A HIERARCHICAL APPROACH TO WIND POWER
POTENTIAL EVALUATION AT PRAIRIE
PEAK, OREGON

by

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A RESEARCH PAPER
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ABSTRACT

A hierarchical approach to the assessment of wind power site potential at Prairie Peak, Oregon, is evaluated. Maps, aerial photographs, and terrestrial photographs are utilized. Data are derived from photographs of wind flagged trees with the aid of an interactive computer program. The technique produces a map of isotachs, lines of equal wind speed, with the aid of the SYMAP computer mapping program. The technique is found useful as a preliminary estimator of site potential. The density of data points appears to be the limiting factor in the accuracy of the approach.

INTRODUCTION

Problem Statement

Prospecting for suitable wind power generation sites requires that large areas be assessed quickly and economically to locate sites of high potential for further analysis and instrumentation. Critical to any primary wind resource evaluation is a means of gaining a quantitative understanding of the general local wind field with respect to mean velocity and direction. Specifically, a representation of wind speed variation over terrain features is considered an essential data requirement.

Objective

The research objective of this study is to assess the use of a hierarchical wind power prospecting technique. This assessment will
evaluate the following components:

1. Analysis of small and large scale maps;
2. Acquisition and analysis of aerial and terrestrial photographs of wind-deformed vegetation;
3. Employment of computer assisted analysis and mapping techniques.

Background Information

Wind power data requirements. Ideally, a site evaluation of wind power potential should involve detailed instrumentation to determine wind velocities throughout various levels of the air column. Such instrumentation would include pressure and temperature gradient analyses and wind direction analysis. Hewson (1975) notes that the minimum requirement for any site is a program of such measurements at heights of 9.1 m and 30 m. Such measurements should cover a period of at least one year and ideally two years. Such short term data should then be compared to long term climatological data to ascertain that the measurements reflect the long run nature of the site.

Measurements of this type involve a substantial investment in time and capital. Sites chosen for such analysis should be put through a preliminary assessment procedure that enables wind researchers to eliminate sites with low potential and concentrate efforts on those sites with the greatest promise.

The importance of accuracy in measurement is emphasized by the fact that the power available from the wind is proportional to the cube of the velocity. Therefore, an error of two miles per hour in wind speed estimation involves an eight-fold error in power estimation. The site
specific nature of wind speed variability requires that the resolution of any prospecting technique be fine enough so points of high velocity are detectable to insure maximum power production.

Ideally, velocity and direction data would be presently available from the large number of weather stations scattered across the United States and Canada. With the exception of a very few stations located in remote areas for research purposes, most are located at airports or near population centers. Airports are rarely located in areas of high winds due to their detrimental effect on aviation. Coty (1976) finds a negative correlation exists between population and high winds. This implies that people tend to settle where wind power potential is low, and that some means of obtaining preliminary wind data without the use of extensive instrumentation is required.

Applicability of wind flagged trees as power potential indicators. The use of trees as indicators of wind power potential is well supported by research concerning the response of vegetation to the effects of the wind (Putnam, 1948; Thomas, 1958; Yoshino, 1973). While most vegetation responds immediately to the wind by bending to absorb energy, many trees and shrubs exhibit long term, permanent effects. Wade and Hewson (1979) divide these effects into several categories:

1. **Mechanical damage** - This includes breakage of branches and leaves, abrasion, and defoliation. These are most often the result of strong persistent winds or short term severe winds as well as from ice particles or other abrasives entrained in the air.
2. **Physiological responses** - These include stomatal closure and the production of hormones and generally occur as a result of wind stress during the growing season. Such responses may have long-term significance as they can lead to internal metabolic conditions which can later affect the growth of the tree.

3. **Anatomical changes** - These include changes in the cell structure such as that found when trees exposed to strong winds develop eccentric radial growth in the lower trunk.

4. **Morphological changes** - These are most apparent in the deformation of the crown from the normally symmetric shape to an asymmetrical banner shape often referred to as flagging. Flagged trees of many species have been studied by a number of investigators (Holroyd, 1970; Lovelius, 1973).

Considerable attention has been given to the latter of these changes, flagging, and its relationship to wind direction and velocity. Wade and Hewson (1979) report, "...our studies of over 20 different species of wind deformed trees at 40 locations having a year or more of wind data indicate the trees are flagged downwind from the prevailing wind direction." They also report their development of several indices of wind speed based upon crown deformation which were calibrated for two widely distributed conifer species: Douglas fir (*Pseudotsuga menziesii*) and Ponderosa pine (*Pinus ponderosa*). These indices are the Griggs-Putnam Index (GPI) and the Deformation Ratio (D). The GPI is a subjective scale based on the degree of deformation of the tree by the wind (Fig. 1). This index is subject to an error of as great as 40 percent, however, due to over or under estimation by the interpreter. The Deformation
Fig. 1. Griggs-Putnam index scale.

\[ D = \frac{a}{\beta} \cdot \frac{Y}{45} \]

