Wind Energy Resource Atlas: Volume 7 - The South Central Region

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WIND ENERGY RESOURCE ATLAS: Volume 7 -
THE SOUTH CENTRAL REGION

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PREFACE

For the purpose of assessing the national wind resource, the United States and its possessions have been divided into twelve regions. For each region, these wind resource assessments are presented in the form of an atlas. The atlases depict in graphic, tabular and narrative form the wind resource on a regional and state level. The information presented in the atlases will help guide homeowners, utilities and industry in decisions concerning the use of the wind as a source of energy.

This atlas of the wind energy resource is composed of introductory and background information, a regional summary of the wind resource, and assessment of the wind resource in each state of the region. Chapter 1 provides background on how the wind resource is assessed and on how the results of the assessment should be interpreted. A description of the wind resource on a regional scale is then given in Chapter 2. The results of the wind energy assessments for each state are assembled in this chapter into an overview and summary of the various features of the regional wind energy resource. Chapter 3 provides an introduction and outline to the descriptions of the wind resource given for each state. Assessments for individual states are presented as separate chapters beginning with Chapter 4. The state wind energy resources are described in greater detail than the regional wind energy resource, and features of selected stations are discussed. This preface outlines the use and interpretation of the information found in the state chapters.

Much of the information in the state chapters is given in graphic or tabular form. As discussed in Section 3.1, the sequence of maps, tables, and graphs is the same in each state chapter. References to these figures and tables are made here with an asterisk (*) in place of the chapter number (e.g., Figure *.1, Table *.2). Similar maps and tables are found in Chapter 2 on the regional wind resource. References to the regional maps and tables are made in brackets [].

Figure*.1 shows the major geographical (mountains, rivers) and cultural (cities, towns) features in the state [Figure 2.1]. This map can be used to orient the reader to the state. Figure *.2 portrays the topography of the state in shaded relief [Figure 2.2]. The shaded relief allows the reader to visualize the character of the terrain surrounding locations of special interest. Superimposed on these state maps (but not on the regional maps) is a grid of dashed lines one-third degree (20') longitude by one-quarter degree (15') latitude. This grid is repeated on nearly all subsequent maps to give the reader an adequate frame of reference for locating the same feature on different maps.

Figure *.3 is a map of the land-surface form [Figure 2.3]. The information presented in Sections 1.6 and 1.8 indicates how the land-surface form is used to designate the terrain features considered to have a typical good exposure to the wind. Awareness of what constitutes well-exposed terrain features is crucial to the proper interpretation of the maps of wind power density.

Figure *.4 and *.5 identify and locate wind data sites relevant to the assessment. All locations in each state for which the National Climatic Center (NCC) has wind data in its archives are shown and named in Figure *.4. However, this assessment is based on a subset of NCC data augmented by data from other sources (see Sections 1.1 and 1.2). Figure *.5 shows the location of all wind data sites used in the assessment. Sections 1.3 through 1.5 briefly describe the methods used to analyze the wind data and evaluate the wind power.

The wind energy resource for a state is illustrated using several maps. The wind power maps represent a careful synthesis of quantitative wind data guided by state-of-the-art concepts on air flow near the earth's surface. Section 1.6 describes how the analysis of the wind data is transformed into the map of annual average wind power density found in Figure *.6 [Figure 2.4]. This map gives the annual average wind power density at typically exposed sites. A discussion of the classes of wind power density in Section 1.7 gives the relationship between mean wind power density (watts/m^2) and mean wind speed (m/s or mph).

A certainty rating is used to provide a measure of the ability to objectively evaluate the wind resource in a grid cell. The certainty ratings are given in the maps of Figure *.7. The degree of certainty with which the wind power can be estimated depends on the quality and quantity of wind data, the complexity of the terrain and concern over the variability of the wind resource over short distances. How these factors are combined to assign a certainty rating is discussed in Section 1.9.

The terrain feature with typical good exposure to the wind in a particular land-surface form resource provides a convenient and essential reference point on which to base the analyses of the wind resource shown in Figure *.6. However, a substantial portion of the terrain may have poorer than typical exposure to the wind and will have a lower wind resource than shown on the wind power maps. The maps of Figure *.8 provide an estimate of the percentage of area in each grid cell that may experience at least each of four different wind power classes. Section 1.10 discusses the assumptions underlying the evaluation of the areal distribution of the wind resource. The area of the state estimated to experience a particular wind power class is given in Table *.1 [Table 2.2]. This table summarizes the contribution made by each grid cell to the areal distribution of wind power for the state.

The annual average wind power density compresses into a single statistic time-varying trends on several time scales, e.g., annual, seasonal, monthly, and daily. In this atlas, the seasonal evolution of the geographical distribution of wind power is shown at the state level. The maps of Figure *.9 give the average wind power density for winter, spring, summer, and autumn. The interpretation of the seasonal average wind power maps is identical to that for the annual average wind power map. For the region, Figure 2.5 shows only the season of maximum power.

Additional information on the time variation and other characteristics of the wind resource in each state is presented for selected locations for which the National Climatic Center placed 1-hourly or 3-hourly time-series data on magnetic tape. Descriptions of the characteristics of the wind resource presented for these stations are given in Section 3.2.

The urge to consider information pertaining to one of these sites as representative of some other location must be tempered with the realization that wind characteristics are extremely site-dependent. The degree of correspondence between the wind characteristics at one site and those at another site depends on the similarity between the topographical setting of the sites, the weather patterns that affect the sites and the obstructions to the wind in the vicinity of the sites.

Table *.2 identifies the stations, and gives their location (see also Figures *.4 and *.5) and annual average wind speed and power density. Figure *.10 shows how the yearly mean speed and power varied during the period of record. The monthly mean wind speed and power over the course of a year are shown in Figure *.11. The hourly mean wind speed over the course of a day is shown in Figure *.12 with a separate curve for each season. Figures *.11 and *.12 indicate the time of year and time of day, respectively, the wind resource is available. Figure *.10, on the other hand, indicates the year-to-year variability that might be expected in the yearly mean resource.

The frequency of occurrence of winds from a particular direction and of winds with a particular speed is shown in Figures *.13 and *.14, respectively. The information on wind direction may be important in assessing the availability of the wind resource relative to surrounding terrain or nearby obstructions. However, it is also important to realize that the wind direction statistics are highly dependent on the location of the instrument site relative to obstructions and major terrain features, e.g., valleys, ridges, and mountain ranges.

Figures *.15 and *.16 portray speed and power frequency statistics in the form of speed and power exceedance curves, respectively. The fraction of the total period of record the speed equals or exceeds a given value is shown in Figure *.15. The power exceedance curve in Figure *.16 gives the fraction of the period of record for which the power exceeds a given value.

As has been shown in the preceding discussion, the order of presentation of the wind resource in this atlas proceeds from a regional perspective in Chapter 2, to a state perspective in the first part of each state chapter, and finally to individual station

descriptions in the last part of the state chapters. Attention given to Chapter 1 and Chapter 3 will make it possible for the reader to properly interpret the wind resource presentations.

N.B. Since the area of Texas is significantly greater than the area of any other state in the South Central region, Texas has been divided along the 100° West Longitude meridian to form two sections, West Texas and East Texas. Wherever possible, the figures are placed on facing pages so that the discussion proceeds as indicated above, but less reduction in map scale is necessary.

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CHAPTER 1: REGIONAL WIND ENERGY RESOURCE ASSESSMENT

Rapid development of wind as a source of commercial electric power is the principal goal of the Federal Wind Energy Program. Utility planning, wind turbine manufacturing and marketing of wind energy conversion systems all depend on detailed wind resource assessments. This atlas of the South Central region's wind resource, a product of the Wind Characteristics Program Element of the Federal Wind Energy Program, represents a major source of information for meeting these various needs.

This wind energy resource atlas is one of twelve such atlases being assembled. These atlases describe the potential wind resources in this and eleven other regions of the United States (see Figure 1.1).

The spatial and temporal resolution of the wind resource in these regional assessments will be depicted in considerably greater detail than that in previously existing national assessments (Reed 1975, Coty 1976, Garate 1977, Elliott 1977). To produce the South Central regional atlas in a timely fashion, only existing relevant data were used. The other atlases will use comparable data sets, analysis techniques and presentations to ensure the comparability of the wind resource assessments.

This atlas of the South Central region combines seven collections of wind resource data: one for the region, and one for each of the six states (Arkansas, Kansas, Louisiana, Missouri, Oklahoma,

FIGURE 1.1. Geographic Division for Regional Wind Energy Assessments

and Texas). At the state level, features of the climate, topography, and wind resource are discussed in greater detail than that provided in the regional discussion, and the data locations on which the assessment is based are mapped. Variations, over several time scales, in the wind resource at selected stations in each state are shown on graphs of monthly average and interannual wind speed and power, and hourly average wind speed for each season. Other graphs present speed, direction, and duration frequencies of the wind at these locations.

The methods used to identify, screen, evaluate, and analyze the various types of data, and to produce the wind energy resource maps and graphs will only be described briefly. [For more detail see Edwards et al. (1981).] However, this discussion will provide the reader with useful background information for interpreting the wind energy resource maps for the South Central region.

1.1 IDENTIFICATION OF WIND DATA SOURCES

The surface wind data on which these atlases have been based were obtained from several sources: the National Climatic Center (NCC), the U.S. Forest Service, university research projects, nuclear and fossil-fueled power plants and their proposed sites, DOE candidate wind turbine sites, and other government and private organizations. The National Climatic Center offers the largest collection of wind data. Surveys and indices of wind data archived at the NCC (Changery 1975, 1978; Changery et al. 1977) are extremely helpful in locating available wind data. The Index of Original Surface Weather Records, published for each individual state by the NCC, provides additional information about stations at which wind data have been taken.

The wind data available from the NCC may be in one or more of three formats: summarized, digitized, and unsummarized. Initially, all wind data are in the unsummarized format consisting of the original station weather records. For many stations, the collection of individual observations has been condensed into wind summaries. Changery et al. (1977) present examples of the various summary formats used and indices of the stations for which wind summaries are available. For still fewer stations (primarily airport stations) the NCC has

put the original one- or three-hourly weather observations on magnetic tape to create a digitized time series of weather (and wind) observations. TDF-14 (NCC 1975) describes the data on these tapes. Table 1.1 indicates the number of stations with wind data in these various formats in the South Central region.

Coastal marine observations tabulated in the Summary of Synoptic Meteorological Observations (SSMO, U.S. Naval Weather Service Command 1975) indicate that wind power of class 3 and above exists off the Louisiana and Texas coasts. However, we have not included these data in our maps because the purpose of this wind atlas is to assess land resources only.

In contrast to the NCC data, which are primarily from inhabited areas, U.S. Forest Service data in the National Fire Weather Data Library (Furman and Brink 1975) are from remote sites in mountainous and forested areas under the jurisdiction of the Federal government (i.e., national forests, national parks, Indian reservations, or Bureau of Land Management areas). However, only one afternoon observation, at about 2 p.m., is digitized per day during the fire weather season.

Wind data from 10 nuclear-fueled power plants or potential plant sites (Verholek 1977) were examined. Other data sets collected by university research projects, state and local air pollution control agencies, or in support of environmental impact statements have also been identified. Wind data now being collected at eight sites in the Panhandle of Texas (Nelson and McGaughey 1980) at anemometer heights of 10m and 50m are indicative of the growing data bank of usable wind measurements in the South Central region.

1.2 WIND DATA SCREENING

Table 1.1 indicates the quantity of wind data available in the South Central region. However, not all of these data need to, or should, be used in a wind resource assessment. Screening procedures were developed to identify stations with the most useful data and to eliminate stations that would not significantly contribute information on the distribution of the wind resource.

TABLE 1.1. Stations with Wind Data in the South Central region and Peripheral Area Screened in Assessment

Source and Type	Screened	Retained
National Climatic Center		
Digitized	139	104
Summarized	142	104
Unsummarized	51	43
National Fire Weather Data Library	51	0
Nuclear & Fossil-Fuel Power Plant	11	11
University Research	3	1
Other	15	4
Mexican	3	3
Total	276	166

Wind data in summarized or digitized format were chosen over unsummarized data. When stations had both summarized and digitized data, the digitized data were used for selected stations to prepare a more extensive characterization of the wind resource. Unsummarized data were used only when no summarized or digitized data were available.

In areas with a high density of stations with wind summaries, those stations appearing to have the best exposure to the wind, greatest number of daily observations, longest period of record, and longest period of unchanged anemometer height and location were usually selected over other nearby stations. When more than one type of summary (see Changery et al. 1977) was available for a given station, the summary covering the longest period of record with constant anemometer height and location, with the greatest number of wind speed and direction classes, and with the highest frequency of daily observations was chosen.

The screening of the National Fire Weather Data Library significantly reduced the number of U.S. Forest Service sites to be considered in this assessment. Table 1.1 shows the effect of screening on the number of sites analyzed. Only sites for which there was quality information pertaining to the wind resource were retained for the final analysis. None of the fire weather data were assessed as pertinent to this study.

1.3 TIME SCALES IN REGIONAL ASSESSMENTS

Several time scales are encountered in the following discussions of the wind resource: annual, seasonal, monthly and diurnal. Annual mean values are generally based on an average of the one- or three- hourly observations of wind speed or power in the period of record; however, a complete calendar year's data (covering January 1 to December 31) is used for calculating individual yearly means. At stations with less than 24 hourly observations or 8 three-hourly observations per day, the values are only representative of the times of day for which the data were taken.

The four seasons are defined as:

- winter - December, January and February
- spring - March, April, and May
- summer - June, July, and August
- autumn - September, October and November.

The phrase "seasonal trends" refers to the change in monthly mean values over the course of the four seasons. Monthly mean values are based on as many hours of data as are available for that month in each year of the period of record. The daily or diurnal cycles of variation in the hourly mean wind power or speed are referenced to local standard time on a 24-hour clock. Midnight is both 00 and 24.

1.4 EVALUATION OF WIND DATA

For the purpose of mapping the geographical variation of the wind resource, wind power density was chosen over wind speed since the power density incorporates in a single number the combined effect of the distribution of wind speeds and the dependence of the power density on air density and on the cube of the wind speed. Quantitative wind data in three formats were evaluated for mean wind power density: digitized, summarized, and unsummarized. The average wind power density, $\bar{P}$, (watts/m²) in a vertical plane perpendicular to the wind direction for stations with one- or three-hourly digitized data was calculated from:

$$\bar{P} = \frac{1}{2n} \sum_{i=1}^n \rho_i V_i^3 \quad (1)$$

where

n = the number of observations in the averaging period

ρ_i = the density (in kg/m^3) computed from the station pressure and temperature

V_i = the wind speed (in m/s) at the i^{th} observation time.

For stations with wind summaries, $\bar{P}$ was calculated from:

$$\bar{P} = \frac{1}{2} \bar{\rho} \sum_{j=1}^c f_j V_j^3 \quad (2)$$

where

$\bar{\rho}$ = the mean air density

c = the number of wind speed classes

f_j = frequency of occurrence of winds in the j^{th} class

V_j = the median wind speed of the j^{th} class.

In those cases for which unsummarized wind data were assessed, the seasonal and annual average speeds, $\bar{V}$, were estimated from a visual examination of one year's original weather records. The wind power density, $\bar{P}$, was then estimated by assuming the speed frequency distribution followed a Rayleigh distribution (Cliff 1977):

$$\bar{P} = 0.995 \bar{\rho} \bar{V}^3 \quad (3)$$

1.4.1 Vertical Adjustment

The anemometer height above the surface rarely was at the 10-m or 50-m reference levels chosen for the presentation of the wind resource. A power law was used to adjust the long-term mean wind speed or power density to the reference level:

$$\frac{\bar{V}_r}{\bar{V}_a} = \left(\frac{Z_r}{Z_a}\right)^\alpha \quad \text{or} \quad \frac{\bar{P}_r}{\bar{P}_a} = \left(\frac{Z_r}{Z_a}\right)^{3\alpha} \quad (4)$$

where

$\bar{V}_{a,r}$ and $\bar{P}_{a,r}$ = the mean wind speed or wind power density at heights $Z_{a,r}$ (the anemometer and reference level), respectively.

α = the power law exponent.

An examination of long-term mean wind speeds at airport locations at which the anemometer height was changed and at tower sites with multiple levels of anemometry indicates an $\alpha \approx 1/7$ to be widely applicable to low surface roughness and well exposed sites from which conventional NCC data are available (Elliott 1979b).

1.4.2 Estimates for Mountainous Areas

The quantitative estimation of wind power over mountains made use of the northern hemisphere upper-air wind climatologies for the 850, 700 and 500 mb constant pressure levels by Crutcher (1959). Since earlier studies had shown a strong correlation between mountaintop and free-air wind speeds (Wahl 1966), the free-air wind speed at mountain summit or ridge crest height was extrapolated (or interpolated) from the mean scalar speeds on the constant pressure surfaces. Estimates of the mountaintop wind speeds were made on a grid one-fourth degree latitude by one-third degree longitude. In each such cell of the grid over mountainous areas, the mean ridge crest or mountain summit elevation and appropriate constant-pressure surface mean wind speeds were estimated. Linear extrapolation provided the mean free-air wind speed at the terrain elevation and the application of a Rayleigh speed distribution gave the mean free-air wind power. The mean wind power at the 10-m and 50-m reference heights was taken to be one-third and two-thirds of the free-air value, respectively, to account for the frictional slowing of the wind near the surface.

These estimates are considered lower limits for exposed ridge crests and mountain summits. Local terrain features in these mountainous regions can enhance the wind power considerably. However, a major uncertainty in mountainous terrain is the representativeness of some of the data upon which the free-air estimates are based (e.g., sheltering by nearby mountains can bias rawinsonde winds).

Wherever possible, these estimates were compared with surface data from ridge crests and mountain summits. In the Boston and Ouachita Mountains of Arkansas, and the Big Bend area of West Texas, over some of the mountainous areas, the wind estimates were adjusted

based on the location of the upper-air recording station and/or the surface data from ridge crests.

1.5 QUALITATIVE WIND INDICATORS

Although more than 200 stations provided the wind resource assessment in the South Central region with quantitative data, these stations were not uniformly distributed. The station location figures for each state show that most NCC stations are located in populated areas. Large areas are devoid of any form of quantitative wind data suitable for this assessment, such as southeastern Oklahoma, western Kansas and western Texas. Furthermore, in areas of complex terrain, most observation sites (except for some U.S. Forest Service fire lookout sites) are confined to valley locations. To evaluate the distribution of the wind resource in data-sparse areas, three qualitative indicators of the wind speed or power were developed for, and employed in, the assessment.

The most widely used technique depended on certain combinations of topographical and meteorological features (Elliott 1979a) that were associated with high or low wind speeds. Those features within the South Central region indicative of high mean wind speeds are:

- gaps, passes, and gorges in areas of frequent strong pressure gradients such as in West Texas
- long valleys extending down from mountain ranges
- high elevation plains and plateaus
- plains and valleys with persistent strong downslope winds associated with strong pressure gradients
- exposed ridges and mountain summits in areas of strong upper-air winds
- exposed coastal sites in areas of
 - 1) strong upper-air winds, or
 - 2) strong thermal/pressure gradients.

Features in the South Central region that signal rather low mean wind speeds are:

- valleys perpendicular to the prevailing winds aloft
- sheltered basins
- short and/or narrow valleys and canyons
- areas of high surface roughness, e.g., forested hilly terrain.

Areas in which the appropriate features occur were determined by examining topographic contour and shaded relief maps and synoptic and climatological maps of sea-level pressure patterns and air flow. This technique was applied to the Arkansas River valley which lies between the Ouachita and Boston Mountains in northwest Arkansas and displays less wind power potential than the bordering ridges to the north and south.

Another example of the important connection between topographical features and sea-level pressure patterns is found along the southern Texas coast where increased wind speeds and wind power are observed compared to surrounding areas. This is caused primarily by the coastal topography and the prevailing pressure differences over the land and water. Eolian land forms and wind-deformed vegetation were not identified in the South Central region and therefore could not be used as qualitative indicators of wind speed.

1.6 WIND POWER MAPS

The production of mean wind power density maps, such as those presented for each state, depended on the coherent synthesis of several pieces of information. The goal of the synthesis process was to present wind power density values representative of sites well exposed to the prevailing strong winds. Hilltops, ridge crests, mountain summits, large clearings, and other locations free of local obstructions to the wind are expected to have good exposure to the wind (see Table 1.2).

In contrast, locations in narrow valleys and canyons, downwind of hills and obstructions, or in forested or urban areas are likely to have poor exposure. The wind power density shown on the maps in this atlas will not be representative of poorly exposed locations. Estimates for ridge crests and summits (the shaded areas on the maps) are lower limits to the wind power expected at exposed sites.

In such areas, local terrain features can enhance the wind power considerably (e.g., by a factor of 2 or 3). By specifying the type of wind exposure to which the map values of wind power pertain, we avoid the ambiguity that typical-location or average-for-the-terrain values might introduce. In this atlas, the terms wind energy, wind power, and wind power density are used synonymously.

To represent the wind resource at well-exposed sites, it was necessary to become extremely familiar with the land-surface form and topography in the vicinity of every data site. Maps were prepared showing the location of stations, the mean wind speed and mean wind power at the reference level, the character of anemometer exposure, and the land-surface form for each state. A great deal of attention was given to the orientation of topographic features with the prevailing wind directions. Only after all this information was assembled were the maps analyzed. The annual maps for each state were merged into a regional mosaic.

1.7 WIND POWER DENSITY CLASSES

The analysis of wind power maps departs from conventional isopleth analyses by showing the boundaries of wind power density classes. Each wind power class represents the range of wind power densities likely to be encountered at exposed sites within an area designated as having that wind power class. Table 1.3 gives the power density limits for the wind power classes used in the atlas for the 10-m (33-ft) and 50-m (164-ft) reference levels. The definitions of the wind power density classes are repeated with the annual wind power map for the region and for each state as a convenience for the reader.

Wind power density is proportional to the third moment of the wind speed distribution and to air density; therefore, a unique correspondence between power density and mean wind speed (the first moment of the speed distribution) does not exist. However, by specifying a Rayleigh wind speed distribution and a standard sea level air density (1.22 kg/m^3), a mean wind speed can be determined for each wind power class limit. The decrease of air density with elevation requires that the mean

Rayleigh speed increase by about 3 percent per 1,000 m elevation (1 percent per 1,000 ft) to maintain the same power density. If the wind speed distribution is more sharply peaked than the Rayleigh distribution, the equivalent mean speed will be slightly higher than the value in Table 1.3. Conversely, a broader distribution of wind speeds will slightly reduce the equivalent mean speed.

1.8 CLASSES OF LAND-SURFACE FORM

The physical characteristics of the land-surface form affect the number of wind turbines that can be sited in exposed places. For example, over 90 percent of the land area in a flat plain may be favorably exposed to the wind; however, in mountainous terrain only the ridge crests and passes, which may be only a small percentage (5 percent) of the land area, may represent exposed sites. The map of classes of land-surface form by Hammond (1964) provided information on the distribution of plains, tablelands, hills and mountains. Several characteristics are coded on this map:

- percentage of land area occupied by surfaces of gentle inclination less than 8 percent slope
- local relief, the maximum difference in elevation within a unit square six miles across
- percentage of gently inclined surfaces that lie in the lower half of the local relief
- land area covered by sand, ice, and standing water
- pattern of major crests, peaks, and escarpments.

The first three characteristics are used in the classification scheme (see Table 1.4); the latter two have been omitted from the maps presented here. A three-character code, for example B3a, designates each class of land-surface form. In this example the "B" indicates that 50 to 80 percent of the area is occupied by gentle slopes; the "3" that the maximum local difference in elevation is 100 to 150 m (300 to 500 ft); and the "a" that more than 75 percent of the gently sloping land is in the lowland. In areas of very little gentle slope (D)

or very low relief and great smoothness (A1), the third designator is omitted.

For each land surface form, the percentage of land area that is representative of well exposed, moderately exposed, and poorly exposed sites has been estimated. These percentages were determined subjectively as a function of the slope, local relief, and profile type. Table 1.2 gives the average percentage of land area that is designated as exposed terrain for the different classes of land-surface form. For simplicity, the percentages shown for each class of land-surface form have been averaged over the range of categories in local relief and profile type found in the South Central region. For example, the 36 percent for open hills is an average for C2 through C4. The average percentage of land area that is designated as exposed terrain ranges from 93 percent in the plains to 3 percent in mountainous areas where the exposed areas are usually the ridge crests and summits.

1.9 CERTAINTY RATING

The analyses of wind power density at exposed sites shown on the wind power maps depend on the subjective integration of several factors: quantitative wind data, qualitative indicators of wind speed or power, the characteristics of exposed sites in various terrain and familiarity with the meteorology, climatology and topography of the region. As a result, the degree of certainty with which the wind power class can be specified depends on:

- the abundance and quality of wind data
- the complexity of the terrain
- the geographic variability of the resource.

