter winds and the thermally-driven west winds.

Five areas were identified as locations with Griggs Class 4 flagging or better. Class 4 corresponds to winds in the 12-18 mph range. The first location is a north/south ridge bisected by the Columbia River just east of Underwood Mountain and Hood River. Strong westerly winds cross this ridge from about 7 miles north to about 4 miles south of the Columbia River. A second area is the rolling plateau just west of The Dalles. Existing wind data have verified that most well exposed locations in this area have winds exceeding an average of 14 mph. The Columbia Hills is also identified as Class 4 flagging area. Nearly five years of wind data at radio station KCIV in this area indicates a mean annual wind speed of 14.6 mph. Satus

FIGURE 6.1.4 The 68 sites surveyed and the helicopter flight path are shown on the map. In each site circle the tree deformation index number is also given. The direction of deformation is noted at most of the sites. The five dashed outline areas show the high wind areas where the tree deformation is at least of a class 4 rating. All ratings are expressed in the Briggs equivalent value.

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

FIGURE 6.1.4 (Cont.) The 68 sites surveyed and the helicopter flight path are shown on the map. In each site circle the tree deformation index number is also given. The direction of deformation is noted at most of the sites. The five dashed outline areas show the high wind areas where the tree deformation is at least of a class 4 rating. All ratings are expressed in the Griggs equivalent value.

FIGURE 6.1.5 These Oak trees at Site 29 show a very strong west wind deformation, Barsch class 5.

FIGURE 6.1.6 Griggs class 4 trees at Site 32 west of KCIV.

Ridge from Potato Butte to Lone Pine Butte has very strong flagging. Average annual wind speeds in this area could be up to 20 mph. The Goodnoe Hills area from Juniper Point to the Goodnoe Hills WTG sites is identified as the fourth strong wind area based on comparative tree deformation. Wind data at two locations in this area indicate the mean annual wind speeds along this ridge exceed 15 mph. A fifth area was noted just north of Badger Gulch. Of the five areas identified as having winds exceeding 12 mph based on wind deformation of trees, three have wind data which verify the conclusion based on vegetation analysis that winds exceed 12 mph.

Northeast Washington Survey

The survey in Northeast Washington covered 3500 square miles in five hours of flying time. The flight path (see Figure 6.1.7) was chosen to investigate exposed ridges above 4000 feet (MSL). Wind deformation was noted at 36 locations noted in Figure 6.1.7. Based on the analysis of the upper air data at Spokane Airport, it appeared that strong winds would be most likely above the 4000-foot level. This was confirmed in the aerial survey, as flagged trees were generally observed above 4000 feet and the direction of flagging was from the southwest. Examples of wind-deformed trees in this area are shown in Figures 6.1.8 and 6.1.9. Table 6.1.3 gives the tree deformation classification at each site.

Among the best locations found in this survey were Sites 2-4, the Mica Peak area; Site 9, northeast of Newport, Washington; and Sites 33 and 34, the ridge east of Lake Roosevelt. Sites 5, 7, 8, 11, 20, 21, and 30 all had Class 4 flagging indicating winds in the 12-18 mph range, but dense forest and poor accessibility would limit immediate development of these locations. BPA's Mica Peak microwave station at Site 4 should be the first site instrumented in the area. Snow and ice appear to be limiting factors in this area, and all anemometers should be rugged and equipped with de-icers.

Central Washington Area

Although a complete aerial survey of the central Washington area was not made, several interesting observations were made in this area, both on

ELEVATIONS IN FEET

NAUTICAL MILES

STATUTE MILES

KILOMETERS

FIGURE 6.1.7 Helicopter site survey route noting locations where wind-deformed vegetation observations were

FIGURE 6.1.8 Site 3, Class 3-4 Douglas-fir

FIGURE 6.1.9 Site 30, Class 4 Douglas-fir.

TABLE 6.1.3 Site tree deformation classification. The Griggs(g) Index speed classifications are given on the next page.

Site No.	Elevation (ft MSL)	TREE DEFORMATION		Direction	Type of Trees*
		Speed Class			
1	4550	G2,3		SW	PP
2	5200	G3,4		SW	PP
3	5200	G3,4		SW	PP,DF,L
4	5200	G4		SSW.	DF
5	5000	G3,4		SSW	DF
6	4000	G3		SW	PP
7	4000	G3,4		SW	PP
8	4150	G4		SW	PP
9	4000	G3,4		SW	DF
10	5000	G2		SW	PP
11	5000	G3,4		SW	PP,DF
12	4000	G2,3		SW	DF
13	3000	G2		SW	PP
14	3000	G1,2		SW	PP
15	3000	G2		SW	PP
16	2800	G2,3		SW	DF,PP
17	2800	G2,3		SW	PP,DF
18	3500	G2,3		SSW	PP,DF
19	4200	G3		SW	PP
20	4500	G3,4		SW	DF,PP
21	4760	G3,4		SW	DF
22	2600	G3		SSW	DF,PP
23	3500	G2,3		SW,N	PP,DF
24	4800	G2		SW	PP
25	4800	G2		SW	DF
26	5000	G3		SW	DF
27	4500	G2		SSW	PP,L
28	6000	G2,3		SW	DF
29	6400	G3		SW	DF,PP
30	4000	G3,4		SW	DF
31	5500	G2,3		SW	PP,DF
32	4500	G2		SW	PP
33	5000	G3,4		SW	DF,PP
34	5500	G4		SW	DF
35	5000	G2,3		SW	PP,DF
36	4700	G2		SSW	PP

*Tree Types: PP=Ponderosa Pine; DF=Douglas-fir; L=Larch

Griggs Class Speed Claassification

Douglas-fir and Ponderosa Pine	
Class	Mean Speed (mph)
G1	6.8-9.2
G2	8.8-11.6
G3	10.4-14.1
G4	12.3-16.6
G5	14.1-19.1

the commercial flight up to Spokane and on a helicopter return flight to Vancouver, Washington after completion of the Northeast Washington survey. A map shown in Figure 6.1.10 indicates observed areas of wind stress.

Active dunes near the Vantage, Washington BPA substation were photographed from a commercial aircraft flying at about 25,000 feet on a flight between Portland and Spokane (see Figure 6.1.11). On the return to the Portland area, low-level aerial photographs were taken from the helicopter in the same area. Relic or inactive dunes with stabilizing vegetation were noted near the Potholes Reservoir (Site 2 in Figure 6.1.10). Active dunes near Vantage (Site 1 in Figure 6.1.10), noted in the commercial flight, showed a general lack of vegetation, active slip faces, and sharp crestlines (see Figure 6.1.12), indicating transport of surface material by persistent west winds. Nearby Wanapum Dam has a mean annual wind speed of 12 mph.

Other locations that appeared to have good wind power potential were the Saddle Mountains (Sites 3 and 4 in Figure 6.1.10) east of Ellensburg, Washington, and the shoulders of the gap between Vantage and the Kittitas Valley (see Site 5 in Figure 6.1.10).

Conclusions and Recommendations

The main conclusion of the aerial survey studies were that:

- . Reconnaissance-level wind surveys of large areas can be accomplished in a relatively short amount of time, using a helicopter;
- . The degree and direction of tree deformation can be readily discerned from a low-flying helicopter, and areas of wind-deformed trees can be reliably used as a tool for identifying locations with strong persistent winds;
- . Three of the five areas selected as having strong winds in the Columbia River Gorge survey had data that verified that the winds were strong;
- . Oblique-angle air photos appear to provide the best documentation of tree deformation; and
- . Upper air data which give mean annual free-air wind velocity provide useful screening criteria for locations which should be investigated in the aerial survey.

FIGURE 6.1.10 Areas that show the effects of strong winds as observed from aerial observations.

FIGURE 6.1.11 Sand dune and scours near Wanapum Dam (lower left)
photographed from 25,000 ft elev.

FIGURE 6.1.12 Sand dune
formations of Figure 6.1.11.

It is recommended that other aerial surveys be conducted in the BPA service area for selecting good anemometer locations. The results of the two surveys described indicate that five sub-areas deserve further investigation and instrumentation in the Columbia Gorge area, and three such sub-areas exist in the Northeast Washington area.

6.2 KITTITAS VALLEY WIND POWER PROSPECTING TRIP

6.2 KITTITAS VALLEY WIND POWER PROSPECTING TRIP

A wind prospecting survey was made in the Yakima/Ellensburg area on 4-6 December 1979 by OSU scientists Robert Baker and Rich Wittrup. The primary objective of the survey was to locate a suitable site for the Water and Power Resources Service (WPRS) wind power monitoring station. Other areas of the Kittitas Valley and nearby ridges were also visited to locate possible BPA wind data stations. A map showing the sites surveyed is shown in Figure 6.2.1.

The Ellensburg area is well known for wind in the Northwest. Wind data taken at the Ellensburg Airport indicate a mean annual speed of 9.3 mph (see Table 6.2.1). The strongest winds occur in the spring and summer as mean monthly values approach 14 mph. However, wind data taken at the Wanapum Dam 25 miles east of Ellensburg, indicate a mean annual speed of 12.0 mph as noted in Table 6.2.1. Mean monthly speeds during the spring and summer often are in the 14-18 mph range. Strong winds persist from the westerly direction as noted in Table 6.2.2 at both locations.

An initial and brief survey was made in this area on 4 December, but it was curtailed due to very poor visibility as dense fog covered the hills and valley. Snow also blanketed the entire area.

The weather conditions improved dramatically on the morning of December 5. We met Bob Hamilton, from the Boise WPRS office, in Yakima and proceeded to Ellensburg. We stopped at the south Umtanum Ridge freeway rest stop (see Figure 6.2.1, site 1) to photograph some slightly flagged trees. The flagging indicated a west direction. The flagged trees appear to be of the Cypress family and have not been calibrated to wind speed. The rest stop area is well exposed except to the west where a high hill blocks the flow. There are many road signs along this freeway warning of hazardous cross winds. There is also a vast expanse of open and well exposed area on top of the mountains between Umtanum and Manastash Ridge and east of the freeway. Unfortunately, the access is restricted since this land is part of the Yakima Firing Range. There is little vegetation except for sage brush which indicated some flagging due to westerly flow.

Scale 1:250,000

CONTOUR INTERVAL 200 FEET
WITH SUPPLEMENTARY CONTOURS AT 100 FOOT INTERVALS

FIGURE 6.2.1

Sites surveyed in the Kittitas Valley and neighboring areas. Proposed anemometer sites and existing wind data sites are noted with closed circles. Site 13 is the Ellensburg Airport, and site 12 is Wanapum Dam. Site 5 is the proposed anemometer site for the Water and Power Resources Service, and Sites 8 and 13 are proposed sites for BPA. The rest of the sites noted were where wind-deformed vegetation photographs were taken.

