NOAA Technical Memorandum NWS WR-166

PRELIMINARY ESTIMATES OF WIND POWER POTENTIAL AT THE NEVADA TEST SITE

Salt Lake City, Utah
July 1981

U.S. DEPARTMENT OF COMMERCE / National Oceanic and Atmospheric Administration / National Weather Service

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National Weather Service Nuclear Support Office
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DEPARTMENT OF COMMERCE
Malcolm Baldrige, Secretary

NATIONAL OCEANIC AND
ATMOSPHERIC ADMINISTRATION
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National Weather
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This Technical Memorandum has been reviewed and is approved for publication by Scientific Services Division, Western Region.

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Salt Lake City, Utah

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PRELIMINARY ESTIMATES OF WIND POWER POTENTIAL AT THE NEVADA TEST SITE

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[Editor's Note: The approach that Mr. Booth has taken in this paper may be a guide to others asked to evaluate the wind power potential at their stations.]

The assessment of the potential for useful conversion of wind power to electrical power is quite complex because of the many factors involved, both of a climatological and an engineering nature. The ultimate assessment in an absolute sense is an engineering problem better left to engineers. The climatologist's capability is in attempting to describe the available wind power for the Nevada Test Site (NTS) and comparing it in a relative sense with what is known for other parts of the country so that engineers can assess the conversion potential. This discussion, therefore, concentrates on climatological aspects of the question.

Climatological factors of concern are the average magnitude of the wind power density (watts/m) and its spatial and temporal variability. The magnitude is obviously of consequence as one factor in assessing the practicality of any wind power conversion machine since sufficient energy must be available to make the device rotate fast enough. The spatial variability of wind power density is especially important in the siting of wind turbines at the NTS because of the large effects of extreme terrain relief in sheltering turbines from the wind (as in some valleys or behind hills) or of providing opportunities for stronger winds (as through siting turbines in the stronger winds of higher altitudes on mountaintops or where winds must speed up in funneling through passes in long ridges). Temporal variability is important because it determines how much of the time useful wind power is available. This steadiness of the wind speed is important in determining if on-line base-load generation (where storage of electrical energy for bridging gaps in wind power availability is difficult) or remote-site low-power generation (where battery storage is possible) is the more practical application of wind power conversion. The timing of the peaks in wind power availability is important for base-load generation because of the advantage which is realized when these coincide with the times of peak energy demand. The variability of the wind speed in space and time is amplified in wind power computations because wind power varies as the cube of wind speed. Thus, a doubling of the wind speed will increase the available wind power by a factor of eight. In terms of temporal variability this fact can result in extremely large peaks and valleys in the wind power availability curve, even for modest changes in wind speed.

A great deal of wind data is available for the NTS but very little of this has been analyzed for wind power. Until studies utilizing these data are available, we are forced to look at such studies as have been published, largely DOE-sponsored and concerned with regional and national characteristics of wind energy availability. These provide a basis for looking at the potential for wind power conversion in the general region of the NTS in comparison with other parts of the country. We can then look at the few available NTS wind power computations and the wind climatology to see how more localized factors might influence the potential at the NTS.

Reed (1975, 1979) and Bray (1980) have shown that, in general, the southwestern United States has low wind power availability, but Bray (1980) has shown that on an annual basis both Las Vegas and Ely are somewhat higher in available wind power than most stations in the region. Bray puts both of these stations in a moderate wind speed category while Lovelock, Nevada, is ranked as a low annual wind speed station that seems more typical of many in the southwest. The somewhat higher values for Las Vegas and Ely are perhaps related to local valley-mountain influences and, in the case of Ely, an altitude effect. Reed (1975) and others point out the extreme variability in wind power availability between closely spaced stations, again realted to terrain and altitude influences. Most stations from which these studies are derived are valley stations, since that is where most cities are located, so nearby station differences are largely a question of valley altitudes above sea level, the orientation of valleys relative to the prevailing winds, and the shielding effect of nearby mountain ranges.