Fig. 2. Deformation ratio illustration.
Ratio provides a less subjective means of assessing the degree of deformation through the calculation of the amount of crown asymmetry and deflection of the trunk from the vertical. The value of D is given by:

$$D = \alpha / \beta + \gamma / 45^\circ$$

where $\alpha$ is the angle between the crown and stem on the leeward side, $\beta$ is the comparable angle on the windward side, and $\gamma$ is the angle between the trunk and true vertical (Fig. 2). This index was developed by making the above angular measurements from photographs taken at ground level from a position normal to the direction of prevailing wind as indicated by the flagging. D has been shown to be well correlated with mean annual wind speed. The relationship between the Deformation Ratio and mean annual wind speed is given by:

$$\bar{V} = 0.95 D + 2.3$$

where $\bar{V}$ is the mean annual wind speed in meters per second and D is the Deformation Ratio. Further research is currently underway to calibrate additional conifer species and to include deciduous trees as indicators of mean annual wind speed and direction.

Substantial evidence exists to support the notion that the data derived from wind flagged trees are sufficient to make first stage evaluations of wind power sites. Mean velocity has been shown to be a sufficient parameter for the estimation of wind power feasibility by Widger (1976) who reports wind power estimates accurate to within at least $\pm 20$ percent utilizing that parameter.
An interesting relationship exists between the velocity response range of the target trees and the velocity operation range of state of the art wind turbine generators. Baker, Hewson and Wade (1979) report that, in general, winds below 3 meters per second are not used by wind power generators. Similarly, light winds have little effect on trees. Conversely, high winds may temporarily damage trees but usually have little permanent effect on their shape. Such high winds, usually above 27 meters per second, are also likely to damage wind turbines which are designed to feather, or shut down, at such velocities. It follows that those winds that leave a permanent record in trees are the very winds being sought by wind power prospectors.

Because trees respond to winds of a persistent and prevailing nature by flagging, they also serve to indicate the suitability of a given site to particular designs of wind generators. Turbines of the horizontal axis design are particularly vulnerable to frequent shifts in wind direction. With each substantial change in direction the heading of the axis must be adjusted which involves a loss of generating capability. Sites which exhibit consistent prevailing winds are best suited to this design type. Vertical axis generators are not hampered by such constraints, but presently exhibit less efficiency and greater startup velocities than horizontal axis types.

RESEARCH PROCEDURE

Study Site

Physical setting. The area chosen for this study is Prairie Peak, located approximately 30 miles (48 km) SW of Corvallis in the Oregon
Coast Range (Fig. 3). Prairie Peak consists of a resistant volcanic dike flanked by less resistant sedimentary materials. The 3400 ft (1036 m) ridge trends E-W with a gently sloping south side and a steep north exposure of approximately twice the slope of the south.

Land use and management. The area is entirely under the management of the U.S. Department of the Interior, Bureau of Land Management (BLM). Initial research of topographic and cadastral maps indicated good road access to the site. These roads are maintained to provide for routine maintenance of several telecommunications towers in place along the ridge.

Douglas Fir (*Pseudotsuga menziesii*) is the dominant tree species on the site. Also present on the lower slopes are Mountain Hemlock (*Tsuga mertensiana*) and Pacific Red Alder (*Alnus rubra*). Numerous clearcuts exist to expose trees to prevailing winds. A large portion of the upper ridge is a grassy bald with trees present as isolated individuals or small clusters. Watering troughs and remnants of fencing indicate a past history of seasonal grazing in the bald areas. No evidence was found to indicate such use is current.

Available data. The site has been instrumented with a contact anemometer by the Wind Power Study Group of the Department of Atmospheric Sciences at Oregon State University. The available data consist of 6643 observations over a period of one year. They have been condensed to provide the following: (Table 1)

1. Mean wind speed for each of 16 compass directions corresponding to every 22.5°.
Fig. 3. Study site location.
Table 1. Anemometer data at Prairie Peak.

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2. Frequency of occurrence of wind from each of the 16 directions.
3. Frequency of wind in each of 17 speed categories.

Data Acquisition

The data acquisition phase of this research was subdivided into four discrete stages in a hierarchical arrangement. These stages progressed from regional analysis of available mapped data through aerial reconnaissance to ground sampling.

Stage I. Examination of topographic maps and maps of the general circulation patterns was undertaken. This analysis indicated that the study site was well exposed to prevailing winds in all seasons. Consultation of generalized wind power potential maps compiled by Baker, et al. (1978) was also undertaken. These maps revealed that the study site was among areas considered to have "moderate-high" power density (expressed in watts/meter²) for the winter months and "moderate" power density for the remaining months.

Stage II. Preliminary aerial reconnaissance was undertaken utilizing two types of light aircraft. In the first instance, a light helicopter was flown directly to the study site and landed on the ridge summit. Use of this type of aircraft enabled the researcher to acquire low altitude vertical aerial photographs and ground samples of vegetation to verify the existence of target species.

For purposes of comparison, similar reconnaissance was undertaken with a light fixed wing aircraft. Landing was not possible with this type of aircraft, but similar flight lines were flown. The flight lines
paralleled the ridge line on the north and south sides. Flights were flown at an altitude of approximately 4000 ft. (1219 m.) to provide a nearly horizontal view of ridge top trees. All flights were flown during periods of calm to avoid introducing additional tree deformation. Photographs were acquired with a hand-held 35 mm camera equipped with a 300 mm telephoto lens. Panchromatic black and white film was used for all photographs in this stage.