TABLE 6.2.1 Mean monthly wind speeds (mph) for the
Ellensburg Airport and Wanapum Dam.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	AVG
Ellensburg AP (1935-38)	4.6	6.5	9.6	11.7	13.6	13.9	13.8	12.4	8.5	6.4	4.9	5.1	9.3
Wanapum Dam (1975-77)	6.9	9.6	12.5	13.8	16.1	18.2	15.7	13.2	9.5	9.9	9.4	8.2	12.0

TABLE 6.2.2 Strong wind directions for December and June for the
Ellensburg Airport and Wanapum Dam including the
percent frequency and the mean wind speed (mph).

<u>Ellensburg AP</u>			<u>Wanapum Dam</u>		
	DEC	JUN		DEC	JUN
Direction	%/ $\bar{V}$	%/ $\bar{V}$	Direction	%/ $\bar{V}$	%/ $\bar{V}$
WNW	9.3/13.0	27.3/19.8	WSW	2.7/10.1	3.7/23.0
NW	11.7/11.8	38.9/18.0	W	28.0/12.4	43.9/23.4
NNW	3.4/17.2	1.9/10.5	WNW	9.6/16.4	13.0/14.8

In the Kittitas Valley, many well deformed wind-flagged trees of both coniferous and deciduous varieties were photographed. The northwest flagging of the Douglas-firs at site 2 indicated a mean annual speed in the 10-14 mph range.

We next drove east to Boylston Mountains and were able to drive to about .25 mi from a well exposed ridge, site 5 in Figure 6.2.1, in our 4-wheel drive vehicle. We hiked to the top of the wind swept ridge and noticed well flagged sage brush. Also, several well flagged deciduous trees were photographed on the slope of the ridge (see Figure 6.2.2). The deformed trees at site 3 indicated a mean annual wind speed in the 10-14 mph range. The tree in Figure 6.2.2 is noticeably deformed by the west wind, especially near the

top. The estimated mean annual wind speed based on this tree deformation is 12-14 mph. At the ridge top the sage brush was deformed by west flow, as noted in Figure 6.2.3.

Kite anemometer measurements were taken at site 5 and indicated moderate to strong west flow as noted in Table 6.2.3. The wind flow was measured for 5 minute periods at the 50, 200, and 350 ft level. The data indicated a significant wind speed change with height above the 200 ft level. This is probably not the true wind profile since the general wind flow changed in time during the measurement period which lasted for over 30 minutes. Normally, a second profile would have been taken and then the two profiles would have been averaged to filter out the short-term speed anomalies. However, a second profile was not taken since we felt the time would be better spent surveying other areas.

TABLE 6.2.3 Kite anemometer data taken at Boylston Mountain, site 5, on 4 December 1979 between 1155 and 1225 PST. Wind speeds are in mph.

<u>Altitude (ft)</u>	<u>50</u>	<u>200</u>	<u>350</u>
$\bar{V}$	19.0	21.0	31.0
I	.11	.12	.13
Direction	250-270°	260°	270°

This area on Boylston Mountain is very well exposed to the wind in all directions. Similar well exposed land area extends eastward at least 10 miles. Site 5 would be an excellent location for the WPRS meteorological station. The security of the equipment also looks good. Local residents questioned indicated that they have not encountered vandalism to fences, gates, or other property in the area and that hunting pressure is generally light.

FIGURE 6.2.2 West-northwest flagged trees at site 4.

FIGURE 6.2.3 West flagged sage brush at site 5.

After leaving the Boylston Mountain site we drove to the Thorp area and photographed many well flagged trees at sites 10 and 11 in Figure 6.2.1 (see Figure 6.2.4). This area shows good west to northwest wind flagging in the 11-14 mph mean annual wind speed range. This would be a good area to install a BPA wind monitoring station.

We next drove east of Ellensburg to the top of the Vantage Grade and stopped at the Ryegrass freeway rest stop (see site 6 in Figure 6.2.1). Well flagged deciduous trees and sage brush were photographed in this area and kite measurements were taken on a hill south of the rest stop. The west winds measured indicated 20-24 mph winds from the 50 to 350 ft level. The data shown in Table 6.2.4 indicated a wind speed maximum at the 200 ft level but only a single profile was taken so the authenticity of this maximum is questionable. BPA has a microwave station north of the freeway that is very well exposed. It is recommended that an anemometer be installed on top of the 100 ft tower to monitor the wind flow.

TABLE 6.2.4 Kite anemometer data taken at site 5 on 4 December 1979 between 1513 and 1532 PST. Wind speeds are in mph.

<u>Altitude (ft)</u>	<u>50</u>	<u>200</u>	<u>350</u>
$\bar{V}$	22.2	26.5	22.0
I	.15	.07	.09
Direction	270°	280°	270°

From the Ryegrass area we drove east down to the town of Vantage and then south to the park across from Wanapum Dam. The deciduous and Douglas-fir trees there indicated very good west wind flagging. This flagging correlates well with the 12 mph mean annual wind speed measured at Wanapum Dam.

The Ellensburg Airport, site 13 in Figure 6.2.1, was also visited to survey the wind deformed vegetation. Northwest wind flagging was very apparent. The estimated mean annual wind speed based on this flagging was 10-12 mph.

An area that was not visited but looks particularly promising due to its good exposure to the strong northwesterly flow is the ridge in the Badger Gap area. This area is about 7 miles south of site 5. The wind flow may funnel

FIGURE 6.2.4 Northwest flagged ponderosa pine tree at site 11.

FIGURE 6.2.5 Looking towards the hills east of the Kittitas Valley. Site 5 and 8 are noted by the arrows.

between the Manastash Ridge and Boylston Mountains and thus may be accelerated as it blows over this ridge. However, the accessibility may be limited due to poor roads and the fact that it is on the Yakima Firing Range.

In summary, 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 looks particularly promising not only due to its exposure to the prevailing westerly flow but also to its exposure to easterly flow that may be of moderate intensity, especially in the winter (see Figure 6.2.5). It is recommended that the WPRS wind data station be located at site 5 and that BPA install a recording anemometer at site 8. It is estimated that the mean annual wind speed in this area is 12-14 mph based on the limited available vegetation surveyed. Another area that deserves monitoring is the Thorp area northwest of Ellensburg. The strong winds flowing down the east side of the Cascades may be stronger in this area compared to further east along the valley floor.

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7.0 WIND FLOW STUDIES AROUND THE CLAYTON, NEW MEXICO
200 KW WIND TURBINE GENERATOR

7.0 WIND FLOW STUDIES AROUND THE CLAYTON, NEW MEXICO 200-KW WIND TURBINE GENERATOR

Purpose and Objectives

In 1981 a cluster of three wind turbines will be sited at BPA's Goodnoe Hills site. This will be the largest array of megawatt-sized wind turbines in the world and will provide answers to many questions regarding the performance of clustered wind turbines. Siting several machines in a small area requires knowledge of how the geometric configuration of turbine sites will affect performance. In order to determine the optimum spacing of wind turbines, it is desirable to develop techniques to characterize the wake of a wind turbine. In anticipation of the studies that will be conducted at Goodnoe Hills, OSU during March 1980 conducted some preliminary studies of wind flow around the 200-KW wind turbine near Clayton, New Mexico.

The main objectives of these studies were:

- . To characterize the wind turbine wake up- and down-wind in terms of wind speed, wind profile, and turbulence structure;
- . To evaluate the effects of both a non-rotating and rotating turbine on the flow field; and
- . To measure both the ambient turbulence around the turbine and turbulence due to the wind turbine.

In addition, measurements were made near the 150-foot Department of Energy (DOE) meteorological tower to check accuracy and precision of the TALA kites.

Description of Turbine and Site

The MOD OA wind turbine was designed and fabricated by the NASA Lewis Research Center under the direction of DOE. The turbine is rated 200-KW at 21 mph with cut-in speed of 10 mph and cut-out speed of 40 mph. The rotor diameter of the turbine is 125 ft and hub height is 100 ft. The nacelle anemometers are shown in Figure 7.1.1 in front of the downwind rotor. The 150-ft meteorological tower is about 400 feet southwest of the turbine and is instrumented at 33, 100, and 150 feet. Instantaneous values of wind and turbine performance data are collected every two minutes and stored on magnetic

tape. The parameters sampled include:

- . Wind speed and direction at all three levels on the met tower;
- . Nacelle anemometer speed and direction;
- . Power output; and
- . Yaw error.

The topography around the wind turbine is relatively flat although there are local irregularities such as trees that border the city to the north and northeast and a large gully which runs west of the WTG. The topography and distance in rotor diameters are shown in Figure 7.1.2.

Comparison of TALA Kite Data with Tower and Nacelle Anemometers

The first experiments at the Clayton site involved tests to evaluate the precision and accuracy of the TALA kite. The three kites were flown at the same height side by side on six occasions in winds that varied from 15-48 mph. The differences between the three units varied from 1.1-3.6%, and the average difference was 2.2%. This level of precision in kite measurements is similar to the 2.7% level found in studies conducted in the Pacific Northwest and reported in Section 3.0.

Seventeen comparisons were made between the TALA kite and the DOE met tower. These comparisons were primarily made at the 100-ft level; however, one comparison was made with three kites at the same height as the tower anemometers. Also, three kites were flown simultaneously at the 33-, 100-, and 150-ft level next to the tower. The power law coefficient, α , for both the tower and the kite profile was .05.

Statistical comparison of all kite data taken near the tower with the tower data is given in Table 7.1.1 and indicates that there were significant discrepancies between the tower and the kite. These errors are much larger than the rms error of 0.5 mph and mean bias of +.008 mph found in comparisons conducted against other towers. Some error may be due to differences in averaging time. Tower data consisted of instantaneous wind speeds every two minutes over the same averaging interval as the TALA kite. Kite measurements were taken generally over 15-minute periods, taking 5-second "eyeball" average wind speeds every 20 seconds. Several 10-minute average periods with 1 second

FIGURE 1. Clayton 200-kw WTG (blade diameter 125 ft). The DOE 150-ft meteorological tower is to the left in the background.

FIGURE 2. Topography map showing the terrain features surrounding the WTG. The city of Clayton is located northeast of the turbine. Spacing circles of 2-9 diameters are also shown.

sampling intervals were taken with the kite. However, the mean bias of 0.9 mph indicates the kites were consistently lower than the tower anemometer.

TABLE 7.1.1 Statistical comparison of anemometer data at the Clayton, New Mexico, wind turbine site.