The annual daily average wind power for selected United States cities, including three Nevada stations, are plotted to the right of Figure 1 for comparison. Lihue, Hawaii, represents a tropical coast station of good exposure to moderately strong winds while Dodge City, Kansas, is fairly typical of the high wind power region embracing the Great Plains and portions of the Rockies. The high annual average value for Whitehall, Montana, is an example of rather extreme terrain effect coupled with a location close to the normal storm track across the northern Rockies. It is located in a river valley that channels strong winds either up or down the valley. Highest average wind speeds at this location occur with wind directions having the greatest frequency of occurrence.

Annual wind power values for the NTS have not as yet been computed. But daily averages for two NTS stations, Yucca Valley (BJY) and Rainier Mesa, for the months of January and July, are available (adapted from Quiring, 1975) and have been plotted on Figure 1. These two stations are representative of BJY and the higher level, relatively flat, and well-exposed summits of NTS mesas (Rainier Mesa). Based on the climatology of wind speeds for these two stations, it appears that the shape of monthly power profiles shown in Figure 1 for Las Vegas and Ely, a regional characteristic, are followed at NTS stations as well. The annual average wind power availability for BJY and Rainier Mesa have, therefore, been estimated on an assumed monthly profile and plotted with the annual values of the other stations for comparison. Table 1, adapted from Barchet and Elliott 1979 study of wind power availability for the Pacific Northwest, assigns a class number to each of several successively larger wind power intervals. The wind power values in the table are for standard heights above ground level of 33 and 164 feet (10 and 50 meters). BJY and Rainier (Figure 1) have estimated annual power availabilities of roughly 150 and 275 watts/m^2, respectively, at tower heights of 88 feet (27 meters). These estimated power levels have been fitted into Barchet and Elliott's power classes by linearly interpolating for 88 feet using the class interval values of the 10- and 50-meter heights of the table. This is not very rigorous since the average wind power increase with height is a logarithmic or power function rather than being linear, but the rate of increase with height is greatly dependent on the very variable atmospheric stability of the layer near the ground. From this interpolation, Rainier fits into the upper end of wind power Class 3 and BJY into Class 2. According to Barchett and Elliott (1979) Class 4 winds or higher represent high annual wind energy potential and any monthly wind power average above 400 watts/m^2 can be considered exceptionally high. For comparison, Barchet and Elliott show that ridgetop sites in Idaho at 10-meter heights above ground fall into classes 4-6 on an annual basis, 6-7 for winter, 2-3 in summer, 4-6 in spring, and 4-6 in the fall. Yet even stations in the lowest wind power class, it is pointed out by Barchet and Elliott, may have adequate power potential for some users, probably depending somewhat on temporal variability (discussed later). From this it is concluded that on the basis of average annual wind power availability alone, the mesa tops above the tree levels would be classified as having a fairly high annual average wind energy potential. Long, narrow and steep-sided ridges oriented more or less normal to the prevailing northwest and southwest winds would be expected to exhibit even higher wind power availability as an annual average. Passes in east-west oriented ridges might also have high potential as, for instance, the one immediately north of Topopah Spring in the Shoshone Mountains of Area 29. Any such site should, of course, be subjected to a period of observation to verify theory. Valley stations like BJY have a very moderate potential based on their likely Class 2 category.

The "steadiness" or temporal variability on various time scales is an important part of the wind power evaluation. Barchet and Elliott are inlcuding interannual, i.e., year-to-year wind power variability in their series of Wind Energy Resource Atlases for the United States, of which only the Northwest Region atlas has, as yet, been published (1979). Average annual wind power can vary appreciably from year to year and average storm intensity. Barchet et al (1979) shows this to be very true for certain stations in the Northwest Region where, for instance, the average annual available wind power for Whitehall, Montana, nearly doubled from 1949 to 1950. Similar interannual variability has not been demonstrated as yet for NTS stations and it is probably nowhere as extreme as for Whitehall.

