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WIND POWER
OREGON STATE UNIVERSITY
DEPARTMENT OF ATMOSPHERIC SCIENCES

REPORT NO. BPA 81-7

DECEMBER 1981

EXECUTIVE SUMMARY

WIND-ENERGY ASSESSMENT STUDIES IN THE GOODNOE HILLS AND CAPE BLANCO AREAS PROGRESS REPORT, OCTOBER 1980-SEPTEMBER 1981

Prepared by

Robert W. Baker, Principal Investigator

and

John E. Wade, P. Ola G. Persson, and Richard W. Katz

Submitted to the

Bonneville Power Administration
Division of Engineering and Construction
Portland, Oregon

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ACKNOWLEDGEMENTS

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Finally, we express our appreciation to BPA for funding this most interesting research. Mr. Nicholas Butler, engineer in charge of this contract for BPA, has been most helpful with his encouragement, suggestions, and professional support. Also, we are indebted to Mr. T.M.(Max) Holder, BPA instrument technician, who has weathered the elements to install and maintain several of the anemometers in the wind data network.

1.0 INTRODUCTION

In 1975 the Bonneville Power Administration (BPA) contracted with Oregon State University (OSU) to investigate the wind power potential in the BPA service area which includes Washington, Oregon, Idaho, western Montana, and northern Nevada. Several promising high wind sites have been found and undoubtedly many more remain to be discovered. Previous BPA Reports 76-1, 77-2, 78-3, 79-4, and 80-5 have documented this research.

This past year the assessment activities have been divided into two primary areas: the Regional Wind Energy Assessment Program, and Wind Energy Assessment Studies in the Goodnoe Hills and Cape Blanco Areas. This report summarizes the work performed in FY81 on Wind Energy Assessment Studies in the Goodnoe Hills and Cape Blanco Areas for the Division of Engineering and Construction at the BPA. The research centers on defining the extent of the wind resource at site specific locations that have been documented as having good wind power potential. The work consists of three tasks: (1) spatial wind surveys in the Goodnoe Hills and Cape Blanco areas; (2) wind turbine generator (WTG) wake measurements at the Goodnoe Hills MOD-2 site, and (3) developing a methodology for sampling the wind flow using a kite anemometer.

The research activities in FY81 on the Regional Wind Energy Assessment Program for the Division of Power Management are described in BPA Report 81-6. This program focuses on the expansion of the wind data network in the BPA service area. Program elements include large area wind power prospecting, data collection and analysis, network wind power analysis, the BPA Small Wind Energy Conversion System (SWECS) Project, and the educational program.

2.0 SPATIAL WIND SURVEYS

Introduction

The wind data collected from fixed place anemometers in the Cape Blanco and Goodnoe Hills/Juniper Point area indicate very good wind power potential as the mean annual wind speeds are in the 16-20 mph range (reference BPA Reports 77-2, 78-3, 79-4, and 80-5). However, the exact extent of the good winds is not known. The Cape Blanco area is heavily wooded which may decrease the wind speed significantly in the lowest few hundred feet on potentially useable land. The Goodnoe Hills/Juniper Point area is made up of an east-west ridgetop overlooking the Columbia River, and well-exposed north facing slopes. There are also benchlands that are well-exposed to the prevailing west flow. This area is mostly grass covered. Although there are no trees to distort the wind field, as in the case of Cape Blanco, the elevation changes in this Gorge area may cause significant flow differences.

Thus, to better define the wind power potential in each of these high wind areas, an ambitious field wind measurement program was undertaken. The spatial wind survey in the Gorge area began in FY80 and is documented in BPA Report 80-5. In FY81 a large benchland area south of the Columbia River was added to the survey area in order to obtain data to compare to the numerical model results of Veenhuizen and Lin (1980).

In March 1981 BPA authorized OSU to commence a field measurement program at Cape Blanco. This program centered on defining the spatial extent of the wind flow on a 4 square mile wooded parcel of land just north of the Cape Blanco Airport. Two 200-ft. meteorological towers were installed in late May 1981 by the landowner (Tom Shipler) and it was subsequently instrumented at the 50 and 200-ft. levels with BPA anemometers.

Wind flow measurements were taken several times in both the Gorge and coastal areas during FY81 under prevailing power producing wind conditions; west flow in the Gorge and south and north flow along the southern Oregon coast. Measurements were made using several hand-held kite anemometers and these data were related to the fixed place anemometer data taken in each area. The ratio of the site kite anemometer wind speed to kite data or fixed place anemometer wind speed at the base (reference site) is termed the wind speed ratio, "r". Spatial wind measurements, as well as wind profiles, were taken. The spatial measurements consisted of flying several kites coincidently.

at prescribed levels at different locations in each study area. In the Cape Blanco area, typically, kite anemometers were flown at the 100, 200, and 350-ft. levels for 30-minute periods several times during the day. In the Gorge study area spatial measurements were taken at the 200-ft. level for 45-minute periods. The height and duration of measurements were determined by physical extent and roughness of the survey area. At Cape Blanco the study area is relatively small and close to the base anemometer at the Cape Blanco BPA site, but the surface roughness is very pronounced. Therefore a 30-minute observation was used but at three different levels to determine roughness effects. However, in the Gorge roughness is not a major factor but the geographical extent of the study area is quite extensive so longer period measurements were taken at just one level, 200 ft.

Wind speed and direction measurements were made using the hand-held kite anemometer in the following manner: a five-second 'eye-ball' average speed reading was taken every 20 seconds and once per minute the wind direction was noted. The data collected were then analyzed with respect to averages and standard deviations. The Turbulence Intensity value was determined by dividing the standard deviation of the speed by the mean speed. Values less than 0.10 indicate smooth flow, those between 0.10-0.20 indicate moderate turbulence levels, and values exceeding 0.20 indicate a high level of turbulence.

The spatial wind measurements were compared to the coincident data at the fixed place anemometer locations. The fixed place anemometers in the Goodnoe Hills/Juniper Point area consisted of a 195-ft. meteorological tower at the Goodnoe Hills MOD-2 site instrumented at the 50 and 195-ft. levels, a 45-ft. level anemometer about .3 mile south of the 195-ft. meteorological tower, a 100-ft. level anemometer at Juniper Point, and a 40 ft. level anemometer on the valley floor northwest of Juniper Point. All of the anemometers, except the latter, consisted of real time monitoring strip chart recorders. A data logger collected mean hourly wind speeds from the 40-ft. tower at the site northwest of Juniper Point on the valley floor. At Cape Blanco the spatial data were compared to the strip chart data taken at the 30-ft. level at the Cape Blanco BPA site and also to coincident kite data taken next to the BPA site. The data collected under north wind measurements during the summer were also compared to the tower data taken on the Shipler property. The two survey areas with fixed place anemometer locations are shown in Figures 2.0.1 and 2.0.2.

Wind profiles were also taken at both study areas by flying two or three kite anemometers simultaneously at different levels. Typical levels were 50 (or 100), 200, and 350 ft. When two kites were used, measurements were taken at the 200 and 350-ft. levels for a prescribed period followed by a five-minute reposition break. The kites were next flown at the 200 and 100(or 50) ft. levels. The two sets of data were compared and an average profile was calculated.