<u>Comparison</u>	<u>Number of Samples</u>	<u>ERROR ANALYSIS</u>			<u>Percent</u>
		<u>Absolute (mph)</u>	<u>Bias (mph)</u>	<u>rms (mph)</u>	
DOE met tower/TALA kite 100 ft.	17	1.2	+0.9	2.2	+4.2
TALA kite/Nacelle 100 ft.	15	1.7	+1.2	4.9	+9.7
DOE met tower/Nacelle 100 ft.					
a) All observations	30	2.2	+2.1	7.0	+11.4
b) Turbine operating	15	2.7	+2.7	8.6	+14.5
c) Turbine not operating	15	1.6	+1.4	4.8	+8.3

The TALA kite and the DOE met tower measurements at 100 ft are also compared statistically in Table 7.1.1 to the anemometer on the wind turbine nacelle. The results indicate that both the tower and kite anemometers recorded higher wind speeds than the nacelle anemometer. The lower readings on the nacelle anemometer are due to modification of the incident wind flow over the nacelle. There may also be some difference due to physical separation between where the kite and the tower measurements were made and the nacelle location. The kite measurements were all made 2 diameters upwind and the met tower is 400 ft southwest of the turbine. Thus there was about 200 ft between the kite and the met tower. Data taken both with the turbine operating and not operating were also examined. In the non-operating mode the nacelle anemometer reads slightly lower (1.4 mph) than the tower; and, with the turbine operating, the difference increases by nearly a factor of two. This indicates the rotating turbine further modifies (decreases) the wind field around the nacelle anemometer.

Downwind Measurements (WTG Not Operating)

Due to a bearing failure the WTG was inoperative from the time we arrived at Clayton till around noon on the 6th of March. During this down time several kite anemometer measurements were taken upwind and downwind of the WTG to note the tower wind shadow and the other flow conditions behind the WTG when it was not working. Measurements were made at the hub height (100 ft) and at distances of 3, 4, 5, 7, and 9D (diameters) downwind and at 2D upwind. These wind measurements were made simultaneously at three locations for a 15-minute period taking 5-second 'eyeball' average wind speeds from the TALA anemometer spring scale every 20 sec. Also, once per minute the wind direction was noted. Thus, 45 speed readings and 15 direction readings were taken every observation period. The speed and direction data were both treated as scalar quantities and averaged to get mean and standard deviation values. A turbulence intensity value, I , was calculated for the speed data by dividing the standard deviation by the mean speed. This value is a measure of gustiness. Values less than 0.10 indicate smooth flow; those between 0.10-0.20 indicate moderate turbulence; and, values greater than 0.20 indicate a high degree of turbulence.

A summary of the wind flow measurements around the shut down WTG is given in Table 7.1.2. The upwind measurements were made off to the side of the WTG and not directly in line with the hub to prevent any damage if the kite broke and flew into the WTG. The "% Difference" measurements are calculated by taking the difference between the upwind and downwind speed and dividing by the upwind speed.

The downwind velocity deficits caused by the inoperative WTG are most noticeable at 3D and 5D downwind. Under southeast flow the deficit averages for Runs 2 and 3 in Table 7.1.2 were about 10% at 3D, 8% at 5D, and 7% at 7D. However, the undisturbed ambient flow measurements for that direction indicated about a 2% decrease at 3D, no decrease at 5D, and about a 6% decrease at 7D (see Runs 3 and 4 in Table 7.1.2). Thus, the resulting net velocity deficit due to the WTG structure appears to be about 8% at 3D and 5D downwind, and negligible at 7D downwind.

When considering winds out of the southwest, the wake effect of the inoperative WTG was not as noticeable. Runs 1 and 6 in Table 7.1.2 show

Table 2. Wind velocity deficits measured when the WTG was working

Run No.	Date/Time (MST)		2D Upwind	3D Downwind	% Difference	5D Downwind	% Difference	7D Downwind	% Difference
1	3 March/1410-1422	$\bar{V}/I$	23.2/.17	22.1/.20	- 4.7	21.9/.20	- 5.6		
		DIR/ σ	210°/9°	200°/7°		210°/17°			
2	5 March/1410-1425	$\bar{V}/I$	24.6/.12	22.5/.13	- 8.5	22.5/.14	- 8.5		
		DIR/ σ (DIR)	150°/7°	180°/8°		160°/8°			
3	5 March/1435-1450	$\bar{V}/I$	24.5/.17	21.6/.19	-11.8			22.8/.19	- 6.9
		DIR/ σ (DIR)	150°/8°	180°/14°				170°/8°	
4	5 March/1520-1535	$\bar{V}/I$	24.0/.11	23.7/.10*	- 1.3	24.0/.09*	0.0		
		DIR/ σ (DIR)	160°/8°	180°/10°		170°/8°			
5	5 March/1555-1610	$\bar{V}/I$	22.4/.10	21.7/.09*	- 3.1			21.1/.11*	- 5.8
		DIR/ σ (DIR)	160°/9°	180°/7°				160°/3°	
6	March/0905-1920	$\bar{V}/I$	28.6/.16	28.0/.15	- 2.1			26.5/.17	- 7.3
		DIR/ σ (DIR)	230°/12°	240°/7°				230°/12°	
7	6 March/0930-0945	$\bar{V}/I$	30.0/.14	30.7/11*	+ 2.3	29.4/.12*	- 2.0		
		DIR/ σ (DIR)	210°/14°	240°/6°		230°/10°			
8	6 March/0950-1005	$\bar{V}/I$	26.9/.19	27.3/.12*	+ 1.5			25.7/.14*	- 4.5
		DIR/ σ (DIR)	220°/9°	240°/7°				240°/8°	

*Measurements taken outside of the wake (Ambient Flow).

about a 3% decrease in the wind speed at 3D, a 6% decrease at 5D, and about a 7% decrease at 7D. However, the measurements in the undisturbed flow taken during Runs 7 and 8 (Table 7.1.2) indicate a natural (ambient) increase in the wind speed at 3D of about 2%, about a 2% decrease at 5D, and a 4% decrease at 7D. Thus, the resulting net velocity deficit appears to be about 5% at 3D, 4% at 5D, and 3% at 7D. These slight differences are close to the level of precision in the kite systems ($\pm 3\%$).

WTG Wake Velocity Deficits (WTG Operating)

About noon on 6 March the WTG became operational and the downwind measurements commenced. A summary of the downwind wake measurements is given in Table 7.1.3. Eleven runs were made under various wind directions. The southwest wind flow measurements are shown in Runs 1-5. The wake deficits at 3D downwind varied from 7-18%. As noted in Table 7.1.2 (in Runs 7 and 8) there appears to be a slight increase of about 2% in the ambient, free stream flow at 3D under southwest flow. Therefore, the net average downwind deficit at 3D is probably about 15%. The net deficit at 5D downwind is about 9%, considering the ambient 2% decrease noted in Table 7.1.2. At 7D downwind the net wake deficit is small, about 3%, making allowances for the differences observed in Run 4 between the free stream and the wake measurements. Under southwest flow the net wake deficit is negligible at 9D.

In Runs 6 and 7 the downwind wake effects under west flow were measured (see Table 7.1.3). In Run 6 the net velocity deficit at 7D downwind was about 20%. There was about a 16% deficit measured directly downwind and the ambient flow outside the wake at 7D was about 4% higher than that measured upwind of the WTG. This is a much higher deficit than that measured at 7D spacing in the other directions. Possibly the air was more stable, since the sun had set about 30 minutes before the run. The turbulence intensity values were lower than those calculated for the southwest winds and the direction deviations were also small. At 5D downwind the net velocity deficit was about 13%, considering the ambient flow was about 9% stronger than that measured in front of the WTG.

Somewhat stable east winds were measured upwind and downwind of the WTG on 8 March. The measurements were made about an hour before sunset under a

TABLE 7.1.3 Wind velocity deficits measured when the WTG was working.

RUN NO.	DATE/TIME (MST)		2D UPWIND	3D DOWN-WIND	% DIFFER-ENCE	5D DOWN-WIND	% DIFFER-ENCE	7D DOWN-WIND	% DIFFER-ENCE	9D DOWN-WIND	% DIFFER-ENCE
1	6 March/1200-1215	$\bar{V}/I$	29.4/.20	25.4/.22		26.1/.20					
		DIR/ σ (DIR)	230°/14°	250°/11°	-13.6	240°/10°	-11.2				
2	6 March/1220-1235	$\bar{V}/I$	28.5/.16	26.4/.20	-7.4			26.8/.21			
		DIR/ σ (DIR)	230°/10°	250°/7°				240°/11°	-6.0		
3	6 March/1435-1450	$\bar{V}/I$	24.8/.16	20.4/.22	-17.7			22.8/.19			
		DIR/ σ (DIR)	230°/9°	220°/9°				240°/4°	-8.1		
4	6 March/1530-1545	$\bar{V}/I$	28.5/.14					26.2/.24			
		DIR/ σ (DIR)	240°/6°					240°/11°	-8.1		
4	6 March/1530-1545	$\bar{V}/I$	28.5/.14					26.9/.13*			
		DIR/ σ (DIR)	240°/6°					230°/6°	-5.6		
5	6 March/1550-1605	$\bar{V}/I$	25.2/.18							23.8/.18	
		DIR/ σ (DIR)	240°/5°							230°/12°	-5.6
5	6 March/1550-1605	$\bar{V}/I$	25.2/.18							23.6/.17*	
		DIR/ σ (DIR)	240°/5°							220°/16°	-6.3
6	7 March/1830-1845	$\bar{V}/I$	24.0/.13					20.2/.17			
		DIR/ σ (DIR)	260°/8°					270°/5°	-15.8		
6	7 March/1830-1845	$\bar{V}/I$	24.0/.13					24.9/.14*			
		DIR/ σ (DIR)	260°/8°					250°/8°	+3.8		
7	7 March/1850-1905	$\bar{V}/I$	23.0/.19			22.0/.11					
		DIR/ σ (DIR)	260°/9°			Missing	-4.3				
7	7 March/1850-1905	$\bar{V}/I$	23.0/.19			25.0/.07*					
		DIR/ σ (DIR)	260°/9°			250°/8°	-8.7				

* Measurements taken out of the wake (Ambient Flow)

TABLE 7.1.3 (Continued)

RUN NO.	DATE/TIME (MST)		2D UPWIND	3D DOWN-WIND	% DIFFERENCE	5D DOWN-WIND	% DIFFERENCE	7D DOWN-WIND	% DIFFERENCE	9D DOWN-WIND	% DIFFERENCE
8	8 March/1655-1710	$\bar{V}/I$	18.8/.12			^{4D} 14.9/.18	-20.7				
		DIR/ σ (DIR)	100°/5°			105°/5°					
8	8 March/1655-1710	$\bar{V}/I$	18.8/.12			19.2/.13*	+2.1				
		DIR/ σ (DIR)	100°/5°			110°/5°					
9	8 March/1715-1730	$\bar{V}/I$	18.5/.10					17.9/.13			
		DIR/ σ (DIR)	100°/6°					110°/6°	-3.2		
9	8 March/1715-1730	$\bar{V}/I$	18.5/.10					17.1/.10*			
		DIR/ σ (DIR)	100°/6°					110°/5°	-7.6		
10	8 March/1735-1750	$\bar{V}/I$	17.9/.13							17.3/.11	
		DIR/ σ (DIR)	100°/5°							110°/5°	-3.4
10	8 March/1735-1750	$\bar{V}/I$	17.9/.13							17.3/.16*	
		DIR/ σ (DIR)	100°/5°							110°/5°	-3.4
11	9 March/0705-0715	$\bar{V}/I$	19.4/.10	15.2/.17	-21.6						
		DIR/ σ (DIR)	350°/8°	340°/7°							
11	9 March/0705-0715	$\bar{V}/I$	19.4/.10	18.1/.15*	-6.7						
		DIR/ σ (DIR)	350°/8°	330°/4°							

* Measurements taken out of the wake (Ambient)

thick overcast sky. The turbulence intensity values and direction deviations were relatively small compared to those previously measured (see Table 7.1.3, Runs 8-10). Measurements were taken at 4D downwind instead of 5D downwind because of the steep-sided gully and power line interference. Those taken at 4D downwind indicated about a 23% net velocity deficit, considering there was about a 2% increase in the ambient flow downwind. At 7D there was no downwind deficit. In fact, at 7D there was a 4% increase.