A certainty rating from 1 (low) to 4 (high), of the wind energy resource estimate has been made for each cell of a one-quarter degree latitude by one-third degree longitude grid on a state-by-state basis by considering the influence of the above three factors of the certainty of the estimate of the wind power class for each cell. The definitions for the certainty ratings are adopted from those used by Voelker et al. (1979) in a resource assessment of U.S. Forest Service tracts. The certainty ratings

for the wind resource assessment are defined as follows:

Rating	DEFINITION
1	<p>The lowest degree of certainty. A combination of the following conditions exists:</p> <ol style="list-style-type: none"> 1) No data exist in the vicinity of the cell. 2) The terrain is highly complex. 3) Various meteorological and topographical indicators suggest a high level of variability of the resource within the cell.
2	<p>A low-intermediate degree of certainty. One of the following conditions exists:</p> <ol style="list-style-type: none"> 1) Little or no data exist in or near the cell, but the small variability of the resource and the low complexity of the terrain suggest that the wind resource will not differ substantially from the resource in nearby areas with data. 2) Limited data exist in the vicinity of the cell, but the terrain is highly complex or the mesoscale variability of the resource is large.
3	<p>A high-intermediate degree of certainty. One of the following conditions exists:</p> <ol style="list-style-type: none"> 1) There are limited wind data in the vicinity of the cell, but the low complexity of terrain and the small mesoscale variability of the resource indicate little departure from the wind resource in nearby areas with data. 2) Considerable wind data exist but in moderately complex terrain and/or in

in areas where moderate variability of the wind resource is likely to occur.

- 4 The highest degree of certainty. Quantitative data exist at exposed sites in the vicinity of the cell and can be confidently applied to exposed areas in the cell because of the low complexity of terrain and low spatial variability of the resource.

The assignment of a certainty rating requires subjective evaluation of the interaction of the factors involved.

1.10 AREAL DISTRIBUTION OF THE WIND RESOURCE

As noted above, the wind power density class values shown on the maps apply only to sites well exposed to the wind. Therefore, the map area designated as having a particular wind power class does not indicate the true land area experiencing this wind power. Instead, there is a complicated and difficult to quantify relationship among the class of land-surface form, the land-surface area and the map value of wind power density. For each land-surface form, the fraction of land area that would be favorably exposed to the winds, i.e., have the wind power density indicated on the map, was estimated (see Table 1.2 for averages in various land-surface forms).

Furthermore, to be able to establish a wind power density for the remaining area, it was also necessary to specify a factor by which the wind power shown on the map is reduced in the less exposed areas. As an additional complication, some land-surface forms, isolated hills and ridges that rise above a nearly flat landscape may even experience a higher power density than the map indicates.

To accommodate these various situations, the land area represented by a given land-surface form was divided into four exposure categories: 1) better exposure than typical for the terrain, 2) exposure typical for that land-surface form, 3) partially sheltered exposure, and 4) very sheltered exposure. The partitioning of the land-surface forms

into the four categories was based on the parameters used to classify the land-surface forms and on the experience of the authors and their co-workers with the terrain represented by the land-surface forms.

In order to adjust the wind power density from the map value to the various exposure categories, the power density was scaled to be 1) greater than, 2) equal to, 3) slightly less than, and 4) much less than the map value power density. The factor by which the map value was adjusted to represent the wind power density in each category was determined by the magnitude of elevation relief given by the middle character of the land-surface form code. (The minimum power density allowed for a category was the median value of wind power density class 1). The scaling factors for the wind power density were based on a conservative application of a power-law type vertical adjustment with the height change specified by the terrain relief code.

In each cell of a grid one-third degree longitude by one-quarter degree latitude, the land-surface form was specified and the wind power class associated with a typically exposed site in that land-surface form was determined. By partitioning the area of the cell into the four exposure categories, and by scaling the wind power class to each category, the contribution of that cell to the areal distribution was determined.

A cell-by-cell representation of the areal distribution is given in a map that indicates the percentage land area in a cell over which the wind power class equals or exceeds a threshold value. Four maps are shown in the chapters on the state wind resources for threshold values of classes 2, 3, 4 and 5.

A summary table of the areal distribution that combines the contributions by each cell is provided for the region and for each state. For each power class, the sum of the area contributed by each exposure category is determined for each state and the region. Summing the area associated with each power class in each cell gives the area of the state or region over which the power class exceeds a given value. The

table gives the estimated land area (km^2) and the percentage of land area associated with each power class.

Both of these presentations of the areal distribution of the wind resource are highly dependent on the estimates used to partition the land area into the four exposure categories and on the scaling of the power density for each category of exposure. Therefore, the areal distribution derived from the wind power and land-surface form maps must be

considered only an approximation. The quantity and quality of wind data and topographic information required to make a highly accurate cell-by-cell appraisal of the wind resource are far beyond the scope of this regional wind resource assessment. However, as wind information becomes available through new measurement programs or through the discovery and processing of existing data sets, the evaluation of the areal distribution of the wind resource can be improved on a cell-by-cell basis.

TABLE 1.2. Land-Surface Form Terrain Features Representative of Exposed Locations

<u>Land-Surface Form</u>	<u>Exposed Feature (Map Value)</u>	<u>Percentage Area</u>
Plains: A1; B1,2	Plains	93
Plains With Hills: A,B3a,b	Open Plains	92
Plains With Mountains: B4-6a,b	Plains (not shaded)	67
	Ridge Crests and Mountain Summits (shaded)	10
Tablelands: B3-6c,d	Tablelands, uplands	81
Open Hills: C2-4	Hilltops and Uplands	36
Open Mountains: C5-6	Broad Valleys (not shaded)	
	Ridge Crests and Mountain Summits (shaded)	10
Hills: D3-4	Hilltops and Uplands	5
Mountains: D5-6	Ridge Crests and Mountain Summits (shaded)	3

-
- (a) Percentage represents an average over the land-surface forms found in the South Central region.
 (b) Shaded areas on the wind maps emphasize that map values are estimates for ridge crests and mountain summit locations.

Classes of Wind Power Density at 10 m and 50 m^(a)

Wind Power Class	10 m (33 ft)		50 m (164 ft)	
	Wind Power Density, watts/m ²	Speed, ^(b) m/s (mph)	Wind Power Density, watts/m ²	Speed, ^(b) m/s (mph)
	0	0	0	0
1	100	4.4 (9.8)	200	5.6 (12.5)
2	150	5.1 (11.5)	300	6.4 (14.3)
3	200	5.6 (12.5)	400	7.0 (15.7)
4	250	6.0 (13.4)	500	7.5 (16.8)
5	300	6.4 (14.3)	600	8.0 (17.9)
6	400	7.0 (15.7)	800	8.8 (19.7)
7	1000	9.4 (21.1)	2000	11.9 (26.6)

(a) Vertical extrapolation of wind speed based on the 1/7 power law.

(b) Mean wind speed is based on Rayleigh speed distribution of equivalent mean wind power density. Wind speed is for standard sea-level conditions. To maintain the same power density, speed increases 5%/5000 ft (3%/1000 m) of elevation.

TABLE 1.4. Scheme of Classification

Slope (1st item)

- A >80% of area gently sloping
- B 50 to 80% of area gently sloping
- C 20 to 50% of area gently sloping
- D <20% of area gently sloping

Local Relief (2nd item)

- 1 0 to 30 m (0 to 100 ft)
- 2 30 to 90 m (100 to 300 ft)
- 3 90 to 150 m (300 to 500 ft)
- 4 150 to 300 m (500 to 1000 ft)
- 5 300 to 900 m (1000 to 3000 ft)
- 6 900 to 1500 m (3000 to 5000 ft)

Profile Type (3rd item)

- a >75% of gentle slope is in lowland
- b 50 to 75% of gentle slope is in lowland
- c 50 to 75% of gentle slope is on upland
- d >75% of gentle slope is on upland

CHAPTER 2: REGIONAL FEATURES

In this chapter, the geography, climate, and average annual and seasonal wind power are described for the South Central region. These features were considered for each state using the methods outlined in Chapter 1. Assessments for each state were combined to depict the wind energy resource potentially available in the South Central region. The areas of the South Central region that appear to have the greatest wind resource potential are also discussed in this chapter.

2.1 GEOGRAPHY AND TOPOGRAPHY

The South Central region, consisting of Arkansas, Kansas, Louisiana, Missouri, Oklahoma, and Texas, covers more than 1,500,000 km² (590,000 mi²) and is about the same size as Alaska and equal to one-fifth the area of the 48 contiguous states. The geographic center of the 48 contiguous states is near Lebanon, Smith County, Kansas, at 39°50' north latitude and 98°35' west longitude.

The South Central region has a population of 26,248,928 (1970) ranging in density from 10.5 per km² (27.3 per mi²) in Kansas to 29.0 per km² (75.1 per mi²) in Louisiana (Table 2.1). Texas has 45 percent of the area and 43 percent of the population.

TABLE 2.1. Land Area and Population of the South Central Region

State	Area		Population in 1970	Population/ km ² (mi ²)
	km ²	mi ²		
Arkansas	137,539	(54,104)	1,923,925	14.0 (36.2)
Kansas	213,063	(82,264)	2,249,071	10.5 (27.3)
Louisiana	125,674	(48,523)	3,643,180	29.0 (75.1)
Missouri	180,486	(69,686)	4,677,399	25.9 (67.1)
Oklahoma	181,090	(69,919)	2,559,253	14.1 (36.6)
Texas	692,404	(267,338)	11,196,730	16.2 (41.9)
South Central	1,530,256	(590,834)	26,248,928	17.2 (44.4)

About one-third of the population of the South Central region lives in the five metropolitan areas that have over one million inhabitants each. In order of decreasing population, these are Dallas-Fort Worth, Texas; Houston, Texas; St. Louis, Missouri; Kansas City, Kansas-Kansas City, Missouri; and New Orleans, Louisiana. The major cities, rivers, uplands, and national parks of the South Central region are shown in Figure 2.1.

The South Central region extends from the interior plains to the coastal plains with a few interior highlands in the east central part. It includes the lower Mississippi Valley from the Mississippi River westward almost to the Rocky Mountains. The Mississippi River is about 140 m (460 ft) above sea level in northern Missouri and makes up the eastern boundary of the region as it flows south to the Gulf of Mexico.

The western boundary of the South Central region is in the Great Plains or High Plains and has an elevation of about 1200 m (4000 ft) except in the western tip of Texas where the Guadalupe Mountains rise to over 2,500 m (8,000 ft.) From the west, the land slopes gradually downward toward the south and east, reaching 300 m (1,000 ft) along a line through central Texas, central Oklahoma, and central Kansas. Higher ground, above 300 m (1,000 ft), also occurs in the Ozark Plateau and Ouachita Mountain region, which is in southern Missouri, eastern Oklahoma and northern Arkansas. The remainder of the region is in the Mississippi alluvial plain or the western Gulf coastal plain, which slopes downward to sea level at the Gulf Coast of Texas and Louisiana. The only major portions of the area that are hilly and mountainous are the western tip of Texas and large parts of Arkansas and Missouri in the east (see Figures 2.2 and 2.3). Otherwise, most of the land area is favorably exposed to the wind.

2.2 CLIMATE

The South Central region is subject to inflow of air masses from three major sources: cold dry air from the Arctic, warm moist air from the tropical Gulf of Mexico, and mild dry westerlies that

cross the Rocky Mountains from the Pacific Ocean. Summers are long and hot. The July temperatures are fairly uniform over the region, averaging about 27°C (80°F) in the north and west and about 29°C (85°F) in the south. January average temperatures are distributed according to latitude with 0°C (32°F) along the northern boundary and 13°C (55°F) along the Gulf Coast.

The climate is generally dry except along the coast. Annual precipitation averages about 40 cm (16 in.) in the Great Plains along the western boundary and increases eastward and southward to about 140 cm (55 in.) in East Texas and Louisiana. Annual snowfall in northern Kansas and Missouri averages 60 cm (24 in.) while the coastal regions seldom receive any snow. Generally, over 300 tornadoes occur in the South Central region each year, the center of activity being in Oklahoma and Kansas. In this region, tornadoes occur slightly more often in the spring than in other seasons. Afternoon is the usual time of formation throughout the year. Tropical cyclones including hurricanes can be expected along the Gulf Coast from May to November. Over 50 hurricanes have been observed in Texas and Louisiana since 1900. Nine out of ten deaths that occur during hurricanes are associated with the flooding that results from the heavy rainfall and the storm surge that accompany the storms.

2.3 WIND POWER IN THE SOUTH CENTRAL REGION

The annual average available wind power density in the South Central region is shown in Figure 2.4. The analyses of mean wind power apply to terrain features that are favorably exposed to the wind, such as mountain summits, ridge crests, hilltops, and uplands (see Section 1.6). However, nearby terrain features may interact with the windfield to cause the wind power at some exposed sites to vary as much as +50 to 100 percent from the assessment value. [See Wegley et al., (1980) for information on terrain features that may increase or reduce wind energy.] In forested or wooded areas, the assessment values are representative of large clearings such as airports with good exposure to the prevailing strong winds. In mountainous regions, the analyses also reflect major valleys. The

percentage of land area that is favorably exposed to the wind strongly depends on the land-surface form (Section 1.8).

The major high wind resource areas (class 4 and higher) of the South Central region are limited to the High Plains of southwestern Kansas, western Oklahoma and the Panhandle of Texas. The ridge crests of the Boston Mountains and Ouachita Mountains in Arkansas, and the extension of the Rocky Mountains in southwestern Texas also provide some high wind resources of class 4 and higher. A brief description of the major (class 4 and higher) wind resource areas follows in Section 2.5. For a more complete discussion of these wind resource areas, refer to the chapters on the states containing these areas.

2.3.1 Certainty Rating of the Wind Resource

Certainty ratings of the wind power were assigned to each grid cell as described in Section 1.9. Maps of the certainty rating in each state accompany the descriptions of that state's wind resource.

The geographical distribution of the certainty ratings ranges from low (1) to high (4). About one-third of the South Central region has been assigned a certainty rating of 4, based primarily on availability of data, low complexity of the terrain, and low spatial variability of the resource. The only areas with a high wind resource (power of class 4 or higher) and a high certainty are parts of the High Plains of western Kansas, and parts of the Texas Panhandle. About 70 percent of the South Central region has wind resource of class 1 and class 2. At least half of this area has been assigned a certainty rating of 4. A certainty rating of 1 or 2 has been assigned to the ridge crest estimates in Arkansas and southwestern Texas, as upper-air wind data were used to approximate the power in these areas.

2.3.2 Areal Distribution

Through the superposition of a grid one-third degree longitude by one-quarter degree latitude over the region, the areal distribution of wind power can be computed as described in Section 1.10. Of the 1,881 grid cells into which the

South Central region is divided, about 250 have exposed areas with class 4 or higher wind power.

Table 2.2 summarizes the results of the computation of the areal distribution for the states of the South Central region. The subjectivity underlying the assignment of exposure partitioning and power scaling warrants reporting the areas and percentages to only two significant digits (see Section 1.10). Thus, individual areas and percentages may not sum to their stated totals. Of the upper four wind power classes, class 4 gives the highest area contribution primarily because of the large expanse of gently sloping plains and tablelands of the Great Plains in Kansas, Oklahoma, and Texas with this power class.

2.4 SEASONAL VARIATIONS IN THE WIND RESOURCE

Throughout most of the South Central region, winter and spring are the seasons of maximum wind power (see Figure 2.5). Areas with a winter maximum include the eastern portions of Missouri, Arkansas, Louisiana, and east central Texas, and the ridge crests or mountaintops of southwestern Texas. The areas in Missouri, Arkansas, Louisiana, and east-central Texas have a class 1 or class 2 resource in the winter and may therefore be considered of little value as a wind resource. The land area of ridge crests and mountaintops in southwestern Texas is small, less than 1,000 km², and so these areas also make a minor contribution to the region's wind resource.

In spring (March, April and May), the upper-air flow decreases in strength as spring progresses from March to May. Because solar insolation is greater in spring than in winter, temperature profiles are less stable and more vertical mixing in the surface layer results. Therefore, near-surface wind speeds over the valleys, basins, and plains of the South Central region are generally greater in spring than in winter.

In summer (June, July and August), mean upper-air wind speeds are low and surface winds are likewise low as the belt of westerly winds moves northward

and the subtropical high moves into the region.

In the autumn (September, October, and November), upper-air wind speeds increase over those in summer, and become essentially the same power class as in the spring.

2.5 MAJOR WIND RESOURCE AREAS

Major areas in the South Central region with high annual average wind power (class 4 and above) are briefly described in this section. For additional detail on these areas, refer to chapters on the state assessments. For the location of place names mentioned in this section, refer to the individual state maps (such as Figures 4.1 and 4.4 for Arkansas).

2.5.1 The High Plains

A class 5 wind resource area of about 23,000 km², less than 2 percent of the area of the South Central region, is found in the northern part of the Texas Panhandle and the western part of the Panhandle of Oklahoma. Class 4 surrounds this area of the Great Plains, in Texas, Oklahoma and Kansas.

2.5.2 Ozark Plateau and Ouachita Mountains

Upper-air winds have been used to estimate class 4 wind power for the Ozark Plateau and Ouachita Mountains, which extend from Arkansas westward into Oklahoma. Although Figure 2.4 shows nearly one-fourth of Arkansas to have class 4 wind power, Table 2.2 shows that only about 6 percent of Arkansas has class 4 wind potential.

2.5.3 Texas Coastal Region

The southern portion of the coast of Texas is estimated to have class 4 wind power for about 50 km (30 mi) inland before surface roughness decreases the power to class 3.

2.5.4 Rocky Mountain Extensions

The ridge crests and mountaintops of the Guadalupe and Davis mountains in the basin and range region of the Rocky Mountain extensions in southwestern Texas

are estimated to have class 4 and occasionally class 5 wind power, based primarily on upper-air wind data.

Surface data taken at Guadalupe Pass also confirms this and suggests that there is some funneling in the passes and valleys.

FIGURE 2.2. Topographic Map of the South Central Region

FIGURE 2.3. Classes of Land-Surface Form in the South Central Region

LAND-SURFACE FORM LEGEND

PLAINS

A1	FLAT PLAINS
A2	SMOOTH PLAINS
B1	IRREGULAR PLAINS, SLIGHT RELIEF
B2	IRREGULAR PLAINS

TABLELANDS

B3c,d	TABLELANDS, MODERATE RELIEF
B4c,d	TABLELANDS, CONSIDERABLE RELIEF
B5c,d	TABLELANDS, HIGH RELIEF
B6c,d	TABLELANDS, VERY HIGH RELIEF

PLAINS WITH HILLS OR MOUNTAINS

A,B3a,b	PLAINS WITH HILLS
B4,a,b	PLAINS WITH HIGH HILLS
B5a,b	PLAINS WITH LOW MOUNTAINS
B6a,b	PLAINS WITH HIGH MOUNTAINS

SCHEME OF CLASSIFICATION

SLOPE (1st LETTER)

A	>80% OF AREA GENTLY SLOPING
B	50-80% OF AREA GENTLY SLOPING
C	20-50% OF AREA GENTLY SLOPING
D	<20% OF AREA GENTLY SLOPING

OPEN HILLS AND MOUNTAINS

C2	OPEN LOW HILLS
C3	OPEN HILLS
C4	OPEN HIGH HILLS
C5	OPEN LOW MOUNTAINS
C6	OPEN HIGH MOUNTAINS

LOCAL RELIEF (2nd LETTER)

1	0 TO 30m (1 TO 100 ft)
2	30 TO 90m (100 TO 300 ft)
3	90 TO 150m (300 TO 500 ft)
4	150 TO 300m (500 TO 1000 ft)
5	300 TO 900m (1000 TO 3000 ft)
6	900 TO 1500m (3000 TO 5000 ft)

HILLS AND MOUNTAINS

D3	HILLS
D4	HIGH HILLS
D5	LOW MOUNTAINS
D6	HIGH MOUNTAINS

PROFILE TYPE (3rd LETTER)

a	>75% OF GENTLE SLOPE IS IN LOWLAND
b	50-75% OF GENTLE SLOPE IS IN LOWLAND
c	50-75% OF GENTLE SLOPE IS ON UPLAND
d	>75% OF GENTLE SLOPE IS ON UPLAND

FIGURE 2.4. Annual Average Wind Power in the South Central Region

Classes of Wind Power Density at 10 m and 50 m^(a)

Wind Power Class	10 m (33 ft)		50 m (164 ft)	
	Wind Power Density, watts/m ²	Speed, ^(b) m/s (mph)	Wind Power Density, watts/m ²	Speed, ^(b) m/s (mph)
	0	0	0	0
1	100	4.4 (9.8)	200	5.6 (12.5)
2	150	5.1 (11.5)	300	6.4 (14.3)
3	200	5.6 (12.5)	400	7.0 (15.7)
4	250	6.0 (13.4)	500	7.5 (16.8)
5	300	6.4 (14.3)	600	8.0 (17.9)
6	400	7.0 (15.7)	800	8.8 (19.7)
7	1000	9.4 (21.1)	2000	11.9 (26.6)

(a) Vertical extrapolation of wind speed based on the 1/7 power law.

(b) Mean wind speed is based on Rayleigh speed distribution of equivalent mean wind power density. Wind speed is for standard sea-level conditions. To maintain the same power density, speed increases 5%/5000 ft (3%/1000 m) of elevation.

TABLE 2.2. Areal Distribution of Wind Power Classes in the South Central Region

Power Class	Land Area (km ²) Equal or Exceeding Power Class						
	South Central	Arkansas	Kansas	Louisiana	Missouri	Oklahoma	Texas
1	1,510,000	140,000	210,000	120,000	180,000	180,000	690,000
2	900,000	6,000	195,000	4,100	80,000	150,000	470,000
3	460,000	4,300	170,000	0	7,700	90,000	190,000
4	190,000	4,300	76,000	0	0	50,000	60,000
5	30,000	91	4,200	0	0	6,900	20,000
6	1,200	0	0	0	0	220	1,100
7	450	0	0	0	0	0	450

Power Class	Percentage Land Area Equal or Exceeding Power Class						
	South Central	Arkansas	Kansas	Louisiana	Missouri	Oklahoma	Texas
1	100.	100.	100.	100.	100.	100.	100
2	60.00	4.50	92.00	3.0	46.0	84.0	70.00
3	30.00	3.20	80.00	0.00	4.5	50.0	33.00
4	13.00	3.20	35.00	0.00	0.0	27.0	14.20
5	2.00	0.07	2.00	0.00	0.0	3.8	6.90
6	0.08	0.00	0.00	0.00	0.0	0.12	0.35
7	0.03	0.00	0.00	0.00	0.0	0.00	0.16

FIGURE 2.5. Seasonal Maximum Wind Power in the South Central Region

CHAPTER 3: STATE FEATURES

The wind resource for each state is described in Chapters 4 through 9. The text of each description is followed by maps, graphs and tables that identify features of the geography and the wind energy resource and summarize the data collected from the observation stations. The sequence of maps, tables and graphs used to depict these features is presented in Table 3.1. In the state descriptions, these illustrations are presented so that related information is on facing pages and can be viewed simultaneously.

To avoid repetition in the following chapters, the general format and content of the various maps, tables and graphs used to describe the wind resource for each state are summarized here.

3.1 MAPS OF STATE FEATURES

The maps of cultural geography show the locations of major cities, rivers and terrain features for each state. The land-surface form maps are reconstructions of portions of the map of classes of land-surface form by Hammond (1964; this is also available at a scale of 1:17,000,000 on Plate 62 in the National Atlas of the United States). The use of the land-surface form map was described in Section 1.8.

Two maps are used to show the locations of stations with wind data. The first map gives the locations and names of the NCC stations with wind data in any form. The other map shows the locations of NCC, fire weather and other data stations that were utilized in this assessment of the wind resource.

The map of annual average wind power is accompanied by maps of the certainty rating of the estimated annual average wind power by grid cell, and maps of the areal distribution of the wind resource by grid cell. The certainty rating, which ranges from 1 (low) to 4 (high), indicates the level of confidence in the estimates of the wind resource in each cell of the grid. The rating is based on the availability of wind data, the complexity of terrain, and the inherent geographical variability of the wind resource (see Section 1.9). The maps of areal distribution give the percentage of land area in each cell estimated to experience an annual average wind power class equal to or exceeding power class 2, 3, 4 and 5 (see Section 1.10).

Maps of the average wind power are presented for each season: winter (December, January, February); spring (March, April, May); summer (June, July, August); and autumn (September, October, November). The legend for the power classes is found with the annual average wind power map.

TABLE 3.1. Maps, Tables and Graphs Used to Depict the Wind Resource

Maps	
Left Hand	Right Hand
Cultural Geography	Topographic Shaded Relief
Land-Surface Form	Legend to Land-Surface Form
NCC Station Locations	Location of Stations Used in Wind Assessment
Annual Average Wind Power	Legend to Wind Power Classes and Table on Areal Distribution
Certainty Rating	Legend for Certainty Rating
Areal Distribution (Power Classes 2 & 3)	Areal Distribution (Power Classes 4 & 5)
Seasonal Average Wind Power (Winter, Summer)	Seasonal Average Wind Power (Spring, Autumn)
Graphs	
Summary Table of Selected Stations	Interannual Speed and Power
Monthly Speed and Power	Diurnal Speed
Directional Frequency	Speed Frequency
Speed Duration	Power Duration

3.2 FEATURES OF SELECTED STATIONS

The analysis of the wind resource on a state and regional basis depends on information from individual stations. For those stations with one or three hourly data on NCC magnetic tapes, a very detailed presentation of the temporal variation and character of the wind resource can be obtained. Graphs portraying various features of the wind resource have been prepared for selected stations in each state and are presented in the state chapters. For each station presented, a brief description of the station's topographical setting and unique features is given in the text preceding the maps and graphs. The geographical area represented by a station varies, depending on the complexity of the local terrain and variability of the wind resource.