The seasonal and diurnal variations of wind power availability are quite large for many stations. Seasonal changes for a number of stations are shown in Figure 1, which generally shows a springtime maximum peaking about April and either a summer or fall minimum. A doubling of daily average available power between minimum and maximum is not uncommon. The changes are generally associated with the weakening of storms and a northward shift in their tracks toward summer. Where seasonal changes are small and a station has a good exposure to available winds in all seasons, the available power may change relatively little from month to month. Lihue, Hawaii, a tropical station with good exposure to the sea, is a good example. Although its available power on either an annual or a monthly basis is not outstanding, its month-to-month steadiness has some salutory implications for power generation. By contrast, Whitehall, Montana, shows extreme seasonal variability, even though its annual average available wind power is high. The daily average wind power peaks in January, a reflection of the large influence of river valley channeling during the time when storms accompanied by strong winds are typically crossing Montana.

The average wind power data for BJY and Rainier Mesa, available only for the months of January and July, show little difference between these winter and summer months (Figure 1). But neither do the curves for Las Vegas and Ely, where the April maxima and late summer to midwinter minima express a regional characteristic that NTS stations also follow. This is evident from Figures 2 and 3 (Quiring, 1968) where it can be seen from mental averaging over all hours in individual months that the daily average winds by month peak close to April for both stations and bottom out at about October for Rainier Mesa and close to January for BJY.

Daily average wind powers at many stations can be misleading if one fails to also consider the cyclical diurnal oscillation of winds and resulting available power. The diurnal cycle of wind speeds for NTS stations, BYJ and Rainier Mesa (Figures 2 and 3), may be characteristic of valley and ridgetop stations in the southwest, but accentuated by BJY by the orientation of Yucca Valley. The diurnal wind cycle results from the daily cycles of solar heating in the lower atmosphere. Up-valley up-slope winds are typical of valley stations during daytime hours, especially in the summer and when the valley axis lies close to the average upper flow directions and the valley's higher end is in the direction of this flow. Nighttime cooling of a thin air layer near the ground on average nights disassociates this layer from the general flow aloft and the cold, more dense air flows slowly downslope, down valley. At ridgetop stations the winds more closely agree with the stronger upper free-air wind speeds, especially when measured on high towers above the moderating influence of shrubs and trees and above whatever thin, cool layer may form at night among the trees.

Average wind power availability, by hour of the day in July and January, for the two NTS stations is shown in Figure 4 (Quiring, 1975). Quiring's original plots were based on computations which had followed Reed's method (1975) of using sea-level density. NTS altitude corrections were obtained from 16 selected correction factors computed by Reed (1979) for southwestern stations of altitudes ranging from 200 to 7600 feet. Linear regression gave correction factors of .786 for Rainier Mesa at 7500 foot altitude and .878 for BJY at 4100 foot altitude. These corrections were applied to Quiring's data to obtain Figure 4. The wind power afternoon peaks of the July diurnal curves for both towers is pronounced with very low wind power available during the night, on the average, at the valley station. The hourly average wind power curves for January show the valley and mesa top stations to be out of phase with each other, BJY showing an afternoon maximum much depressed from its July counterpart, but still quite peaked, while Rainier Mesa on the average exhibits its greatest wind power at night. The diurnal power oscillations, as with those on a seasonal scale, may have significant implications with respect to base-load conversion, but not so much so for remote-site low power generation where battery storage is possible for bridging gaps in power availability.