The limited measurements taken under north flow on 9 March indicated about a 15% velocity deficit at 3D downwind. Measurements were not made further downwind because the wind shifted 40°. Further measurements could not be made downwind of the WTG because of power line and large building obstructions in the fairground area southeast of the turbine.

In summary, the wake velocity deficits were generally largest within 4 diameters of the WTG. The results are summarized in Figure 7.1.3. These deficits were on the order of 15-20%. At 5D downwind the velocity deficits measured were about 10%. Past 5D downwind the deficits were generally negligible, although under stable west flow a 20% deficit was measured 7D downwind. For the limited amount of data taken, the deficits appear reasonable and approximate the wake model results of Aerovironment, Inc. (Walker, 1980).*

FIGURE 7.1.3 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

* Personal communication with Dr. Stel Walker

Wake Profile Measurements

Wind velocity measurements were taken about 1.5 diameters downwind and across the wake. These data are summarized in Tables 7.1.4 a and b and measurement locations are shown in Figure 7.1.4.

FIGURE 7.1.4 Downwind wake measurement points.

The first set of measurements was made 100 ft to the left and right of centerline. The wind speeds were about 19% stronger in the tip wake of the WTG than at the centerline (see Table 7.1.3). When sampling the wind flow farther out from the center of the wake it was discovered that the ambient flow was slightly less than that measured in the tip wake. These measurements were taken both at the 100-ft and 150-ft level as noted in Table 7.1.4. The turbulence levels were the greatest at the centerline but were still only of moderate intensity. The highest turbulence was observed below the 100-ft level. An attempt was made to fly the kite anemometers at the 40-ft level but the winds fluctuated too much to keep the kite airborne. For the brief time the kite was in the air near the tip wake it oscillated in large looping rolls from near the ground to 40-50 ft aloft. The kite was apparently following the rolling vortices coming off the tips of the blades of the WTG. At higher altitudes these turbulent fluctuations were greatly modified.

Some Problems Encountered in Taking Wake Measurements

In taking wake measurements with the kite anemometer system, or for that matter with any other measurement system, maintaining the sensor at or near the center line of the wake was crucial. At times there were problems

TABLE 7.1.4a Wind speed measurements across the wake 1.5D downwind
(hub height, wind direction 120°, 1818-1828 MST, 8 March 1980,
readings taken every 15 seconds).

Height		(B)			(A)		(C)	
		Nacelle $\bar{V}$	100' left of Centerline	% Diff. ¹	Centerline	% Diff. ¹	100' right of Centerline	% Diff. ¹
100'	$\bar{V}/I$	24.1	25.3/.11	+5.0	20.7/.12	-14.1	24.6/.10	+2.1

TABLE 7.1.4b Cross-section wind speed measurements across the wake 1.5D downstream
(wind direction 140°, readings taken every 15 seconds, 8 March 1980).

Height/Time (MST)		(A)			(C)		(D)	
		Nacelle $\bar{V}$	Centerline	% Diff. ¹	100' right of Centerline	% Diff. ¹	200' right of Centerline	% Diff. ¹
100'/2003-2013	$\bar{V}/I$	18.3	14.3/.11	-21.9	20.2/.11	+10.4	19.0/.13	+3.8
150'/2017-2027	$\bar{V}/I$	17.8	15.3/.11	-14.0	22.1/.08	+24.2	21.1/.07	+18.5

¹ % difference based on the nacelle $\bar{V}$.

getting the desired spacing due to obstacles such as the 20-40 ft high trees north of the WTG, buildings, or the numerous power lines in the area.

The variability in the wind direction also caused a few problems. Twice the wind direction changed during the course of a run so much that the WTG shifted orientation. Thus, the measurements had to be started over again. Fortunately, the portable measuring system can be easily and quickly repositioned.

Also it was observed that the WTG often did not face directly into the wind but was at a 10-15 degree angle to it. This was an acceptable operating mode until the speed differences between the two Nacelle anemometers was sufficient to cause the WTG to yaw. Thus the wake often would move downstream at a slight angle from the centerline of the WTG. Hence the orientation of the Nacelle anemometer had to be closely observed to insure proper downwind orientation.

Also, at times ambient wind direction changes downwind caused the wake to meander. In such cases finding the downwind centerline was difficult.

It is expected that the drifting of the wake would be most pronounced at distances of 5D or greater from the WTG. For the most part the mean wind directions taken in the free stream and wake did not differ by more than 10 degrees (see Table 7.1.2). However, there was a 20 degree difference noted in Run 7 (Table 7.1.2) at 7D downwind; also, the standard deviation of the direction fluctuations was greater in the ambient flow than that in the wake which was usually not the case.

8.0 STATISTICAL ANALYSIS OF WIND POWER AND WIND SPEED DATA
AT BPA SITES AND NWS STATIONS

8.0 STATISTICAL ANALYSIS OF WIND POWER AND WIND SPEED DATA AT BPA SITES AND NWS STATIONS

Introduction

This report summarizes the initial results of a statistical study of wind speed and wind power data at specific locations in the Pacific Northwest. The overall objective of the study is to describe and model wind power at selected sites in Oregon, Washington, and Nevada, both for the individual locations and for a network consisting of the individual sites. The results of the study will be used as input to simulation programs designed to investigate the impact of a network of wind farms at these locations on regional energy potential.

Specific objectives of this study include (1) description of the probability distributions of hourly wind speed and wind power data at the selected locations; (2) extension of the relatively short-period data base available for these sites using long-term wind speed data from nearby National Weather Service (NWS) stations; and (3) development and evaluation of statistical models of hourly, monthly, and seasonal wind power. This report describes the distributions of wind speed and wind power at the selected sites and the distributions of wind speed at the NWS stations and discusses briefly the results of initial efforts to relate wind speed data at the wind power sites to the corresponding data at the NWS stations.

Six potential wind power sites discussed here are Augspurgen Mountain, Cape Blanco, Goodnoe Hills, KCIV, Kennewick, and Wells. These site locations are shown in Figure 8.1.1. Hourly wind speed data are currently available at these sites for the two-year period from 1 December 1976 through 30 November 1978. The hourly wind speed data at these locations were transformed into hourly wind power data using the power curve appropriate for each site's elevation which ranges from 200 feet at Cape Blanco to 7538 feet at Wells. This power curve was created by taking the wind speed required for a given power output from the Boeing MOD-2 turbine and translating from hub height to anemometer height using the power law with an alpha factor of 0.2. The resulting curve of wind speed versus power output is characterized by four distinct regions of behavior. For wind speeds below the cut-in value, and a

second higher value (the knee of the curve), the power output increases as the wind speed increases. Above the knee value to the cut-out wind speed, the power from the generator is constant regardless of the wind speed. At the cut-out wind speed the power generated drops to zero and remains there for all higher wind speeds.

FIGURE 8.1.1 Locations of six wind power data stations used in the network study. Also noted are the NWS station locations.

Long-period records of hourly or three-hourly wind data were obtained for five NWS stations in the region: Astoria, Portland, Pendleton, Sexton Summit, and Elko, also shown in Figure 8.1.1. At least 30 years of wind speed data are available for each station.

Wind Power Distributions at Network Sites

The probability distributions of wind power at the six network sites will be described in this section. First the distributions at the individual sites are examined and then the distributions for the network of power sites as a whole are described.

Individual Sites

The statistics discussed include the sample size, the mean, standard deviation, and coefficient of variation (COV) of the empirical distribution, and the probabilities that the wind power will be zero (the minimum), 2.5 MW (the maximum), and any value between. The coefficient of variation, the standard deviation divided by the mean, is used as the dimensionless measure of variability. This measure allows the comparison of variability between distributions in which the variance (standard deviation) increases with the mean, such as wind speed or wind power.

Because of the nature of the transformation of wind speed to wind power, the distribution of wind power at individual sites is a mixed distribution (in a statistical sense), consisting of a discrete distribution corresponding to values of power equal to zero and 2.5 MW and a continuous distribution of the range between these two extreme values. The mixed nature of this distribution obviously has an impact on the values of the statistics of the distribution of power, as well as important implications in efforts to model wind power distributions. For example, the standard deviation of the distribution appears to be influenced more strongly by the magnitude of the probability associated with the discrete extreme points than by variations or differences in the continuous portion of the distribution. This influences the variability of wind power at a site, increasing this variability over that of the wind speed at the site.

The annual mean values of power range from 1.28 MW at Augspurger to 0.76 MW at Wells. The COV range from 1.28 at Kennewick to 0.78 at Augspurger with the mean coefficient approximately equal to one. The values of the standard deviation correspond closely to the magnitude of the probability associated with the discrete extreme points of the distribution. Generally, the larger

these probabilities, the larger the coefficient of variation for the same value of the mean.

The empirical probabilities associated with discrete portions of the distribution (maximum and minimum power) indicate that the probability of minimum power (zero MW) ranges from 0.20 at Augspurger to 0.38 at Kennewick, whereas the probability of maximum power (2.5 MW) ranges from 0.114 at KCIV to 0.257 at Goodnoe Hills. Thus, the relative likelihoods of maximum to minimum power at the six stations range from less than 0.5 at Kennewick and KCIV to greater than 1.0 at Augspurger.

More detailed information concerning the continuous portion of the distributions can be obtained by rescaling the empirical probabilities. The end points of the empirical distribution corresponding to probabilities of zero or 2.5 MW are dropped as these values are the result of many different wind speeds. The remaining values of the distribution are divided into five classes by 0.5 MW increments. These rescaled probabilities lend to decreases as the power values increase, particularly from class 2 to class 3. For larger class values, a considerable amount of fluctuation can be observed. In general, the probabilities would be expected to decrease as power increased for the continuous portion of the distribution; these fluctuations may be due to certain biases in the wind speed data (preferences for certain values) and effect of these biases when wind speeds are translated into wind power.