A table listing the stations for which graphs and summaries of the features of the wind resource are presented precedes the series of graphs. Height adjustments were made only to obtain estimates of the average wind speed and power at 10 m and 50 m given in this table. No attempt was made to adjust to a reference height any of the other wind characteristics (e.g., diurnal wind speeds, frequency distributions of wind speed, wind direction, speed and power duration, etc.) presented in the graphs for selected stations. Caution should therefore be used in comparing and interpreting station plots.

In the plots of interannual wind power and speed, the first line of each station graph contains the station name and state. The second line contains the WBAN number. In all other plots, the first line on each station graph contains the station identification that corresponds to the name and location listed in the table and the month and year of the selected period of record. Only one period of record with constant anemometer height was plotted for most stations, even though some stations had several periods of record. However, if there was uncertainty as to which period had better anemometer exposure or if two periods with similar exposure indicated substantially different wind characteristics, two periods of record were plotted. Usually, periods when the anemometer was located on a mast directly on the ground were preferred to periods when the anemometer was located on the roof of a building.

The second line of each graph contains the WBAN number, the anemometer height (Z) in m and location, and the annual average wind speed (V) in m/s and wind power (P) in watts/m². V and P are adjusted to 10 m for the graphs of interannual and monthly average wind power and speed and are at anemometer height (Z) for all other graphs.

The coded information listed with the anemometer height is one of the following (Changery 1978):

R - indicates the anemometer was located on the roof of a control tower, operations building, hangar or other similar structure. Normal mast heights were 2 to 4 m (6 to 12 ft) above roof line; however, many inner-city locations used considerably taller masts. The listed height is elevation above ground level, not roof level; the "R" indicates an exposure type.

G - indicates the anemometer was located on a mast attached directly to the ground. Most anemometers at airport locations changed from a roof to ground exposure by the early 1960s.

B - indicates a beacon tower exposure. For these locations, neither R nor G was considered satisfactory.

UNK - indicates that documentation on instrument heights was not available.

If information on exposure was unavailable, no exposure code is given.

On a few station plots, an E follows the annual average wind power. If a pressure or temperature observation is missing, the wind power for that observation is computed using an air density based on station elevation. If the number of missing observations exceeds 25% of the total, then an E is used to designate that the wind power is an estimated value.

Up to 18 graphs of the same type may appear on one page to allow for station-to-station comparison. The scale of each set of plots was determined by the maximum range of values found for all stations in the region.

3.2.1 Interannual Wind Speed and Power

The plots of interannual wind speed and power portray the variations of the yearly average over all periods of record. The beginning and ending of each period of record with constant anemometer height and location are designated by a "plus" symbol on the wind power curve and by a "diamond" symbol on the wind speed curve. If the anemometer height was unknown, a height of 10 m was assumed. Only yearly mean wind speeds based on 12 months' data (January through December) were plotted.

Year-to-year deviations from the long-term annual average may not be a reliable indicator of the deviations at nearby sites or areas (Elliott 1979b). Changes in instrument exposure from local development and other factors can affect interannual variations in wind speed and power.

3.2.2 Monthly Average Wind Power and Speed

Graphs of the monthly average wind power and speed portray the monthly and seasonal trends of the wind. Stations with less than five years of observations may not show reliable seasonal trends. Also, stations in complex terrain may not represent the seasonal trends in nearby areas because of the influence of nearby terrain. Most of the station curves are within the 0 to 400 watts/m² range.

3.2.3 Diurnal Wind Speed by Season

The diurnal variation in wind speed according to season is plotted on graphs containing four curves, one for each season. Local standard time (LST) is used with hour 24 as midnight and hour 1 as the beginning hour. For National Weather Service and Federal Aviation Administration Stations, the diurnal curves are based on 24 observations daily for periods ending before 1965, and on 8 observations daily for periods ending after 1964. For Air Force stations, the diurnal curves are usually based on 24 observations daily regardless of the period. The diurnal curves for Navy stations are based on 24 observations daily for periods ending before March 1972 and on 8 observations daily for periods ending after February 1972.

3.2.4 Directional Frequency and Average Speed

Graphs of the annual average frequency of occurrence show the percentage of time that the observed wind direction was from each of 16-point compass sectors and the average wind speed of all observations in each sector. Some stations show a definite bias toward 8-point compass observations. The coincidence of peaks in the two curves indicates that the highest wind speeds occur from the prevailing directions. Caution should be used in applying these data to other sites, because nearby terrain and obstructions strongly influence the wind directions. Some of the directional data presented may not be reliable or representative because of the anemometer location.

3.2.5 Annual Average Wind Speed Frequency

Graphs of the annual average frequency of observed wind speeds are shown in 1 m/s intervals about each whole m/s wind speed. Along with the observed distribution, a Rayleigh wind speed distribution based on the annual mean speed is shown. Some of the stations show pronounced peaks in the observed distribution; these peaks reflect observer bias toward certain wind speeds, such as 2, 5, and 8 m/s (5, 10, and 15 knots). This bias occurs more frequently in records prior to 1960. Because many of the wind instruments used had a threshold velocity of about 1.5 m/s (3 knots), the frequency of observations in the 1 m/s class is often lower than the frequency of the calm and 2 m/s classes.

3.2.6 Annual Average Wind Speed and Power Duration

The percentage of time that a given wind speed or power is exceeded is shown in two sets of graphs. Abrupt changes in the slope of the duration curves for speed and power usually correspond to peaks in the speed frequency distribution caused by observer bias and instrument threshold velocity. Points are plotted at 1 m/s intervals for the speed duration curves. Points are plotted every 50 watts/m² up to 500 watts/m² and every 100 watts/m² up to 1000 watts/m² in the power duration curves.

ARKANSAS

CHAPTER 4: ARKANSAS

Arkansas has an area of 137,539 km² (53,104 mi²) and a population of 1,923,293 (1970). Almost one-third of the people live in one of the four metropolitan areas: Fayetteville-Springdale, Fort Smith, Little Rock-North Little Rock, and Pine Bluff (see Figure 4.1). There are five land regions: 1) The Ozark Plateau, often called the Ozark Mountains, extends across the northern part of the state. 2) The Ouachita Mountains are a series of ridges and valleys in west-central Arkansas. Here Blue Mountain rises to 799 m (2623 ft). 3) The Arkansas Valley, between the Ozark Plateau and the Ouachita Mountains, is generally lower than the highland regions to the north and south, but contains a few mountains including Magazine Mountains which at 839 m (2753 ft), is the highest point in the state. 4) The Mississippi alluvial plain, where most of Arkansas' crops are grown, extends along the Mississippi River and covers the eastern third of Arkansas. 5) The western Gulf coastal plain extends northward from Louisiana into southwestern and southcentral Arkansas, where the elevation is 17 m (55 ft) above sea level. The topographic relief map, shown in Figure 4.2, and the map of land-surface forms, shown in Figure 4.3, help to illustrate the positions of these land areas.

Arkansas' July temperatures average 26 to 27°C (78 to 80°F) in northwestern Arkansas and 28 to 29°C (82 to 84°F) in the lowlands. In January, temperatures average from 2 to 6°C (36 to 42°F) in the northwest and 6 to 9°C (42 to 48°F) in the south and east. Yearly precipitation averages about 140 cm (42 in.) but ranges from 100 cm (40 in.) in the mountainous northwest to about 140 cm (55 in.) in west and west-central Arkansas.

Available wind data from the National Climatic Center (NCC) are mostly located near the major population centers. The areas where data were nonexistent were the mountainous areas of the north-central and west-central portions of the state. Figures 4.4 and 4.5 show the locations of data stations used in this assessment.

4.1 ANNUAL AVERAGE WIND POWER

The annual average available wind power density in Arkansas is shown in Figure 4.6. The analyses of mean wind

power apply to terrain features that are favorably exposed to the wind, such as mountain summits, ridge crests, hilltops, and uplands (see Section 1.6).

However, nearby terrain features may interact with the windfield to cause the wind power at some exposed sites to vary as much as ± 50 to 100 percent from the assessment value. [See Wegley et al. (1980) for information on terrain features that may increase or reduce wind energy.] In forested or wooded areas, the estimates are representative of large clearings, such as airports, with good exposure to the prevailing strong winds. In mountainous regions, the analyses also reflect major valleys. The percentage of land area that is favorably exposed to the wind strongly depends on the land-surface form (Section 1.8).

An annual average wind power of class 4 is found in the highly exposed areas in the Ozark Plateau and Ouachita Mountains, in northwest and west-central Arkansas.

The remainder of the state has low wind power, with an annual average of class 1. The Arkansas Valley is sheltered between the Ozark Plateau and the Ouachita Mountains. The Mississippi alluvial plain in the east, and the western Gulf coastal plain in the south, are both flat areas with low wind power even over cleared areas that are well exposed to the wind.

4.1.1 Certainty Rating of the Wind Resource

Certainty ratings of the wind power values in Arkansas vary from 1 to 4 (see Figure 4.7). The highest wind power in the state is class 4, found in the Ozark Plateau and the Ouachita Mountains in northwestern and west-central Arkansas. These are also the areas with the lowest certainty rating, with a value of 1. Three areas have the highest certainty rating of 4, all of which have wind power values of 1. These areas are in the extreme northeast and southwest, as well as one in the center of the state. The rest of Arkansas has a certainty rating of 3.

The windiest areas in the Ozark Plateau and Ouachita Mountains have a

certainty rating of only 1 because the ridges and valleys cause high variability in the wind power. The northern Ozark Plateau has a certainty rating of 3 since data were plentiful in the area near Fayetteville, Harrison, and Flippin.

Availability of data also accounts for the high certainty ratings of 4 in the northeast near Walnut Ridge and Blytheville, in the southwest near Texarkana and El Dorado, and in the center of the state near Little Rock and Jacksonville. These areas also have quite level land-surface forms. The remainder of Arkansas is also quite level but has a certainty rating of 2 because data were scarce in these areas.

4.1.2 Areal Distribution

The areal distribution of wind power in Arkansas is shown in Figure 4.8. The percent of area in each grid cell with wind power equal to or greater than the designated class is given for classes 2, 3, 4, and 5. Although nearly one-third of the grid cells are included under class 4 wind power, only 6 percent of the actual land area is estimated to experience wind power of that magnitude (see Table 4.1). This is because only the ridges and peaks of the Ozark Plateau and Ouachita Mountains are exposed to the higher winds, while most of the area is sheltered. An additional 4 percent of the land is estimated to be in class 2, leaving about 95 percent of the total land area in Arkansas under class 1 wind power.

4.2 SEASONAL WIND POWER

Wind power maps for each season are shown in Figure 4.9. The higher elevations experience the greatest wind power in winter and spring. Except for class 2 wind power over northeastern Arkansas in winter and spring, class 1 wind power predominates in every season over the Arkansas Valley, the Mississippi alluvial plain in the east, and the western Gulf coastal plain in the south.

4.2.1 Winter

Moderately strong winds over northwestern Arkansas in the winter result in class 5 wind power over the peaks and ridges of the Ozark Plateau and Ouachita Mountains. The northeastern

part of the state is affected by frequent, strong northerly winds and experiences class 2 wind power in the winter. Otherwise, class 1 wind power prevails over the plains.

4.2.2 Spring

Class 4 wind power is found over the Ozark Plateau and Ouachita Mountains with class 2 and 3 in the uplands bordering these areas. Northeastern Arkansas continues to experience some strong northerly winds in the spring, resulting in class 2 wind power. Class 1 wind power persists over the remainder of the state. The winds are more predominantly from the south as the subtropical anticyclone develops over the southeastern United States.

4.2.3 Summer

Fairly light southerly winds prevail over Arkansas in the summer. Wind power of class 1 covers most of the state, and the highest elevations only experience class 2 wind power. The southern anticyclone becomes established in summer in the southeastern states and the pressure gradient is weak both at the surface and aloft.

4.2.4 Autumn

Autumn winds are only slightly stronger than the winds in the summer, but the direction is more variable as the westerlies move down from the north. The wind power profile looks the same as in the summer, with class 2 wind power over mountain ridges and peaks in northwest Arkansas, and class 1 wind power over the rest of the state.

4.3 FEATURES OF SELECTED STATIONS

Table 4.2 gives the location and annual wind speed and power of twelve stations in Arkansas. Additional wind information for these stations is illustrated in Figures 4.10 through 4.16. Each of these stations is described below.

Blytheville is in the Mississippi alluvial plain in northeastern Arkansas. Its wind characteristics are consistent with wind data at nearby stations in Arkansas as well as in southeastern Missouri and western Tennessee.

El Dorado is located in southern Arkansas, in the level terrain of the western Gulf coastal plain. Its anemometer appeared to have good exposure on a roof top, although the winds are consistently lighter than those at surrounding stations at all seasons.

Fayetteville Airport lies in a flat valley of the Ozark Plateau in northwest Arkansas. Hilltops and uplands should have up to one class higher wind power than the airport, which is somewhat sheltered from the prevailing strong winds.

Flippin, located in northern Arkansas in the Ozark Plateau, is sheltered by surrounding higher ridges.

Fort Smith is in the Arkansas River valley near the state's western border and is sheltered by mountains to the north and south. It has fairly good exposure to westerly winds, but prevailing winds are easterly.

Harrison appears representative of the Ozark Plateau, although only two years of digitized data are available for this location. Hills and mountains of over 2,000 ft in elevation are located within 5 miles to the west and southwest of the airport and may shield the winds from these directions.

Jacksonville, the location of the Little Rock AFB, appears to have good exposure.

Little Rock is east of the Ouachita Mountains in the Mississippi alluvial plain. It has good exposure to the wind, and its wind power estimate is consistent with the values at surrounding stations.

Pine Bluff is southeast of Little Rock and representative of the Mississippi alluvial plains.

Texarkana, in southwest Arkansas, is listed for two different time periods with different anemometer heights. The average wind speed was 20 percent lower from 1959 to 1964 than from 1948 to 1953. Texarkana is in a class 1 wind power region.

Walnut Ridge is near the western edge of the Mississippi alluvial plain. Its wind characteristics are typical for northeastern Arkansas, with wind power

slightly lower than at nearby Bytheville.

4.3.1 Interannual Wind Power and Speed

Of the eleven selected stations in Arkansas, three have selected periods of record of 10 years or more during which the anemometer was not moved. These stations are Fort Smith, Little Rock Airport, and Jacksonville. Interannual variations at these stations do not coincide (Figure 4.10). The only apparent similarity in data from these stations is the relative maximum during 1961, which is evident at all three places. Most other interannual fluctuations do not coincide.

4.3.2 Monthly Average Wind Power and Speed

Except for Texarkana (1948-53), all stations in Arkansas show maximum wind during March (see Figure 4.11). Texarkana (1948-53) shows a maximum wind in January. This January maximum is primarily due to the period of record (1948 to 1953) when unusually severe winter storms were experienced in January. This is also shown by the Pine Bluff record from nearly the same period, which has a relatively slight maximum in January. The other noteworthy feature of the monthly average wind power graphs is the relative maximum for Little Rock Air Force Base, Pine Bluff, and Texarkana in September. Daily average temperatures drop most rapidly during September as the jet stream migrates southward and causes strong winds associated with these strong temperature gradients. In every case, the summer months of July and August show the minimum potential for utilizing wind energy.

4.3.3 Diurnal Wind Speed by Season

The diurnal wind speed graphs are similar for all the stations in Arkansas (see Figure 4.12). The highest winds usually occur during the late morning and early afternoon hours, 1000 to 1500 local standard time (LST). Wind speeds are lowest during the night. These generalizations hold true for each season. The greatest diurnal variations occur in the spring and summer, with the least variation in the winter. Fayetteville and Flippin, both valley stations, experience the greatest

variation, with a difference near 3 m/s between day and night time wind speeds.

4.3.4 Directional Frequency and Average Speed

Southerly flow prevails over Arkansas during the spring, summer, and autumn. Each station shows a maximum or relative maximum frequency of wind from the south, except Fort Smith (see Figure 4.13). Fort Smith is located in the Arkansas Valley, north of the Ouachita Mountains which block the south winds. Fort Smith experiences mostly easterly winds. Walnut Ridge and Blytheville, in northeastern Arkansas, show a relative maximum of northerly winds, since they are affected by northerly flow during the winter. Harrison and Flippin have a relative maximum of northerly winds, due to the predominant northwesterly flow in winter over the Ozark Plateau.

The maximum average wind speeds occur in the winter and spring, when the wind direction is generally from the west-northwest and south respectively.

The graphs of average wind speed generally show peaks for the west-northwest and the south.

4.3.5 Annual Average Wind Speed Frequency Distribution

Annual average wind speed frequencies are given in Figure 4.14. Observer bias accounts for peaks at 2 and 5 m/s, which correspond to 5 and 10 kts. A relative minimum of 1 m/s at most of the stations is accounted for because wind must reach a threshold speed before the anemometer will record it.

4.3.6 Annual Average Wind Speed and Power Duration

The percentage of time that a given wind speed or power is exceeded is shown in Figures 4.15 and 4.16. Abrupt changes in the slope of the duration curves correspond to peaks in the speed frequency distribution caused by observer bias and the threshold speed of the anemometer.

FIGURE 4.1. Geographic Map of Arkansas

FIGURE 4.2. Topographic Map of Arkansas

FIGURE 4.3. Land-Surface Form Map for Arkansas

LAND-SURFACE FORM LEGEND

PLAINS

A1	FLAT PLAINS
A2	SMOOTH PLAINS
B1	IRREGULAR PLAINS, SLIGHT RELIEF
B2	IRREGULAR PLAINS

TABLELANDS

B3c,d	TABLELANDS, MODERATE RELIEF
B4c,d	TABLELANDS, CONSIDERABLE RELIEF
B5c,d	TABLELANDS, HIGH RELIEF
B6c,d	TABLELANDS, VERY HIGH RELIEF

PLAINS WITH HILLS OR MOUNTAINS

A,B3a,b	PLAINS WITH HILLS
B4,a,b	PLAINS WITH HIGH HILLS
B5a,b	PLAINS WITH LOW MOUNTAINS
B6a,b	PLAINS WITH HIGH MOUNTAINS

SCHEME OF CLASSIFICATION

SLOPE (1st LETTER)

A	>80% OF AREA GENTLY SLOPING
B	50-80% OF AREA GENTLY SLOPING
C	20-50% OF AREA GENTLY SLOPING
D	<20% OF AREA GENTLY SLOPING

OPEN HILLS AND MOUNTAINS

C2	OPEN LOW HILLS
C3	OPEN HILLS
C4	OPEN HIGH HILLS
C5	OPEN LOW MOUNTAINS
C6	OPEN HIGH MOUNTAINS

LOCAL RELIEF (2nd LETTER)

1	0 TO 30m (1 TO 100 ft)
2	30 TO 90m (100 TO 300 ft)
3	90 TO 150m (300 TO 500 ft)
4	150 TO 300m (500 TO 1000 ft)
5	300 TO 900m (1000 TO 3000 ft)
6	900 TO 1500m (3000 TO 5000 ft)

HILLS AND MOUNTAINS

D3	HILLS
D4	HIGH HILLS
D5	LOW MOUNTAINS
D6	HIGH MOUNTAINS

PROFILE TYPE (3rd LETTER)

a	>75% OF GENTLE SLOPE IS IN LOWLAND
b	50-75% OF GENTLE SLOPE IS IN LOWLAND
c	50-75% OF GENTLE SLOPE IS ON UPLAND
d	>75% OF GENTLE SLOPE IS ON UPLAND

FIGURE 4.4. NCC Station Locations in Arkansas

FIGURE 4.5. Location of Stations-Used in Arkansas Wind Assessment

FIGURE 4.6. Arkansas Annual Average Wind Power

Classes of Wind Power Density at 10 m and 50 m^(a)

Wind Power Class	10 m (33 ft)		50 m (164 ft)	
	Wind Power Density, watts/m ²	Speed, ^(b) m/s (mph)	Wind Power Density, watts/m ²	Speed, ^(b) m/s (mph)
	0	0	0	0
1	100	4.4 (9.8)	200	5.6 (12.5)
2	150	5.1 (11.5)	300	6.4 (14.3)
3	200	5.6 (12.5)	400	7.0 (15.7)
4	250	6.0 (13.4)	500	7.5 (16.8)
5	300	6.4 (14.3)	600	8.0 (17.9)
6	400	7.0 (15.7)	800	8.8 (19.7)
7	1000	9.4 (21.1)	2000	11.9 (26.6)

(a) Vertical extrapolation of wind speed based on the 1/7 power law.

(b) Mean wind speed is based on Rayleigh speed distribution of equivalent mean wind power density. Wind speed is for standard sea-level conditions. To maintain the same power density, speed increases 5%/5000 ft (3%/1000 m) of elevation.

TABLE 4.1. Areal Distribution (km²) of Wind Power Classes in Arkansas

Power Classes	Land Area	% Land Area	Cumulative Land Area	% Cumulative Land Area
1	130,000	95.0	140,000	100.00
2	1,800	1.3	6,000	4.50
3	0	0.0	4,300	3.20
4	4,200	3.1	4,300	3.20
5	91	0.7	91	.07
6	0	0.0	0	0.00
7	0	0.0	0	0.00

FIGURE 4.7. Certainty Rating of Arkansas Wind Resource

CERTAINTY RATING LEGEND

Rating	Definition
1	<p>The lowest degree of certainty. A combination of the following conditions exists:</p> <ol style="list-style-type: none"> 1) No data exist in the vicinity of the cell. 2) The terrain is highly complex. 3) Various meteorological and topographical indicators suggest a high level of variability of the resource within the cell.
2	<p>A low-intermediate degree of certainty. One of the following conditions exists:</p> <ol style="list-style-type: none"> 1) Little or no data exist in or near the cell, but the small variability of the resource and the low complexity of the terrain suggest that the wind resource will not differ substantially from the resource in nearby areas with data. 2) Limited data exist in the vicinity of the cell, but the terrain is highly complex or the mesoscale variability of the resource is large.
3	<p>A high-intermediate degree of certainty. One of the following conditions exists:</p> <ol style="list-style-type: none"> 1) There are limited wind data in the vicinity of the cell, but the low complexity of terrain and the small mesoscale variability of the resource indicate little departure from the wind resource in nearby areas with data. 2) Considerable wind data exist but in moderately complex terrain and/or in areas where moderate variability of the resource is likely to occur.
4	<p>The highest degree of certainty. Quantitative data exist at exposed sites in the vicinity of the cell and can be confidently applied to exposed areas in the cell because of the low complexity of terrain and low spatial variability of the resource.</p>

FIGURE 4.8. Areal Distribution of Wind Resource in Arkansas (Power Classes 2 and 3); Percent of Land Area With or Exceeding Power Class Shown

Class 4

Class 5

FIGURE 4.8 (Continued). Areal Distribution of Wind Resource in Arkansas (Power Classes 4 and 5); Percent of Land Area With or Exceeding Power Class Shown

Winter

Summer

FIGURE 4.9. Seasonal Average Wind Power in Arkansas (Winter, Summer)

Spring

Autumn

FIGURE 4.9 (Continued). Seasonal Average Wind Power in Arkansas (Spring, Autumn)

TABLE 4.2. Arkansas Stations With Graphs of the Wind Characteristics

Station	Station Name ^(a)	Latitude, Degrees North	Longitude, Degrees West	Elevation of Station, m	Period of Record, Month/Year	Annual Average Wind Speed, m/s				Annual Average Wind Power, watts/m ²		
						Anemometer Height, m	At Anemometer Height, m	At 10 m	At 50 m	At Anemometer Height, m	At 10 m	At 50 m
Rlytheville, Arkansas	Rlytheville AFB	35.97	89.95	80	05/60-12/70	4.6	3.1	3.4	4.3	56	78	156
El Dorado, Arkansas	Goodwin Airport	33.22	92.80	82	07/49-12/54	17.1	3.3	3.1	3.9	60	48	95
Fayetteville, Arkansas	Fayetteville Airport	36.00	94.17	381	07/49-12/54	16.5	3.7	3.4	4.3	96	78	155
Flippin, Arkansas	Flippin CAA	36.30	92.60	215	07/51-12/54	17.7	2.9	2.7	3.4	54	42	84
Fort Smith, Arkansas	Municipal Airport	35.33	94.37	141	08/60-12/78	7.0	3.3	3.5	4.4	46	54	107
Harrison, Arkansas	Harrison Airport	36.27	93.15	419	01/67-12/68	7.6	4.0	4.2	5.2	73	82	163
Jacksonville, Arkansas	Little Rock AFB	34.92	92.15	103	08/56-12/70	4.3	2.4	2.8	3.5	32	46	92
Little Rock, Arkansas	Adams Field Airport	34.73	92.23	84	11/59-12/75	6.1	3.5	3.8	4.8	53	66	131
Pine Bluff, Arkansas	Grider Field Airport	34.17	91.93	63	10/48-02/54	11.3	3.4	3.3	4.2	62	59	117
Texarkana, Arkansas	Webb Field Airport	33.45	94.00	112	06/59-08/64	8.2	3.4	3.5	4.4	53	58	115
Texarkana, Arkansas	Webb Field Airport	33.45	94.00	112	08/48-08/53	9.8	4.0	4.0	5.1	87	88	175
Walnut Ridge, Arkansas	Municipal Airport	36.13	90.93	84	04/49-12/54	9.1	3.2	3.3	4.1	62	64	128

(a) AFB-Air Force Base; CAA-Civil Aeronautics Administration Facility.