Qualitative analysis of the photographs acquired during this stage revealed extensive flagging of the ridge top trees along the entire length of the ridge. Quantitative data were not extracted from the photographs acquired during this stage as views normal to the prevailing wind direction could not be guaranteed.

Stage III. Completion of the first two stages of evaluation indicated that further analysis was warranted. Ground studies were undertaken to assess the response of trees in the immediate vicinity of the anemometer site. Terrestrial photos of 14 trees were acquired from within an area surrounding the anemometer mast. A hand-held 35 mm camera with 50 mm lens was utilized in this stage. A spirit level was mounted on the back of the camera to allow for inference of true vertical from the edge of the film frame. Trees were scaled by the ocular method.

The location of each sample relative to the anemometer mast was determined by taking azimuths with a Brunton compass and pacing the distance. The sample locations were then mapped (Fig. 4).
Fig. 4. Anemometer site flagged tree locations.
Stage IV. In the final stage of this procedure, a full scale sampling effort was undertaken. Selection of the sampling procedure involved the consideration of a number of limiting criteria. These criteria are related to the interpretability of the photographs acquired. Among the limiting factors are:

1. Visible flagging - The windward and leeward sides of each tree must be differentiated during the quantitative analysis. As the photographs must be acquired from a position normal to the prevailing wind direction as indicated by the flagging, this direction must be apparent to the photographer in the field.

2. Photographable position - The entire tree, from ground level to the topmost branch, must be visible from the normal position. No obstacles may exist between the target tree and photo acquisition site.

3. Visibility and accessibility - The tree and photo site must both be accessible by the researcher following a point to point transect line. This criterion selects against trees on the "far side" of stands, and trees not visible from the preceding sample point. Trees located on very steep slopes or other similarly inaccessible sites were also not sampled.

It was not possible to establish a purely random sampling technique once the limitations outlined above were fully considered. Some adjustments to established sampling techniques were utilized to support the validity of statistical relationships developed later in this study. A line census technique developed for sampling African wildlife (Matzke, 1976) was modified to fit the unique sampling situation encountered at
Prairie Peak. In the Matzke study, a variable width cell was utilized to reflect the change in distance that it was possible to see. At Prairie Peak a parallel situation was observed. In this case, varying densities of stands were encountered. As transects were run from the top of the ridge, the distance between each successive sample was adjusted to reflect that density. The more dense the stand, the more frequent the samples, and vice versa. The lateral distance from the transect line to each sample was also affected in a like manner. Where target trees were plentiful the transect ran essentially linearly. Where fewer target trees were available, the sample area was expanded laterally. This stratification accounts for the non-linear appearance of many of the transects.

At each sample point the following data were acquired:

1. Photograph of the entire tree - This image was acquired with a hand-held 35 mm camera equipped with a 50 mm lens from a position normal to the prevailing wind direction.

2. True vertical and scale - These data were determined by having an assistant stand to one side of the tree holding a graduated seven ft. staff with spirit level attached.

3. Elevation - This was determined with a field altimeter calibrated to benchmarks or other reference points of known elevation.

4. Temperature - A Centigrade thermometer was hung in the tree near ground level and the temperature recorded. (These data were acquired to make altimeter corrections. These corrections
were later found to be unnecessary as barometric conditions remained very stable during the sampling periods.)

5. Direction of flagging - This was determined by aligning the compass with the most elongated branches.

6. Slope - The slope at each sample tree was determined with a field clinometer. The slope was measured over a distance of approximately 10 m along the slope above and below the tree.

7. Aspect - This was determined with the Brunton compass.

The sampling procedure was divided over eight transects. A total of 45 trees were sampled.

Data Analysis

Determination of mean wind velocities. All of the photographs were analyzed in a like manner. An interactive program, developed by Dr. Jon Kimerling of the Department of Geography, Oregon State University, was utilized. This program makes use of a Tektronix Graphics Terminal and SAC sonic digitizer. The program serves to calculate the trigonometric relationships required to determine the Deformation Ratio. The sonic digitizer is employed to provide accurate x,y coordinates for the following points on the photograph: top of tree; bottom of tree; most windward branch of the top one-third of the tree; the most leeward branch of the top one-third of the tree; and the top and bottom points of the true vertical. The program outputs a graphic representation of the tree, the value of the Deformation Ratio, and the mean wind velocity (Fig. 5). The results are displayed in Tables 2 and 3.
TREE SPECIES: DF #1

ALPHA: 49.6'
BETA:  33.8'
GAMMA: 9.8'

DEFORMATION RATIO: 1.7
ANNUAL MEAN WINDSPEED: 3.2 TO 4.6 METER/SEC

INDEX NUMBERS TO TAPE? (Y OR N)

Fig. 5. Example of graphic computer output.
Table 2
Calculated Velocities at Anemometer Site

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<th>Sample</th>
<th>Deformation Ratio (D)</th>
<th>Mean Velocity (meters per second)</th>
<th>Mean Velocity (mph)</th>
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Table 3
Calculated Velocities for Sample Points

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<td>Mean Velocity (mph)</td>
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Power law correction of calculated velocities. Once the indicated velocities were calculated for each tree they were adjusted from tree height to a standard reference height. This was accomplished through the use of the power law which is expressed as:

\[ V_b = V_a / (H_a / H_b)^p \]

where \( V_b \) is the velocity at tree height, \( V_a \) is the velocity at the reference height, \( H_a \) is the reference height, and \( H_b \) is the height of the tree, \( p \) is the Power Law coefficient. The value of \( p \) has been shown to vary widely with surface roughness and other variables (Irwin, 1979). Wade (1980) reports that a \( p \) value of 0.14 is best suited for use in areas of rough terrain. That value has been utilized for the power law corrections in this study.