The statistics for the seasonal distributions of power indicate that the mean power is greatest in the summer at all of the sites except Wells. The average power ranges from 0.72 MW at Kennewick to 1.07 MW at Wells in winter, from 0.62 MW at Wells to 1.40 MW at Augspurger in summer, and from 0.58 MW at Wells to 1.31 MW at Augspurger in fall. The COV is minimum in the summer at all sites except Wells, ranging from 0.74 at Augspurger to 1.2 at Kennewick. The maximum variability occurs in the winter at Augspurger and Cape Blanco and in the fall for the other sites.

The probabilities of zero power range from 0.226 at Wells to 0.427 at Kennewick in winter, from 0.192 at KCIV to 0.338 at Wells in summer, and from 0.184 at Augspurger to 0.446 at Wells in fall. The probabilities of zero power generally are lower in summer than in winter or fall. The probabilities of maximum power range from 0.107 at KCIV to 0.244 at Wells in winter, from

0.083 at Wells to 0.323 at Goodnoe Hills in summer, and from 0.104 at Wells to 0.229 at Cape Blanco in fall.

Total Network

When determining the probability distribution of wind power for the total network of six sites, a problem arises as to the treatment of missing data. If only those hours are considered for which wind observations are available at all sites, then a substantial reduction in sample size occurs. For example, wind observations are available at all six sites on only 3,896 (22.2%) of the 17,520 ($2 \times 365 \times 24$) hours in the two-year period. (The actual sample sizes at the individual sites ranged from 10,814 at Augspurger to 15,462 at Kennewick). This substantial reduction in sample size seriously detracts from our ability to obtain a reliable representation of the probability distribution of wind power for the network as a whole, particularly when the sample is separated into seasons or is stratified by other factors.

To overcome this sample size problem, the missing data for a given site were replaced by the mean wind power value for that site computed from the sample of wind power data available for the site. For example, the 6,706 missing wind power values for Augspurger were replaced by the mean wind power value for Augspurger based on the 10,814 hourly values actually available. Thus, the augmented data sample for the total network consisted of 17,520 hourly wind power values. This replacement of missing data will not affect the mean values of the empirical probability distribution of wind power, but it may result in a slight reduction (under estimate) in the standard deviation and COV of the distribution.

The distribution for the network as a whole, unlike the distribution of wind power at the individual sites, is essentially a continuous distribution. The probability of zero power for the total system is very small, approximately 0.02. The mean of the annual distribution is 6.02 MW and the standard deviation is 2.65 MW, corresponding to a COV of 0.44. Full power output of the network would be 15 MW. The distribution is positively skewed with a long tail to the right extending out to power values in excess of 13 MW (of course, these values are associated with very small probabilities). The shape of this distribution suggests that a model based

on the lognormal or Weibul distribution may provide a good fit to the empirical distribution of power.

The distributions of total system wind power for winter and fall are quite similar overall, being somewhat more peaked than the annual distribution. Both winter and fall have mean power values less than the annual mean value. The reduction in mean power values more than offsets the reduction in standard deviation for these seasons so that the fall and winter seasons have higher COVs (more variability) than the annual distribution. The distribution for the summer season has a broader, flatter peak, with a higher mean and lower COV than the annual power values.

Wind Speed Distributions

Although the primary goal of this work is to obtain distributions of wind power for the network, it is also important for several reasons to examine the probability distributions of wind speed. Assessing the adequacy of the wind power data base for the network requires that comparisons be made between data for the network sites and data for other stations in the region having a longer period of record (i.e., the NWS stations). From a meteorological point of view, it is more meaningful to make such comparisons in terms of wind speeds rather than in terms of wind power.

Network Sites

The distributions of wind speeds for the six network sites are first described, based on the two-year period of record (1 December 1976 to 30 November 1978). In addition to the annual distributions, the distributions for the four seasonal time periods are also considered.

Annual Data

Cape Blanco has the highest mean speed (19.2) and Kennewick the highest COV (0.74). KCIV has both the lowest mean speed (13.8) and the smallest COV (0.50). Note that the variability of wind speeds is less than that of the power calculated from these speeds.

The frequency polygons of the annual wind speed data all indicate distributions with substantial degrees of positive skewness. This type of

distributional shape is in good agreement with previous studies; wind speed data have been commonly fit with positively skewed distributions, including the lognormal distribution and the Weibull distribution.

The frequency polygons for all the network sites have relatively high frequencies of low wind speeds; that is speeds that would result in little or no wind power output. At the other extreme, wind speeds high enough to require the shut down of wind machines, while quite unlikely, do sometimes occur. An especially noticeable characteristic of the wind speed frequency polygons is the regular pattern of alternating increases and decreases in relative frequencies for adjacent class intervals. We believe that this behavior is attributable, not to any physical phenomenon, but simply to biases in the subjective process of reducing strip chart data by 'eyeball' averaging the mean hourly wind speed.

Seasonal Data

The seasonal wind speed data for the network sites exhibit essentially the same characteristics as the annual observations. Specifically, the frequency polygons are positively-skewed distributions. The pattern in the means and COVs among the network sites for the seasonal data are roughly consistent with those discussed earlier for the annual data.

Large seasonal variations in these descriptive statistics, nevertheless, are evident for some of the network sites. The widest range in mean wind speeds occurs at Wells, with a fall mean of 11.9 mph and winter mean of 18.7 mph, whereas the widest range in COV occurs at Goodnoe Hills, from 0.55 in the summer to 0.81 in the fall. On the other hand, several sites have a very small degree of seasonal variation in means.

NWS Stations

The distributions of wind speeds for the five NWS stations having long periods of record were analyzed. The primary interest is to determine to what degree the data for the two-year time period (coinciding with the time period for the network data) are representative of the data from the entire historical record. To make this determination, wind speed distributions and

related statistics are considered for both the short-time period and the long-time period.

The frequency polygons for the annual wind speed data all indicate distributions with substantial degrees of positive skewness. The seasonal wind speed data frequency polygons have similar shapes.

Comparing the two time periods, it is evident from the frequency polygons that the short-time period has less variability (i.e., a tighter distribution than the long period). This reduction in variability can also be seen from the COVs, which reveal that the short-time period variability is less for every season at each station. For the annual wind speed data, these changes in coefficients of variation range from 0.03 at Elko and Sexton Summit to 0.10 at several sites and seasons.

The mean wind speeds for the two time periods, however, show no consistent pattern of change. No agreement in these differences in mean values is apparent, whether among stations or among seasons.

In summary, for the five NWS stations having long-term speed records, the short-time period (two years) does not appear to be very representative of the entire historical record. While no shift in mean speed is apparent, the short-term data have substantially less variability. The source of this change in variability is unknown, although it may possibly be attributed to fluctuations in meteorological conditions. (In particular, this short time period is known to have been quite anomalous in the Pacific Northwest with respect to certain other meteorological variables such as precipitation).

Relationship Between Network Sites and NWS Stations

It is of interest to directly relate the wind speed observations at the NWS stations to the network data. If the network wind speed observations could be estimated relatively accurately from the NWS station data, then the adequacy of the network data could be tested in a straightforward manner. Namely, the NWS stations could be used to generate additional estimated network data. This enlarged network data set could then be compared to the original observations.

To determine to what extent network wind speed observations can be estimated from the NWS station data, pairwise correlations have been computed

for each possible combination of a single network site with a single NWS station. The absolute values of the correlations are generally quite small, ranging from 0.01 between Wells and Sexton Summit and between Cape Blanco and Pendleton to 0.46 between Goodnoe Hills and Pendleton and between Kennewick and Pendleton. These results indicate that network wind speeds probably cannot be estimated very accurately directly from NWS station data.

Another way to make comparisons between network sites and NWS stations is in terms of the distributions of wind speeds. While both the network sites and NWS stations have similarly-shaped positively-skewed distributions, the means for these two groups of stations differ markedly. All the network sites have higher mean wind speeds and larger standard deviations than the NWS stations. However, the COV in the two groups are roughly comparable. The COV at the network sites range from 0.46 at Augspurger to 0.81 at Goodnoe Hills and Kennewick in the fall. The same statistic ranges from 0.49 at Portland in the summer to 0.92 at Elko in the fall. In addition to ratio of the COV of wind power to COV of wind speeds at the network sites is roughly constant over all seasons at each site. This ratio is 1.5 at Augspurger, Cape Blanco, and Goodnoe Hills and 2 at KCIV and Wells with Kennewick falling in between at 1.8. This indicates that the increased variability of the longer-term record at the NWS stations over the short-term record will probably be reflected in the variability of power from the network sites over a longer period.

In summary, for the NWS stations, the distributions of wind speeds for the short time period are not very representative of the entire historical record. These results suggest that the short time period of data available for the network sites also may not be very representative of the unknown long-term wind speed distributions at these sites. In particular the variability of wind speeds and thus wind power would appear to be underestimated by the two-year record at the network sites. However, the lack of statistical relationship between the NWS stations and the network sites on an hourly comparison precludes specific inferences as to the direction and magnitudes of biases in the wind speed data base.

Overall Summary

The probability distributions of wind power at the six network sites and for the total network were described in Section 2. It was pointed out that the distribution of wind power at individual 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.

The probability distributions of wind speeds for both the network sites and the NWS stations were described in Section 3. 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.

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9.0 WIND FLOW ANALYSIS AND PREDICTION

9.0 WIND FLOW ANALYSIS AND PREDICTION

Introduction

The wind flow analysis in the Columbia River Gorge during 1979/1980 was divided into three areas. First, the case study started last year using a new method for computing the surface horizontal pressure gradient force was completed and an additional case was analyzed to include the complex terrain of the Rocky Mountains. The second phase of this year's work 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 final phase of this year's work was to develop a statistical scheme to predict the winds in the Columbia Gorge.

Pressure Gradient Force Analysis

A. Background and Review of Pressure Gradient Force

The pressure gradient force, the main force driving the winds, must be accurately represented in order to understand observed winds and to forecast the winds. The current method of determining surface pressure gradients is to reduce station pressures to sea level. However, this process, which is a function of station pressure and temperature, yields erroneous results in complex terrain. Therefore, an attempt was made to represent the surface horizontal pressure gradient more accurately by using the techniques developed by Bellamy (1945) and Sangster (1960).

The procedure developed last year enabled the calculation of the horizontal pressure gradient force (HPGF) at a regular array of points in the Pacific Northwest. Once the pressure gradient force was determined, there was a need to depict it in an understandable way. Therefore, the geostrophic stream function was derived from the HPGF and analyzed on maps of the region.