FIGURE 4.10. Interannual Wind Power and Speed for Arkansas

FIGURE 4.11. Monthly Average Wind Power and Speed for Arkansas

FIGURE 4.12. Diurnal Wind Speed by Season for Arkansas

— PERCENT FREQUENCY LEFT ORDINATE - PERCENT
 - - - - - WIND SPEED RIGHT ORDINATE - M/S
 PNL-3195 WERA-7
 ABSCISSA - WIND DIRECTION

FIGURE 4.13. Directional Frequency and Average Wind Speed for Arkansas

— ACTUAL DISTRIBUTION ORDINATE — PERCENT
 - - - RAYLEIGH DISTRIBUTION ABSCISSA — M/S
 PNL-3195 WERA-7

FIGURE 4.14. Annual Average Wind Speed Frequency for Arkansas

ORDINATE - PERCENT
ABSCISSA - M/S

PNL-3195 WERA-7

FIGURE 4.15. Annual Average Wind Speed Duration for Arkansas

ORDINATE - PERCENT
 ABSCISSA - WATTS/M²
 PNL-3195 WERA-7

FIGURE 4.16. Annual Average Wind Power Duration for Arkansas

KANSAS

CHAPTER 5: KANSAS

Kansas, which had a population of 2,249,071 in 1970, has an area of 213,063 km² (82,264 mi²). About 65 percent of the people live in cities. The metropolitan areas of Kansas City, Topeka, and Wichita are all located in the eastern half of the state (Figure 5.1).

Kansas varies in elevation from Mount Sunflower at 1,231 m (4,039 ft) in northwestern Kansas down to 207 m (680 ft) in the southeastern plains (Figure 5.2). There are two major geographic areas: the dissected till plains, often called the glaciated region, covers the northeastern part of the state. The High Plains (part of the Great Plains) cover the western two-thirds of Kansas, sloping upward from about 457 m (1,500 ft) in the east to about 1,200 m (4,000 ft) at the Colorado border (see Figure 5.3).

Temperatures average from 0°C (32°F) in January to 26°C (79°F) in July uniformly throughout the state. The state receives about 43 cm (17 in.) of snow each year. The southeast gets more than 100 cm (40 in.) of precipitation while the western border receives about 41 cm (16 in.).

Wind data stations in Kansas, identified in Figures 5.4 and 5.5, are primarily found along the more populated areas of the state. Data is generally sparse for the north and western borders of the state, however the consistency of data allows for a representative sampling.

5.1 ANNUAL AVERAGE WIND POWER

The annual average available wind power density in Kansas is shown in Figure 5.6. In areas of complex topography, the analyses of mean wind power apply to terrain features that are favorably exposed to the wind, such as hilltops and uplands (see Section 1.6). However, nearby terrain features may interact with the windfield to cause the wind power at some exposed sites to vary as much as +50 to 100 percent from the assessment value. [See Wegley et al. (1980) for information on terrain features that may increase or reduce wind energy.] In forested or wooded areas, the estimates are representative of large

clearings, such as airports, with good exposure to the prevailing strong winds. The percentage of land area that is favorably exposed to the wind strongly depends on the land-surface form (see Section 1.8).

The annual average wind power for Kansas (Figure 5.6) ranges from class 2 to class 4 throughout the state. Class 4 and 5 wind power estimates are primarily restricted to the High Plains areas in the southern and western portions of the state where there is little surface friction or roughness that would reduce the potential wind power.

Annual average wind power is class 3 in most of the north-central and eastern areas of Kansas. Here the terrain is slightly more complex than in southwestern Kansas, and represents an area of transition between the high plains to the west, and the low plains to the east. The class 3 area includes the Solomon and Republican Rivers, and extends southward into the eastern (lower) portions of the Arkansas River including Wichita.

Wind data from the extreme northeastern portion of Kansas indicate that less wind power (class 2) is available than is found in western and central Kansas. Northeastern Kansas, being lower in elevation and more densely populated than other areas of Kansas, exhibits less wind power potential than the higher, less populated areas. Open hills and woodlands in eastern Kansas also increase surface roughness and decrease potential wind power in the area.

5.1.1 Certainty Rating of the Wind Resource

The wind power estimates for the densely populated areas in northeastern Kansas and along the major rivers within the state have a certainty rating of 4 (see Figure 5.7) because of the availability of existing data and the low complexity of the terrain (plains with low hills). The Solomon River, the Republican River, the Kansas River and the Arkansas River areas are included within the area of certainty rating 4.

Most other sections of the state in remote locations, away from the cities

and major watersheds, have been assigned a certainty rating of 2. This includes nearly all of western Kansas except for the areas where good data were available such as Dodge City, Gordon City, Goodland, and Russell. Although few year-round data were available from much of western Kansas, the wind power estimates in these areas here are assigned a certainty rating of 2 because of the uniformity of surface terrain, vegetation, and small spatial variability of the wind resource in these areas.

5.1.2 Areal Distribution

The areal distribution of wind power in Kansas is illustrated in Figure 5.8. The numbers identify the percentage of area in each cell of the grid in which the wind power equals or exceeds the threshold value. Most of the state experiences class 3 and 4 winds with a combined spatial frequency of nearly 75 percent while class 2 represents approximately 12 percent (see Table 5.1). The percentage of grid boxes within each power category closely corresponds to the percentage of land area within each power category, due to the uniformity of the terrain and the lack of small local variances.

5.2 SEASONAL WIND POWER

Wind power maps for each season are shown in Figure 5.9. The season of maximum wind power is spring, while summer is the season of lowest wind power over the entire state.

5.2.1 Winter

Winter is the second windiest season in Kansas. The wind power estimates for winter in Kansas appear much like the annual average estimates, ranging in strength from class 2 in the low plains and valleys in northeastern Kansas, to classes 4 and 5 in the higher western plains. Class 5 encompasses the extreme southwest corner of the state. Class 4 is the dominant class in winter, covering nearly 50 percent of the area. Even though upper-level winds are strongest during the winter months, and are predominantly westerly, the winter wind power in the plains of Kansas is generally 20 to 40 percent less than in the spring, largely due to the stability of the colder air near the surface and the strength of the low-level jet.

5.2.2 Spring

In the spring, the entire state of Kansas experiences its strongest potential for utilizing wind power. All areas of the state except for the extreme eastern portion are estimated to have class 5 and 6 wind power. The high plains in western and southwestern Kansas experience the greatest wind power (class 6) during the spring. Throughout the slightly lower plains in the mid-section of the state, the wind resource is estimated at class 5. Further eastward and lower in elevation, the wind is reduced to class 4, dropping as low as class 3 in extreme northeastern Kansas, near the Missouri River valley.

5.2.3 Summer

In the summer, wind power is class 3 or less over the entire state. Summertime wind power patterns are similar to those of winter and spring, but lesser in magnitude, with summer showing the least potential of any season. The highest wind rating (class 3) is found in the western High Plains, dropping to class 2 in east-central Kansas, and class 1 in the lower elevations of extreme eastern Kansas.

5.2.4 Autumn

In autumn, wind power potential increases from summer as the jet stream migrates southward and the upper air winds intensify, causing a stronger pressure gradient and generally stronger surface winds over Kansas. An area of class 4 wind power is estimated in the High Plains of southwestern Kansas. The remainder of the western two-thirds of the state has class 3 wind power, dropping to class 1 near the Kansas and Missouri River valleys in extreme northeastern Kansas.

5.3 Features of Selected Stations

Table 5.2 gives the location and annual wind speed and power density of eighteen stations in Kansas. Graphs of other features of the wind resource at these stations are shown in Figures 5.10 to 5.16. Each of these stations is described separately below.

Anthony, situated near Bluff Creek, appears to be representative of the south-central plains extending to the Oklahoma border.

Chanute, Martin Johnson Airport, is believed to have good anemometer exposure, and shows strongest winds from the south, as do most other stations.

Concordia, located near the south bank of the Republican River, has a relatively low anemometer height but good exposure in all directions.

Dodge City is located near the Arkansas River in the high plains of Kansas. Relatively flat terrain contributes to good exposure to the wind from all directions. Dodge City data are believed to be representative of most areas along the upper Arkansas River and the plains of southwestern Kansas.

Emporia, located in east-central Kansas, is significant in that it bisects the lower plains between Wichita and Topeka. Largely due to an anemometer height of over 12 meters, Emporia is believed to have good exposure in all directions.

Fort Leavenworth Army Air Field is located in extreme northeastern Kansas near the Missouri River valley, and is representative of low-lying sheltered areas in the Missouri River valley north of Kansas City. Its average wind power never exceeds class 1 in any season.

Fort Riley Army Air Field is located in east-central Kansas where the Republican River meets the Kansas River. Even though the anemometer height is one of the lowest of all selected stations, Fort Riley is believed to be representative of the areas in the Kansas River valley west of Topeka.

Garden City, situated in the high plains west of Dodge City, has good anemometer exposure, and appears representative of areas in the western high plains.

Goodland Airport, located near the Colorado border in the northwestern high plains, shows relatively strong winds compared to eastern Kansas, and is representative of the extreme northwestern portion of the state.

Hill City Airport, on the upper Solomon River in the north-central plains, appears to be geographically representative of the area between Smokey Hill River and Nebraska. However, the data seems questionable.

Hutchinson Naval Air Station, located in central Kansas along the Arkansas River, has good anemometer exposure in all directions and provides key data from the area northwest of Wichita.

Lebo, situated in east-central Kansas, has good site exposure to the wind from all directions and is probably representative of much of southeastern Kansas, although only two years and four months of data were available.

Olathe Naval Air Station is probably representative of extreme east-central Kansas and the low plains near the Missouri border.

Russell Municipal Airport appears representative of the central plains of Kansas, although the anemometer has a roof top exposure and there is a higher obstruction (building) in one direction.

Salina Airport, near the Smokey Hill River in central Kansas, is representative of east-central Kansas and appears to have good exposure in all directions.

Salina Air Force Base (site of the current airport), just southwest of Salina, shows lower wind speed and power than nearby Salina Airport (1952-54). This was possibly due to anemometer exposure.

Topeka Airport is located in the Kansas River valley. The data are representative of areas in the Kansas River valley and other low-lying areas in the northeastern plains of Kansas.

Wichita, the largest city in south-central Kansas, is located near the Arkansas River and provides long-term data from the plains bordering Oklahoma.

5.3.1 Interannual Average Wind Power and Speed

Seven stations selected had periods of record of 10 or more years during which the anemometer was not moved. These are: Concordia, Dodge City, Goodland, Olathe, Russell, Topeka, and Wichita. These represent several of the major population areas, and provide data from most of the different geographical areas in Kansas.

Many of the interannual variations at these seven stations are similar

(Figure 5.10). For example, 1959 was a relatively high wind speed year at Wichita, Russell, and Dodge City, followed by a 2 year plunge to a relatively low wind speed year in 1961 at all three stations. All these stations except Wichita had peak wind speeds during 1964.

5.3.2 Monthly Average Wind Power and Speed

Except for Salina, all stations in the state of Kansas show maximum wind energy during the spring in the months of March and April. However, Salina shows a maximum during June, along with another maximum during March and April. This is apparently due to the specific years within the period of record from 1952 to 1954. These years were particularly windy in June, evidenced by the wind records from Emporia and Hill City. These stations were also active during the period 1952 to 1954, and also show relative maxima for the month of June. The June maximum has been reduced slightly in the Hill City and Emporia records, due to averaging additional years into the record. At stations with less than three years of data, monthly trends may not be reliable or consistent with the long-term mean trends.

5.3.3 Diurnal Wind Speed by Season

Strong uniformity is evident in all the selected station records of diurnal wind speed by season. There is not only strong uniformity between stations, but also between all seasons at each station. All stations have the highest wind speeds during the daylight hours, with increasing wind speeds during periods of heating and decreasing wind speeds during afternoon and evening periods of cooling. Minimum wind speeds generally occur during the night.

5.3.4 Directional Frequency and Average Speed

The directional frequency (Figure 5.13) of the prevailing winds over the state of Kansas appears to be similar throughout the state with the maximum frequency occurring from a southerly direction. Prevailing winds are southerly at all selected stations except Hill City, which shows an even distribution of winds from each direction. This may result from a poor anemometer exposure to the south and/or increased surface roughness to the south due to local topographical features of the south fork of the Solomon River.

5.3.5 Annual Average Wind Speed Frequency Distribution

Observed data at most selected stations closely fits Rayleigh distributions rather well except in a few cases of observer bias (Figure 5.14). Observer bias is most evident at Anthony, Emporia, Gordon City, Hill City, Lebo, and Salina (1952-54), all of which had periods of observations in the 1940s and 1950s. This observer bias is generally not apparent at stations with observations in the 1960s and 1970s. Two stations - Fort Leavenworth and Fort Riley - show a high frequency of calms, probably due to their sheltered locations in river valleys and their low anemometer heights.

5.3.6 Annual Average Wind Speed and Power Duration

The percentage of time that a certain wind speed and power is exceeded is shown in Figures 5.15 and 5.16. Abrupt changes in the slopes of the duration curves correspond to peaks in the speed frequency distribution caused by observer bias and the threshold speed of the anemometer.

FIGURE 5.1. Geographic Map of Kansas

FIGURE 5.2. Topographic Map of Kansas

FIGURE 5.3. Land-Surface Form Map for Kansas

LAND-SURFACE FORM LEGEND

PLAINS

A1	FLAT PLAINS
A2	SMOOTH PLAINS
B1	IRREGULAR PLAINS, SLIGHT RELIEF
B2	IRREGULAR PLAINS

PLAINS WITH HILLS OR MOUNTAINS

A, B3a, b	PLAINS WITH HILLS
B4, a, b	PLAINS WITH HIGH HILLS
B5a, b	PLAINS WITH LOW MOUNTAINS
B6a, b	PLAINS WITH HIGH MOUNTAINS

OPEN HILLS AND MOUNTAINS

C2	OPEN LOW HILLS
C3	OPEN HILLS
C4	OPEN HIGH HILLS
C5	OPEN LOW MOUNTAINS
C6	OPEN HIGH MOUNTAINS

HILLS AND MOUNTAINS

D3	HILLS
D4	HIGH HILLS
D5	LOW MOUNTAINS
D6	HIGH MOUNTAINS

TABLELANDS

B3c, d	TABLELANDS, MODERATE RELIEF
B4c, d	TABLELANDS, CONSIDERABLE RELIEF
B5c, d	TABLELANDS, HIGH RELIEF
B6c, d	TABLELANDS, VERY HIGH RELIEF

SCHEME OF CLASSIFICATION

SLOPE (1st LETTER)

A	>80% OF AREA GENTLY SLOPING
B	50-80% OF AREA GENTLY SLOPING
C	20-50% OF AREA GENTLY SLOPING
D	<20% OF AREA GENTLY SLOPING

LOCAL RELIEF (2nd LETTER)

1	0 TO 30m (1 TO 100 ft)
2	30 TO 90m (100 TO 300 ft)
3	90 TO 150m (300 TO 500 ft)
4	150 TO 300m (500 TO 1000 ft)
5	300 TO 900m (1000 TO 3000 ft)
6	900 TO 1500m (3000 TO 5000 ft)

PROFILE TYPE (3rd LETTER)

a	>75% OF GENTLE SLOPE IS IN LOWLAND
b	50-75% OF GENTLE SLOPE IS IN LOWLAND
c	50-75% OF GENTLE SLOPE IS ON UPLAND
d	>75% OF GENTLE SLOPE IS ON UPLAND

FIGURE 5.4. NCC Station Locations in Kansas

FIGURE 5.5. Location of Stations Used in Kansas

FIGURE 5.6. Kansas Annual Average Wind Power

Classes of Wind Power Density at 10 m and 50 m^(a)

Wind Power Class	10 m (33 ft)		50 m (164 ft)	
	Wind Power Density, watts/m ²	Speed, ^(b) m/s (mph)	Wind Power Density, watts/m ²	Speed, ^(b) m/s (mph)
	0	0	0	0
1	100	4.4 (9.8)	200	5.6 (12.5)
2	150	5.1 (11.5)	300	6.4 (14.3)
3	200	5.6 (12.5)	400	7.0 (15.7)
4	250	6.0 (13.4)	500	7.5 (16.8)
5	300	6.4 (14.3)	600	8.0 (17.9)
6	400	7.0 (15.7)	800	8.8 (19.7)
7	1000	9.4 (21.1)	2000	11.9 (26.6)

(a) Vertical extrapolation of wind speed based on the 1/7 power law.

(b) Mean wind speed is based on Rayleigh speed distribution of equivalent mean wind power density. Wind speed is for standard sea-level conditions. To maintain the same power density, speed increases 5%/5000 ft (3%/1000 m) of elevation.

TABLE 5.1. Areal Distribution (km²) of Wind Power Classes in Kansas

Power Classes	Land Area	% Land Area	Cumulative Land Area	% Cumulative Land Area
1	16,000	7.8	210,000	100.00
2	25,000	12.0	195,000	92.00
3	95,000	45.0	170,000	80.00
4	70,000	33.0	76,000	35.00
5	4,200	2.0	4,200	2.02
6	0	0.0	0	0.00
7	0	0.0	0	0.00

FIGURE 5.7. Certainty Rating of Kansas Wind Resource

CERTAINTY RATING LEGEND

Rating	Definition
1	<p>The lowest degree of certainty. A combination of the following conditions exists:</p> <ol style="list-style-type: none"> 1) No data exist in the vicinity of the cell. 2) The terrain is highly complex. 3) Various meteorological and topographical indicators suggest a high level of variability of the resource within the cell.
2	<p>A low-intermediate degree of certainty. One of the following conditions exists:</p> <ol style="list-style-type: none"> 1) Little or no data exist in or near the cell, but the small variability of the resource and the low complexity of the terrain suggest that the wind resource will not differ substantially from the resource in nearby areas with data. 2) Limited data exist in the vicinity of the cell, but the terrain is highly complex or the mesoscale variability of the resource is large.
3	<p>A high-intermediate degree of certainty. One of the following conditions exists:</p> <ol style="list-style-type: none"> 1) There are limited wind data in the vicinity of the cell, but the low complexity of terrain and the small mesoscale variability of the resource indicate little departure from the wind resource in nearby areas with data. 2) Considerable wind data exist but in moderately complex terrain and/or in areas where moderate variability of the resource is likely to occur.
4	<p>The highest degree of certainty. Quantitative data exist at exposed sites in the vicinity of the cell and can be confidently applied to exposed areas in the cell because of the low complexity of terrain and low spatial variability of the resource.</p>

Class 2

Class 3

FIGURE 5.8. Areal Distribution of Wind Resource in Kansas (Power Classes 2 and 3); Percent of Land Area With or Exceeding Power Class Shown. An asterisk denotes 100%.

FIGURE 5.8 (Continued). Areal Distribution of Wind Resource in Kansas (Power Classes 4 and 5); Percent of Land Area With or Exceeding Power Class Shown. An asterisk denotes 100%.

FIGURE 5.9. Seasonal Average Wind Power in Kansas (Winter, Summer)

FIGURE 5.9 (Continued). Seasonal Average Wind Power in Kansas (Spring, Autumn)

TABLE 5.2. Kansas Stations With Graphs of the Wind Characteristics

Station	Station Name (a)	Latitude, Degrees North	Longitude, Degrees West	Elevation of Station, m	Period of Record, Month/Year	Annual Average Wind Speed, m/s				Annual Average Wind Power, watts/m ²			
						Anemometer Height, m	At Anemometer Height, m	At 10 m	At 50 m	Anemometer Height, m	At 10 m	At 50 m	
Anthony, Kansas	Anthony CAA	37.17	98.08	404	01/48-12/50	18.0	5.6	5.2	6.5	231	180	358	
Chanute, Kansas	Martin Johnson Airport	37.67	95.48	299	12/59-12/64	16.2	5.9	5.5	6.9	202	164	328	
Concordia, Kansas	Blosser Airport	39.55	97.65	449	06/62-12/78	6.4	5.4	5.8	7.3	159	193	384	
Dodge City, Kansas	Municipal Airport	37.77	99.97	796	04/61-12/78	6.1	5.8	6.2	7.8	183	226	451	
Emporia, Kansas	Emporia Kansas	38.33	96.20	369	11/50-12/54	12.2	5.7	5.5	7.0	210	193	384	
Ft. Leavenworth, Kansas	Sherman Field AAF	39.37	94.92	236	11/66-12/70	4.0	2.7	3.1	3.9	42	62	124	
Ft. Riley, Kansas	Marshall AAF	39.05	96.77	324	04/61-12/70	4.0	3.4	3.9	4.9	82	122	243	
Garden City, Kansas	Garden City CAA	37.97	100.82	867	01/48-06/50	13.4	5.5	5.3	6.6	254	224	446	
Goodland, Kansas	Renner Field Airport	39.37	101.70	1112	05/65-12/78	6.1	5.7	6.2	7.8	176	218	434	
Hill City, Kansas	Municipal Airport	39.38	99.83	671	01/49-12/54	7.3	4.8	5.0	6.3	154	176	351	
Hutchinson, Kansas	Hutchinson NAS	37.92	97.90	479	10/52-04/58	18.3	6.2	5.7	7.1	272	210	419	
Lebo, Kansas	Lebo CAA	38.42	98.80	352	05/48-09/50	17.4	5.5	5.1	6.4	215	170	338	
Olathe, Kansas	Olathe NAS	38.83	94.88	328	09/59-01/70	4.3	3.9	4.4	5.6	81	117	233	
Russell, Kansas	Municipal Airport	38.87	98.82	568	01/65-12/78	8.8	6.0	6.1	7.6	199	210	418	
Salina, Kansas	Salina Airport	38.82	97.57	389	01/52-12/54	7.0	5.3	5.6	7.0	188	219	436	
Salina, Kansas	Salina AFB	38.80	97.63	392	04/56-05/65	4.3	4.3	4.8	6.1	115	166	330	
Topeka, Kansas	Billard Airport	39.07	95.63	269	08/64-12/78	6.1	4.2	4.5	5.6	95	117	234	
Wichita, Kansas	Municipal Airport	37.65	97.42	404	07/67-12/78	7.6	5.4	5.6	7.0	169	190	378	

(a) CAA-Civil Aeronautics Administration Facility; AAF-Army Air Field; NAS-Naval Air Station; AFB-Air Force Base.

FIGURE 5.10. Interannual Wind Power and Speed for Kansas

FIGURE 5.11. Monthly Average Wind Power and Speed for Kansas

+---+ WINTER ◆---◆ SPRING
 ⊕---⊕ SUMMER ▣---▣ AUTUMN
 PNL-3195 WERA-7

ORDINATE - M/S
 ABSCISSA - HOUR

FIGURE 5.12. Diurnal Wind Speed by Season for Kansas

PERCENT FREQUENCY LEFT ORDINATE PERCENT
WIND SPEED RIGHT ORDINATE M/S
PNL-3195 WERA-7 ABCISSA WIND DIRECTION

FIGURE 5.13. Directional Frequency and Average Wind Speed for Kansas

—— ACTUAL DISTRIBUTION ORDINATE - PERCENT
 RAYLEIGH DISTRIBUTION ABSCISSA - M/S
 PNL-3195 WERA-7

FIGURE 5.14. Annual Average Wind Speed Frequency for Kansas

ORDINATE - PERCENT
ABSCISSA - M/S

PNL-3195 WERA-7

FIGURE 5.15. Annual Average Wind Speed Duration for Kansas

ORDINATE - PERCENT
ABSCISSA - WATTS/M²
PNL 3195 WERA-7

FIGURE 5.16. Annual Average Wind Power Duration for Kansas

LOUISIANA

CHAPTER 6: LOUISIANA

Louisiana has an area of 125,674 km² (48,523 mi²) and its population was 3,643,180 in 1970. About five-eighths of the people live in seven metropolitan areas: Alexandria, Baton Rouge, Lafayette, Lake Charles, Monroe, New Orleans, and Shreveport. These areas are fairly evenly distributed around the state (see Figure 6.1).

The state's elevation varies from 163 m (535 ft) at Driskill Mountain in northern Louisiana to 1.5 m (5 ft) below sea level at New Orleans (Figure 6.2). Louisiana was once part of an ancient bay of the Gulf of Mexico and was built to its present size by deposition of silt carried by the Mississippi and other rivers (see Figure 6.3).