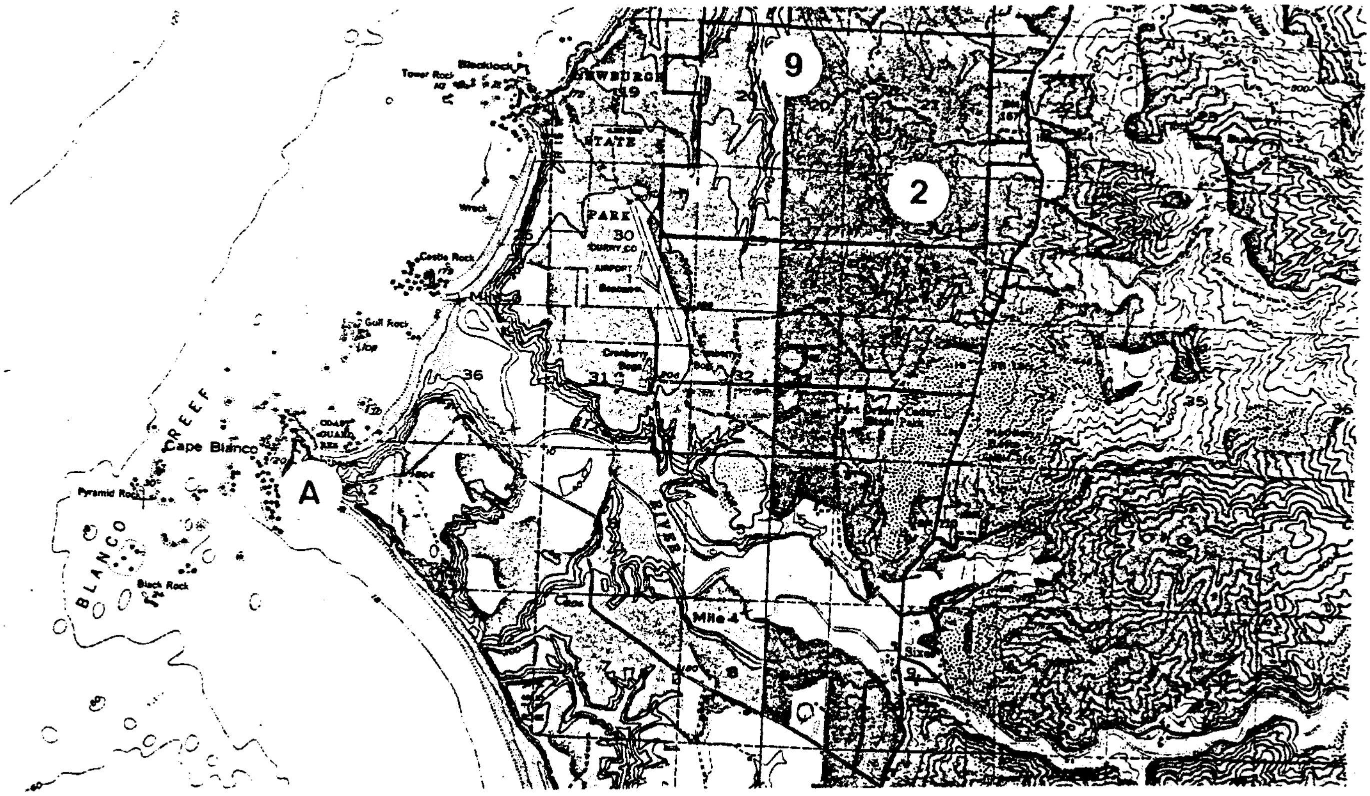

FIGURE 2.0.1: Cape Blanco study area showing the anemometer sites (A-Cape Blanco BPA 30', 2 & 9 - 200' meteorological towers).

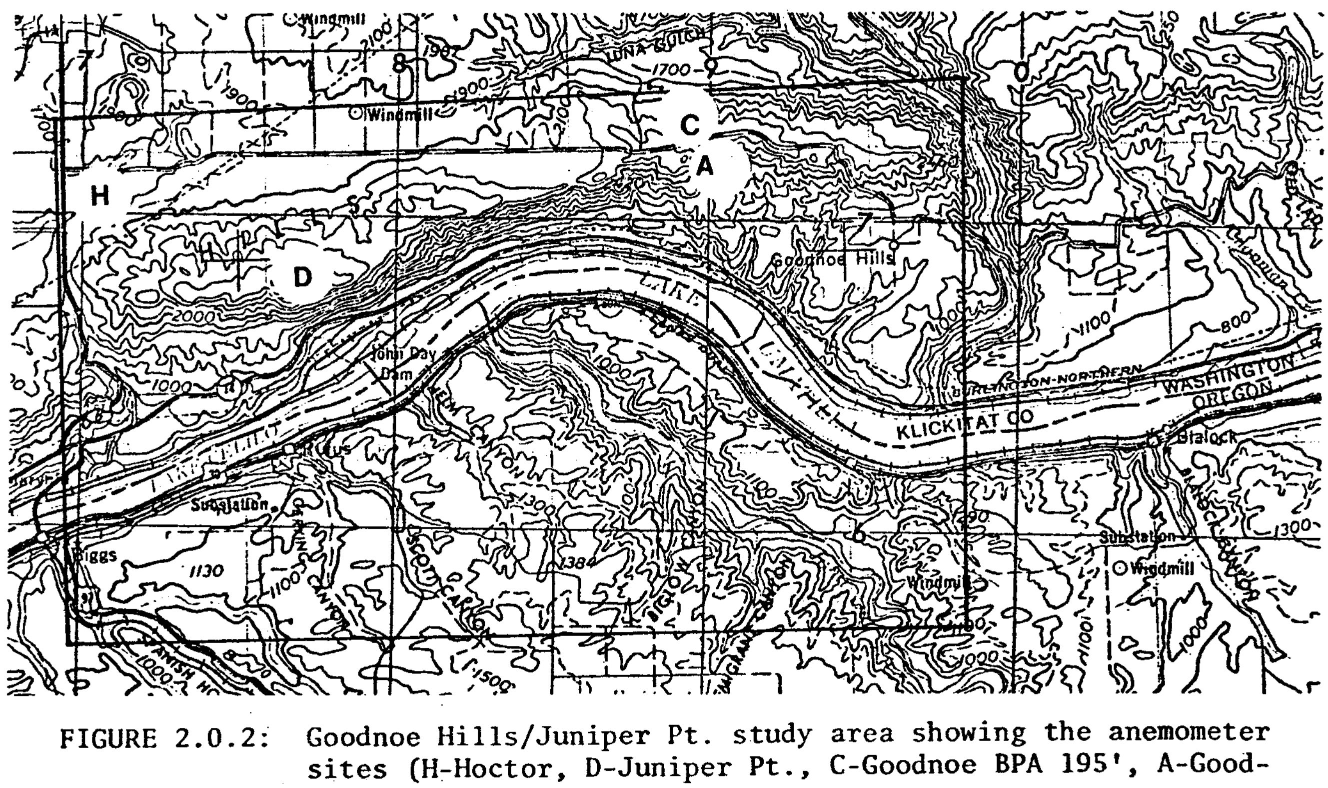

FIGURE 2.0.2: Goodnoe Hills/Juniper Pt. study area showing the anemometer sites (H-Hoctor, D-Juniper Pt., C-Goodnoe BPA 195', A-Goodnoe OSU 45').