The standard reference height employed in this analysis was 100 ft. (30.48 m). This value was chosen for two reasons. Firstly, the anemometer height at which the reference data was collected is 100 ft. (30.48 m). Comparison of the indicated velocities calculated from trees in the immediate vicinity of the anemometer was facilitated by standardizing them to this reference height. Secondly, the hub height of many state of the art wind generators is approximately this height. Adjustment of all data points to this height allows for ready analysis of wind speeds with reference to wind power potential. The adjusted wind velocities for both the anemometer site and entire study area are summarized in Table 4.
Table 4. Velocities adjusted from tree level to 100 ft.

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<th>Sample Tree</th>
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<th>V₁₀₀ (mph)</th>
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Comparison of calculated and known values. Only one point within the entire study area is represented by known wind speed values. This point is the anemometer site. Adjusted wind speeds calculated for trees in the immediate vicinity of the anemometer site were compared with the known wind speed for the site. All trees in the area were flagged from the SW. Consultation of the anemometer data indicates that the mean annual speed from the SW is 12.1 miles per hour. Analysis of the calculated values indicates that all but one are within a 90 percent accuracy range of the known value. Wade and Hewson (1979) report that anemometers are subject to an error of as great as ± 11 percent. It appears that the adjusted wind speeds are well within this range, and therefore accurately reflect the wind velocities to which the trees have been exposed. Inspection of the imagery revealed that the one outlying tree had an unusual shape which indicates the possibility of non-wind influences.

Analysis of sample point values. Statistical analysis of the data collected from the 45 sample points was restricted by the lack of known values against which to compare them. As indicated by the data in Table 1, the wind regime at the anemometer site is very complex. The directional data obtained from the flagged trees reflect that complexity (Fig. 6).

Development of a computer assisted map of isotachs, lines of equal wind speed, was undertaken to produce a graphic representation of the interaction between wind velocities and terrain features. This map was produced via the SYMAP program, developed by the Harvard University Laboratory for Computer Graphics and Spatial Analysis. Isotachs are produced by interpolating a continuous surface in the regions where
Fig. 6. Wind direction at Prairie Peak, Oregon.
there are no data points based upon the distances to and values of the neighboring points. By overlaying the computer assisted map onto the topographic map, a visual representation of the interaction between terrain features and wind velocities is developed (Fig. 7).

**Quantitative analysis of results.** As previously noted, the existence of only one point of known value (anemometer site) creates difficulty in attempting to analyze the resulting values in a quantitative fashion. General relationships between wind speed and terrain features have been previously researched (Frenkie, 1962; Holroyd, 1970). Slopes of the cross-sectional shape of the south exposure of Prairie Peak serve to accelerate upslope wind velocities much in the manner of the air flow over an aircraft wing. Regression analysis of the wind speed values against elevation was conducted. The resulting correlation coefficient \( r = +0.3829 \) was found significant at the .001 level (Fig. 8). The sample points appear to reflect the general upslope acceleration.

**Qualitative analysis of results.** Analysis of the map constructed from the SYMAP output allows identification of areas of high wind velocities and therefore high wind power potential. High wind velocities are depicted in areas where ridges are exposed to prevailing winds. The effect of funnelling through stream valleys is also evidenced.

**DISCUSSION AND CONCLUSIONS**

**Discussion of Results**

Quantitative and qualitative analysis of the results obtained during this study support the validity of the technique as a means of
Fig. 7. Isotachs at Prairie Peak, Oregon.

ISOTACHS AT PRAIRIE PEAK, OREGON
Contour Interval 50 Feet
Isotachs in Mph

l : < 8 mph
II : > 13 mph
Fig. 8. Scatter diagram: wind speed and elevation.
attaining a preliminary assessment of the wind power potential at a
given site. Due to the complex nature of wind fields in rough terrain,
it is difficult to assess the absolute accuracy of the final output
products. With reference to a first stage evaluation procedure, the
technique displays a number of advantages:

1. Speed - large areas can be assessed quickly by eliminating
   from consideration those which do not exhibit such basic cri-
teria as exposure to regional wind systems, etc.

2. Economy - The use of hand-held 35 mm photographic equipment
   and light aircraft allows the initial stages of evaluation
   to be undertaken with minimal funding. Such equipment is
   routinely available to the agencies and organizations most
   interested in such research. No detailed training of person-
   nel is required beyond basic photographic skills. Flight
   crews should be somewhat familiar with the special requirements
   of air photography acquisition missions.