The eastern Gulf coastal plain covers most of the area east of the Mississippi River. The Mississippi alluvial plain lies along the Mississippi River, and includes the Mississippi delta and several ancient channels of the Mississippi. The western Gulf coastal plain extends from the Mississippi alluvial plain westward into Texas. Marshes extend inland for about 32 km (20 mi) from the Gulf of Mexico.

Louisiana is one of the wettest states, with a yearly average rainfall of 142 cm (56 in.). Its average January temperature is 13°C (55° F). The July average is 28°C (82°F).

Stations with available wind data from the National Climatic Center (NCC) are shown in Figure 6.4. Of these, seventeen were used in the assessment (Figure 6.5). Although data were sparse throughout the state, variations were minimal and therefore considered representative.

6.1 ANNUAL AVERAGE WIND POWER

The annual average available wind power density in Louisiana is shown in Figure 6.6. In areas of complex topography, the analyses of mean wind power apply to terrain features that are favorably exposed to the wind, such as hilltops and uplands (see Section 1.6). However, nearby terrain features may interact with the windfield to cause the wind power at some exposed sites to vary as much as ± 50 to 100 percent from the

assessment value. [See Wegley et al. (1980) for information on terrain features that may increase or reduce wind energy.] In forested or wooded areas, the estimates are representative of large clearings, such as airports, with good exposure to the prevailing strong winds. The percentage of land area that is favorably exposed to the wind strongly depends on the land-surface form (Section 1.8).

The annual average wind power for Louisiana is shown in Figure 6.6. Class 2 wind power is the highest class existing within the state and occurs in a small area along the Mississippi River delta and along exposed shorelines of the Gulf of Mexico. Class 1 power prevails over the remainder of the state.

6.1.1 Certainty Rating of the Wind Resource

The wind power estimates for most of the state have a certainty rating of 4 due to the low complexity of terrain and the availability of data (Figure 6.7). These areas, for the most part, coincide with the more populated areas of the state. Certainty ratings of 1 and 2 cover the remaining portions of the state in areas where data were nonexistent and a small or moderate variability of the resource was evident. These areas cover the west-central region and lower elevations of the state where much of the land is unpopulated and/or marsh.

6.1.2 Areal Distribution

The areal distribution of wind power in Louisiana is illustrated in Figure 6.8. The numbers identify the percentage of area in each cell of the grid in which the wind power equals or exceeds the threshold value. Due to low elevation and low windspeed, Louisiana's annual average wind power estimates are restricted to classes 1 and 2. Of these two classes, the percentage of land area receiving class 2 is very small with 3 percent compared to the area receiving class 1 with 97 percent (see Table 6.1).

6.2 SEASONAL WIND POWER

Wind power maps for each season are shown in Figure 6.9. As seen in this figure, Louisiana shows little variation from season to season. Class 1 remains the major power class, although wind power is greater in winter and spring than in summer and autumn.

6.2.1 Winter

Winter is the only season when class 4 wind power is observed and is found at Burrwood, on the tip of the Mississippi River delta. Class 3 is restricted to the Mississippi River delta and exposed shorelines along the Gulf of Mexico. Class 2 occurs in the southeast corner of the state and near coastal areas in the south. The cold air masses dominating the eastern U.S. during this season cause east to southeast winds on the coast and are believed to account for the increase. Wind power is highest along the coast and decreases inland as the land increases in roughness.

6.2.2 Spring

During spring, class 2 wind power is evident along the coastal areas, but class 1 occurs over the rest of the state. During the spring, the pattern established closely aligns with that of the winter, and seasonal transition is quite apparent along the coastal areas.

6.2.3 Summer

In summer, class 1 wind power is observed throughout the entire state as the subtropical high pressure extends westward from the Atlantic Ocean. As is the case with most states under this subtropical system, light and variable winds are the predominant wind pattern.

6.2.4 Autumn

During autumn, wind power classes resemble those observed on the annual average wind power map. Class 1 continues to dominate the state except for the extreme southeast portion where class 2 is limited to the Mississippi delta. In this season, colder and more unstable air masses remain north of the state and show little influence.

6.3 FEATURES OF SELECTED STATIONS

Table 6.2 gives the location and annual wind speed and power density of twelve stations in Louisiana. Graphs of other features of the wind resource at these stations are shown in Figures 6.10 to 6.16. The majority of these stations occupy the lower two-thirds of the state.

Alexandria's Esler Field Airport lies in central Louisiana and because of its central location, period of record, and small variances in wind power, is representative of the central region.

Baton Rouge's Ryan Field Airport, situated in the flat plains of the southeastern portion of the state near the Mississippi River, is representative of the area in the east and south. Data from the station are comparable to those from nearby stations.

Boothville is located in the extreme southeastern edge of the state about 2 km from the Gulf of Mexico. This station receives class 2 wind power in all seasons except summer.

Burrwood, located on a small peninsula in the Mississippi delta, appears well exposed to ocean winds off the Gulf of Mexico. Unlike other stations in Louisiana, diurnal variations at Burrwood are very small.

Fort Polk is located in the west central portion of the state in the flat plains but on the fringe of the irregular plains. Only daytime observations, 0700 to 1600 LST, were available from this station.

Lafayette Airport, located in the south-central portion of the state, is representative of land area far enough inland to be free of land and sea-breeze effects. Although the anemometer height for the period was 16.8 m, wind speed and power align closely with those at other inland stations.

Lake Charles Airport is located in the southwestern part of the state with data spanning nearly 17 years at one site and 10 years at another site just several miles to the southwest. Both sites indicate class 1 wind power.

Monroe Airport is located in the flat plains in the northeastern part of the

state. Data cover an 8-year period and present a valid representation of the northeast area.

Moisant International Airport is located in the lower southeastern portion of the state. The data cover a 19-year period and coincide to those of New Orleans Naval Air Station, which cover a period of about 12 years.

Shreveport Airport is located in the northwestern portion of the state and has a station elevation of 82 m. This elevation is second only to Fort Polk of the stations identified. The annual average wind speed is slightly higher than Barksdale Air Force Base, located east-northeast of Shreveport Airport, but still shows good correlation.

6.3.1 Interannual Wind Power and Speed

Interannual graphs show little variation for those stations with 10 or more years of data except for Boothville and Lake Charles. Boothville shows small variation until 1976 and 1977 when wind power dropped and then increased, causing a fluctuation from 70 W/m^2 to 160 W/m^2 . This variation does not coincide very well with that at New Orleans. The other station showing a significant change was Lake Charles in the period between 1951 and 1956 when wind power decreased rather sharply from 150 W/m^2 to near 60 W/m^2 and then remained steady.

6.3.2 Monthly Average Wind Power and Speed

Monthly average wind power and speed maxima occur for the majority of the locations during late winter and early spring. The only station with winter entirely dominating is Burrwood where the maximum occurs in January.

6.3.3 Diurnal Wind Speed by Season

All stations, with the exception of Burrwood, show uniformity in all seasons. Burrwood, because of its proximity to water and minimum land mass, receives small diurnal variation resulting in winds remaining nearly constant throughout the day.

6.3.4 Directional Frequency and Average Speed

Good correlations exist for directional frequency. Directional maxima are from the south for the stations located in the northern portions of the state. Otherwise, directional frequencies are generally evenly distributed for the directions north clockwise through south, with frequency minima from west evident for all stations in Louisiana.

6.3.5 Annual Average Wind Speed Frequency Distribution

The graphs for Louisiana show that the Rayleigh distribution does not equate well to the actual distribution.

6.3.6 Annual Average Wind Speed and Power Duration

These graphs serve to give a visual representation of the percentage of time a given wind speed or power is exceeded. As is easily observed, favorable speed and/or power thresholds are quite restricted throughout all selected stations. Abrupt changes correspond to peaks in the threshold speed frequency distribution caused by observer bias and the threshold speed of the anemometer.

FIGURE 6.1. Geographic Map of Louisiana

FIGURE 6.2. Topographic Map of Louisiana

FIGURE 6.3. Land-Surface Form Map for Louisiana

LAND-SURFACE FORM LEGEND

PLAINS

A1	FLAT PLAINS
A2	SMOOTH PLAINS
B1	IRREGULAR PLAINS, SLIGHT RELIEF
B2	IRREGULAR PLAINS

PLAINS WITH HILLS OR MOUNTAINS

A,B3a,b	PLAINS WITH HILLS
B4,a,b	PLAINS WITH HIGH HILLS
B5a,b	PLAINS WITH LOW MOUNTAINS
B6a,b	PLAINS WITH HIGH MOUNTAINS

OPEN HILLS AND MOUNTAINS

C2	OPEN LOW HILLS
C3	OPEN HILLS
C4	OPEN HIGH HILLS
C5	OPEN LOW MOUNTAINS
C6	OPEN HIGH MOUNTAINS

HILLS AND MOUNTAINS

D3	HILLS
D4	HIGH HILLS
D5	LOW MOUNTAINS
D6	HIGH MOUNTAINS

TABLELANDS

B3c,d	TABLELANDS, MODERATE RELIEF
B4c,d	TABLELANDS, CONSIDERABLE RELIEF
B5c,d	TABLELANDS, HIGH RELIEF
B6c,d	TABLELANDS, VERY HIGH RELIEF

SCHEME OF CLASSIFICATION

SLOPE (1st LETTER)

A	>80% OF AREA GENTLY SLOPING
B	50-80% OF AREA GENTLY SLOPING
C	20-50% OF AREA GENTLY SLOPING
D	<20% OF AREA GENTLY SLOPING

LOCAL RELIEF (2nd LETTER)

1	0 TO 30m (1 TO 100 ft)
2	30 TO 90m (100 TO 300 ft)
3	90 TO 150m (300 TO 500 ft)
4	150 TO 300m (500 TO 1000 ft)
5	300 TO 900m (1000 TO 3000 ft)
6	900 TO 1500m (3000 TO 5000 ft)

PROFILE TYPE (3rd LETTER)

a	>75% OF GENTLE SLOPE IS IN LOWLAND
b	50-75% OF GENTLE SLOPE IS IN LOWLAND
c	50-75% OF GENTLE SLOPE IS ON UPLAND
d	>75% OF GENTLE SLOPE IS ON UPLAND

FIGURE 6.4. NCC Station Locations in Louisiana

FIGURE 6.5. Location of Stations Used in Louisiana Resource Assessment

FIGURE 6.6. Annual Average Wind Power in Louisiana

Classes of Wind Power Density at 10 m and 50 m^(a)

Wind Power Class	10 m (33 ft)		50 m (164 ft)	
	Wind Power Density, watts/m ²	Speed, ^(b) m/s (mph)	Wind Power Density, watts/m ²	Speed, ^(b) m/s (mph)
	0	0	0	0
1	100	4.4 (9.8)	200	5.6 (12.5)
2	150	5.1 (11.5)	300	6.4 (14.3)
3	200	5.6 (12.5)	400	7.0 (15.7)
4	250	6.0 (13.4)	500	7.5 (16.8)
5	300	6.4 (14.3)	600	8.0 (17.9)
6	400	7.0 (15.7)	800	8.8 (19.7)
7	1000	9.4 (21.1)	2000	11.9 (26.6)

(a) Vertical extrapolation of wind speed based on the 1/7 power law.

(b) Mean wind speed is based on Rayleigh speed distribution of equivalent mean wind power density. Wind speed is for standard sea-level conditions. To maintain the same power density, speed increases 5%/5000 ft (3%/1000 m) of elevation.

TABLE 6.1. Areal Distribution (km²) of Wind Power Classes in Louisiana

Power Classes	Land Area	% Land Area	Cumulative Land Area	% Cumulative Land Area
1	120,000	97.0	120,000	100.00
2	4,100	3.0	4,100	3.00
3	0	0.0	0	0.00
4	0	0.0	0	0.00
5	0	0.0	0	0.00
6	0	0.0	0	0.00
7	0	0.0	0	0.00

FIGURE 6.7. Certainty Rating of Louisiana Wind Resource

CERTAINTY RATING LEGEND

Rating	Definition
1	<p>The lowest degree of certainty. A combination of the following conditions exists:</p> <ol style="list-style-type: none"> 1) No data exist in the vicinity of the cell. 2) The terrain is highly complex. 3) Various meteorological and topographical indicators suggest a high level of variability of the resource within the cell.
2	<p>A low-intermediate degree of certainty. One of the following conditions exists:</p> <ol style="list-style-type: none"> 1) Little or no data exist in or near the cell, but the small variability of the resource and the low complexity of the terrain suggest that the wind resource will not differ substantially from the resource in nearby areas with data. 2) Limited data exist in the vicinity of the cell, but the terrain is highly complex or the mesoscale variability of the resource is large.
3	<p>A high-intermediate degree of certainty. One of the following conditions exists:</p> <ol style="list-style-type: none"> 1) There are limited wind data in the vicinity of the cell, but the low complexity of terrain and the small mesoscale variability of the resource indicate little departure from the wind resource in nearby areas with data. 2) Considerable wind data exist but in moderately complex terrain and/or in areas where moderate variability of the resource is likely to occur.
4	<p>The highest degree of certainty. Quantitative data exist at exposed sites in the vicinity of the cell and can be confidently applied to exposed areas in the cell because of the low complexity of terrain and low spatial variability of the resource.</p>

FIGURE 6.8. Areal Distribution of Wind Resource in Louisiana (Power Classes 2 and 3); Percent of Land Area With or Exceeding Power Class Shown. An asterisk denotes 100%.

FIGURE 6.9. Seasonal Average Wind Power in Louisiana (Winter, Summer)

Spring

Autumn

FIGURE 6.9 (Continued). Seasonal Average Wind Power in Louisiana (Spring, Autumn)

TABLE 6.2. Louisiana Stations With Graphs of the Wind Characteristics

Station	Station Name (a)	Latitude, Degrees North	Longitude, Degrees West	Elevation of Station, m	Period of Record, Month/Year	Annual Average Wind Speed, m/s				Annual Average Wind Power, watts/m ²		
						Anemometer Height, m	At Anemometer Height, m	At 10 m	At 50 m	At Anemometer Height, m	At 10 m	At 50 m
Alexandria, Louisiana	Esler Field Airport	31.38	92.30	33	02/60-10/77	6.7	2.8	3.0	3.7	44	52	104
Raton Rouge, Louisiana	Ryan Field Airport	30.53	91.15	24	02/59-12/78	6.1	3.5	3.7	4.7	54	67	133
Rothville, Louisiana	Rothville WFO	29.33	89.40	4	05/71-12/78	6.1	3.9	4.2	5.3	78	96	192
Rurrwood, Louisiana	Rurrwood SPL	28.97	89.38	4	10/56-12/64	10.1	4.8	4.8	6.1	139	139	276
Ft. Polk, Louisiana	Ft. Polk AAF	31.05	93.18	101	08/62-12/70	12.2	3.1	3.0	3.8	49	45	90
Lafayette, Louisiana	Municipal Airport	30.20	91.98	13	07/48-03/58	16.8	3.7	3.4	4.3	73	59	117
Lake Charles, Louisiana	Lake Charles Airport	30.12	93.22	5	03/62-12/78	6.7	3.9	4.1	5.2	73	87	173
Lake Charles, Louisiana	Lake Charles Airport	30.22	93.15	5	03/50-05/60	11.9	3.9	3.8	4.8	95	88	176
Monroe, Louisiana	Monroe Airport	32.52	92.03	29	01/50-12/58	10.4	3.4	3.4	4.3	66	65	130
New Iberia Louisiana	New Iberia Airport	30.03	91.88	8	01/61-10/64	47.5	2.4	1.9	2.4	33	17	34
New Orleans, Louisiana	Moisant Int'l Airport	30.03	90.03	9	12/59-12/78	6.1	3.5	3.8	4.8	58	72	143
New Orleans, Louisiana	New Orleans NAS	29.83	90.02	2	11/58-02/72	4.3	2.4	2.7	3.4	31	45	89
Shreveport, Louisiana	Municipal Airport	32.47	93.82	82	11/66-12/78	6.1	3.4	3.7	4.6	50	62	123
Shreveport, Louisiana	Barksdale AFB	32.50	93.68	51	05/63-12/70	4.0	2.6	2.9	3.7	35	52	104

(a) WFO-Weather Bureau Office; SPL-Special Purpose Office; AAF-Army Air Field; NAS-Naval Air Station; AFB-Air Force Base.

(b) Daytime observations only.

FIGURE 6.10. Interannual Wind Power and Speed for Louisiana

FIGURE 6.12. Diurnal Wind Speed by Season for Louisiana

— PERCENT FREQUENCY LEFT ORDINATE - PERCENT
 - - - WIND SPEED RIGHT ORDINATE - M/S
 PNL-3195 WERA-7
 ABSISSA - WIND DIRECTION

FIGURE 6.13. Directional Frequency and Average Wind Speed for Louisiana

——— ACTUAL DISTRIBUTION ORDINATE - PERCENT
 - - - - RAYLEIGH DISTRIBUTION ABSCISSA - M/S
 PNL-3195 WERA-7

FIGURE 6.14. Annual Average Wind Speed Frequency for Louisiana

ORDINATE - PERCENT
ABSCISSA - M/S
PNL 3195 WERA-7

FIGURE 6.15. Annual Average Wind Speed Duration for Louisiana

ORDINATE - PERCENT
ABSCISSA - WATTS/M²

PNL-3195 WERA-7

FIGURE 6.16. Annual Average Wind Power Duration for Louisiana

MISSOURI

CHAPTER 7: MISSOURI

Missouri has an area of 180,486 km² (69,686 mi²) and in 1970 its population was 4,697,399. Nearly seven-tenths of Missouri's population lives in five metropolitan areas: Columbia, Kansas City, St. Joseph, St. Louis and Springfield (Figure 7.1). Missouri ranges in elevation from Taum Sauk Mountain, 540 m (1,772 ft), to 70 m (230 ft) along the St. Francis River, both in southeastern Missouri (Figure 7.2).

Missouri has four land regions. The dissected till plains, north of the Missouri River, were once covered by glaciers. The Osage Plain is prairie land in western Missouri. In southern Missouri, the Ozark Plateau, with forested hills and low mountains, is the state's largest land area. The southeastern corner of Missouri extends into the Mississippi alluvial plain (see Figure 7.3).

January temperatures average -2°C (29°F) in the north to 3°C (38°F) in the south while July temperatures average 26°C (79°F) to 27°C (81°F). Precipitation varies from 130 cm (50 in.) in the southeast to 76 cm (30 in.) in the northwest.

Wind data stations in Missouri, identified in Figures 7.4 and 7.5, are mostly concentrated in the central and western portions of the state. Data in mountainous portions of the south along the Arkansas border were very scarce. Of the available data, good correlation existed between stations, thereby confirming reliability of the data.

7.1 ANNUAL AVERAGE WIND POWER

The annual average available wind power density in Missouri is shown in Figure 7.6. The analyses of mean wind power apply to terrain features that are favorably exposed to the wind, such as mountain summits, ridge crests, hilltops, and uplands (see Section 1.6).

However, nearby terrain features may interact with the windfield to cause the wind power at some exposed sites to vary as much as +50 to 100 percent from the assessment value. [See Wegley et al. (1980) for information on terrain

features that may increase or reduce wind energy]. In forested or wooded areas, the estimates are representative of large clearings, such as airports, with good exposure to the prevailing strong winds. In mountainous regions, the analyses also reflect major valleys. The percentage of land area that is favorably exposed to the wind strongly depends on the land-surface form (Section 1.8).

The annual average wind power map for Missouri shows a region of class 1 wind power in southeastern Missouri with class 2 wind power extending over exposed upland areas of the Ozark Plateau (such as Springfield) and westward and northward across the rest of the state.

7.1.1 Certainty Rating of Wind Resources

A high certainty rating of 4 is given for much of the non-mountainous areas of western and northern Missouri, the St. Francis River basin of southeastern Missouri, and a small area in south-central Missouri (Figure 7.7). However, these areas are estimated to have a low annual average wind resource (class 1 or 2). No areas in Missouri combine a high certainty rating with a large wind resource (class 4 or greater).

7.1.2 Areal Distribution

The areal distribution of wind power in Missouri is shown in Figure 7.8. The percentage of area in each grid cell with wind power equal to or greater than the designated class is given for classes 2, 3, 4, and 5. Table 7.1 lists power class, land area, and percent of land area with a power class. Missouri shows class 1, 2, and 3 wind power. Class 4 wind power is significantly characteristic of only the highest ridges and peaks. One percent of the land area is estimated to experience class 3 wind power. Over 63 percent of the land area in Missouri experiences class 1 wind power, and nearly 37 percent of the land area is estimated to experience class 2 wind power.

7.2 SEASONAL WIND VARIATIONS

Wind power maps for each season are shown in Figure 7.9. Spring is the season of maximum wind power over most of

the state, with winter lagging close behind. The major difference between the winter and spring maps is that the Missouri River valley region north and west of the Ozark Plateau has a power rating of 2 in winter and 3 in the spring. Summer is the season of minimum wind power, with a rating of 1 over almost the entire state.

7.2.1 Winter

In the winter, class 3 wind power is estimated for northeastern and southwestern Missouri and higher elevations on the Ozark Plateau. Class 2 wind power covers southeastern Missouri and extends northwest through the Missouri River valley.

7.2.2 Spring

In spring, class 3 wind power occurs over most of the western and northern part of the state, including upland areas in the Ozark Plateau. Class 2 wind power occurs in southeastern Missouri, extending northwestward into the Missouri River valley.

7.2.3 Summer

In the summer, the entire state has class 1 wind power. Wind speeds average between 3 and 4.5 m/s for all of the anemometer locations during the summer months.

7.2.4 Autumn

Class 2 wind power is also estimated over southwestern and northeastern Missouri. Elsewhere, class 1 wind power prevails.

7.3 FEATURES OF SELECTED STATIONS

Table 7.2 gives the locations and annual wind speed and power densities of 18 reporting stations in Missouri. Graphs of other features of the wind resource are shown in Figures 7.10 to 7.16. Four of the stations are located in the northern part of the state, north of the Missouri River, which flows from west to east through north-central Missouri. Five stations are located along the banks of the Missouri River. St. Louis is located on the western bank of the Mississippi River, which runs from north to south along the eastern border of the state. Two stations are located on the Ozark Plateau, and three stations

are found in the Mississippi alluvial plain of extreme southeastern Missouri. Four stations are located in the rolling hills of south-central Missouri at the foot of the Ozarks.

Advance is located in the alluvial plains of extreme southeastern Missouri, near the Wappapello Reservoir, 109 m above sea level.

Butler is situated in the foothills of the Ozark Mountains, with good exposure to the predominantly southerly winds in the area.

Chillicothe is located near the intersection of the Grand and Thompson rivers in north-central Missouri, with an elevation of 235 m above sea level. The smooth plains should permit an excellent site exposure.

Columbia is situated at the base of the Ouachita Mountain foothills, north of the Missouri River. The anemometer, with 14 years of wind observations, is located at the airport with good exposure to prevailing southerly winds.

Farmington is located in the foothills of the Ouachita Mountains in east-central Missouri. The site appears slightly sheltered by higher hills in the surrounding area.

Fort Leonard Wood is located in the gently sloping open hills of south-central Missouri, with an anemometer height of 4.0 m. Anemometer exposure appears fair to the predominantly southerly winds.

Grandview is located on the east-central border of Missouri in a region of irregular plains with few gently sloping hills. The anemometer is located at Richards-Gebaur AFB, with an anemometer height of 5.5 m. The anemometer location is considered fair due to the uneven terrain. However, 8 years of wind data are available for the site.

Joplin is located on the open plains of southwestern Missouri near the Kansas border. The anemometer is located at Joplin Airport. The flat plains, combined with the airport location, should provide an excellent site exposure.

Kansas City is situated on the Missouri River near the western border of the state. The anemometer is located at Kansas City Municipal Airport, at an elevation of 228 m above sea level. The anemometer is 6.7 m above ground level. The site appears representative of lowland areas near the Missouri River.

Kirksville is situated 140 km (90 mi) north of Columbia, in north-central Missouri. The low hills and gently rolling plains should offer good site exposure.

Malden, located on the Mississippi alluvial plain in southeastern Missouri, 65 km (40 mi) south of Advance, appears to have excellent anemometer exposure to the prevailing southerly winds of the region.

Marshall is located near the Missouri River, 160 km (100 mi) east of Kansas City, on a flat plain.

New Florence is located about 65 km (40 mi) east-northeast of Columbia and about 100 km (65 mi) west-northwest of St. Louis.

St. Joseph is located in the Missouri River valley, about 65 km (40 mi) north-northwest of Kansas City, on the western border of the state.

St. Louis' Lambert Field Airport is located near the intersection of the Missouri and Mississippi rivers and appears to have good exposure to the winds. The prevailing wind direction graph shows two peaks, south and north-northwest, of approximately equal intensity. Urban and residential areas may not have as much power as the airport because of higher surface roughness.

Springfield is situated on the Ozark Plateau, in southwestern Missouri. Annual wind power ranges from class 1 in the summer and autumn, to class 2 and 3 in the winter and spring. The airport data seem to be representative of upland areas in the Ozark Plateau.