2.1 CAPE BLANCO WIND FLOW STUDIES

Wind flow measurements were taken in the Cape Blanco area under south and north wind conditions. Two field trips were made to measure the south storm winds on 23-25 March and 8 April 1981. North wind measurements were made on three different field trips; 19-20 May, 20-22 July, and 5-7 August 1981. Individual trip reports were prepared for BPA describing the results of each trip. The following analysis is a summary of the findings of the five field trips.

The wind flow measurement site locations are shown in Figure 2.1.1. Site A is where the 30-ft. level BPA anemometer is located and site 1 is where kite anemometer measurements were taken.

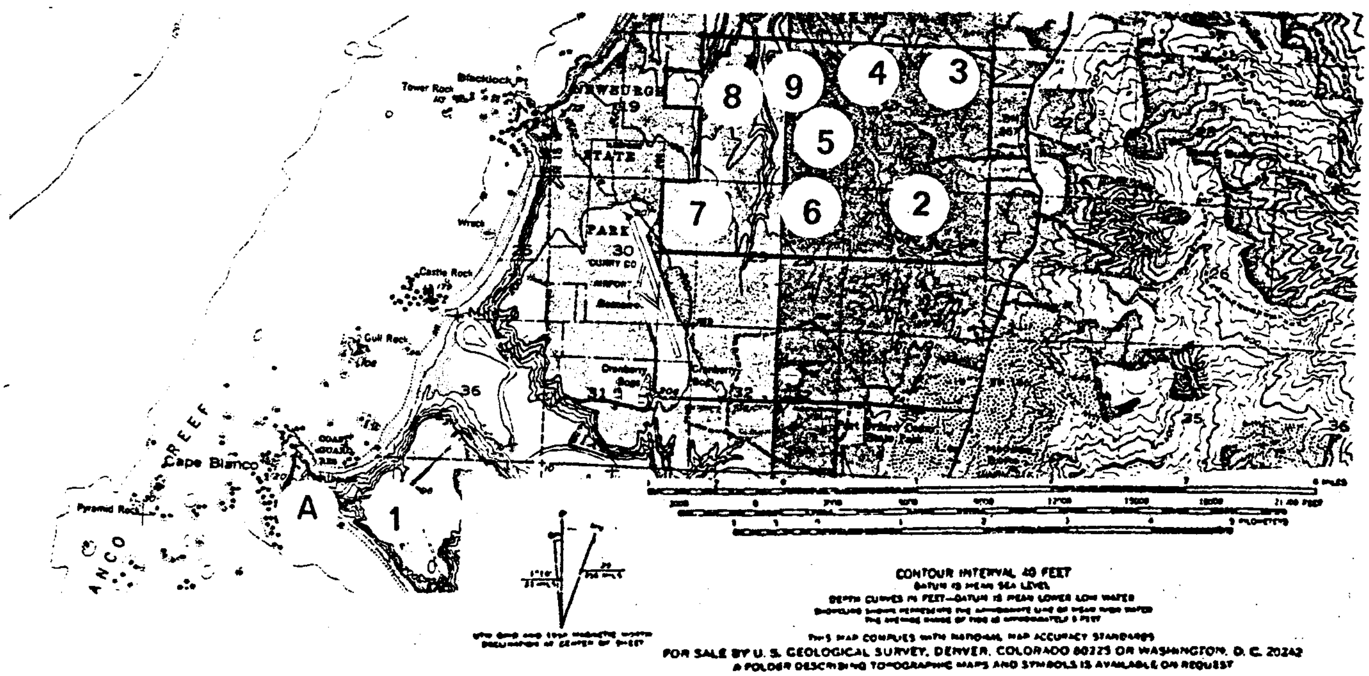

FIGURE 2.1.1: Wind flow measurement locations. Fixed place anemometers are located at sites A, 2, and 9.

For north and south flow measurements the r values were about the same at each inland site at the 350 ft. and 200 ft. levels. The 350 ft. values averaged about .71 (±.05) and the 200 ft. values averaged about .66 (±.05). At the 100 ft. level the north flow r values were slightly higher than those under south flow, as the north flow r value averaged about .64 compared to .60 for south flow. However, these results are inconclusive since the data base is not large. Also, the relationships may be somewhat high on a diurnal basis since data were only taken during the daytime. The meteorological tower data indicates that under north winds the flow on the Shipler property becomes decoupled from the flow at the Cape at night, as there is a significant diurnal variation with low wind speeds at night compared to steady and moderate intensity night winds at the Cape. Thus the nighttime ratios will be significantly lower than the daytime values. The south winds seem to track somewhat systematically at both sites, so there may not be significant diurnal variations in the r values.

The turbulence values at the inland sites were 2-3 times higher than those at the Cape at all levels and often were in the .15-.30 range. Also, there is considerable wind speed shear at the inland sites especially in the lowest 100 ft. The α values frequently were in the .25-.40 range between the 50 ft. and 200 ft. levels at both inland towers.

The kite wind profiles over the Cape at site 1 indicate a low level speed maximum with south flow below 100 ft. such that the wind speeds at the 30 ft. BPA anemometer approximate those at the 200 ft. level. However, under north winds, there is considerable shear in the lowest 350 ft. as the α value appears to be about .25. Mean profiles under north and south flow are given in Figures 2.1.2 and 2.1.3.

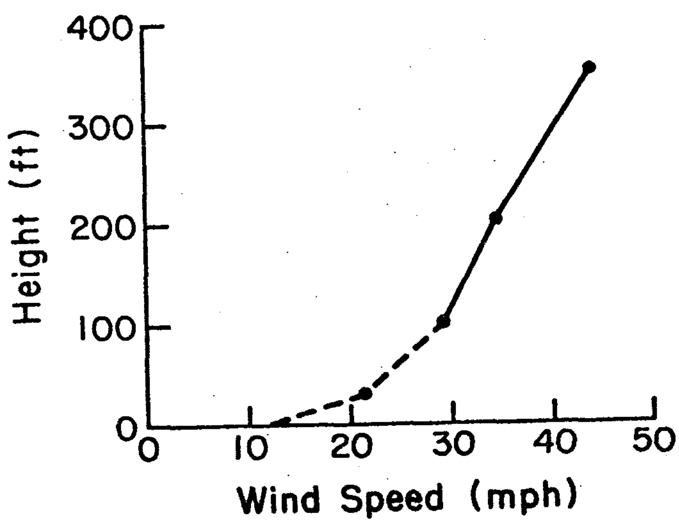

FIGURE 2.1.2: Mean north wind profile over the tip of Cape Blanco. The dashed line is an estimated curve.