B. Theory

From the pressure gradient force, the geostrophic wind, $\vec{V}_g$, at each grid point was determined from the relation

$$(1) \quad \vec{V}_g = \frac{1}{f} \hat{k} \times (-g \nabla_p D)$$

or in component form

$$(2a) \quad u_g = \frac{g}{f} \frac{\partial D}{\partial y} = \frac{1}{f} \text{ (y-component of HPGF)}$$

$$(2b) \quad v_g = \frac{-g}{f} \frac{\partial D}{\partial x} = \frac{-1}{f} \text{ (x-component of HPGF)}$$

where

u_g = east/west component of the geostrophic wind

v_g = north/south component of the geostrophic wind

g = acceleration due to gravity

f = Coriolis parameter, equal to $2 \Omega \sin \theta$ where

$\Omega = 7.272 \times 10^{-5} \text{ sec}^{-1}$ is the rotation rate of the earth

and θ is the latitude of the grid point.

$D = z - z_r$ with z the surface elevation and z_r the height in a reference atmosphere at which the station pressure would be observed.

The geostrophic wind was then used to calculate the geostrophic relative vorticity, ζ_g , at the grid points from

$$(3) \quad \zeta_g = \frac{\partial v_g}{\partial x} - \frac{\partial u_g}{\partial y}$$

where v_g and u_g are defined as before.

From the geostrophic winds and relative vorticities, the geostrophic streamfunction was computed using a relaxation method, an iterative numerical scheme used to solve partial differential equations.

C. Results and Conclusions

The results using a modified pressure gradient force were not much improved over using the sea level pressure gradient force. All the features that the sea level pressure analysis captured were also evident in the geostrophic streamfunction (see Figures 9.1.1 and 9.1.2).

The results of the larger case study, covering the western two-thirds of the United States and Southern Canada, indicated that the modified pressure gradient force analysis tended to improve the analysis of surface pressures in the mountainous regions.

While the reduction of pressures to sea level resulted in a large gradient of pressure on the eastern slopes of the Rocky Mountains, the modified version lessened the gradient and made the analysis of Midwest synoptic scale systems more symmetric; i.e., the gradients were more nearly equal on the western and eastern edges of the system.

The geostrophic surface winds determined from both analyses, while not in agreement with observed winds due to friction and local orographic effects, showed that the modified pressure analyses yielded better results than sea level pressure analyses in the mountainous regions. There was very little difference over the flat areas.

Even though the modified surface pressure analyses do not provide a large improvement over sea level pressure analyses, the modified version should yield better, more reliable, and consistent analyses in short-range subjective forecasting.

FIGURE 9.1.1 Sea level pressure analysis, 19 November 1978, 1000 PST.

FIGURE 9.1.2 Streamfunction analysis (solid lines) for 19 November 1978, 1000 PST. Arrows (→) represent geostrophic wind speed (in knots) calculated from modified pressure gradient; wind barbs (—\) represent observed wind speeds (in knots) at synoptic observation stations (o) wind power sites (*).

Correlation Study

A. Introduction

The correlation coefficient, ρ , measures the strength of a linear relationship between two random variables. The sample correlation coefficient, r , is an estimate of ρ . This study calculated the sample correlation coefficient between pressure gradient force, both modified and sea level, and wind speed; 850 mb winds at Salem, Oregon, and Spokane, Washington, and wind speed; and the surface to 850 mb temperature difference, a measure of atmospheric stability, and wind speed.

Since the pressure gradient force is the main force driving the winds, its value was determined at five wind power sites: Augspurger Mountain, Sevenmile Hill, Juniper Point, Goodnoe Hills, and Roosevelt. For each time period (0100, 0400, 0700, 1000, 1300, 1600, 1900, 2200 PST) and for each station, a value for $\nabla_p D$, the modified horizontal pressure gradient force (HPGF), was determined using techniques developed last year. The HPGF was calculated, using synoptic observation data* from Astoria, Portland, The Dalles, and Pendleton, Oregon, every three hours of every third day for the two-year period 1978-1979. The use of every third day helped to insure the independence of the data, since synoptic-scale atmospheric motions have a time scale of approximately two days. The stratification by hour eliminated the dependence of the data within each day.

The equation for the modified HPGF was previously derived to be

$$(1) \quad (\nabla D)_p = (\nabla D)_\sigma + R/g (T - T_r) \nabla_p (\ln p_s)$$

where R is the gas constant, g is gravitational acceleration, p_s the station pressure, T the station temperature, $\nabla = \hat{i} \frac{\partial}{\partial x} + \hat{j} \frac{\partial}{\partial y}$, T_r is the temperature in a reference atmosphere given the station's observed pressure, and $D = Z - Z_r$ where Z is the elevation of the station and Z_r the elevation in a reference atmosphere given the station's observed pressure. Since the Columbia River Gorge is oriented very nearly east-west, only the east-west component was

*Available from the National Climatic Center, Asheville, NC.

computed

$$(5) \quad \left(\frac{\partial D}{\partial x} \right)_p = \left(\frac{\partial D}{\partial x} \right)_\sigma + \frac{R}{g} (T - T_r) \frac{\partial}{\partial x} (\ln p_s)$$

Cubic equations of the form

$$(6) \quad ax^3 + bx^2 + cx + d = \text{"value"}$$

and its derivative in the x-direction

$$(7) \quad 3ax^2 + 2bx + c = \text{"value"}$$

were used to compute T and T_r (from 6) and $\left(\frac{\partial D}{\partial x} \right)_\sigma$ and $\frac{\partial}{\partial x} (\ln p_s)$ (from 7).

The distance from Astoria, Oregon, to the various wind power sites was represented by x ; and a , b , c , and d were coefficients determined from the original synoptic data. A value for the HPGF was then obtained for each time period on the days selected.

The correlations of wind power site data with the 850 mb (~ 5000 feet) wind speed was determined to see if downward mixing of momentum influenced the surface winds. The twice daily (0400 PST and 1600 PST) 850 mb wind data from Salem, Oregon, and Spokane, Washington, were used in the calculations.

The correlation of a stability measure with the wind power site wind speed was performed to determine what effect the low-level atmospheric stability had on the surface winds. A simple measure of stability was used--the 850 mb to surface temperature difference. The surface temperatures, T , at the wind power sites were determined when the terms for the modified HPGF were computed (see (6) above). The 850 mb temperatures at the wind power sites were determined by linear interpolation of the Salem, Oregon, and Spokane, Washington, 850 mb temperatures. Since upper air sounding data are collected only twice per day, a linear interpolation in time was performed to fill in the time periods between sounding reports.

For unstable conditions, where the surface temperature is warmer than the upper-level air, the 850 mb wind should mix downward more freely. For stable conditions, where the temperature increases with height, downward mixing of momentum should be limited.

B. Results

When the signed pressure gradient force (PGF) and the wind speed ($|\vec{V}|$) are plotted on a scattergram, one would expect a non-linear relationship over the entire range of pressure gradient force values, as shown in Figure 9.1.3. Because of the non-linearity of the relationship, the correlations were expected to be small. Table 9.1.1 showed this to be the case for Augspurgen Mountain, with values below about 0.300.

FIGURE 9.1.3 Expected relationship of wind speed and signed pressure gradient force.

The correlations increased, indicating a greater linear relationship, as the stations further east were analyzed. A maximum of 0.708 occurred at Goodnoe Hills.

The scattergrams for Augspurgen Mountain and Goodnoe Hills for 0100 PST are shown in Figures 9.1.4 and 9.1.5. The Augspurgen Mountain scattergram was similar to the expected relationship, but the Goodnoe Hills scattergram indicated a near linear relationship. Very large negative pressure gradient force values were associated with small wind speeds, whereas moderately large positive pressure gradient force values were associated with very

large wind speeds. This pattern existed for most of the time periods and stations east of Augspurgen Mountain.

TABLE 9.1.1 Correlation coefficients between the modified pressure gradient force and wind speed for 5 wind power sites in the Columbia River Gorge. Times, across the top, are Pacific Standard Time.

	<u>0100</u>	<u>0400</u>	<u>0700</u>	<u>1000</u>	<u>1300</u>	<u>1600</u>	<u>1900</u>	<u>2200</u>
Augspurgen Mtn.	.121	.130	.172	.057	.210	.283	.230	-.078
Sevenmile Hill	.554	.486	.500	.485	.412	.512	.493	.407
Juniper Point	.588	.586	.464	.312	.380	.478	.542	.461
Goodnoe Hills	.708	.675	.569	.464	.423	.419	.563	.576
Roosevelt	.599	.629	.491	.490	.491	.482	.606	.364

FIGURE 9.1.4 Scattergram of wind speed and modified pressure gradient force at 7 a.m. PST for Augspurgen Mountain. Numbers on graph represent number of observations at that point. Maximum number of observations was 244.

FIGURE 9.1.5 Scattergram of wind speed and modified pressure gradient force at 7 a.m. PST for Goodnoe Hills. Numbers on graph represent number of observations at that point. Maximum number of observations was 244.

The correlation of the magnitude of the pressure gradient force ($|PGF|$) and wind speed, Table 9.1.2, which is expected to be large, never exceeds 0.25 at Sevenmile Hill, Juniper Point, Goodnoe Hills, and Roosevelt. Correlations obtained for Augspurger Mountain were much larger, especially during the daytime hours (0700-1900).

TABLE 9.1.2 Same as Table 9.1.1, using the magnitude of the modified pressure gradient force.

	<u>0100</u>	<u>0400</u>	<u>0700</u>	<u>1000</u>	<u>1300</u>	<u>1600</u>	<u>1900</u>	<u>2200</u>
Augspurger Mtn.	.386	.295	.517	.490	.553	.538	.469	.383
Sevenmile Hill	-.189	-.226	-.004	.138	.179	.228	.112	-.008
Juniper Point	-.186	-.206	-.053	.032	-.041	-.119	-.183	-.216
Goodnoe Hills	-.121	-.174	-.188	-.052	.013	-.040	-.030	-.226
Roosevelt	-.080	-.175	-.049	.130	.144	.144	.067	.040

The expected relationship between the $|\text{PGF}|$ and $|\vec{V}|$, Figure 9.1.6, was not evident on any but the Augspurger Mountain scattergram (see Figures 9.1.7 and 9.1.8 for examples). There was much scatter in the plots.

FIGURE 9.1.6 Expected relationship of wind speed and the magnitude of the pressure gradient force.

FIGURE 9.1.7 Scattergram of the magnitude of the pressure gradient force and wind speed at 7 a.m. PST for Augspurgen Mountain.

FIGURE 9.1.8 Scattergram of the magnitude of the pressure gradient force and wind speed at 7 a.m. PST for Goodnoe Hills.

These same patterns existed in the plots and correlations of the signed pressure gradient force and u and v components of the wind.