3. Accuracy - Within the limits necessary to gain an understanding
   of the site potential, the technique exhibits good accuracy.
   It must be noted that final decisions concerning emplacement
   of wind turbine generating systems cannot and should not be
   made until a thorough instrumentation of the site indicates
   installation at the site to be cost effective. The extent of
   instrumentation required before this decision is reached is,
   of course, a function of the overall cost of the system being
   considered. In the case of large, 1-2 MW systems, such instru-
   mentation and further research should be extensive. On the
other hand, in the case of small capacity units, such wind
flagged trees should be sufficient to warrant installation.

Several limitations to the application of this technique should be
noted:

1. Site accessibility - The site under investigation must be
accessible to researchers during the ground sampling phase.
The absence of road access adds additional cost factors in
terms of time and money.

2. Existence of target vegetation - At present, this technique
requires the presence of Douglas Fir (Pseudotsuga menziesii)
or Ponderosa Pine (Pinus ponderosa) as indicator species.
Additional quantitative indexing of a broad range of species
must be accomplished before more extensive geographic utility
is possible.

3. Weather restrictions - The aerial and ground based stages of
evaluation are both restricted by local weather conditions.
Flight conditions must be clear and calm. Clarity is required
for acquisition of low level aerial photography and for visual
inspection of flagging. Calm is required for two reasons.
Firstly, trees must not be in the act of bending or swaying
in the wind at the time of imagery acquisition or deformation
will be over or under estimated. Secondly, as flights are
routinely flown at relatively low levels, windy conditions
present extreme low altitude turbulence which can endanger the
safety of the flight. These weather restrictions could easily
relegate the use of the technique to the more stable summer
months in the Pacific Northwest.
Conclusions

As evidenced by the map output, the resolution of the technique as applied in this study provides a basic understanding of the nature of the local wind regime. Increasing the density of data points would provide an even more detailed understanding of the situation. This could be accomplished by one of two approaches: (1) increased ground sampling, or (2) aerial acquisition of data point values. The former approach is not considered as a first choice as the increased time and effort involved would serve to negate the basic advantages of the technique. The latter approach seems the most likely to produce additional data within the cost and time constraints of preliminary surveys. However, additional photo interpretation techniques need development.

In its present state as applied in this study, the technique described presents a valuable tool in the process of prospecting for wind power sites. The actual applicability of the study site with reference to wind power production is not addressed, as such a consideration is outside the scope of this research. Additionally, such a question may not be answered without detailed knowledge of the design features of the particular wind turbine being considered.

Further research needs. The applicability and accuracy of this approach could be improved with additional research. Areas of particular interest would be the calibration of additional tree species; photogrammetric research covering the gathering of data from oblique and vertical photographs; and broadening the scope of coverage by including additional environmental indicators of wind power potential such as sand dunes, snow drifts, etc.


Wade, John E. Personal communication, 1980.

APPENDIX I

Graphic Analysis of Deformation

and Corresponding Photographs
TREE SPECIES: DF #1

ALPHA: 48.4'
BETA: 35.2'
GAMMA: 6.4'

DEFORMATION RATIO: 1.5

ANNUAL MEAN WINDSPEED: 3.1 TO 4.4 METER/SEC

INDEX NUMBERS TO TAPE? (Y OR N)
TREE SPECIES: C'F 0 2

ALPHA: 33.4°
BETA: 17.6°
GAMMA: 5.5°

DEFORMATION RATIO: 2.0

ANNUAL MEAN WINDSPEED: 3.5 TO 5.0 METER/SEC

INDEX NUMBERS TO TAPE? (Y OR N)
TREE SPECIES: DF 3

ALPHA: 48.0°
BETA: 38.8°
GAMMA: 2.5°

DEFORMATION RATIO: 1.3

ANNUAL MEAN WINDSPEED: 2.9 TO 4.2 METER/SEC

INDEX NUMBERS TO TAPE? (Y OR N)
TREE SPECIES: DF # 4

ALPHA: 36.2'
BETA: 26.1'
GAMMA: 2.7'

DEFORMATION RATIO: 1.4

ANNUAL MEAN WINDSPEED: 3.0 TO 4.3 METER/SEC

INDEX NUMBERS TO TAPE? (Y OR N)
TREE SPECIES: DF 05

\[ \begin{align*}
\text{ALPHA:} & \quad 31.8' \\
\text{BETA:} & \quad 26.7' \\
\text{GAMMA:} & \quad 3.4' \\
\end{align*} \]

DEFORMATION RATIO: 1.2

ANNUAL MEAN WINDSPEED: 2.9 to 4.1 METER/SEC

INDEX NUMBERS TO TAPE? (Y OR N)
TREE SPECIES: DF 06

ALPHA: 42.1°
BETA: 24.5°
GAMMA: 4.6°

DEFORMATION RATIO: 1.8

ANNUAL MEAN WINDSPEED: 3.3 TO 4.8 METER/SEC

INDEX NUMBERS TO TAPE? (Y OR H)
TREES SPECIES: DF 7

ALPHA: 36.8°
BETA: 17.7°
GAMMA: 6.6°

DEFORMATION RATIO: 2.2

ANNUAL MEAN WINDSPEED: 3.6 TO 5.2 METER/SEC

INDEX NUMBERS TO TAPE? (Y OR N)