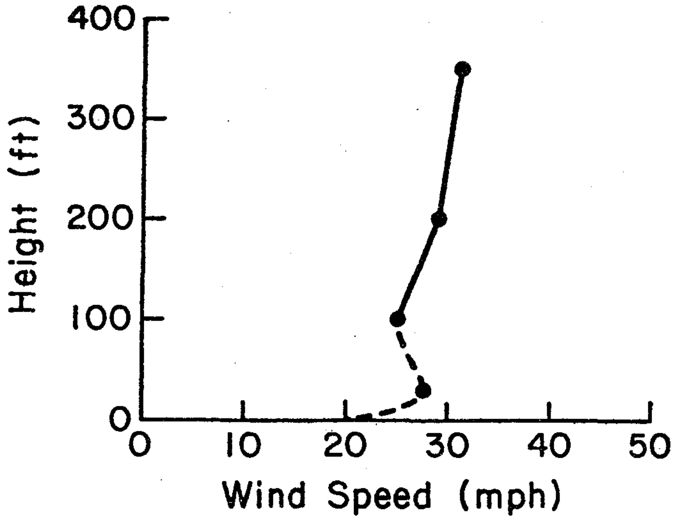

FIGURE 2.1.3: Mean wind profile under south wind over the tip of the Cape. The dashed line is an estimated curve.

2.2 JUNIPER POINT AREA WIND FLOW STUDIES

Over the last one and one-half years, simultaneous spatial observations have been made with kite anemometers during thirty-five different time periods in the Juniper Point area. Data from four fixed anemometer sites have been used in conjunction with the kite anemometer data to present our current understanding of the temporal and spatial extent of the wind resource in the Juniper Point area. Our results, however, are limited by the temporal resolution of our data. Figure 2.2.1 shows the locations of the various sites in the Juniper Point area. Wind speed ratios, r_i (≡ wind speed at any site i/wind speed at site D) and wind direction deviations, ΔWD_i (≡ WD at any site i - WD at site D) were computed for all sites.

Site H is located in the Klickitat Valley at the base of Juniper Point, upwind of the ridge for northwesterly winds (the prevailing wind direction). The average wind speed ratio using the data from the 40 ft. anemometer at site H is given by $\bar{r}_H$. Diurnal and seasonal variations of $\bar{r}_H$, shown in Figure 2.2.2, reveal the existence of two distinct wind regimes in the Juniper Point area during the spring, summer, and fall seasons. The daytime wind regime is probably due to the reasonably good vertical mixing that occurs during this time. Due to this vertical mixing, wind speed ratios within the Klickitat Valley are fairly high. The values of $\bar{r}_H$ (at the 40 ft. level) are consistently 0.75 during this regime. Slightly higher wind speed ratios were observed at the 200 ft. level at sites within the Klickitat Valley using kite anemometer data. This daytime wind regime occurs for about 7 hours per day in the spring, 9 hours per day in the summer, and 5 hours per day in the fall.

The nocturnal wind regime is most likely due to the growth of a stable nocturnal boundary layer. Low wind speeds are observed at site H in the Klickitat Valley, within the nocturnal boundary layer, while wind speeds at site D at the top of the ridge reach their higher diurnal values during the early evening and nighttime. This results in very low wind speed ratios of 0.25-0.30 at site H. The duration of this nocturnal wind regime at site H is about 11 hours per day in the spring, 9 hours per day in the summer, and 13 hours per day in the fall. Each of the transitional periods between the day-time wind regime and the nocturnal wind regime lasts about 3 hours. The quantification of the duration times within each wind regime for sites on the slopes of Juniper Point is crucial for determining the spatial extent of the wind resource on Juniper Point during these three seasons.

In winter, the diurnal pattern of $\bar{r}_H$ shows much less difference between daytime and nighttime than during the other seasons. The wind speed ratios are nearly constant, with night time values of about 0.3 and daytime values approaching 0.55. Since low-level cold air inversions are probably quite common and may occur during daytime hours as well as during the night, the low daytime values of $\bar{r}_H$ during the wintertime may be due to the decoupling of the airflow at low levels in the Klickitat Valley from that near the ridgetops.

Spatial kite-anemometer data from March 27, 1980 to August 25, 1981, were used to deduce the detailed spatial distribution of the wind speeds and wind directions during the daytime wind regime. The average wind speed ratios were filtered using statistical confidence criteria, and the data were divided into two wind direction categories. Most of the data were for the case of northwesterly winds, the most prevalent wind direction in the area. The average wind speed ratios at 200 ft. ranged from 0.73 to 1.02 under north-