Because of the unusual correlations and scatter plots, correlations were performed using only the positive pressure gradient forces, and then only the negative values. The results for positive values were much improved and the scattergrams agreed with what was to be expected; i.e., large (small) wind speeds associated with large (small) pressure gradient forces. Negative pressure gradient force correlations were not improved except at Augspurgen Mountain and a few values for Sevenmile Hill.

From this it can be seen that the funneling effect of the Columbia Gorge was being "felt" at Augspurgen Mountain when the pressure gradient force was positive or negative. This was probably due to the central location of Augspurgen Mountain in the Gorge and the steepness and narrow width of the Gorge in that area. The other stations in this study "felt" the influence of the funneling only when the pressure gradient force was westerly or positive (high pressure on the coast and low pressure inland). When the pressure gradient force was easterly (negative), the winds at Sevenmill Hill, Juniper Point, Goodnoe Hills, and Roosevelt probably did not respond to the pressure, no matter how large or small it was, because of the shallowness of the Gorge and short funneling distance from the eastern edge of the Gorge to the wind power sites.

Correlations were calculated using sea level pressure gradients (Table 9,1.3) in place of the modified pressure gradient. The results were about the same as those using the modified pressure gradient, with neither one doing better than the other when all the results were considered.

The correlations between the modified pressure gradient force and wind speed were calculated by season--March-May, June-August, September-November, December-February. The number of observations per time period was substantially reduced; therefore, one must be cautious when interpreting the results.

TABLE 9.1.3 Same as Table 9.1.1, using Sea Level Pressure Gradient Force in place of the modified pressure gradient force.

	<u>SLPGF and $\vec{V}$</u>							
	<u>0100</u>	<u>0400</u>	<u>0700</u>	<u>1000</u>	<u>1300</u>	<u>1600</u>	<u>1900</u>	<u>2200</u>
Augspurgen Mtn.	-.057	-.081	.172	.010	.206	.236	.208	-.107
Sevenmile Hill	.554	.477	.482	.475	.402	.458	.486	.408
Juniper Point	.540	.564	.468	.331	.420	.503	.542	-.495
Goodnoe Hills	.634	.633	.571	.484	.424	.500	.566	.584
Roosevelt	.583	.612	.522	.534	.560	.566	.600	.364

	<u>SLPGF and $\vec{V}$</u>							
	<u>0100</u>	<u>0400</u>	<u>0700</u>	<u>1000</u>	<u>1300</u>	<u>1600</u>	<u>1900</u>	<u>2200</u>
Augspurgen Mtn.	.425	.400	.553	.518	.563	.469	.451	.349
Sevenmile Hill	.051	-.052	.054	.176	.266	.207	.131	.038
Juniper Point	-.039	-.004	.068	.098	.045	-.088	-.142	-.143
Goodnoe Hills	-.036	-.008	-.042	.034	.056	.058	.023	-.120
Roosevelt	.085	.042	.248	.314	.323	.255	.227	.211

At most stations the PGF and $|\vec{V}|$ had a good correlation for all seasons. Again, this was not to be expected (recall Figure 9.1.3). When the $|\text{PGF}|$ and $|\vec{V}|$ were correlated, the results revealed a division between the warm season (spring and summer) and the cool season (fall and winter). Most of the values for the warm season were positive, whereas most of the values for the cool season were negative. The reason for this stratification of values is uncertain.

Augspurgen Mountain seems to be the only station whose results agreed with the expected results. Sevenmile Hill, Juniper Point, Goodnoe Hills, and Roosevelt did not agree with expected results except when the pressure gradient force was positive. A partial explanation of this is that topography has an important role on the effects of the large-scale pressure gradient force on the wind. In addition, important local effects, much smaller than the synoptic network data used, could not be determined; thus, their influence is uncertain.

The seasonal correlation between the 850 mb winds and the observed winds at two of the wind power sites was very small overall (Table 9.1.4). Augspurger Mountain wind speeds showed some spring time correlation with the upper-level winds at Spokane, Washington, and almost no correlation with the Salem, Oregon upper-level winds. The results for Goodnoe Hills were better, with generally higher correlations throughout the year, especially with Spokane, Washington.

Due to the small number of observations each season and the distance between sounding site and wind power site, interpretation is difficult. There seems to be higher correlation between the Spokane upper-level winds and the Goodnoe Hills winds in the afternoon. One possible explanation is that both are in eastern Washington and the boundary layer grows to a height that includes the 850 mb level. This seems reasonable, particularly in the warm season, since 850 mb is somewhat under 5000 feet and Goodnoe Hills is about 2600 feet above mean sea level. A boundary layer depth of 2500 feet (or 750 meters) is not unusual, so that downward mixing of momentum can occur.

The correlation to 7 a.m. (p.m.) winds was an attempt to see if there was a lag time between the time the sounding was taken and the observed surface winds. The small number of observations does not allow a conclusion to be reached, and all the hourly data should be investigated.

The stability/wind speed correlations, Table 9.1.5, showed small correlations at Augspurger Mountain and larger correlations in the less mountainous regions of Juniper Point and Goodnoe Hills.

Since wind speeds generally increase with height, it seems reasonable that large negative values of stability are associated with larger wind speeds and that wind speed decreases as stability increases. This seems to be the case at Goodnoe Hills and for a few time periods at Juniper Point. Since Augspurger Mountain is in the central portion of the Cascade Mountains, the stability parameter derived for Augspurger Mountain may not be representative of the true atmospheric conditions.

TABLE 9.1.4 Correlation of 850 mb winds at Salem and Spokane with winds at Augspurger Mountain and Goodnoe Hills. Upper air soundings were taken at 0400 and 1600 PST.

<u>AUGSPURGER MOUNTAIN</u>				
<u>SALEM</u>	<u>0400</u>	<u>0700</u>	<u>1600</u>	<u>1900</u>
Spring	-.176	-.172	-.178	.083
Summer	.045	.015	-.081	-.067
Fall	-.047	-.199	.014	.078
Winter	--	--	--	--
<u>SPOKANE</u>	<u>0400</u>	<u>0700</u>	<u>1600</u>	<u>1900</u>
Spring	.367	.297	.174	.386
Summer	.197	.184	.215	.221
Fall	.071	-.165	.043	-.063
Winter	--	--	--	--
<u>GOODNOE HILLS</u>				
<u>SALEM</u>	<u>0400</u>	<u>0700</u>	<u>1600</u>	<u>1900</u>
Spring	-.248	-.154	.400	-.082
Summer	-.005	-.175	.156	.153
Fall	.066	.014	-.093	.108
Winter	--	--	--	--
<u>SPOKANE</u>	<u>0400</u>	<u>0700</u>	<u>1600</u>	<u>1900</u>
Spring	.307	.353	.513	.199
Summer	.253	.186	.367	.547
Fall	.317	.332	.162	.170
Winter	--	--	--	--

TABLE 9.1.5 Stability/wind speed correlations.

	<u>0100</u>	<u>0400</u>	<u>0700</u>	<u>1000</u>	<u>1300</u>	<u>1600</u>	<u>1900</u>	<u>2200</u>
Augspurger Mtn.	.187	.084	-.102	-.216	-.107	.022	-.065	.108
Juniper Point	-.308	-.361	-.166	-.061	-.207	-.070	-.417	-.347
Goodnoe Hills	-.266	-.305	-.431	-.545	-.468	-.170	-.380	-.502

C. Conclusions

Correlations are much higher and are in agreement with expected relationships at wind power sites when the pressure gradient force is directed from the west to the east (high pressure on the coast and low pressure inland). Topographic effects and local pressure fluctuations can partially explain some of the discrepancies between actual and expected results. Seasonal correlations showed a warm season/cool season stratification. The reasons for this stratification are uncertain.

The correlations between upper air (850 mb) winds at Salem and Spokane and the surface winds at Augspurger Mountain were generally small, with somewhat better results for the Goodnoe Hills data. The results of the stability/wind speed computations showed a similar pattern.

The pressure gradient force is probably more important in areas such as Augspurger Mountain than at the wind power sites in the eastern part of the Columbia River Gorge, where stability and the upper-level winds might have more important roles in determining the local winds.

A multiple regression analysis using these variables should give some insight as to the relative importance of the variables and the intercorrelations of the variables.

Wind Flow Prediction

A. Introduction

The final phase of this year's study was to develop a method for predicting the winds at Goodnoe Hills, Washington. A model output statistics (MOS) approach was employed. This method determines a statistical relationship between a predictand and output variables from a numerical model. An advantage of this procedure is that it objectively accounts for numerical model inaccuracies. A disadvantage is that the method requires a large archive of model output and, if the model changes significantly, new output must be archived and the equations rederived.

This technique has been used successfully in many applications, including temperature forecasts and cloud amount (Glahn and Lowry, 1972), and surface winds at various synoptic observation stations (Carter, 1975).

For the purpose of predicting the winds at Goodnoe Hills, wind data (predictands) at Goodnoe Hills and Limited-Area Fine Mesh (LFM) model output (predictors) at Goodnoe Hills were tabulated for the period June 1979 through May 1980. The data were gathered from LFM output received at Oregon State University, Department of Atmospheric Sciences, and divided into a warm season (April-September) and a cool season (October-March).

The independent variables used were the east-west and north-south sea level pressure gradient force (EW and NS HPGF), since the pressure gradient force drives the winds; the observed winds at Goodnoe Hills at the time the model was initialized, also known as persistence; the 700 mb height and the 700 mb relative humidity. The last two were included, since they were readily available and were possibly correlated to other variables not available. Table 9.1.6 shows the initialization time, forecast times, predictors and predictand. A forward regression was then used to determine a predictive equation for each forecast period. Data were readily available at OSU to do a 12, 24, and 48-hr forecast with the 4 A.M. initialization. However, only a 12-hr forecast could be made with available data for the 4 P.M. initialization.

TABLE 9.1.6 Predictand and predictors used in the model output statistics (MOS) method for predicting the winds in the Columbia River Gorge.

4 A.M. INITIALIZATION DAY X			4 P.M. INITIALIZATION DAY X
12 hr. fcst	24 hr. fcst	48 hr. fcst	12 hr. fcst
predictand 4 p.m./DAY X observed $ \vec{V} $	4 a.m./DAY X+1 $ \vec{V} $	4 a.m./DAY X+2 $ \vec{V} $	4 a.m./DAY X+1 $ \vec{V} $
predictors			
(1) EW HPGF			
(2) NS HPGF			
(3) 700 mb height	same	same	same
(4) Relative humidity at 700 mb			
predictor 4 a.m./X obs. $ \vec{V} $ at Goodnoe Hills	4 a.m./X obs. $ \vec{V} $	4 a.m./X obs. $ \vec{V} $	4 p.m./X obs. $ \vec{V} $

B. Results

Of 172 possible observational periods to be used in the regression, approximately 120 had one or more pieces of missing data. As indicated earlier, a large archive of data is necessary for this technique to be useful. Since the number of observations was reduced to about 50, only the warm season equations were determined.