40
TREE SPECIES: DF #8

ALPHA: 47.2°
BETA: 19.2°
GAMMA: 7.5°

DEFORMATION RATIO: 2.6

ANNUAL MEAN WINDSPEED: 3.9 TO 5.7 METER/SEC

INDEX NUMBERS TO TAPE? (Y OR N)
TREE SPECIES: DF #9

ALPHA: 31.2'
BETA: 20.3'
GAMMA: 1.2'

DEFORMATION RATIO: 1.6

ANNUAL MEAN WINDSPEED: 3.1 TO 4.5 METER/SEC

INDEX NUMBERS TO TAPE? (Y OR N)
TREE SPECIES: DF  # 10

ALPHA: 33.0°
BETA: 23.4°
GAMMA: 14°

DEFORMATION RATIO: 1.4

ANNUAL MEAN WINDSPEED: 3.0 TO 4.3 METER/SEC

INDEX NUMBERS TO TAPE? (Y OR N)
TREE SPECIES: DF 011

ALPHA: 37.2'
BETA: 19.1'
GAMMA: 9.6'

DEFORMATION RATIO: 2.2

ANNUAL MEAN WINDSPEED: 3.6 TO 5.1 METER/SEC

INDEX NUMBERS TO TAPE? (Y OR N)
TREE SPECIES: DF  # 12

\begin{align*}
\text{ALPHA:} & \quad 38.6' \\
\text{BETA:} & \quad 18.3' \\
\text{GAMMA:} & \quad 5.7'
\end{align*}

DEFORMATION RATIO:  2.2

ANNUAL MEAN WINDSPEED:  3.6 TO 5.2 METER/SEC

INDEX NUMBERS TO TAPE? (Y OR N)
TREE SPECIES: DF  #13

\[ \begin{align*}
\text{ALPHA:} & \quad 41.0' \\
\text{BETA:} & \quad 22.8' \\
\text{GAMMA:} & \quad 7.7'
\end{align*} \]

DEFORMATION RATIO: 2.0

ANNUAL MEAN WINDSPEED: 3.4 TO 4.9 METER/SEC

INDEX NUMBERS TO TAPE? (Y OR N)
TREE SPECIES: DF # 14

ALPHA: 38.4'
BETA: 27.3'
GAMMA: 5.6'

DEFORMATION RATIO: 1.5

ANNUAL MEAN WINDSPEED: 3.1 TO 4.4 METER/SEC

INDEX NUMBERS TO TAPE? (Y OR N)
TREE SPECIES: DF #16

\[\begin{align*}
\text{ALPHA:} & \quad 36.3' \\
\text{BETA:} & \quad 30.5' \\
\text{GAMMA:} & \quad 2.4'
\end{align*}\]

DEFORMATION RATIO: 1.2

ANNUAL MEAN WINDSPEED: 2.9 TO 4.1 METER/SEC

INDEX NUMBERS TO TAPE? (Y OR N)
TREE SPECIES: DF 0 17

ALPHA: 29.7'
BETA: 22.3'
GAMMA: 8.4'

DEFORMATION RATIO: 1.3

ANNUAL MEAN WINDSPEED: 2.9 TO 4.2 METER/SEC

INDEX NUMBERS TO TAPE? (Y OR N)
TREE SPECIES: DF  # 18

ALPHA:  27.5°
BETA:  19.6°
GAMMA:  2.1°

DEFORMATION RATIO:  1.4

ANNUAL MEAN WINDSPEED:  3.0 TO 4.3 METER/SEC

INDEX NUMBERS TO TAPE? (Y OR N)
TREE SPECIES: DF  # 19

ALPHA:  30.4'
BETA:   11.0'
GAMMA:  0.1'

DEFORMATION RATIO:  2.8

ANNUAL MEAN WINDSPEED:  4.0 TO 5.0 METER/SEC

INDEX NUMBERS TO TAPE?  (Y OR N)
TREE SPECIES: DF  # 20

ALPHA:  41.4'
BETA:   17.5'
GAMMA:  2.8'

DEFORMATION RATIO:  2.4

ANNUAL MEAN WINDSPEED: 3.0 TO 5.4 METER/SEC

INDEX NUMBERS TO TAPE? (Y OR N)
TREE SPECIES: DF  # 21

ALPHA: 33.8'
BETA: 19.3'
GAMMA: 0.8'

DEFORMATION RATIO: 1.8

ANNUAL MEAN WINDSPEED: 3.3 TO 4.7 METER/SEC

INDEX NUMBERS TO TAPE? (Y OR N)
TREE SPECIES: DF  # 22

ALPHA: 18.0'
BETA: 20.6'
GAMMA: 0.2'

DEFORMATION RATIO: 0.9

ANNUAL MEAN WINDSPEED: 2.6 TO 3.7 METER/SEC

INDEX NUMBERS TO TAPE? (Y OR N)
TREE SPECIES: DF W 23

ALPHA: 44.3'
BETA: 38.1'
GAMMA: 9.4'