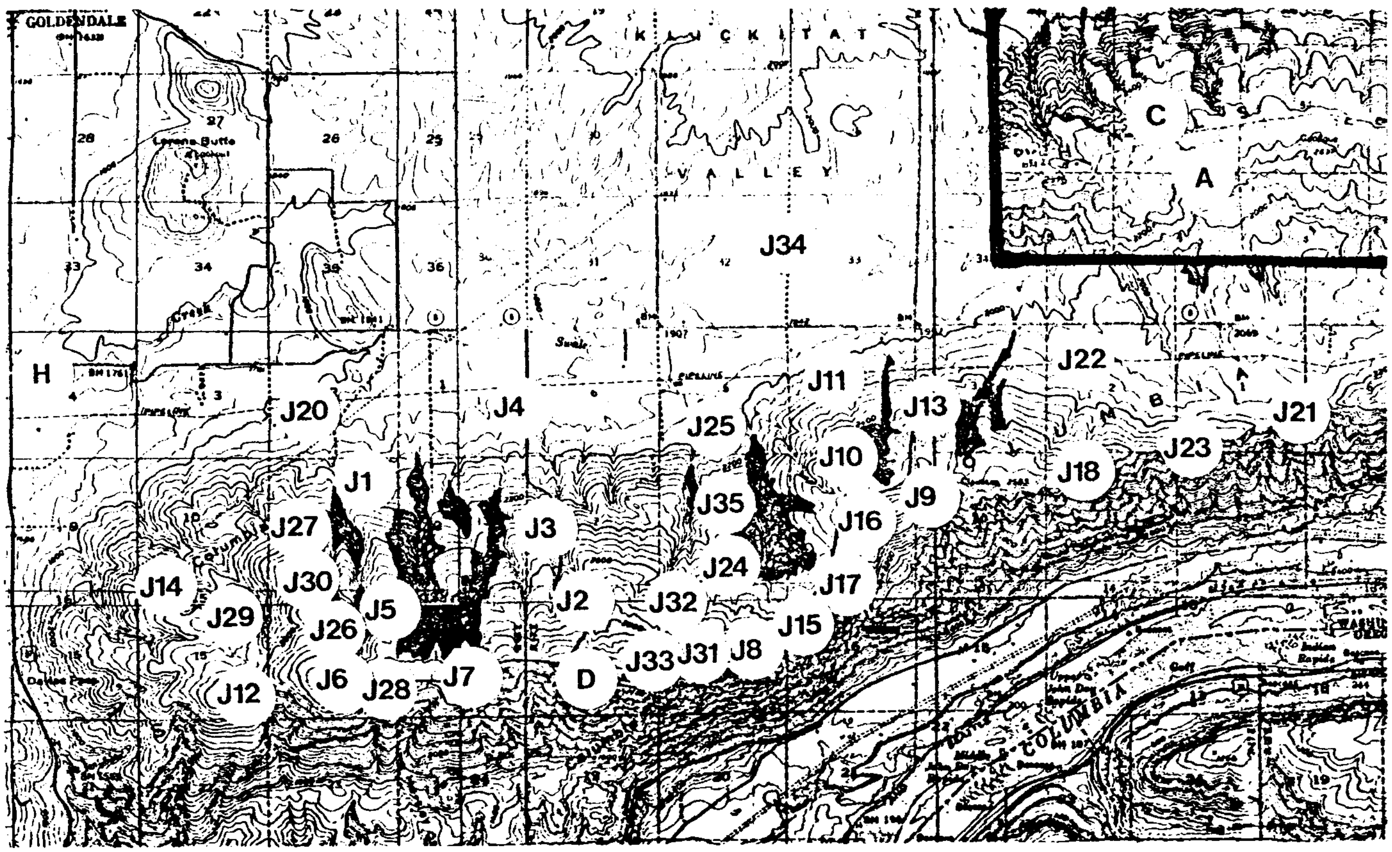

FIGURE 2.2.1: The locations of the fixed anemometer sites (single letter sites) and the kite anemometer sites (numbered sites) used in the Juniper Point spatial surveys. The Goodnoe Hills anemometer sites located east of the Juniper Point area are shown in the inset.

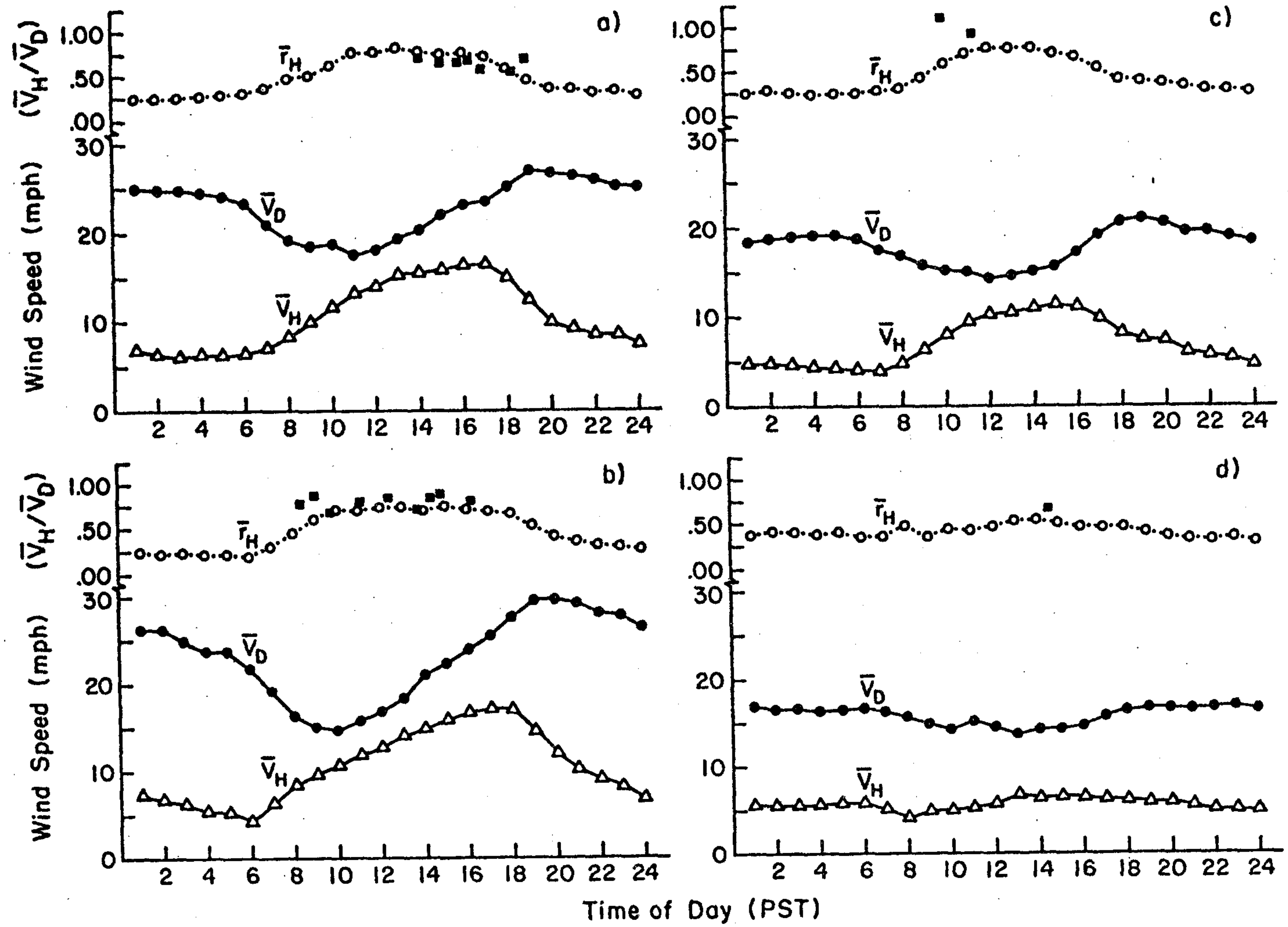

FIGURE 2.2.2: Diurnal variations of $\overline{r}^*_H[=\overline{V_H/V_D}^*]$ (o), $\overline{V}^*_D$ (•), and $\overline{V}^*_H$ (Δ) averaged for the seasons a) spring (March-May), b) summer (June-Aug.), c) fall (Sept.-Nov.), and d) winter (Dec.-Feb.). Values of r_H for the times of the spatial observations are plotted (■).

westerly winds. The lowest wind speed ratios were observed near the base of the ridge, while slightly higher ratios were observed on the flatter terrain away from the ridge in the Klickitat Valley. The highest wind speed ratios were observed along the ridgecrest. The low wind speed ratios near the base of the ridge may be due to the "stagnation effect," caused by higher pressure near the base of the ridge on the upwind side. This phenomena has also been noted by Mason and Sykes (1979). Some channeling of the wind along the contours of the ridge was noted from the wind direction data.

2.3 GOODNOE HILLS AREA WIND FLOW STUDIES

Introduction

Beginning in January, 1981, numerous spatial wind distribution surveys were conducted in the Goodnoe Hills area. The procedures for these surveys were very similar to those for the Juniper Point area. The site locations are shown in Figure 2.3.1. Fixed anemometer sites are designated as for the Juniper Point area survey. For the Goodnoe Hills area surveys, the base point anemometer, to which the data were related, was located at the 195 ft. level on the BPA tower at site C. Fifteen different kite anemometer sites were also used, including five sites south of the Columbia River.

Our data appear to substantiate the separation of the Goodnoe Hills survey area into three geographical areas. These areas are: 1) the western end of the Goodnoe Hills ridge (sites G1, G2, A, C) situated at 2300-2600 ft. MSL, 2) the eastern end of the Goodnoe Hills ridge (sites G4, G5, G6, G8), situated at 2300-2500 ft. MSL, and 3) the rolling, lower elevation farmlands south of the Goodnoe Hills ridge, including the area just south of the Columbia River (sites G12-G14, R1-R5). Area 3 is at about 1200-1400 ft. MSL, approximately 1000-1200 ft. above the level of the Columbia River. Site G3, situated at the highest point on the Goodnoe Hills ridge (2700 ft.), appears to be a "border" site between areas 1 and 2. Sites in areas 1 and 2 will be referred to as the western and the eastern ridge sites, respectively, while sites in area 3 will be referred to as lower elevation sites. Site D on Juniper Point will be grouped with the western ridge sites, since the wind characteristics at this site are fairly similar to those at the western ridge sites. However, since this site is fairly far removed from the Goodnoe Hills area, data from site D will not be emphasized in the discussions.