The diurnal profiles of available wind energy are averaged by hour but say nothing of the inter-daily, i.e., the day-to-day persistence, of these patterns. The diurnal oscillation on any given day may be much suppressed or even reversed depending on the large-scale pressure regime affecting a station. Wind power averages may be highly weighted toward a few strong wind days while near-calm conditions with little available power may be the normal condition. Bray (1980) does good service in providing inter-daily wind power persistence probabilities for numbers of southwestern stations. Although NTS data are not included, his tables are at least indicative. Probabilities (Table 2) are reproduced for Las Vegas for greater than or equal to (GE) and for less than (LT) the stated wind power thresholds for up to the indicated number of days, given that a day of such wind power conditions has just occurred. Tables are given for each month. They show a very high probability for the lowest all-hours wind power category to persist for several days. These statistics suggest the infrequency of storms accompanied by higher winds, even in wintertime, and the well-known nocturnal temperature inversion's tendency to decouple near-surface winds from stronger winds aloft. Quiring (1975) produced Table 3 which, while not showing persistence statistics, does show the percent of hours in each of the months January and July, and annually, when low wind speeds of 1 - 10 mph can be expected for the NTS stations, BJY and Rainier Mesa. The average available power at these low speeds for the same months is shown to be very small, suggesting that useful power may not be available from wind turbines over a significant part of the time.

A final consideration is assessing wind power conversion practicality for baseload power is the degree of coincidence between electrical power demand and wind power availability. Demand at the NTS during weekday daytime hours is shown in Figure 5 (Quiring, 1980) for each of the four seasons. Winter is seen to be the month of highest daytime energy demand. Although curves for nighttime demand are not shown, it is clear that demand drops appreciably during the night in the winter season as is suggested by the drop-off of the daytime curves for other seasons. Wind power availability on the average is seen from Figure 4 to be lower in the midwinter month of January than it is in the summer month of July but not appreciably so. Assuming some drop-off in power demand at night in January, it appears that average availability of wind power at Rainier Mesa is somewhat out-of-phase with the NTS daytime demand maximum. The peaking of power demand in daytime hours during the other season, especially summertime, is more in phase with the average afternoon maximum in wind power availability, both at BJY and Rainier Mesa. Little wind power is available on the average during nighttime hours at the valley station, especially during the summer months, but neither is electrical power demand very high at this time of day.

Other reports are in preparation which should shed more light on the wind power potential for the NTS. Sullivan and Mason, Tucson, Arizona, is under contract to Holmes and Narver, Inc., to evaluate the wind power potential at the NTS in a more definitive manner than attempted here. It should be completed by early 1981. Pacific Northwest Laboratory, under contract to Department of Energy (DOE), is expected to produce a second volume in a series of 12, this one titled Wind Energy Resources Atlas - The Southwest Region, which will examine the wind power variability with time and topography in the southwest. It is also scheduled for publication in early 1981. The United States Air Force MX-Missile Project, if approved, contemplates an ambitious wind and solar insolation measurements and analysis program in valleys and on ridgetops in nearby central Nevada. Measurements may start as early as March 1981, but results will likely not be available for many months thereafter. It will be managed by Pacific Northwest Laboratory, Hanford, Washington. Some NTS wind data will assuredly be used in the first two of these studies and probably in the MX study as well.

SUMMARY

On the basis of the few computations using NTS data, it appears that annual average wind power availability at the NTS is somewhat better than at most stations in the southwest for which computations are available. Annual average wind power availability is estimated to be fairly high on the mesa tops (approaching 300 wats/m^2) and probably on several other ridgetops and favorably exposed mountain passes on the NTS. The percentage of low wind hours is high in all seasons with the possible exception of springtime, however, and persistence of favorably strong winds for periods of several days at a time is rather low. This is especially true at valley stations. There is a pronounced diurnal cycle in wind power availability, especially in the summertime, with little nighttime availability on the average at the valley stations. Although no NTS power computations have been made for spring or fall months, examination of wind climatology at the NTS and seasonal trends of wind power at other southwestern stations show springtime months to have the highest average wind power availability with fall having the lowest. Baseload electrical power requirements

would most likely require alternate electrical energy sources to augment and bridge gaps in wind-supplied energy and the cost-effectiveness of this use of renewable wind energy would have to be determined. Remote-site wind power conversion where battery storage of the produced electrical energy could bridge all gaps in wind power availability may prove more reliable and cost effective. Reports are in preparation by other organizations which should help to provide more definitive answers to wind power applications for the NTS.