DEFORMATION RATIO: 1.4

ANNUAL MEAN WINDSPEED: 3.0 TO 4.3 METER/SEC

INDEX NUMBERS TO TAPE? (Y OR N)
TREE SPECIES: DF  # 24

ALPHA:  36.7'
BETA:   31.1'
GAMMA:  3.0'

DEFORMATION RATIO:  1.2

ANNUAL MEAN WINDSPEED:  2.9 TO 4.1 METER/SEC

INDEX NUMBERS TO TAPE? (Y OR N)
TREE SPECIES: DF  # 25

ALPHA: 30.5'
BETA: 19.9'
GAMMA: 4.0'

DEFORMATION RATIO: 1.6

ANNUAL MEAN WINDSPEED: 3.1 TO 4.5 METER/SEC

INDEX NUMBERS TO TAPE? (Y OR N)
TREE SPECIES: DF 26

ALPHA: 41.2'
BETA: 15.3'
GAMMA: 1.1'

DEFORMATION RATIO: 2.7

ANNUAL MEAN WINDSPEED: 4.0 TO 5.8 METER/SEC

INDEX NUMBERS TO TAPE? (Y OR N)
TREE SPECIES: DF  #27

ALPHA:  38.9'
BETA:   21.6'
GAMMA:  1.2'

DEFORMATION RATIO:  1.8

ANNUAL MEAN WINDSPEED: 3.3 TO 4.8 METER/SEC

INDEX NUMBERS TO TAPE? (Y OR N)
TREE SPECIES: DF #28

ALPHA: 26.7'
BETA: 22.2'
GAMMA: 8.9'

DEFORMATION RATIO: 1.2

ANNUAL MEAN WINDSPEED: 2.8 TO 4.1 METER/SEC

INDEX NUMBERS TO TAPE? (Y OR N)
TREE SPECIES: DF # 29

ALPHA: 46.2°
BETA: 33.6°
GAMMA: 1.6°

DEFORMATION RATIO: 1.4

ANNUAL MEAN WINDSPEED: 3.0 TO 4.3 METER/SEC

INDEX NUMBERS TO TAPE? (Y OR N)
TREE SPECIES: DF 3B

ALPHA: 34.6'
BETA: 19.7'
GAMMA: 1.7'

DEFORMATION RATIO: 1.8

ANNUAL MEAN WINDSPEED: 3.3 TO 4.7 METER/SEC

INDEX NUMBERS TO TAPE? (Y OR N)
TREE SPECIES: DF # 31

\[ \text{ALPHA: } 39.6' \]
\[ \text{BETA: } 23.6' \]
\[ \text{GAMMA: } 33' \]

DEFORMATION RATIO: 1.8

ANNUAL MEAN WINDSPEED: 3.3 to 4.7 METER/SEC

INDEX NUMBERS TO TAPE? (Y OR N)
TREE SPECIES: DF  # 32

ALPHA: 40.5'
BETA:  34.1'
GAMMA:  1.4'

DEFORMATION RATIO:  1.2

ANNUAL MEAN WINDSPEED:  2.8 TO 4.1 METER/SEC

INDEX NUMBERS TO TAPE? (Y OR N)
TREE SPECIES: DF  #33

ALPHA: 35.4'
BETA: 30.0'
GAMMA: 1.8'

DEFORMATION RATIO: 1.2

ANNUAL MEAN WINDSPEED: 2.8 TO 4.1 METER/SEC

INDEX NUMBERS TO TAPE? (Y OR N)
TREE SPECIES: DF  # 34

ALPHA: 38.4°
BETA: 28.6°
GAMMA: 8.3°

DEFORMATION RATIO: 1.3

ANNUAL MEAN WINDSPEED: 2.9 TO 4.2 METER/SEC

INDEX NUMBERS TO TAPE? (Y OR N)
TREE SPECIES: DF  W 35

ALPHA: 44.9°
BETA: 26.2°
GAMMA: 0.6°

DEFORMATION RATIO: 1.7

ANNUAL MEAN WINDSPEED: 3.2 TO 4.7 METER/SEC

INDEX NUMBERS TO TAPE? (Y OR H)
TREE SPECIES: DF  # 36

ALPHA: 29.7'
BETA: 21.7'
GAMMA: 8.0'

DEFORMATION RATIO: 1.4

ANNUAL MEAN WINDSPEED: 3.0 TO 4.2 METER/SEC

INDEX NUMBERS TO TAPE? (Y OR N)
TREE SPECIES: DF 37

ALPHA: 44.3'
BETA: 25.2'
GAMMA: 5.2'

DEFORMATION RATIO: 1.9

ANNUAL MEAN WINDSPEED: 3.3 TO 4.8 METER/SEC

INDEX NUMBERS TO TAPE? (Y OR N)
TREE SPECIES: DF  #38

ALPHA: 27.4'
BETA: 20.4'
GAMMA: 8.2'