The initial analysis of the Goodnoe Hills spatial surveys was similar to the analysis of the Juniper Point spatial surveys. Wind speed ratios, r_i, and wind direction deviations, ΔWD_i, for any site i, were computed. However, daily averaged wind speed ratios, $\bar{r}_i^D$, were computed, since large day-to-day variations in the wind speed ratios were noted. These day-to-day variations in $\bar{r}_i^D$ were similar in magnitude and sign for sites within the same geographical region, but generally differed from region to region. The variations were quite large at the lower elevation sites, where the

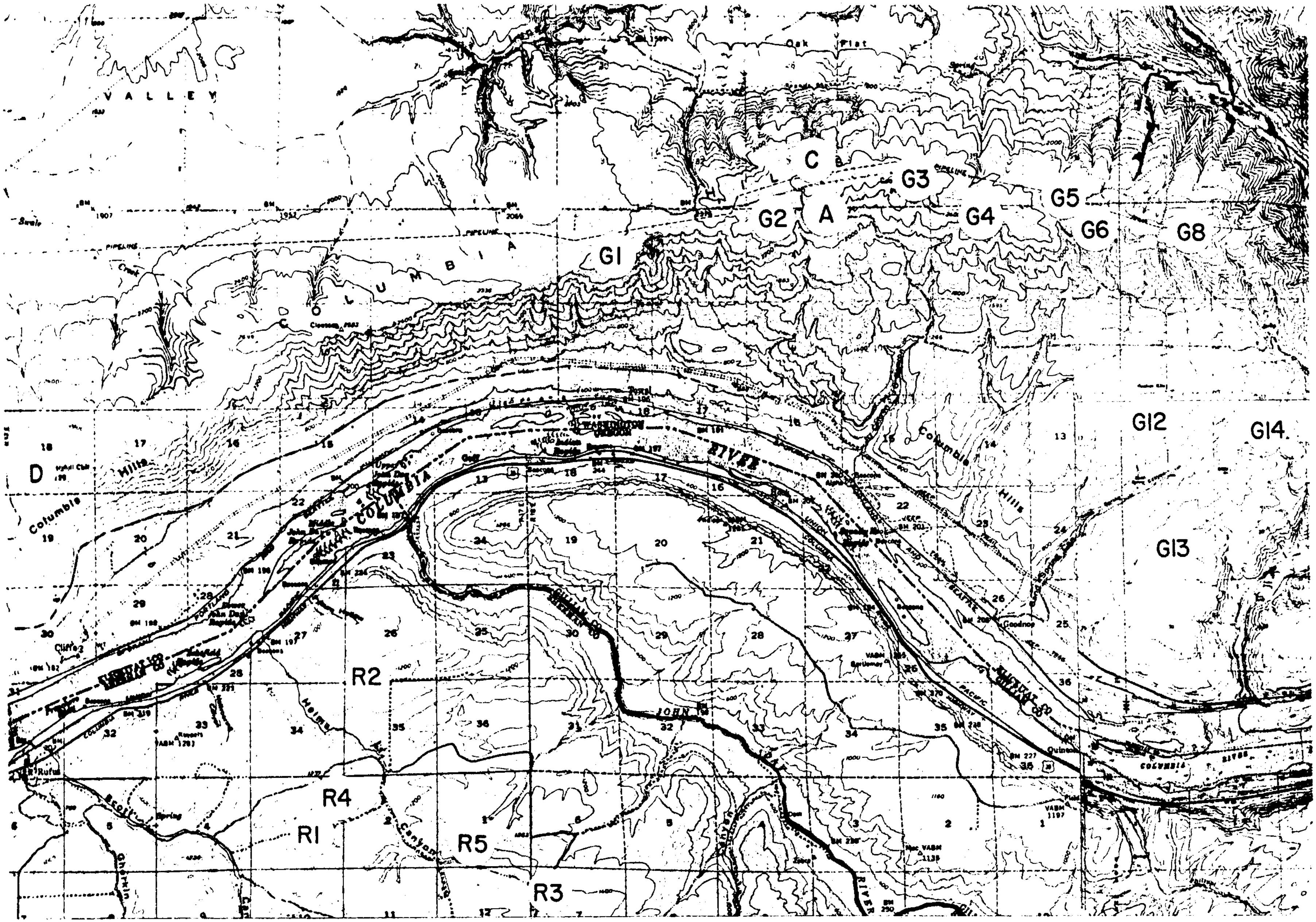

FIGURE 2.3.1: Fixed anemometer sites (single letter sites) and kite anemometer sites in the Goodnoe Hills area.

values of $\overline{r}_i^D$ appeared to group themselves into three categories of three days each. The average wind speed ratios at the lower elevation sites for these categories ranged ~0.6-0.8 for category 1, ~1.0-1.1 for category 2, and ~1.1-1.4 for category 3. It is suggested that these categories are related to stability, where conditions of no vertical mixing is associated with low wind speed ratios at the lower elevation sites, weak vertical mixing is associated with moderate wind speed ratios at these sites, and strong vertical mixing is associated with large wind speed ratios at these sites. A qualitative assessment of the atmospheric stability during these nine days appears to support this suggestion. However, quantitative temperature data are needed for actual verification. Assuming that it is justified to relate the $\overline{r}_i^D$ categories to atmospheric stability, the variations of the average wind speed ratios at different sites and different geographical areas with stability is shown in Figure 2.3.2. One can see that large variations occur for the lower elevation sites, while the other two geographical areas, especially the western ridge sites, show much less variation.