The final equation and R^2 value are shown below. The R^2 value is a measure of the total variation about the mean of the predictand accounted for by the regression equation.

4 a.m. initialization:

12 hr. forecast, $R^2 = 0.317$

$$|\vec{V}| = 4.48 + 9.58 \times (\text{relative humidity}) + 0.39 \times (\text{persistence})$$

24 hr. forecast, $R^2 = 0.185$

$$|\vec{V}| = 4.85 + 18.49 \times (\text{relative humidity}) + 0.18 \times (\text{persistence})$$

48 hr. forecast, $R^2 = 0.053$

$$|\vec{V}| = 15.00 + 9.74 \times (\text{relative humidity})$$

4 p.m. initialization:

12 hr. forecast, $R^2 = 0.411$

$$|\vec{V}| = 166.05 + 0.96 \times (\text{EW HPGF}) - 0.52 \times (\text{700 mb height}) \\ + 0.58 \times (\text{persistence})$$

From the R^2 value it can be seen that the predictability of the winds decreases rapidly with time; i.e., the 12-hour forecasts performed reasonably well, even with a limited number of variables, whereas the 24- and 48-hour forecasts performed poorly. Some reasons for the poor predictive capability is that these forecasts are for long periods of time (up to 48 hours), there were very few variables available, and the LFM model does not do well for the Pacific coast due to a lack of data over the ocean.

For the 24-hour and 48-hour forecast, relative humidity was the first variable entered, while for both 12-hour forecasts, persistence was the first variable chosen. The selection of persistence first in the 12-hour forecasts was not surprising. The selection of relative humidity as the first variable for the 24-hour and 48-hour forecasts was not anticipated. The fact that the 24-hour and 48-hour regressions explained very little of the variance and the possible relationship of relative humidity to other atmospheric variables that may be useful in predicting the winds should not make the results too surprising.

Additional variables and observations, such as those available to the Techniques Development Laboratory of the National Weather Service, are necessary to better predict the winds, especially on a long-term basis.

Glossary

GEOSTROPHIC STREAM FUNCTION: A parameter of two-dimensional, non-divergent geostrophic flow, which is constant along each streamline.

GEOSTROPHIC VORTICITY: The vorticity of the geostrophic wind.

GEOSTROPHIC WIND: The horizontal wind velocity in which the coriolis force balances the pressure gradient force.

STABILITY: The response of the atmosphere to an initial displacement of a parcel of air in which the parcel either is accelerated away from its initial position (unstable), remains at the new position (neutral); or is returned to its original position (stable).

VORTICITY: A measure of the local rotation of a fluid flow.

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10.0 KLICKITAT COUNTY SWECS PROJECT

10.0 KLICKITAT COUNTY SWECS PROJECT

Introduction

The Bonneville Power Administration is sponsoring a wind energy pilot project in cooperation with the Klickitat County Public Utility District. There will be 12 SWECS (small wind energy conversion systems) installed in the county by the end of 1981. These windmills will range in electrical output from 2 to 10 kW and will supplement residential use.

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 grid.

The Oregon State University Wind Power Group has been working in conjunction with BPA on the site surveys and site selections for the 12 SWECS in Klickitat County, a county that has many suitable sites for wind turbine generators.

Selection and Installation of the First Two Windmills

BPA made an early purchase of two Enertech windmills. Following the siting criteria outlined in the next section, the O.S.U. Wind Power Group recommended two windmill sites. The 2.1 kW machines were installed at Ed Hocter's residence near Goldendale and Elmo Beeks' residence at Murdock in March 1980. The Enertech windmills can produce about 3400 kWh a year at a 10 mph mean annual wind speed site.

The cost of these windmills came to \$8000 each, which includes installation. They are erected on 60' free-standing towers. Like all other future windmill recipients, Ed Hocter and Elmo Beeks have the option to purchase the windmills at 10% of their cost after the five-year test period.

Site Survey and Selection

The first two windmill sites were selected from previous knowledge via research by the O.S.U. Wind Power Group. The Klickitat County P.U.S. received 98 applications for the remaining 10 windmills. An investigation of each of the 98 sites was conducted in order to select 18 anemometer sites. These anemometer sites will collect wind data to be used in selection of the remaining 10 windmill sites. The applicant sites, anemometer sites, and the two windmill locations are shown in Figure 10.1.1.

A checklist of important siting criteria was applied to each site in order to determine its potential for wind energy. One of the initial indications used in the site survey was the evidence or lack of wind-deformed vegetation. The degree of flagging in trees increases as the wind speeds get stronger. The classifications in the Griggs-Putnam Index for Douglas-fir and Ponderosa Pine, developed by Hewson and Wade (1979), give one a good idea of the annual average wind speed in a locality.

It was important to select the anemometer sites within a wide distribution across the county, despite the concentration of residences in the two main towns, Goldendale and White Salmon. Some of the sites needed to be located with public exposure taken into consideration. The residents of Klickitat County and outsiders traveling through the area should be able to view some of the work BPA and Klickitat Co. PUD are doing to evaluate the use of residential wind energy.

A prerequisite to any site selection is to study the physiographic characteristics of the potential sites. Good exposure to the prevailing winds exist when there are no topographical barriers that create turbulence and bias the average wind speeds of the area. Airflow over features such as ridges, hills, cliffs, valleys, and gorges have different patterns. The wind shear created over such terrain can affect the performance of a wind turbine generator. It can cause stress on the blades and affect the power output.

Wind speeds usually increase with height. The rate of change in the wind speeds with elevation is affected by surface roughness. Wegley, et al., (1980) have developed a table of "Wind Speed Extrapolation Factors for Sites in Areas of Different Surface Roughness". This table allows one to extrapolate wind speeds from one height to another. When looking at the

* - WINDMILL

★-ANEMOMETER RECIPIENTS

extrapolation factors, one notices that they grow farther apart with increased surface roughness. Therefore, it is highly recommended that wooded areas or urban environments be avoided in order to avoid wind shear problems.

Local obstructions such as buildings, trees, and towers create wakes of turbulence that may reduce the output or impart stress on a windmill. Wind turbine generators must be placed far enough downwind from large obstacles to minimize interference. The general rule for siting downwind from obstructions is to be a distance of 10 heights of the obstruction downwind from it.

A site must have sufficient space within property boundaries for the location of a windmill. For this particular SWECS project, the specific placement of a windmill should be within 100'-500' of a house or transformer and 100' from telephone, power lines, and property boundaries. Any distance over 500' from a house or transformer would require thicker cable, which would increase the cost to transmit the power. The distances of 100' from buildings, lines, and borders are based on 60' towers, the most likely height for all of the windmills. Also, there needs to be space for guyed towers. Up to two-thirds the height of the tower is required for the radius around the base of the tower.

A good reference source for siting windmills is "A Siting Handbook for Small Wind Energy Conversion Systems" by H. L. Wegley, et al., of Battelle Pacific Northwest Laboratory. It was prepared in March 1980 for the U. S. Department of Energy. Refer to the footnote at the bottom of this page.

Installation of Anemometers

All 20 anemometers were installed during the months of June and July with the exception of one. Due to the early availability of a Natural Power anemometer, one was installed at Site 12 in February atop an old windmill tower at a height of about 30'.

Eighteen of the anemometers are being used to determine the siting of 10 windmills, and the other two anemometers were installed at about the 45' level on the windmill towers at the Beeks and Hocter residences.

*Wegley, H.L., J.V. Ramsdell, M.M. Orgill, and R.L. Drake, Siting Handbook for Small Wind Energy Conversion Systems, DOE Report PNL-2521 Rev. 1, NTIS, Springfield, VA.

Most of the other anemometers were installed atop 30' masts. One of the anemometers was installed on the top of an old windmill tower at about the 50' level.

The SWECS project is using two different types of anemometers. There are 15 Natural Power units and five Aeolian Kinetics' MS-778's. The Natural Power unit is an accumulator (wind-run) anemometer that should be read at least twice daily. The MS-778 is a solid state device that stores data at set intervals adjustable from one second to 60 hours. Each increment of storage has 256 consecutive data points, each data point containing four decimal digits. Each MS-778 unit in the SWECS project contains three increments of storage. The data are extracted using a "milking machine" and put on cassette and/or paper tape printout. The windmills have MS-778's on their towers so that in the future power output can be compared with wind speeds at prescribed intervals. The other three MS-778's are presently located at three other sites in the county. Representative anemometer sites can be seen in Figures 10.1.2 and 10.1.3. Each of the anemometer recipients has signed an agreement with the Klickitat County P.U.D. for participation in the SWECS project.

Data Collection and Analysis

The people who were loaned Natural Power units were given log books to keep record of the data. It was recommended that data be recorded at least twice a day: perhaps once in the morning or mid-afternoon, and again in the evening. Hopefully, the recording times will be done consistently to one's convenience.

The usefulness of SWECS depends upon the timing, strength, and duration of productive winds; thus, wind data should reveal the fluctuations within local wind regimes. For example, if a five-hour wind of 25 mph, say between 3:00 and 8:00 p.m., is averaged over an otherwise calm 24-hour period, the apparent average wind is 5.2 mph. The potential power calculated from one daily wind reading would hide the real output.

At the time of each reading, a one-minute sample is taken, along with the estimated wind direction. These data are recorded in the log book. The pages of data are forwarded to the Klickitat County P.U.D. at the end of

FIGURE 10.1.2 Anemometer sites

FIGURE 10.1.3 Anemometer sites

each month. Then the P.U.D. forwards the data to the B.P.A.'s Walla Walla office who, in turn, forwards it to the B.P.A.'s Portland office for analysis. Data will be taken at each site for 9-12 months.

The O.S.U. Wind Power Group has the responsibility for extracting the data from the MS-778 anemometers. B.P.A. will analyze the data from these units. The MS-778's may be moved around at later dates in order to obtain wind.

Final Steps and Conclusions

The selection of the 10 windmill sites will follow the analysis of the anemometer data by B.P.A. B.P.A. will purchase different kinds of windmills in the range of 2 to 10 kW. The average cost of each windmill will be about \$12,000. Each windmill site may retain their anemometers. The remaining anemometers will be dismantled and perhaps used for a future anemometer loan program being arranged by B.P.A.

B.P.A. will be able to obtain some important information about SWECS during the five-year test period. Questions remain whether SWECS can operate harmoniously with utilities' systems.

The SWECS project in Klickitat County may generate interest in small wind generation in the future. Presently, SWECS are expensive at 15¢ or more per kWh, but the increase in electrical rates and cheaper costs of SWECS through mass production may make SWECS an attractive supplemental source of energy for residential use in the future.