DEFORMATION RATIO: 1.3

ANNUAL MEAN WINDSPEED: 2.9 TO 4.2 METER/SEC

INDEX NUMBERS TO TAPE? (Y OR N)
TREES SPECIES: DF #39

\[ \begin{align*}
\text{ALPHA:} & \quad 39.7' \\
\text{BETA:} & \quad 31.8' \\
\text{GAMMA:} & \quad 2.3'
\end{align*} \]

DEFORMATION RATIO: 1.3

ANNUAL MEAN WINDSPEED: 2.9 TO 4.2 METER/SEC

INDEX NUMBERS TO TAPE? (Y OR N):
TREE SPECIES: DF 48

ALPHA: 29.6'
BETA: 28.6'
GAMMA: 1.4'

DEFORMATION RATIO: 1.5

ANNUAL MEAN WINDSPEED: 3.0 TO 4.4 METER/SEC

INDEX NUMBERS TO TAPE? (Y OR N)
TREE SPECIES: DF # 41

ALPHA: 43.6°
BETA: 33.9°
GAMMA: 1.0°

DEFORMATION RATIO: 1.3

ANNUAL MEAN WINDSPEED: 2.9 TO 4.2 METER/SEC

INDEX NUMBERS TO TAPE? (Y OR N)
TREE SPECIES: DF  # 42

ALPHA: 34.2°
BETA: 26.5°
GAMMA: 8.4°

DEFORMATION RATIO: 1.3

ANNUAL MEAN WINDSPEED: 2.9 TO 4.2 METER/SEC

INDEX NUMBERS TO TAPE? (Y OR N)
TREE SPECIES: DF 43

\begin{align*}
\text{ALPHA:} & \quad 26.4' \\
\text{BETA:} & \quad 23.5' \\
\text{GAMMA:} & \quad 8.3'
\end{align*}

DEFORMATION RATIO: 1.1

ANNUAL MEAN WINDSPEED: 2.8 TO 4.0 METER/SEC

INDEX NUMBERS TO TAPE? (Y OR N)

75
TREE SPECIES: DF # 44

ALPHA: 31.9'
BETA: 25.7'
GAMMA: 92'

DEFORMATION RATIO: 1.2

ANNUAL MEAN WINDSPEED: 2.9 TO 4.1 METER/SEC

INDEX NUMBERS TO TAPE? (Y OR N)
TREE SPECIES: DF  # 45

Alphabet: 41.7'
Beta: 22.3'
Gamma: 1.2'

Deformation ratio: 1.9

Annual mean windspeed: 3.4 to 4.8 meter/sec

Index numbers to tape? (Y or N)
APPENDIX II

SYMAP Output
### Absolute Value Range Applying to Each Level

**Minimum** (Excluding 1100 and 1101)

<table>
<thead>
<tr>
<th>Interval</th>
<th>Lower</th>
<th>Upper</th>
</tr>
</thead>
<tbody>
<tr>
<td>Below</td>
<td>4.06</td>
<td>4.23</td>
</tr>
<tr>
<td>Above</td>
<td>6.06</td>
<td>6.12</td>
</tr>
</tbody>
</table>

**Maximum** (Including 1100 and 1101)

<table>
<thead>
<tr>
<th>Interval</th>
<th>Lower</th>
<th>Upper</th>
</tr>
</thead>
<tbody>
<tr>
<td>Below</td>
<td>8.37</td>
<td>8.44</td>
</tr>
<tr>
<td>Above</td>
<td>10.10</td>
<td>10.16</td>
</tr>
</tbody>
</table>

### Percentage of Total Absolute Value Range Applying to Each Level

<table>
<thead>
<tr>
<th>Level</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>15.66%</td>
</tr>
<tr>
<td>2</td>
<td>18.27%</td>
</tr>
<tr>
<td>3</td>
<td>19.67%</td>
</tr>
<tr>
<td>4</td>
<td>20.71%</td>
</tr>
<tr>
<td>5</td>
<td>20.71%</td>
</tr>
</tbody>
</table>

### Frequency Distribution of Data Value Range in Each Level

<table>
<thead>
<tr>
<th>Level</th>
<th>Frequency Distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>LLLLLL LLLL</td>
</tr>
<tr>
<td>2</td>
<td>LLLLLL LLLL</td>
</tr>
<tr>
<td>3</td>
<td>LLLLLL LLLL</td>
</tr>
<tr>
<td>4</td>
<td>LLLLLL LLLL</td>
</tr>
<tr>
<td>5</td>
<td>LLLLLL LLLL</td>
</tr>
</tbody>
</table>

### Symbol Representation

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1</td>
</tr>
<tr>
<td>B</td>
<td>2</td>
</tr>
<tr>
<td>C</td>
<td>3</td>
</tr>
<tr>
<td>D</td>
<td>4</td>
</tr>
<tr>
<td>E</td>
<td>5</td>
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<tr>
<td>H</td>
<td>8</td>
</tr>
<tr>
<td>I</td>
<td>9</td>
</tr>
</tbody>
</table>

### Additional Notes

- The symbol representation above shows the frequency distribution of data value ranges in each level.
- The table includes the absolute value range and the percentage of the total absolute value range for each level.
- The frequency distribution is indicated by a symbol representation.
APPENDIX III

Preliminary Aerial Reconnaissance Photographs
Vertical Photographs of Study Area