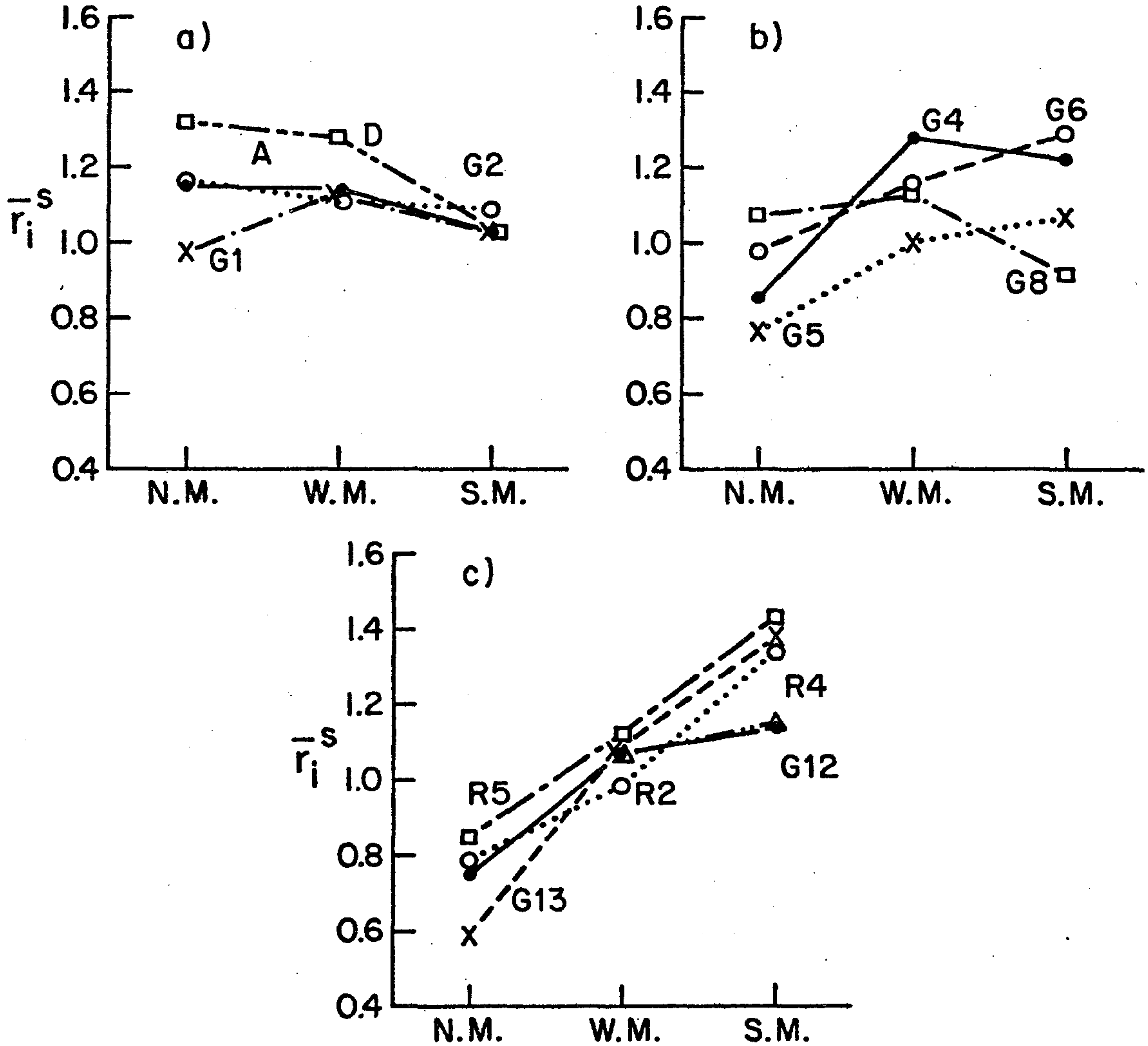

FIGURE 2.3.2:Average wind speed ratios, $\bar{r}_i^s$, as a function of the stability classifications for (a) western ridge sites, (b) eastern ridge sites, and (c) lower elevation sites. Stability categories of no vertical mixing (N.M.), weak vertical mixing (W.M.), and strong vertical mixing (S.M.) are used.

3.0 GOODNOE HILLS MOD-2 WAKE STUDIES

Introduction

It is forseen that large megawatt-size wind turbine generators (WTG) will be grouped in arrays or clusters at high wind sites. Each array may contain a few to possibly hundreds of WTGs. The capacity or number of WTGs at each wind farm will in part be governed by the spatial extent of the strong wind flow, the spacing of the WTGs and land area availability. The following discussion addresses WTG spacing.

There has been a considerable amount of work on wind turbine wakes and cluster design using numerical and physical modeling. Of the numerical models developed, Lissaman's model appears to be the most widely used (Lissaman, 1977, and Walker and Lissaman, 1978).

Until recently there has been little work done in taking physical measurements of the wind flow around an operational WTG. Lockheed has performed wake studies around the Clayton 200 kW WTG using the laser dopplar radar, but due to instrument and field problems there were no conclusive results. In March 1980 three scientists from Oregon State University used kite anemometers to take wake measurements around the Clayton WTG. The study which is described in the OSU report to BPA titled "Wind Flow Study Around the Clayton, New Mexico 200 kw Wind Turbine Generator" indicated that beyond 5 diameters downwind of the operating WTG the wake velocity deficit measured at the hub height was generally less than 10% for most of the eleven runs. The deficits at 3-5 diameters downwind were 15-20%. For the limited amount of data taken the deficits appear reasonable and approximate the wake model results of Aerovironments, Inc. (personal communication with Dr. Stel Walker). Lateral spatial measurements were also made 1.5 diameters behind the WTG at the 100 and 150-ft level. The wind speeds were about 20% stronger at the edge of the wake than directly behind the WTG and the flow outside the wake was slightly less than that measured at the edge of the wake. Also, the turbulence in the wake was generally not high except below the 100-ft level where it was very difficult to fly the kite anemometer in the large rolling vortices coming off of the rotor.

Proposed Goodnoe Hills Program

With the encouraging results from the Clayton study,it was proposed to take wake measurements using kite anemometers at the Goodnoe Hills MOD-2 site in FY81. The objectives of this work were two-fold; first, to take measurements to define the wake, and second, to verify Aerovironment's wake model which has not yet been verified in simple terrain. However, with the shutdown of the three MOD-2 WTG's in June 1980, because of mechanical problems, the field testing was temporarily cancelled. These studies are now being planned to take place in the spring and summer of 1982. An outline of the study program follows.

The three 2.5 MW WTG's that have a 300 ft. blade diameter are positioned in a triangular pattern as noted in Figure 3.0.1. This pattern was selected in order to measure the direct affect of the wake of the upwind WTG on that of the downwind unit under prevailing flow directions. The spacing is 5, 7, and 10 diameters (D). The BPA 195 ft. meteorological tower, instrumented with wind speed and direction sensors at the 50 ft. and 195 ft. levels, is located between WTG 2 and 3. The DOE (Project) 350 ft. meteorological tower, instrumented at the 33, 50, 200, and 350 ft. levels is located near WTG 1. The WTG cluster is located on a crest of a long east/west ridge. The elevation of WTG 1 is 2622 ft., WTG 2 is at 2573 ft., and WTG 3 is at 2566 ft. It is proposed to take measurements around WTG 1 or 3 since terrain is relatively smooth and there are few obstructions such as buildings or power lines upwind and downwind of these two WTG's. There is a large gully east of WTG 2, as well as the BPA substation which severely limits measurements downwind of this unit.