Tarkio is located in extreme northwestern Missouri about 80 km (50 mi) north-northwest of St. Joseph. The region is characterized by gently rolling hills and plains. The site is located in the Tarkio River valley. The surrounding terrain is higher than the valley.

Vichy is located about 50 km (30 mi) north-northeast of Fort Leonard Wood, a region characterized by rolling hills and prevailing south-southwesterly winds. Annual wind power varies between class 1 and 2.

7.3.1 Interannual Wind Power and Speed

Columbia, St. Louis and Springfield have 15 or more years of continuous record during which the wind power was about 100 W/m^2 with a variation not exceeding 20 percent for the records. The anemometer at Columbia was 14.8 m above ground level whereas the anemometers at St. Louis and Springfield were at 6.1 m. The Vichy record, with nearly 17 years of data, shows wind power of about 100 W/m^2 in 1948, gradually decreasing to about 50 in 1963, but increasing to 75 in 1964, the last year shown. Vichy, with the anemometer 13.7 m above ground, is centrally located with respect to the other three stations. The Vichy record corresponds somewhat to an earlier record, 1945-1953 at St. Louis when its anemometer was at a height of 14 m.

7.3.2 Monthly Average Wind Power and Speed

Wind power and speed do not vary greatly over the state of Missouri. Across the state, wind power varies from class 1 to class 3 annually. All of the stations show a wind power and speed maximum in March between 150 and 300 W/m^2 . Butler has the highest wind power, with a maximum of 300 W/m^2 in the late winter months.

Wind power drops to below 100 W/m^2 at all locations in the summer months of July and August. The entire state is characterized by an average wind power of only class 1 for the summer months.

7.3.3 Diurnal Wind Speed by Season

All 18 stations presented for Missouri indicate maximum wind speeds during the afternoon for all seasons. Minimum diurnal variations occur during the autumn and winter months, with peaks near 1200 local standard time (LST).

Maximum diurnal variations occur during the spring and summer months, with peaks near 1500 LST. Average afternoon wind speeds exceed 6 m/s at Butler,

Joplin, Kirksville, and New Florence during the winter and spring months, and at St. Joseph and Chillicothe during the spring months.

7.3.4 Directional Frequency and Average Speed

Light southerly winds near 4 m/s prevail at most of the stations in Missouri (Figure 7.13). Advance and Tarkio show a secondary peak of 4 m/s from the north. Chillicothe, Kirksville, and Marshall have no pronounced peaks, with wind speeds averaging less than 3 m/s from all directions.

7.3.5 Annual Average Wind Speed Frequency

Observer biases are evident in the actual distributions for Advance, Butler, Chillicothe, Farmington, Joplin, Kirksville, Malden, Marshall, New Florence, Tarkio, and Vichy (Figure 7.14). This bias is often reflected in pronounced peaks of 2, 5, and 8 m/s (5, 10, and 15 kts).

7.3.6 Annual Average Wind Speed and Power Duration

The percentage of time a given wind speed and power is exceeded is shown in Figures 7.15 and 7.16. Abrupt changes in the slope of the duration curves usually correspond to peaks in the speed frequency distribution caused by observer bias and instrument threshold velocity.

FIGURE 7.1. Geographic Map of Missouri

FIGURE 7.2. Topographic Map of Missouri

FIGURE 7.3. Land-Surface Form Map for Missouri

LAND-SURFACE FORM LEGEND

PLAINS

A1	FLAT PLAINS
A2	SMOOTH PLAINS
B1	IRREGULAR PLAINS, SLIGHT RELIEF
B2	IRREGULAR PLAINS

TABLELANDS

B3c,d	TABLELANDS, MODERATE RELIEF
B4c,d	TABLELANDS, CONSIDERABLE RELIEF
B5c,d	TABLELANDS, HIGH RELIEF
B6c,d	TABLELANDS, VERY HIGH RELIEF

PLAINS WITH HILLS OR MOUNTAINS

A, B3a,b	PLAINS WITH HILLS
B4,a,b	PLAINS WITH HIGH HILLS
B5a,b	PLAINS WITH LOW MOUNTAINS
B6a,b	PLAINS WITH HIGH MOUNTAINS

SCHEME OF CLASSIFICATION

SLOPE (1st LETTER)

A	>80% OF AREA GENTLY SLOPING
B	50-80% OF AREA GENTLY SLOPING
C	20-50% OF AREA GENTLY SLOPING
D	<20% OF AREA GENTLY SLOPING

OPEN HILLS AND MOUNTAINS

C2	OPEN LOW HILLS
C3	OPEN HILLS
C4	OPEN HIGH HILLS
C5	OPEN LOW MOUNTAINS
C6	OPEN HIGH MOUNTAINS

LOCAL RELIEF (2nd LETTER)

1	0 TO 30m (1 TO 100 ft)
2	30 TO 90m (100 TO 300 ft)
3	90 TO 150m (300 TO 500 ft)
4	150 TO 300m (500 TO 1000 ft)
5	300 TO 900m (1000 TO 3000 ft)
6	900 TO 1500m (3000 TO 5000 ft)

HILLS AND MOUNTAINS

D3	HILLS
D4	HIGH HILLS
D5	LOW MOUNTAINS
D6	HIGH MOUNTAINS

PROFILE TYPE (3rd LETTER)

a	>75% OF GENTLE SLOPE IS IN LOWLAND
b	50-75% OF GENTLE SLOPE IS IN LOWLAND
c	50-75% OF GENTLE SLOPE IS ON UPLAND
d	>75% OF GENTLE SLOPE IS ON UPLAND

FIGURE 7.4. NCC Station Locations in Missouri

FIGURE 7.5. Location of Stations Used in Missouri Wind Assessment

FIGURE 7.6. Missouri Annual Average Wind Power

Classes of Wind Power Density at 10 m and 50 m^(a)

Wind Power Class	10 m (33 ft)		50 m (164 ft)	
	Wind Power Density, watts/m ²	Speed, ^(b) m/s (mph)	Wind Power Density, watts/m ²	Speed, ^(b) m/s (mph)
	0	0	0	0
1	100	4.4 (9.8)	200	5.6 (12.5)
2	150	5.1 (11.5)	300	6.4 (14.3)
3	200	5.6 (12.5)	400	7.0 (15.7)
4	250	6.0 (13.4)	500	7.5 (16.8)
5	300	6.4 (14.3)	600	8.0 (17.9)
6	400	7.0 (15.7)	800	8.8 (19.7)
7	1000	9.4 (21.1)	2000	11.9 (26.6)

(a) Vertical extrapolation of wind speed based on the 1/7 power law.

(b) Mean wind speed is based on Rayleigh speed distribution of equivalent mean wind power density. Wind speed is for standard sea-level conditions. To maintain the same power density, speed increases 5%/5000 ft (3%/1000 m) of elevation.

TABLE 7.1. Areal Distribution (km²) of Wind Power Classes in Missouri

Power Classes	Land Area	% Land Area	Cumulative Land Area	% Cumulative Land Area
1	96,000	54.0	180,000	100.00
2	72,000	41.0	80,000	46.00
3	7,700	4.4	7,700	4.50
4	0	0.0	0	0.00
5	0	0.0	0	0.00
6	0	0.0	0	0.00
7	0	0.0	0	0.00

FIGURE 7.7. Certainty Rating of Missouri Wind Resource

CERTAINTY RATING LEGEND

Rating	Definition
1	<p>The lowest degree of certainty. A combination of the following conditions exists:</p> <ol style="list-style-type: none">1) No data exist in the vicinity of the cell.2) The terrain is highly complex.3) Various meteorological and topographical indicators suggest a high level of variability of the resource within the cell.
2	<p>A low-intermediate degree of certainty. One of the following conditions exists:</p> <ol style="list-style-type: none">1) Little or no data exist in or near the cell, but the small variability of the resource and the low complexity of the terrain suggest that the wind resource will not differ substantially from the resource in nearby areas with data.2) Limited data exist in the vicinity of the cell, but the terrain is highly complex or the mesoscale variability of the resource is large.
3	<p>A high-intermediate degree of certainty. One of the following conditions exists:</p> <ol style="list-style-type: none">1) There are limited wind data in the vicinity of the cell, but the low complexity of terrain and the small mesoscale variability of the resource indicate little departure from the wind resource in nearby areas with data.2) Considerable wind data exist but in moderately complex terrain and/or in areas where moderate variability of the resource is likely to occur.
4	<p>The highest degree of certainty. Quantitative data exist at exposed sites in the vicinity of the cell and can be confidently applied to exposed areas in the cell because of the low complexity of terrain and low spatial variability of the resource.</p>

FIGURE 7.8. Areal Distribution of Wind Resource in Missouri (Power Classes 2 and 3); Percent of Land Area With or Exceeding Power Class Shown

FIGURE 7.8 (Continued). Areal Distribution of Wind Resource in Missouri (Power Classes 4 and 5); Percent of Land Area With or Exceeding Power Class Shown

FIGURE 7.9. Seasonal Average Wind Power for Missouri (Winter, Summer)

FIGURE 7.9 (Continued). Seasonal Average Wind Power for Missouri (Spring, Autumn)

TABLE 7.2. Missouri Stations With Graphs of the Wind Characteristics

Station	Station Name ^(a)	Latitude, Degrees North	Longitude, Degrees West	Elevation of Station, m	Period of Record, Month/Year	Annual Average Wind Speed, m/s				Annual Average Wind Power, watts/m ²			
						Anemometer Height, m	At Anemometer Height, m	At 10 m	At 50 m	At Anemometer Height, m	At 10 m	At 50 m	
Advance, Missouri	Advance CAA	37.10	89.92	109	01/48-11/49	21.3	4.1	3.7	4.7	102	74	147	
Rutler, Missouri	Rutler CAA	38.30	94.03	265	01/50-12/54	8.8	4.8	4.9	6.1	151	159	317	
Chillicothe, Missouri	Chillicothe CAA	39.78	93.50	235	01/48-12/50	7.6	4.6	4.8	6.0	113	127	253	
Columbia, Missouri	Municipal Airport	38.97	92.37	238	12/50-12/64	14.6	4.6	4.4	5.5	109	93	185	
Farmington, Missouri	Farmington CAA	37.77	90.40	274	04/52-12/54	16.5	3.9	3.7	4.6	86	69	138	
Ft. Leonardwood Missouri	Ft. Leonardwood AAF	37.73	92.15	351	11/66-12/70	4.0	3.3	3.7	4.7	58	86	172	
Grandview, Missouri	Richards-Gebaur AFB	38.83	94.58	336	02/62-12/70	5.5	3.8	4.1	5.2	71	92	183	
Joplin, Missouri	Joplin Airport	37.17	94.50	301	01/48-12/54	14.3	5.4	5.2	6.5	186	159	318	
Kansas City, Missouri	Municipal Airport	39.12	94.58	228	07/63-09/72	6.7	4.3	4.6	5.8	83	99	196	
Kirksville, Missouri	Cannon Memorial Airport	40.10	92.55	296	01/48-12/54	25.9	5.2	4.6	5.8	156	104	207	
Malden, Missouri	Malden CAA	36.60	89.98	92	01/50-12/54	8.5	4.0	4.1	5.2	89	95	190	
Marshall, Missouri	Marshall CAA	39.10	93.20	237	01/48-04/50	20.4	4.6	4.1	5.2	120	88	176	
New Florence, Missouri	New Florence CAA	38.88	91.43	269	01/48-04/50	17.7	5.6	5.2	6.5	165	129	258	
St. Joseph, Missouri	St. Joseph Airport	39.77	94.92	262	01/65-12/78	6.1	4.1	4.4	5.6	97	120	239	
St. Louis, Missouri	Lambert Field Airport	38.75	90.38	172	01/60-12/78	6.1	4.3	4.6	5.8	92	114	227	
Springfield, Missouri	Municipal Airport	37.23	93.38	388	03/62-12/78	6.1	4.4	4.7	5.9	88	109	217	
Tarkio, Missouri	Tarkio CAA	40.45	95.37	282	01/48-12/50	8.8	3.5	3.5	4.5	94	99	198	
Vichy, Missouri	Vichy Airport	38.13	91.77	341	01/48-12/64	13.7	4.4	4.2	5.3	88	77	153	

(a) CAA-Civil Aeronautics Administration Facility; AAF-Army Air Field; AFB-Air Force Base.

FIGURE 7.10. Interannual Wind Power and Speed for Missouri

FIGURE 7.11. Monthly Average Wind Power and Speed for Missouri

——— WINTER ♦ - - - ♦ SPRING
 ⊕ - - ⊕ SUMMER ▣ - - ▣ AUTUMN
 PNL-3195 WERA-7

ORDINATE - M/S
 ABSCISSA - HOUR

FIGURE 7.12. Diurnal Wind Speed by Season for Missouri

— PERCENT FREQUENCY LEFT ORDINATE - PERCENT
 - - - WIND SPEED RIGHT ORDINATE - M/S
 PNL 3195 WERA-7
 ABSCISSA - WIND DIRECTION

FIGURE 7.13. Directional Frequency and Average Wind Speed for Missouri

— ACTUAL DISTRIBUTION ORDINATE - PERCENT
 - - - RAYLEIGH DISTRIBUTION ABSCISSA - M/S
 PNL-3195 WERA-7

FIGURE 7.14. Annual Average Wind Speed Frequency for Missouri

ORDINATE - PERCENT
ABSCISSA - M/S

PNL-3185 WERA-7

FIGURE 7.15. Annual Average Wind Speed Duration for Missouri

ORDINATE - PERCENT
ABSCISSA - WATTS/M²

PNL-3185 WERA-7

FIGURE 7.16. Annual Average Wind Power Duration for Missouri

OKLAHOMA

CHAPTER 8: OKLAHOMA

Oklahoma, with an area of 181,098 km² (69,919 mi²), has a population of 2,559,253 (1970). Over half the people in Oklahoma live in three metropolitan areas: Oklahoma City, Tulsa, and Lawton. Geographic and topographic features are shown in Figures 8.1 and 8.2.

Oklahoma has four types of land form areas (see Figure 8.3). The Red Beds Plains extend from Kansas southward to Texas through the middle of Oklahoma, sloping downward from west to east. The Gypsum Hills, west of the Red Beds Plains, extend westward to the High Plains in the Panhandle of Oklahoma, where Black Mesa, the highest point in Oklahoma, rises 1,516 m (4,973 ft) above sea level. The Ozark Plateau extends into northeastern Oklahoma from Missouri and Arkansas. The Ouachita Mountains are in the southeastern part of the state along the Arkansas border.

Oklahoma has more than 200 man-made lakes and about 100 small natural lakes. The average daily temperature varies from 28°C (83°F) in July to 4°C (39°F) in January. Annual rainfall ranges from 130 cm (50 in.) in the southeast to 38 cm (15 in.) in the western Panhandle.

Wind data stations in Oklahoma are fairly well distributed (Figures 8.4 and 8.5). Data consisted of an equal number of digitized or summarized data and unsummarized data. Only the southeastern portion of the state near the Ouachita Mountains was lacking in data. However, data along the Texas and Arkansas borders provided reasonable analysis integration.

8.1 ANNUAL AVERAGE WIND POWER

The annual average available wind power density in Oklahoma is shown in Figure 8.6. The analyses of mean wind power apply to terrain features that are favorably exposed to the wind, such as hilltops, uplands and open plains (see Section 1.6). However, nearby terrain features may interact with the windfield to cause the wind power at some exposed sites to vary as much as +50 to 100 percent from the assessment value. [See Wegley et al. (1980) for information on terrain features that may increase or reduce wind energy.] In forested or wooded areas, the estimates are

representative of large clearings, such as airports, with good exposure to the prevailing strong winds. In mountainous regions, the analyses also reflect major valleys. The percentage of land area that is favorably exposed to the wind strongly depends on the land-surface form (Section 1.8).

The annual average wind power map for Oklahoma shows class 4 or higher wind power in the High Plains, Gypsum Hills, and Ozark-Ouachita highlands along the Arkansas border (see Figure 8.6).

The High Plains is a physical subdivision that includes western Texas, the Panhandle of Oklahoma, western Kansas and a small part of eastern Colorado. The Oklahoma Panhandle slopes upward from east to west. The western part of the Panhandle is an extension of the Rocky Mountain Piedmont. Because southerly winds prevail over Oklahoma, the highest wind power, class 5, shown in Figure 8.6, covers much of the western Panhandle. In particular, class 5 is most dominant at Black Mesa, which is Oklahoma's highest elevation, where the wind can flow freely.

Gypsum Hills, between the Red Beds Plains and the Oklahoma Panhandle, is generally a plain with a few hills. Class 4 wind power is found over most of the open plains of this area, with possibly class 5 on the hilltops; the land surface slopes downward from west to east, and the wind power generally decreases in the same direction. Summits, crests, and exposed windward areas in the Ozark Plateau and Ouachita Mountains are estimated to have class 4 wind power.

8.1.1 Certainty Rating of the Wind Resource

High certainty ratings of 4 are given for the Red Beds Plains, an area of moderate to low wind resource, and part of Gypsum Hills, an area of high wind resource (Figure 8.7). Certainty ratings of 3 are assigned to the southern part of the Gypsum Hill area and the southeast corner of Oklahoma because of the limited wind data in that vicinity.

Due to the sparsity of the wind data, the Oklahoma Panhandle, part of Gypsum Hills, and part of the Red Beds Plains are given a certainty rating of 2. However, the Panhandle and the Gypsum Hills are

Hills are estimated to have a wind resource of classes 4 and 5. The Ozark and Ouachita Mountains have a low certainty rating of 1, since there are no surface data for this area.

8.1.2 Areal Distribution

More than half the state has class 2 and 3 wind power. About one-fifth (23 percent) is estimated to have class 4 wind power, including the western Panhandle, the Gypsum Hills in the west, and the crests of the Ozark and Ouachita mountains in the east. The areal distribution of wind power classes is given in Table 8.1 and shown in graphic form in Figure 8.8. A small area (4 percent of the total) near Black Mesa has power of classes 5 and 6, which is the highest wind power found in Oklahoma.

8.2 SEASONAL WIND POWER

Wind power maps for each season are shown in Figure 8.9. The season of the highest wind power for Oklahoma is spring. The seasons of the lowest wind power are summer and autumn. Wind power for all four seasons has the same general distribution as the annual average wind power. The highest wind power is in the Oklahoma Panhandle; wind power decreases as one moves east. High wind powers are also estimated for the higher elevations in the Ozark and Ouachita mountains near the Arkansas border.

8.2.1 Winter

In the winter, class 5 wind power is estimated for Black Mesa and the Ozark-Ouachita highlands. Classes 3 and 4 wind powers are found in Gypsum Hills and the Red Beds Plains while a small area around the Ozark-Ouachita highlands has wind power of class 2. Generally, the high wind power in winter is associated with strong winds from the north or northwest after a cold front passes through Oklahoma. A very small part of the Arkansas River valley between the Ozark Plateau and the Ouachita Mountains has class 1 wind power because the prevailing wind is obstructed for this valley area.

8.2.2 Spring

Spring is the season of maximum wind power throughout Oklahoma, primarily because of strong southerly winds. In spring, class 6 wind power is found in

the Panhandle and Gypsum Hills. The terrain of Red Beds Plains slopes upward from east to west. The winds increase with elevation, creating class 5 wind power in the west and class 3 in the east. Class 2 wind power is found in the Arkansas River valley north of the Ouachita Mountains, and in the Red River valley south of the Ouachita Mountains. These valleys are sheltered from the prevailing southerly winds.

8.2.3 Summer

In summer, winds become much lighter and the wind power is reduced over all of Oklahoma. Class 3 wind power is found at the highest altitudes in the Oklahoma Panhandle and the Gypsum Hills. Class 1 and 2 are estimated over the remaining areas.

8.2.4 Autumn

In autumn, the pattern of wind resource is much the same as in summer, except that the wind power has increased. Class 3 wind resource extends through central Oklahoma and class 2 extends almost to the higher elevations in the east. The increased wind power is caused as the storm tracks move southward during autumn.

8.3 FEATURES OF SELECTED STATIONS

The location, annual wind speed, and power density of thirteen stations are shown in Table 8.2. There are two sets of wind characteristics near Oklahoma City; one at Oklahoma City Airport and one at Will Rogers Airport. In addition, Vance AFB and Enid Airport are near each other. Therefore, the wind power data at two close stations can be compared.

Altus, on the east side of the Salt Fork Red River, is in the southwestern part of Oklahoma. The observation station is at Altus Air Force Base, which is located northwest of the city. The runway of the airport is oriented north and south and parallels the prevailing wind direction. The observed wind data appear to be low for this station when compared to the nearby stations of Hobart, Clinton, and Wichita Falls, which all have higher wind power than Altus.

Ardmore is in the southern part of Oklahoma and is situated midway between Dallas and Oklahoma City. The Civil Aeronautics Administration (CAA) facility

was located south of downtown Ardmore from 1948 to 1954, when data used in this assessment were taken.

Clinton is located in the southern part of Gypsum Hills, which is gently sloping upland. The elevation of the station is nearly 600 m (1,900 ft), so the airport appears well exposed to the prevailing southerly wind.

Enid is in the northern part of the Red Beds Plains and is a major station of the Chicago Rock Island and Pacific Railroad. The wind data of two stations near Enid were listed. Both of the stations are located northwest of Enid, with the Enid Airport being north of Vance AFB. The anemometer height at Vance is lower than the anemometer height at the Enid airport. However, the wind power is greater at Vance AFB. This could be due to differing anemometer exposure at each station. Enid data are from 1949 to 1959 and Vance AFB data are from 1959 to 1970.

Ft. Sill is located about 110 km (70 mi) northwest of Ardmore, Oklahoma, and just north of Lawton, Oklahoma, which is the third largest city of Oklahoma. The southerly winds over Ft. Sill may be partly obstructed by the city of Lawton.

Gage is in the northwest Gypsum Hills area and is believed to have good anemometer exposure during the period of record (1948-64). The airport is located at an elevation of 669 m (2,200 ft).

Gene Autrey, where Ardmore AFB is located, is a small town 13 km (8 mi) northwest of Ardmore. The anemometer is 4 m above ground and the annual average wind speed is only 2.9 m/s, thus the anemometer exposure is questionable. Only four years' wind data (1955 to 1959) are available for Gene Autrey.

Hobart is in southwestern Oklahoma. The airport is located 6.4 km (4 mi) southeast of Hobart and appears well exposed to the southerly wind.

Oklahoma City is in central Oklahoma and also in the central Red Beds Plains. It is the largest city of Oklahoma. Wind data for two stations in Oklahoma City, Oklahoma City and Will Rogers Airports, are available. Oklahoma City Airport is south-east of Oklahoma City and Will Rogers Airport is located in the southwest part of Oklahoma City. Two sets of wind data

observed at Oklahoma City are presented here for comparison. From 1945 to 1954, the anemometer was at 21.3 m. From 1965 to 1978, the anemometer was at 6.1 m, which resulted in lower readings. Both stations appear to have good exposure to the prevailing southerly wind.

Ponca City is in the north-central part of Oklahoma. The airport is located north-northwest of Ponca City. The height of the anemometer is 20.4 m, and the wind data are similar to the data taken at Oklahoma City Airport when the anemometer was at 21.3 m.

Tulsa, the second largest city of Oklahoma, is located in the northeastern part of Oklahoma on the Arkansas River. The airport is located north of the city (Figure 8.4).

8.3.1 Interannual Wind Power and Speed

The interannual wind power and speed are shown in Figure 8.10 in which eight stations had selected periods of record of 10 years or more. The two charts of Oklahoma City, for Oklahoma City and Will Rogers Airports, are slightly less than 200 W/m^2 since 1960. During 1958, the wind power, compared to the long-term mean, was low at all six stations of record. The mean interannual variability is about 60 W/m^2 .

8.3.2 Monthly Average Wind Power and Speed

March is the month of maximum wind power and speed at all stations (Figure 8.11). Though, during most of March, strong southerly winds blow over Oklahoma, strong northerly winds also occur briefly after the passage of a cold front. The minimum wind power and speed are found in July or August at all stations.

The monthly variation at all states is less than 200 W/m^2 with exception of Oklahoma City and Clinton. Oklahoma City (with the anemometer at 21.3 m) and Clinton have the largest seasonal/monthly variations, with about a ratio of 3 between March and July.

8.3.3 Diurnal Wind Speed by Season

Figure 8.12 shows that all thirteen stations in Oklahoma indicated maximum daily wind speeds during the late morning and early afternoon for all seasons. The

magnitude of the diurnal variation with season varies from station to station, and the only significant difference of variation among seasons for each station is that winter generally has less variation than spring.

8.3.4 Directional Frequency and Average Speed

The direction of maximum frequency at all stations is south. However, high frequencies of north winds were also found at all stations. The high average wind speeds seem to accompany either southerly winds or northerly winds (Figure 8.13).

8.3.5 Annual Average Wind Speed Frequency

Observer biases are readily apparent in the records for Ardmore, Enid Airport,

Gage, Hobart, Oklahoma City (1945-54), and Ponca City, as peaks usually occur at 2, 5, and 8 m/s (5, 10, and 15 kts) as shown in Figure 8.14. A high frequency of calms at Gene Autrey makes the data or site exposure appear questionable. The Rayleigh distribution approximates the actual annual average frequency distribution very well at Clinton, Vance AFB, and Oklahoma City Airport (with anemometer height of 4.0 m).