Because of the steeply sloping topography downwind northeast and southeast of WTG 1 and 3, measurements will only be taken when the wind direction at hub height is from 240-280 degrees. The wind data indicate that the majority of the power producing winds are from this sector. Measurements will be taken using 6-8 kite anemometers flown simultaneously. Hub height (200 ft.) measurements will be taken approximately two diameters (600 ft.) upwind of WTG 1 or 3 to measure the ambient flow into the WTG. Simultaneous hub height measurements will be taken downwind at 3, 5, 7, and 9D. Also, measurements will be taken at hub height laterally across the wake at 3, 5, 7, or 9D to measure the spreading of the wake. Profile measurements flying three kites simultaneously at the 50, 200, and 350 ft. levels up and downwind of the WTG are also planned. These measurements

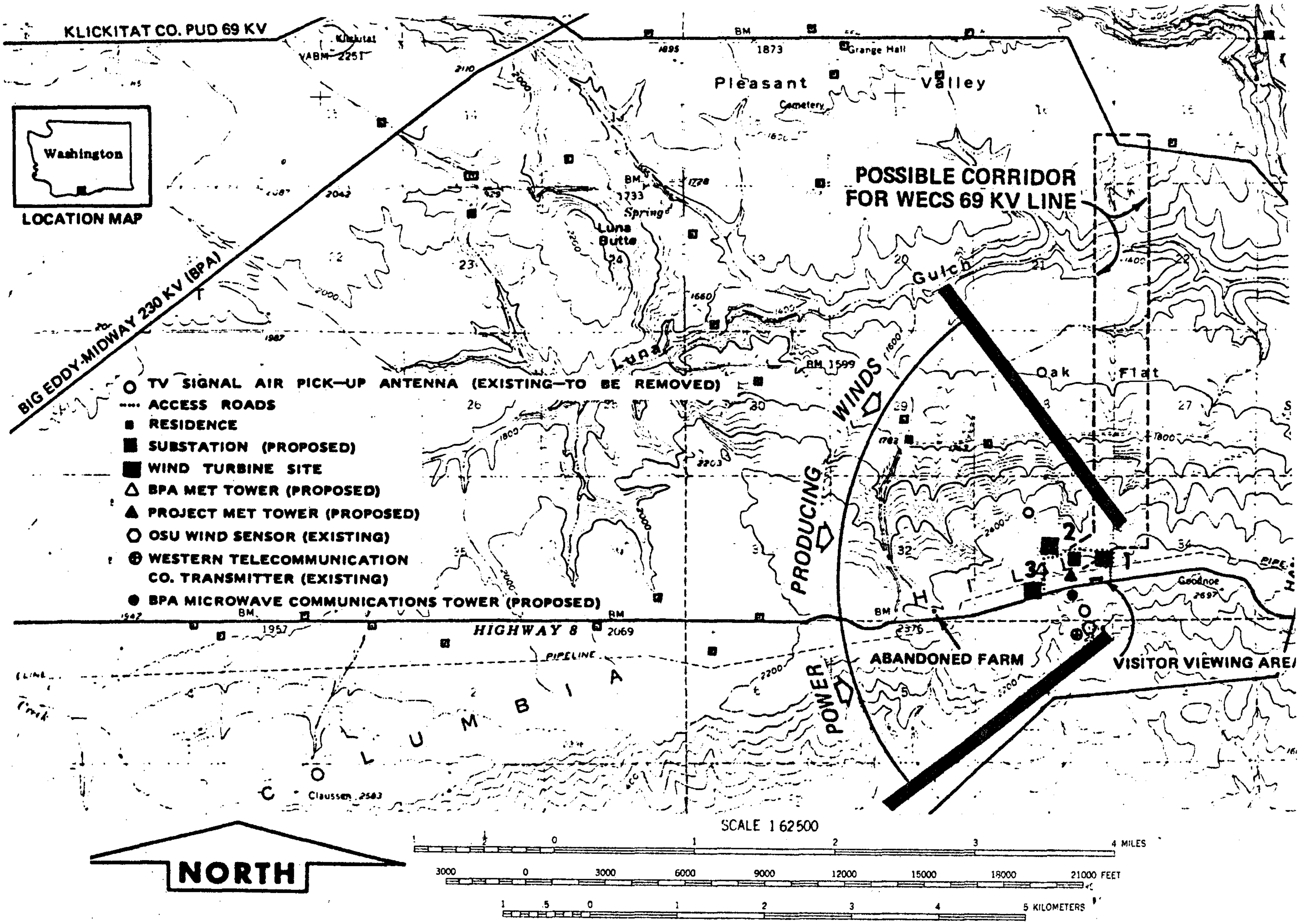

FIGURE 3.0.1: MOD-2 WTG layout at Goodnoe Hills.

will be made for a 15-20 minute period while the WTG is operating and then while it is shut down. Wind speed differences between the kite anemometers in operating and non-operating conditions will reveal the velocity deficits downwind of the turbine. These measurements will be made under daytime and nighttime flow conditions as the ambient stability is a critical governor of the downwind wake structure and persistence.

The measured data will be analyzed along with the wind data taken at both meteorological towers and the machine data taken from the WTG. Also a UVW anemometer will be installed on either the BPA or DOE towers to measure the ambient turbulence level. The field data will be compared to wake model predictions.

Further work will also be done to develop an array computer model using the basic elements of a refined discrete wake model. This model will estimate the array interactive performance. While the proposed computer model will have limitations, such as level terrain conditions, uniform wind field, etc., it will yield important insight as to WTG layout at specific sites.

4.0 A METHODOLOGY FOR SAMPLING THE WIND FLOW USING A KITE ANEMOMETER

Over the past three years the TALA Kite has been used extensively by OSU in defining wind characteristics throughout the BPA service area. These portable anemometers have provided information on wind speed change with height, degree of gustiness, spatial variation of the wind flow and have been used to measure wind speed deficits in the wake of a large horizontal axis wind turbine.

During this contract period,detailed statistical analyses of TALA Kite data were undertaken to test and refine our methodology for using kite anemometers. The statistical analysis had two objectives. The first was to establish the validity of the kite anemometer data and relate the kites accuracy and precision to that of tower mounted anemometers. The second objective was to determine an optimum sampling strategy in terms of measurement interval and frequency of measurements in which both bias and precision errors were minimized.

The results indicated a mean bias error for 2430 speed observations of +0.25 mph which means that the kites read slightly higher than the tower anemometers. For 2050 direction observations the mean direction error was 4 degrees.

The results also indicated that precision errors decrease with longer sampling period and with higher frequency sampling intervals. Sampling period was found to have the most significant effect on precision error. The results indicated that one is better off taking samples every 20 seconds over a 30-minute period than taking samples every 10 seconds over a 15-minute period. Precision error is directly related to the standard deviation of the parameter and inversly-related to the square root of the number of samples. So if in turbulent wind conditions the standard deviation of the wind speed is twice as large as a less turbulent situation, one would have to collect about 4 times as many observations to achieve the same level of precision errors.

We also found that precision errors for both kite and tower mounted anemometers are similar and that although precision errors were smaller at the lowest level tested (50 ft.), the error as a percent of the speeds measured was constant at both the 50 ft. and 195 ft. levels. These results indicate that the height of measurement has no real effect on the precision of measurement.

The total error in mean wind statistics is composed of both the precision error and the bias error and was found to be 0.6 mph for speed and 1.1° for direction. These errors are close to those generally recommended for anemometers in atmospheric diffusion studies (Hoffnagle _et al._, 1981). Based on these promising results further work should continue on development of a methodology for relating the variation of speed, direction and altitude of the kite to the u, v and w components of turbulence. This information would be useful in characterizing the degree of thermal turbulence or mixing in the atmosphere, as well as provide empirical data to parameterize wake models currently under testing and development at OSU.