8.3.6 Annual Average Wind Speed and Power Duration

Figures 8.15 and 8.16 show the percentage of time that a given wind speed or power is exceeded. Abrupt changes in the slope of the duration curves correspond to peaks in the speed frequency distribution caused by observer bias and instrument threshold velocity.

FIGURE 8.1. Geographic Map of Oklahoma

FIGURE 8.2. Topographic Map of Oklahoma

DF- 0.980

FIGURE 8.3. Land-Surface Form Map for Oklahoma

LAND-SURFACE FORM LEGEND

PLAINS

A1	FLAT PLAINS
A2	SMOOTH PLAINS
B1	IRREGULAR PLAINS, SLIGHT RELIEF
B2	IRREGULAR PLAINS

TABLELANDS

B3c,d	TABLELANDS, MODERATE RELIEF
B4c,d	TABLELANDS, CONSIDERABLE RELIEF
B5c,d	TABLELANDS, HIGH RELIEF
B6c,d	TABLELANDS, VERY HIGH RELIEF

PLAINS WITH HILLS OR MOUNTAINS

A,B3a,b	PLAINS WITH HILLS
B4,a,b	PLAINS WITH HIGH HILLS
B5a,b	PLAINS WITH LOW MOUNTAINS
B6a,b	PLAINS WITH HIGH MOUNTAINS

SCHEME OF CLASSIFICATION

SLOPE (1st LETTER)

A	>80% OF AREA GENTLY SLOPING
B	50-80% OF AREA GENTLY SLOPING
C	20-50% OF AREA GENTLY SLOPING
D	<20% OF AREA GENTLY SLOPING

OPEN HILLS AND MOUNTAINS

C2	OPEN LOW HILLS
C3	OPEN HILLS
C4	OPEN HIGH HILLS
C5	OPEN LOW MOUNTAINS
C6	OPEN HIGH MOUNTAINS

LOCAL RELIEF (2nd LETTER)

1	0 TO 30m (1 TO 100 ft)
2	30 TO 90m (100 TO 300 ft)
3	90 TO 150m (300 TO 500 ft)
4	150 TO 300m (500 TO 1000 ft)
5	300 TO 900m (1000 TO 3000 ft)
6	900 TO 1500m (3000 TO 5000 ft)

HILLS AND MOUNTAINS

D3	HILLS
D4	HIGH HILLS
D5	LOW MOUNTAINS
D6	HIGH MOUNTAINS

PROFILE TYPE (3rd LETTER)

a	>75% OF GENTLE SLOPE IS IN LOWLAND
b	50-75% OF GENTLE SLOPE IS IN LOWLAND
c	50-75% OF GENTLE SLOPE IS ON UPLAND
d	>75% OF GENTLE SLOPE IS ON UPLAND

FIGURE 8.4. NCC Station Locations in Oklahoma

FIGURE 8.5. Location of Stations Used in Oklahoma Wind Assessment

FIGURE 8.6. Oklahoma Annual Average Wind Power

Classes of Wind Power Density at 10 m and 50 m^(a)

Wind Power Class	10 m (33 ft)		50 m (164 ft)	
	Wind Power Density, watts/m ²	Speed, ^(b) m/s (mph)	Wind Power Density, watts/m ²	Speed, ^(b) m/s (mph)
	0	0	0	0
1	100	4.4 (9.8)	200	5.6 (12.5)
2	150	5.1 (11.5)	300	6.4 (14.3)
3	200	5.6 (12.5)	400	7.0 (15.7)
4	250	6.0 (13.4)	500	7.5 (16.8)
5	300	6.4 (14.3)	600	8.0 (17.9)
6	400	7.0 (15.7)	800	8.8 (19.7)
7	1000	9.4 (21.1)	2000	11.9 (26.6)

(a) Vertical extrapolation of wind speed based on the 1/7 power law.

(b) Mean wind speed is based on Rayleigh speed distribution of equivalent mean wind power density. Wind speed is for standard sea-level conditions. To maintain the same power density, speed increases 5%/5000 ft (3%/1000 m) of elevation.

TABLE 8.1. Areal Distribution (km²) of Wind Power Classes in Oklahoma

Power Classes	Land Area	% Land Area	Cumulative Land Area	% Cumulative Land Area
1	24,000	15.0	180,000	100.00
2	63,000	34.0	150,000	84.00
3	40,000	22.0	90,000	50.00
4	43,000	23.0	50,000	27.00
5	6,700	3.7	6,900	3.80
6	220	0.1	220	0.12
7	0	0.0	0	0.00

FIGURE 8.7. Certainty Rating of Oklahoma Wind Resource

CERTAINTY RATING LEGEND

Rating	Definition
1	<p>The lowest degree of certainty. A combination of the following conditions exists:</p> <ol style="list-style-type: none"> 1) No data exist in the vicinity of the cell. 2) The terrain is highly complex. 3) Various meteorological and topographical indicators suggest a high level of variability of the resource within the cell.
2	<p>A low-intermediate degree of certainty. One of the following conditions exists:</p> <ol style="list-style-type: none"> 1) Little or no data exist in or near the cell, but the small variability of the resource and the low complexity of the terrain suggest that the wind resource will not differ substantially from the resource in nearby areas with data. 2) Limited data exist in the vicinity of the cell, but the terrain is highly complex or the mesoscale variability of the resource is large.
3	<p>A high-intermediate degree of certainty. One of the following conditions exists:</p> <ol style="list-style-type: none"> 1) There are limited wind data in the vicinity of the cell, but the low complexity of terrain and the small mesoscale variability of the resource indicate little departure from the wind resource in nearby areas with data. 2) Considerable wind data exist but in moderately complex terrain and/or in areas where moderate variability of the resource is likely to occur.
4	<p>The highest degree of certainty. Quantitative data exist at exposed sites in the vicinity of the cell and can be confidently applied to exposed areas in the cell because of the low complexity of terrain and low spatial variability of the resource.</p>

FIGURE 8.8. Areal Distribution of Wind Resource in Oklahoma (Power Classes 2 and 3); Percent of Land Area With or Exceeding Power Class shown. An asterisk denotes 100%.

FIGURE 8.8 (Continued). Areal Distribution of Wind Resource in Oklahoma (Power Classes 4 and 5); Percent of Land Area With or Exceeding Power Class Shown

FIGURE 8.9. Seasonal Average Wind Power for Arkansas (Winter, Summer)

FIGURE 8.9 (Continued). Seasonal Average Wind Power for Arkansas (Spring, Autumn)

TABLE 8.2. Oklahoma Stations With Graphs of the Wind Characteristics

Station	Station Name (a)	Latitude, Degrees North	Longitude, Degrees West	Elevation of Station, m	Period of Record, Month/Year	Annual Average Wind Speed, m/s				Annual Average Wind Power, watts/m ²		
						Anemometer Height, m	At Anemometer Height, m	At 10 m	At 50 m	At Anemometer Height, m	At 10 m	At 50 m
Altus, Oklahoma	Altus AFB	34.65	99.27	414	08/56-12/70	3.7	4.0	4.7	5.9	103	159	316
Ardmore, Oklahoma	Ardmore CAA	34.30	97.15	264	07/48-12/54	9.1	4.3	4.4	5.5	114	118	236
Clinton, Oklahoma	Clinton-Sherman AFB	35.37	99.20	588	08/58-03/69	4.0	5.1	5.8	7.3	158	235	468
Enid, Oklahoma	Vance AFB	36.33	97.90	392	03/59-12/70	4.0	4.9	5.6	7.1	152	226	451
Enid, Oklahoma	Enid Airport	36.38	97.80	351	01/49-01/59	11.6	4.6	4.5	5.7	126	118	236
Ft. Sill, Oklahoma	Ft. Sill ASC	34.67	98.50	363	07/60-12/70	4.0	3.7	4.3	5.4	90	134	267
Gage, Oklahoma	Gage Airport	36.30	99.77	669	07/48-12/64	7.6	5.4	5.7	7.1	192	216	430
Gene Autrey Oklahoma	Ardmore AFB	34.30	97.02	222	05/55-01/59	4.0	2.9	3.3	4.1	49	73	145
Hobart, Oklahoma	Hobart Airport	35.00	99.05	474	02/49-12/54	8.2	5.7	5.8	7.3	198	215	429
Oklahoma City, Oklahoma	Oklahoma City Airport	35.40	97.60	384	01/45-05/54	21.3	6.7	6.0	7.6	337	244	485
Oklahoma City, Oklahoma	Will Rogers Airport	35.40	97.60	391	10/65-12/78	6.1	5.1	5.5	6.9	145	179	357
Ponca City, Oklahoma	Ponca City Airport	36.73	97.10	309	07/48-12/54	20.4	6.3	5.7	7.1	258	190	379
Tulsa, Oklahoma	Tulsa Airport	36.20	95.90	204	12/60-12/78	7.0	4.8	5.0	6.3	121	141	281

(a) AFB-Air Force Base; CAA-Civil Aeronautics Administration Facility; ASC-Army Signal Corp.

FIGURE 8.10. Interannual Wind Power and Speed for Oklahoma

FIGURE 8.11. Monthly Average Wind Power and Speed for Oklahoma

FIGURE 8.12. Diurnal Wind Speed by Season for Oklahoma

— PERCENT FREQUENCY LEFT ORDINATE - PERCENT
 - - - WIND SPEED RIGHT ORDINATE - M/S
 PNL-3195 WERA-7
 ABSCISSA - WIND DIRECTION

FIGURE 8.13. Directional Frequency and Average Wind Speed for Oklahoma

— ACTUAL DISTRIBUTION ORDINATE - PERCENT
 - - - RAYLEIGH DISTRIBUTION ABSCISSA - M/S
 PNL-3195 WERA-7

FIGURE 8.14. Annual Average Wind Speed Frequency for Oklahoma

ORDINATE - PERCENT
ABSCISSA - M/S

PNL-3195 WERA-7

FIGURE 8.15. Annual Average Wind Speed Duration for Oklahoma

ORDINATE - PERCENT
ABSCISSA - WATTS/M²

PNL-3195 WERA-7

ALTUS OK 08/56-12/70
13902 Z= 3.7 G. V= 4.0. P= 103E

ARDMORE OK 07/48-12/54
13965 Z= 9.1 R. V= 4.3. P= 114

CLINTON OK 08/58-03/69
3932 Z= 4.0 G. V= 5.1. P= 158E

ENID OK 01/49-01/59
13909 Z= 11.6 R. V= 4.6. P= 126

ENID OK 03/59-12/70
13909 Z= 4.0 G. V= 4.9. P= 152E

FT. SILL OK 07/60-12/70
13945 Z= 4.0 G. V= 3.7. P= 90E

GAGE OK 07/48-12/64
13975 Z= 7.6 R. V= 5.4. P= 192

GENE AUTREY OK 05/55-01/59
13903 Z= 4.0 G. V= 2.9. P= 49

HOBART OK 02/49-12/54
93986 Z= 8.2 R. V= 5.7. P= 198

OKLAHOMA CITY OK 04/59-12/70
13919 Z= 4.0 G. V= 4.6. P= 120E

OKLAHOMA CITY OK 01/45-05/54
13967 Z= 21.3 R. V= 6.7. P= 337

OKLAHOMA CITY OK 10/65-12/78
13967 Z= 6.1 G. V= 5.1. P= 145

PONCA CITY OK 07/48-12/54
13969 Z= 20.4 B. V= 6.3. P= 258

TULSA OK 12/60-12/78
13968 Z= 7.0 G. V= 4.8. P= 121

FIGURE 8.16. Annual Average Wind Power Duration for Oklahoma

TEXAS

CHAPTER 9: TEXAS

Texas, the second largest state in the U. S., covers an area of 692,402 km² (267,338 mi²). Three-fifths of its area and seven-eighths of its population of 11,196,730 (1970) are east of 100° west longitude, the meridian used here to define the eastern boundary of the Texas Panhandle. The largest cities in Texas are Dallas-Fort Worth, Houston, and San Antonio (see Figure 9.1). For the purpose of illustration, Texas has been divided into two areas: West Texas and East Texas.

Texas has four main land regions: the western Gulf coastal plain, the north-central plains, the Great Plains and the basin and range region. These four main land regions are further divided into ten sub-regions: the Trans-Pecos Region, High Plains Region, Low Rolling Plains, Edwards Plateau, North-Central Region, South-Central Region, Southern Region, Lower Valley, Upper Coast and East Texas (see Section 9.3). The fertile coastal plain extends inland up to 500 km (300 mi) and rises to an elevation of 90 m (300 ft) above sea level. The north-central plains, in north-central Texas, include the Black and Grand prairies. The Edwards Plateau, in south-central Texas, is the southern part of the treeless grassy Great Plains that extend northward through the Panhandle of Texas at an elevation of 1,200 m (4,000 ft). In the western-most part of Texas, south of New Mexico, the basin and range region includes extensions of the Rocky Mountains. Guadalupe Peak, 2,667 m (8,751 ft) high, the highest peak in the Guadalupe Mountains, is also the highest point in Texas (see Figures 9.2 and 9.3).

In winter the coldest area is the Panhandle in the northwest, with an average January temperature of 2°C (35°F). The January temperature along the Oklahoma border averages 5°C (41°F) and increases southward becoming 16°C (60°F) at Brownsville in the lower Rio Grande valley.

The July temperatures are more uniform, being nearly 30°C (86°F) inland where it is dry, 28°C (82°F) along the humid coast and 24°C (75°F) in the Guadalupe Mountains.

Annual precipitation generally decreases from east to west as the elevation increases. East Texas precipitation averages 130 cm (50 in.) annually whereas parts of West Texas average only 30 cm (12 in.) per year. During periods of drought, the strong winds in the Great Plains often carry away the soil in widespread dust storms.

Hurricanes occur along the coast every two or three years, generally between May and November. Tornadoes often occur with hurricanes as well as with other types of severe weather. Texas averages over 100 tornadoes per year.

Wind data stations in Texas are shown in Figures 9.4 and 9.5. East Texas provided ample data for comparison. West Texas data were available near populated areas but sparse in areas such as that along the Rio Grande River.

9.1 ANNUAL AVERAGE WIND POWER

The annual average available wind power density in Texas is shown in Figure 9.6. The analyses of mean wind power apply to terrain features that are favorably exposed to the wind, such as mountain summits, ridge crests, hilltops, and uplands (see Section 1.6). However, nearby terrain features may interact with the windfield to cause the wind power at some exposed sites to vary as much as +50 to 100 percent from the assessment value. [See Wegley et al. (1980) for information on terrain features that may increase or reduce wind energy.] In forested or wooded areas, the estimates are representative of large clearings, such as airports, with good exposure to the prevailing strong winds. In mountainous regions, the analyses also reflect major valleys. The percentage of land area that is favorably exposed to the wind strongly depends on the land-surface form (Section 1.8).

The annual average wind power is estimated to be class 3, 4, and 5 at higher elevations in the Guadalupe, Davis, and Santiago mountains in the Trans-Pecos region of West Texas. These higher estimates are representative of the exposed mountain summits and ridge crests in the mountain ranges.

Alternating prevailing winds from the east and west contribute to lower wind powers (class 1 and 2) in most of these surrounding mountains.

Large areas of class 3, 4, and 5 average wind power also exist in the plains regions of the Panhandle and northwestern areas of Texas. An increase in wind power class occurs toward the north. Prefrontal large-scale surface pressure gradients and strong winds aloft partially account for class 5 wind power in the northwest Panhandle.

Most of the area along the central and southern Gulf Coast of Texas has class 3 and 4 wind power. This area extends 20 mi (30 km) to 50 mi (80 km) inland from the Gulf of Mexico. This region is virtually unsheltered by any topographical features and is totally exposed to the prevailing southeasterly winds of this area. Class 4 wind power extends some 30 mi (50 km) inland along the coast line of southern Texas.

Hills of the Brady Mountains southeast of San Angelo are estimated to average wind power of class 2. This area contains irregular hills ranging from 1,000 to 3,000 ft (300 to 1,000 m) in height.

A large area of class 1 wind power is located in northeastern Texas and a narrowing sector extends southwestward from this area to near Hondo, Texas. The wind power in this zone is restricted by higher terrain of the Edwards Flat to the north and by the forests and woodlands of this entire region, composed of both broadleaf deciduous and needleleaf evergreen trees.

9.1.1 Certainty Rating of the Wind Resource

Certainty ratings of the wind power estimates for Texas vary from 1 to 4 (Figure 9.7). Certainty rating 4 coincides with more populated areas of the state. Certainty rating 3 existed in areas such as along the Gulf Coast where large variability was probable, and the Davis Mountains where data were limited but variability was small. Ratings 1 and 2 are noted in areas of rather sharp topographical variation like the Big Bend region.

Low certainty ratings in the hill country of south-central Texas are also due to sparse data and hilly terrain. Large geographic variations in wind power occur.

9.1.2 Areal Distribution

In West Texas, nearly 94 percent of the total area exhibits class 4 or lower wind power. Only in the extreme northwestern corner of the high plains, in the Texas Panhandle, and in the highest ridge crest elevations in the Davis and Guadalupe mountains of the Trans-Pecos area is class 5 wind power estimated to exist. Table 9.1 and Figure 9.8 show that more area in West Texas shows class 2 wind power than any other class (32 percent of the total area). Class 3 is the next most common wind power in West Texas representing 25 percent of the area. Class 1 to class 3 winds cumulatively amount to about 80 percent of the geographical area in West Texas.

Low certainty ratings in the hill country of south-central Texas are also due to sparse data and hilly terrain. Large geographic variations in wind power occur.

In East Texas, most of the area exhibits class 2 wind power (46 percent), and nearly 98 percent of East Texas shows winds from class 1 to class 3. Only along the lower Texas coast, where the sea breeze prevails, is class 4 wind power observed. Here the temperature gradient caused by the coastal boundary and the lack of surface roughness over the area contribute to the relatively high wind power class.

9.2 SEASONAL WIND POWER

Wind power maps for each season are shown in Figure 9.9. In West Texas, spring is the season of maximum wind power, except for the area in the higher elevations of the Davis Mountains, which shows a maximum in the winter. In East Texas, spring is also the windiest season, with a maximum in extreme southern Texas. Summer and autumn are the calmest seasons of the year with only class 1 wind resource over most of East Texas.

9.2.1 Winter

In most of West Texas, winter is second to spring as the windiest season of the year. In some of the higher elevations in the Davis Mountains of the Trans-Pecos area, winds are at a maximum during winter. Figure 9.9 shows these areas where class 7 winds are estimated. The winter maximum observed at these high elevations is due primarily to the upper air jet stream advancing southward during this season and causing stronger westerly winds several thousand feet above sea level.

In East Texas, winter is also the second windiest season of the year with a maximum of class 4 wind power, along the immediate coastal areas of the south. The remainder of East Texas demonstrates winds from class 1 to class 3.

9.2.2 Spring

In spring, nearly all of Texas demonstrates a maximum wind power potential. Only in the mountain crests in West Texas is the season of maximum potential wind power at a time other than spring. In West Texas, wind classes increase toward the high plains in the north, from class 2 in the Edwards Plateau area of southwestern Texas, to class 6 in the high plains of the northern Panhandle.

East Texas shows a spring minimum of class 1 wind power in the northeastern areas bordering on Louisiana, and a spring maximum of class 5 wind power along the coastal areas of southeastern Texas from Brownsville to Corpus Christi. A relative minimum of class 2 wind power is found throughout east-central Texas.

9.2.3 Summer

Summer is the calmest season of the year in west Texas, and the second calmest season of the year in east Texas. A majority of the state demonstrates class 1 wind power during the summer, generally occurring through the central part of the state, with class 2, the second most prevalent wind class, appearing in north-central and south-central Texas. Only in the extreme northern Panhandle, the immediate lower Texas coast, and around Laredo is wind resource as strong as class 3 observed during summer.

9.2.4 Autumn

Like summer, autumn is a relatively weak season with respect to wind power. Except for immediate coastal areas, and northwestern Texas including the high rolling plains of the Panhandle, most of the state demonstrates class 1 wind power during the autumn. Class 4 wind power is the highest class observed in Texas during the autumn, and appears in the high plains of the Panhandle. East Texas shows class 1 wind power over much of the area, except for the dominant sea breeze along the coast, and the increasing westerlies in extreme northern sections of the area.

9.3 FEATURES OF SELECTED STATIONS

Table 9.2 gives the location and annual wind speed and power density of 52 stations representing the 10 regions of Texas. Graphs of other features of the wind resource are shown in Figures 9.10 to 9.16.

The Trans-Pecos Region contains El Paso, Guadalupe Pass, Marfa, Salt Flat, and Wink. This region is located in the western portion of Texas bounded by the Pecos River to the east and the Rio Grande to the south and west. Estimated areas of class 3, 4 and 5 power are located along the Guadalupe, Davis, and Santiago mountain ranges that divide the Trans-Pecos Region in half.

The High Plains Region contains Amarillo, Big Spring, Dalhart, Lubbock, and Midland. This region is composed of the northern and western sections of the Texas Panhandle. This entire plains area appears well exposed to the winds, and stations within this region show good representation for the region as a whole.

The Low Rolling Plains contain Childress, Clarendon, Abilene, and Wichita Falls. This region makes up the eastern portion of the Texas Panhandle. Less than two years' data were available from Clarendon, but these data appeared characteristic of the surrounding area.

Edwards Plateau contains Del Rio, San Angelo, and Junction. This region is south of the Low Rolling Plains and is

bordered on the west by the Pecos River and on the east by the Colorado River. Data from the locations appear more representative of lowland areas than upland areas and hilltops on the Edwards Plateau.

The North-Central Region contains Dallas, Fort Hood, Fort Worth, Mineral Wells, Sherman, and Waco. This region is just east of the low Rolling Plains and the northern half of the Edwards Plateau. The eastern half of north-central Texas marks the beginning of a large forested area that covers most of northeast Texas. However, these selected sites appear quite representative of the exposed areas in that region.

The South-Central Region contains Austin, Beeville, Corpus Christi, Kingsville, and San Antonio. This region, located south of the North-Central Region, extends to the central Gulf Coast of Texas. With the prevailing wind direction from the south to southeast, the wind power classes in this region increase as they approach the unrestricted areas along the coast.

The Southern Region contains Alice, Cotulla, and Laredo. This region extends eastward from the Rio Grande to the South-Central Region and a small section of the lower Gulf Coast of Texas. Prevailing winds from the southeast influence this region as well as the smooth plains of the coast.

The Lower Valley contains Brownsville, Harlingen, and Port Isabel. This region is situated along the year-round, fertile farm lands of the lower Rio Grande. The prevailing southeasterly winds cause wind classes to decrease as distance increases from the unrestricted coastal areas.

The Upper Coast contains Galveston, Houston, Matagorda Island, Palacios, Port Arthur, and Victoria. This region extends inland 40 mi (65 km) to 80 mi (130 km) from the Gulf Coast between the Louisiana border and the San Antonio River. Wind classes in this region decrease toward the northern portions due to an increase in forested land cover.

East Texas contains Bryan, Longview, Lufkin, and Tyler. This region covers the heavily wooded section of northeast Texas. Although these locations are exposed sites, class 1 and 2 powers appear characteristic of this entire forested area.

9.3.1 Interannual Wind Power and Speed

Large interannual variations are apparent for many of the stations (Figure 9.10). At stations with the largest interannual variations such as San Angelo and El Paso, differences in wind power between years can be as much as 250 percent. The magnitude of these variations is not similar from different periods of record at a single station and must be treated with caution. San Angelo, for example, shows a much larger interannual variation during the latter part of the period of record (1968 to 1978) than the earlier portion of the record (1954 to 1964).

The interannual curves may also indicate individual years with relatively high or low wind energy. For example, the records from Brownsville and Corpus Christi indicate that 1967 was a high wind speed year in southern Texas, while nearly all station records show a relative maximum occurred in 1950.

9.3.2 Monthly Average Wind Power and Speed

Spring is the season of maximum wind power and speed at all stations except Matagorda and Clarendon, which show relative maximums during November (Figure 9.11). Throughout Texas, the lowest wind speeds occur generally during the months of July, August, and September. The windier months usually indicate a 50 percent increase in available wind power from the calmer summer months.

Because of the short period of record at Matagorda and Clarendon, the monthly trends shown may deviate significantly from the long-term average. The Clarendon record, for example, is based on data from only one year, and the relatively high power shown in November is apparently not representative of the long-term average. The Matagorda record is based on four years of data (1956-1959) and shows a maximum in

November. The Port Isabel record is based on two years of data during the same period (1958-1959) and also shows a maximum during November. Clearly, these years were not representative of the long-term averages.

9.3.3 Diurnal Wind Speed by Season

All the stations presented for Texas indicate maximum daily wind speeds during the afternoon for all seasons (Figure 9.12). Maximum wind speeds generally occur during the afternoon (1200 to 1500 LST) with very little variation from season to season. Wind speeds during the night show little variation, but generally reach a minimum near 0600 LST during all seasons at most stations.

The magnitude of the diurnal variation with season varies from station to station, but is generally greatest in the spring and summer. This is due primarily to periods of most intense daytime heating occurring during the spring and summer, and maximum diurnal variation in temperature as well as wind speed. Except for the higher elevations, this is true for most of Texas.

9.3.4 Directional Frequency and Average Speed

The prevailing strong winds are generally from the southwest to southeast over most of Texas (Figure 9.13). Terrain influences this phenomenon very little, as shown by the widespread occurrence of the predominant south winds regardless of location. This effect is largely due to the position of Texas with

respect to the Gulf of Mexico, and high pressure (the Bermuda High) to the east which dominates in the eastern Gulf waters causing south winds.

In coastal areas, prevailing strong winds are generally southeasterly rather than southerly as found in areas further inland. Coastal stations such as Corpus Christi and Port Isabel show prevailing southeast winds, while the records from inland stations such as Waco and Fort Worth indicate strong maxima from the south.

9.3.5 Annual Average Wind Speed Frequency

Observer biases are readily apparent in the records for Port Isabel, Tyler, Cotulla, Alice, Marfa, Wink, and Childress as peaks usually occur at 2, 5, and 8 m/s (Figure 9.14). A large frequency of calms (nearly 20 percent) at El Paso/Biggs, Lufkin, and Junction makes either the data or site exposure questionable. Many of the stations such as Austin or Fort Hood show very little observer bias, and their Rayleigh distributions approximate the actual distributions quite well.

9.3.6 Annual Average Wind Speed and Power Duration

The percentage of time that a given wind speed or power is exceeded is shown in Figures 9.15 and 9.16. Abrupt changes in the slope of the duration curves correspond to peaks in the speed frequency distribution caused by observer bias and instrument threshold velocity.

FIGURE 9.1a. Geographic Map of West Texas

FIGURE 9.1b. Geographic Map of East Texas

FIGURE 9.2. Topographic Map of Texas

FIGURE 9.3. Land-Surface Form Map of Texas

LAND-SURFACE FORM LEGEND

PLAINS

A1	FLAT PLAINS
A2	SMOOTH PLAINS
B1	IRREGULAR PLAINS, SLIGHT RELIEF
B2	IRREGULAR PLAINS

TABLELANDS

B3c,d	TABLELANDS, MODERATE RELIEF
B4c,d	TABLELANDS, CONSIDERABLE RELIEF
B5c,d	TABLELANDS, HIGH RELIEF
B6c,d	TABLELANDS, VERY HIGH RELIEF

PLAINS WITH HILLS OR MOUNTAINS

A,B3a,b	PLAINS WITH HILLS
B4,a,b	PLAINS WITH HIGH HILLS
B5a,b	PLAINS WITH LOW MOUNTAINS
B6a,b	PLAINS WITH HIGH MOUNTAINS

SCHEME OF CLASSIFICATION

SLOPE (1st LETTER)

A	>80% OF AREA GENTLY SLOPING
B	50-80% OF AREA GENTLY SLOPING
C	20-50% OF AREA GENTLY SLOPING
D	<20% OF AREA GENTLY SLOPING

OPEN HILLS AND MOUNTAINS

C2	OPEN LOW HILLS
C3	OPEN HILLS
C4	OPEN HIGH HILLS
C5	OPEN LOW MOUNTAINS
C6	OPEN HIGH MOUNTAINS

LOCAL RELIEF (2nd LETTER)

1	0 TO 30m (1 TO 100 ft)
2	30 TO 90m (100 TO 300 ft)
3	90 TO 150m (300 TO 500 ft)
4	150 TO 300m (500 TO 1000 ft)
5	300 TO 900m (1000 TO 3000 ft)
6	900 TO 1500m (3000 TO 5000 ft)

HILLS AND MOUNTAINS

D3	HILLS
D4	HIGH HILLS
D5	LOW MOUNTAINS
D6	HIGH MOUNTAINS

PROFILE TYPE (3rd LETTER)

a	>75% OF GENTLE SLOPE IS IN LOWLAND
b	50-75% OF GENTLE SLOPE IS IN LOWLAND
c	50-75% OF GENTLE SLOPE IS ON UPLAND
d	>75% OF GENTLE SLOPE IS ON UPLAND

FIGURE 9.4a. NCC Station Locations in West Texas

FIGURE 9.5a. Location of Stations Used in West Texas Wind Assessment

FIGURE 9.5b. Location of Stations Used in East Texas Wind Assessment

FIGURE 9.6a. West Texas Annual Average Wind Power

FIGURE 9.6b. East Texas Annual Average Wind Power

Classes of Wind Power Density at 10 m and 50 m^(a)

Wind Power Class	10 m (33 ft)		50 m (164 ft)	
	Wind Power Density, watts/m ²	Speed, ^(b) m/s (mph)	Wind Power Density, watts/m ²	Speed, ^(b) m/s (mph)
	0	0	0	0
1	100	4.4 (9.8)	200	5.6 (12.5)
2	150	5.1 (11.5)	300	6.4 (14.3)
3	200	5.6 (12.5)	400	7.0 (15.7)
4	250	6.0 (13.4)	500	7.5 (16.8)
5	300	6.4 (14.3)	600	8.0 (17.9)
6	400	7.0 (15.7)	800	8.8 (19.7)
7	1000	9.4 (21.1)	2000	11.9 (26.6)

(a) Vertical extrapolation of wind speed based on the 1/7 power law.

(b) Mean wind speed is based on Rayleigh speed distribution of equivalent mean wind power density. Wind speed is for standard sea-level conditions. To maintain the same power density, speed increases 5%/5000 ft (3%/1000 m) of elevation.

TABLE 9.1. Areal Distribution (km²) of Wind Power Classes in Texas

Power Classes	Land Area	% Land Area	Cumulative Land Area	% Cumulative Land Area
1	220,000	30.0	690,000	100.00
2	280,000	39.0	470,000	70.00
3	140,000	19.0	190,000	33.00
4	44,000	7.3	60,000	14.20
5	19,000	6.5	20,000	6.90
6	560	0.2	1,100	0.35
7	450	0.2	450	0.16

CERTAINTY RATING LEGEND

Rating	Definition
1	<p>The lowest degree of certainty. A combination of the following conditions exists:</p> <ol style="list-style-type: none"> 1) No data exist in the vicinity of the cell. 2) The terrain is highly complex. 3) Various meteorological and topographical indicators suggest a high level of variability of the resource within the cell.
2	<p>A low-intermediate degree of certainty. One of the following conditions exists:</p> <ol style="list-style-type: none"> 1) Little or no data exist in or near the cell, but the small variability of the resource and the low complexity of the terrain suggest that the wind resource will not differ substantially from the resource in nearby areas with data. 2) Limited data exist in the vicinity of the cell, but the terrain is highly complex or the mesoscale variability of the resource is large.
3	<p>A high-intermediate degree of certainty. One of the following conditions exists:</p> <ol style="list-style-type: none"> 1) There are limited wind data in the vicinity of the cell, but the low complexity of terrain and the small mesoscale variability of the resource indicate little departure from the wind resource in nearby areas with data. 2) Considerable wind data exist but in moderately complex terrain and/or in areas where moderate variability of the resource is likely to occur.
4	<p>The highest degree of certainty. Quantitative data exist at exposed sites in the vicinity of the cell and can be confidently applied to exposed areas in the cell because of the low complexity of terrain and low spatial variability of the resource.</p>

FIGURE 9.7a. Certainty Rating of West Texas Wind Resource

FIGURE 9.7b. Certainty Rating of East Texas Wind Resource

FIGURE 9.8a. Areal Distribution of Wind Resource in West Texas (Power Classes 2 and 3); Percent of Land Area With or Exceeding Power Class Shown. An asterisk denotes 100%.

FIGURE 9.8a (Continued). Areal Distribution of Wind Resource in West Texas (Power Classes 4 and 5); Percent of Land Area With or Exceeding Power Class Shown. An asterisk denotes 100%.

FIGURE 9.8b. Areal Distribution of Wind Resource in East Texas (Power Classes 2 and 3); Percent of Area With or Exceeding Power Class Shown. An asterisk denotes 100%.

FIGURE 9.8b (Continued). Areal Distribution of Wind Resource in East Texas (Power Classes 4 and 5); Percent of Land Area With or Exceeding Power Class Shown. An asterisk denotes 100%.

FIGURE 9.9a. Seasonal Average Wind Power in West Texas (Winter, Summer)

FIGURE 9.9a (Continued). Seasonal Average Wind Power in West Texas (Spring, Autumn)

FIGURE 9.9b. Seasonal Average Wind Power in East Texas (Winter, Summer)

FIGURE 9.9b (Continued). Seasonal Average Wind Power in East Texas (Spring, Autumn)

TABLE 9.2a. West Texas Stations With Graphs of the Wind Characteristics

Station	Station Name ^(a)	Latitude, Degrees North	Longitude, Degrees West	Elevation of Station, m	Period of Record, Month/year	Annual Average Wind Speed, m/s				Annual Average Wind Power, watts/m ²		
						Anemometer Height, m	At Anemometer Height, m	At 10 m	At 50 m	At Anemometer Height, m	At 10 m	At 50 m
Amarillo, Texas	English Field Airport	35.23	101.70	1099	05/61-12/78	7.0	6.2	6.6	8.3	216	252	501
Amarillo, Texas	English Field Airport	35.23	101.70	1099	10/56-05/61	10.1	5.5	5.5	6.9	156	156	310
Big Spring, Texas	Big Spring SAWR	32.30	101.45	779	05/59-12/70	4.6	4.7	5.2	6.6	116	162	323
Childress, Texas	Childress Airport	34.43	100.28	596	08/50-12/54	10.4	5.2	5.2	6.5	161	159	316
Clarendon, Texas	Clarendon Airport	34.95	100.93	874	07/48-05/50	17.7	6.1	5.6	7.0	237	186	370
Dalhart, Texas	Dalhart Airport	36.02	102.55	1217	12/48-09/54	19.2	6.7	6.1	7.7	332	251	500
Del Rio, Texas	International Airport	29.37	100.92	314	03/64-12/78	7.0	4.4	4.7	5.9	85	99	197
El Paso/Riggs Texas	Riggs AFB	31.83	106.40	1196	01/56-04/66	4.0	3.0	3.4	4.3	58	86	172
El Paso, Texas	International Airport	31.80	106.40	1200	04/64-12/78	11.3	3.6	3.6	4.5	66	63	125
Guadalupe Pass, Texas	Guadalupe Pass CAA	31.83	104.80	1662	07/48-08/50	17.7	8.9	8.2	10.4	887	695	1385
Lubbock, Texas	West Texas AT	33.65	101.82	990	10/65-12/78	6.1	5.0	5.4	6.8	131	162	323
Marfa, Texas	Marfa Airport	30.25	103.88	1481	07/48-12/54	17.1	5.0	4.6	5.8	166	132	263
Midland, Texas	Mid-Odessa RAT	31.93	102.20	871	12/59-12/78	6.7	5.2	5.5	6.9	133	158	315
Salt Flat, Texas	Salt Flat CAA	31.75	105.05	1131	07/51-12/54	8.5	3.5	3.6	4.6	92	98	196
San Angelo, Texas	Mathis Field Airport	31.37	100.50	585	09/61-12/78	6.1	4.5	4.8	6.1	96	119	237
Wink, Texas	Winkler County Airport	31.78	103.20	858	07/48-12/54	9.1	4.3	4.3	5.4	107	111	222

(a) SAWR-Supplementary Aviation Weather Reporting; AFB-Air Force Base; CAA-Civil Aeronautics Administration Facility; AT-Air Terminal; RAT-Regional Air Terminal.

TABLE 9.2b. East Texas Stations With Graphs of the Wind Characteristics

Station	Station Name ^(a)	Latitude, Degrees North	Longitude, Degrees West	Elevation of Station, m	Period of Record, Month/Year	Annual Average Wind Speed, m/s				Annual Average Wind Power, watts/m ²		
						Anemometer Height, m	At Anemometer Height, m	At 10 m	At 50 m	At Anemometer Height, m	At 10 m	At 50 m
Abilene, Texas	Municipal Airport	32.43	99.68	537	05/60-12/78	6.1	5.2	5.5	7.0	134	166	330
Abilene/Dyess, Texas	Dyess AFB	32.43	99.85	542	05/62-12/70	4.0	3.9	4.4	5.5	80	119	237
Alice, Texas	Alice Airport	27.73	98.03	55	07/48-12/54	8.2	4.9	5.0	6.3	146	159	316
Austin, Texas	Mueller Airport	30.30	97.70	183	07/61-12/78	6.1	4.1	4.4	5.5	80	99	197
Beeville, Texas	Chase Field NAAS	28.37	97.67	62	02/62-02/72	4.3	3.4	3.9	4.9	65	94	187
Brownsville, Texas	Rio Grande Int'l Airport	25.90	97.43	10	11/66-12/78	6.1	5.0	5.4	6.8	144	178	355
Bryan, Texas	Bryan AFB	30.67	96.55	84	10/51-06/58	7.3	3.3	3.4	4.3	56	64	128
Corpus Christi, Texas	Corpus Christi NAS	27.68	97.28	6	07/61-02/72	3.7	4.9	5.7	7.2	130	200	399
Corpus Christi, Texas	Corpus Christi Airport	27.77	97.50	17	09/60-12/78	7.0	5.4	5.7	7.2	167	194	388
Cotulla, Texas	Municipal Airport	28.45	99.22	141	10/49-12/54	8.2	4.2	4.3	5.4	94	102	204
Dallas, Texas	Dallas NAS	32.73	96.97	143	08/66-12/78	4.6	3.6	4.0	5.0	64	90	178
Dallas/Love Texas	Love Field WBAS	32.85	96.85	159	04/58-01/74	6.1	5.0	5.4	6.7	123	152	303
Ft. Hood, Texas	Gray AFB	31.07	97.82	312	01/65-06/70	3.0	4.2	5.0	6.3	88	146	292
Ft. Worth, Texas	Carswell AFB	32.78	97.43	191	05/57-12/70	4.0	3.8	4.3	5.5	84	125	249
Ft. Worth, Texas	Greater SW Int'l Airport	32.83	97.05	175	05/63-08/74	6.7	4.5	4.7	5.9	102	121	241
Galveston, Texas	Scholes Field Airport	29.27	94.85	8	07/48-12/58	14.0	5.7	5.4	6.8	191	165	329
Harlingen, Texas	Harlingen AFB	26.23	97.67	11	08/52-03/57	10.7	4.4	4.3	5.4	121	118	235
Houston, Texas	Intercontinental Airport	29.98	95.35	37	06/69-12/78	6.1	3.4	3.6	4.5	50	62	123

(a) AFB—Air Force Base; NAAS—Naval Auxiliary Air Station; NAS—Naval Air Station; WBAS—Weather Bureau Airport Station.

TABLE 9.2b (Continued). East Texas Stations With Graphs of the Wind Characteristics

Station	Station Name ^(a)	Latitude, Degrees North	Longitude, Degrees West	Elevation of Station, m	Period of Record, Month/Year	Annual Average Wind Speed, m/s				Annual Average Wind Power, watts/m ²		
						Anemometer Height, m	At Anemometer Height, m	At 10 m	At 50 m	At Anemometer Height, m	At 10 m	At 50 m
Houston/Hobby, Texas	Hobby Airport	29.65	95.28	16	07/60-05/69	6.1	4.4	4.7	5.9	102	126	251
Junction, Texas	Junction Airport	30.50	99.77	521	04/50-12/64	7.3	3.0	3.2	4.0	45	51	103
Kingsville, Texas	Kingsville NAAS	27.50	97.80	18	02/67-12/78	6.1	3.8	4.1	5.2	84	104	207
Laredo, Texas	Municipal Airport	27.53	99.47	153	06/47-02/61	11.9	5.3	5.2	6.6	152	141	281
Longview, Texas	Longview Airport	32.38	94.72	121	09/50-12/54	21.3	4.8	4.3	5.4	118	85	170
Lufkin, Texas	Angellina County Airport	31.23	94.75	89	04/65-12/78	6.1	3.2	3.5	4.4	45	56	111
Matagorda Is., Texas	Matagorda Is. ^(b) Air Field	28.33	96.45	2	08/55-12/59	18.3	6.0	5.5	6.9	231	178	355
Mineral Wells, Texas	Municipal Airport	32.78	98.07	286	06/48-12/64	8.5	4.7	4.8	6.0	119	127	254
Palacios, Texas	Palacios Airport	28.72	96.25	5	04/49-12/58	8.5	4.7	4.9	6.1	115	123	245
Port Arthur, Texas	Jefferson County Airport	29.95	94.02	9	11/60-12/78	6.1	4.3	4.6	5.8	90	111	222
Port Isabel, Texas	Port Isabel ^(b) NAAS	26.17	97.33	9	11/57-07/60	Unk ^(c)	6.2	6.2	7.8	254	254	506
San Antonio, Texas	International Airport	29.53	98.47	243	09/61-12/78	7.0	4.2	4.5	5.6	79	92	183
Sherman, Texas	Perrin AFB	33.72	96.67	232	04/57-12/70	4.3	4.2	4.7	5.9	95	137	273
Tyler, Texas	Tyler Airport	32.37	95.40	173	05/50-12/54	21.6	4.8	4.3	5.5	144	103	206
Victoria, Texas	Victoria Airport	28.85	96.92	33	07/64-12/78	6.1	4.4	4.8	6.0	102	126	251
Waco, Texas	Municipal Airport	31.62	97.22	157	02/64-12/78	7.0	4.8	5.0	6.3	119	139	276
Waco/Connally, Texas	James Connally AFB	31.63	97.07	145	05/58-07/66	4.0	3.5	4.0	5.1	67	100	199
Wichita Falls, Texas	Wichita Falls Airport	33.97	98.48	307	04/61-12/78	6.4	5.3	5.6	7.1	158	191	381

(a) NAAS-Naval Auxiliary Air Station; AFB-Air Force Base.

(b) Daytime observations only.

(c) Unk- Anemometer height is unknown. Height of 10m was assumed for estimating wind speed and power at 10 and 50 m.

FIGURE 9.10b. Interannual Wind Power and Speed for East Texas

FIGURE 9.10a. Interannual Wind Power and Speed for West Texas

FIGURE 9.10b (Continued). Interannual Wind Power and Speed for East Texas

FIGURE 9.11a. Diurnal Wind Speed by Season for West Texas

FIGURE 9.11b. Diurnal Wind Speed by Season for East Texas

——— WINTER ♦ — — — SPRING
 ⊕ — — — SUMMER ⊞ — — — AUTUMN
 PNL-3196 WERA-7

ORDINATE — M/S
 ABSCISSA — HOUR

HOUSTON TX 06/69-12/78
12960 Z= 6.1 G. V= 3.4, P= 50

JUNCTION TX 04/50-12/64
13973 Z= 7.3 R. V= 3.0, P= 45

KINGSVILLE TX 02/67-12/78
12928 Z= 6.1 G. V= 3.8, P= 84

LAREDO TX 06/47-02/61
12920 Z=11.9 R. V= 5.3, P= 152

LONGVIEW TX 09/50-12/54
3901 Z=21.3 R. V= 4.8, P= 118E

LUFKIN TX 04/65-12/78
93987 Z= 6.1 G. V= 3.2, P= 45

MATAGORIA IS. TX 08/55-12/59
12956 Z=18.3 R. V= 6.0, P= 231E

MINERAL WELLS TX 06/48-12/64
93985 Z= 8.5 R. V= 4.7, P= 119

PALACIOS TX 04/49-12/58
12935 Z= 8.5 R. V= 4.7, P= 115

PORT ARTHUR TX 11/60-12/78
12917 Z= 6.1 G. V= 4.3, P= 90

PORT ISABELL TX 11/57-07/60
12957 Z= UNK V= 6.2, P= 254

SAN ANTONIO TX 09/61-12/78
12921 Z= 7.0 G. V= 4.2, P= 79

SHERMAN TX 04/57-12/70
13923 Z= 4.3 G. V= 4.2, P= 95E

TYLER TX 05/50-12/54
13972 Z=21.6 R. V= 4.6, P= 144

VICTORIA TX 07/64-12/78
12912 Z= 6.1 G. V= 4.4, P= 102

WACO/CONNALLY TX 05/58-07/66
13928 Z= 4.0 G. V= 3.5, P= 67E

WACO TX 02/64-12/78
13959 Z= 7.0 G. V= 4.8, P= 119

WICHITA FALLS TX 04/61-12/78
13966 Z= 6.4 G. V= 5.3, P= 158

FIGURE 9.11b (Continued). Diurnal Wind Speed by Season for East Texas

FIGURE 9.12a. Monthly Average Wind Power and Speed for West Texas

FIGURE 9.12b. Monthly Average Wind Power and Speed for East Texas

FIGURE 9.12b (Continued). Monthly Average Wind Power and Speed for East Texas

— PERCENT FREQUENCY LEFT ORDINATE - PERCENT
 - - - WIND SPEED RIGHT ORDINATE - M/S
 PNL-3195 WERA-7
 ABSCISSA - WIND DIRECTION

FIGURE 9.13a. Directional Frequency and Average Speed for West Texas

— PERCENT FREQUENCY LEFT ORDINATE - PERCENT
 WIND SPEED RIGHT ORDINATE - M/S
 PNL 3195 WERA-7
 ABSISSA - WIND DIRECTION

FIGURE 9.13b. Directional Frequency and Average Speed for East Texas

— PERCENT FREQUENCY LEFT ORDINATE – PERCENT
 WIND SPEED RIGHT ORDINATE – M/S
 PNL 3195 WERA-7
 ABSISSA – WIND DIRECTION

FIGURE 9.13b (Continued). Directional Frequency and Average Speed for East Texas

— ACTUAL DISTRIBUTION ORDINATE - PERCENT
 - - - RAYLEIGH DISTRIBUTION ABSCISSA - M/S
 PNL-3195 WERA-7

FIGURE 9.14a. Annual Average Wind Speed Frequency for West Texas

— ACTUAL DISTRIBUTION ORDINATE - PERCENT
 - - - RAYLEIGH DISTRIBUTION ABSCISSA - M/S

PNL 3195 WERA-7

FIGURE 9.14b. Annual Average Wind Speed Frequency for East Texas

— ACTUAL DISTRIBUTION ORDINATE - PERCENT
 - - - RAYLEIGH DISTRIBUTION ABSCISSA - M/S

PNL-3195 WERA-7

FIGURE 9.14b (Continued). Annual Average Wind Speed Frequency for East Texas

ORDINATE - PERCENT

ABSCISSA - M/S

PNL-3195 WERA-7

AMARILLO TX 10/56-05/61
23047 Z=10.1 G, V= 5.5, P= 156

AMARILLO TX 05/61-12/78
23047 Z= 7.0 G, V= 6.2, P= 216

BIG SPRINGS TX 05/59-12/70
23005 Z= 4.6 G, V= 4.7, P= 116E

CHILDRESS TX 08/50-12/54
23007 Z=10.4 R, V= 5.2 P= 161

CLARENDON TX 07/48-05/50
23072 Z=17.7 B, V= 6.1, P= 237

DALHART TX 12/48-09/54
93042 Z=19.2 R, V= 6.7, P= 332

DEL RIO TX 03/64-12/78
22010 Z= 7.0 G, V= 4.4, P= 85

EL PASO/BIGGS TX 01/56-04/66
23019 Z= 4.0 G, V= 3.0, P= 58E

EL PASO TX 04/64-12/78
23044 Z=11.3 R, V= 3.6, P= 66

GUADALUPE PASSTX 07/48-08/50
23055 Z=17.7 B, V= 8.9, P= 887

LUBBOCK TX 10/65-12/78
23042 Z= 6.1 G, V= 5.0, P= 131

MARFA TX 07/48-12/54
93035 Z=17.1 R, V= 5.0, P= 166

MIDLAND TX 12/59-12/78
23023 Z= 6.7 G, V= 5.2, P= 133

SALT FLAT TX 07/51-12/54
23059 Z= 8.5 R, V= 3.5, P= 92

SAN ANGELO TX 09/61-12/78
23034 Z= 6.1 G, V= 4.5, P= 96

WINK TX 07/48-12/54
23040 Z= 9.1 R, V= 4.3, P= 107

FIGURE 9.15a. Annual Average Wind Speed Duration for West Texas

ORDINATE - PERCENT
ABSCISSA - M/S

PNL-3195 WERA-7

FIGURE 9.15b. Annual Average Wind Speed Duration for East Texas

ORDINATE - PERCENT

ABSCISSA - M/S

PNL-3196 WERA-7

FIGURE 9.15b (Continued). Annual Average Wind Speed Duration for East Texas

ORDINATE - PERCENT
ABSCISSA - WATTS/M²

PNL-3195 WERA-7

FIGURE 9.16a. Annual Average Wind Power Duration for West Texas

ORDINATE - PERCENT
ABSCISSA - WATTS/M²

PNL-3195 WERA-7

FIGURE 9.16b. Annual Average Wind Power Duration for East Texas

ORDINATE - PERCENT
ABSCISSA - WATTS/M²
PNL-3195 WERA-7

FIGURE 9.16b (Continued). Annual Average Wind Power Duration for East Texas

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