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Table 1. Average wind power density classes for 10- and 50-meter heights above ground level (after Barchet and Elliott, 1979) and for 27-meter height of BJY and Rainier Mesa wind towers (interpolated). The estimated annual average wind power density for Rainier Mesa and BJY stations have been inserted in their appropriate classes.

Wind Power Class	Wind Power Density (watts/m²) 10 m (33 ft)	27 m (88 ft) (interpolated)	50 m (164 ft)
	0	0	0
1			
	100	142	200
2		BJY - 150	
	150	213	300
3		Rainier - 275	
	200	284	400
4			
	250	355	500
5			
	300	426	600
6			
	400	568	800
7			
	1000	1420	2000

Table 2. - PROBABILITY(%), BY MONTH, OF WIND(TOTAL) PERSISTING ABOVE, AND BELOW, THRESHOLDS FOR UP TO ONE WEEK - LAS VEGAS, NEVADA

(WATTS/M²)	JANUARY								FEBRUARY								MARCH								APRIL							
THRESHOLD	.GE. THRESH DAYS				.LT. THRESH DAYS				.GE. THRESH DAYS				.LT. THRESH DAYS				.GE. THRESH DAYS				.LT. THRESH DAYS				.GE. THRESH DAYS				.LT. THRESH DAYS			
	2	3	5	7	2	3	5	7	2	3	5	7	2	3	5	7	2	3	5	7	2	3	5	7	2	3	5	7	2	3	5	7
60	49	20	3	0	81	63	40	25	54	26	5	1	70	48	21	8	65	38	13	5	61	36	10	3	69	47	21	9	52	24	5	2
100	36	11	0	0	85	72	52	35	50	23	3	0	78	60	36	21	53	25	5	1	68	46	18	7	60	32	8	2	65	42	15	6
140	27	7	0	0	87	76	57	44	38	13	1	0	79	64	40	25	46	21	4	0	73	53	28	14	56	27	5	1	71	50	24	11
180	24	5	0	0	90	80	63	49	36	10	0	0	83	68	46	31	41	16	3	0	77	59	36	22	48	20	3	0	74	54	30	16
220	20	5	0	0	91	83	67	54	33	7	0	0	86	73	53	40	37	11	2	0	81	66	45	31	42	14	2	0	79	62	37	20

	MAY								JUNE								JULY								AUGUST							
THRESHOLD	.GE. THRESH DAYS				.LT. THRESH DAYS				.GE. THRESH DAYS				.LT. THRESH DAYS				.GE. THRESH DAYS				.LT. THRESH DAYS				.GE. THRESH DAYS				.LT. THRESH DAYS			
	2	3	5	7	2	3	5	7	2	3	5	7	2	3	5	7	2	3	5	7	2	3	5	7	2	3	5	7	2	3	5	7
60	73	54	30	17	55	30	9	3	74	56	31	16	53	29	8	2	69	48	24	14	52	27	7	2	60	38	15	6	57	33	12	5
100	62	38	15	6	69	45	20	10	61	39	16	6	66	45	20	7	53	30	12	5	71	52	29	17	44	22	5	1	73	54	31	20
140	53	27	6	2	73	53	29	16	53	27	6	0	75	55	30	15	41	20	5	1	83	68	47	33	33	14	3	0	83	68	48	33
180	47	19	3	0	79	62	39	24	42	20	4	0	81	65	42	28	29	13	3	0	89	80	63	52	21	7	1	1	88	76	61	48
220	41	18	2	0	82	67	45	30	35	16	3	0	85	71	51	36	27	11	2	0	93	87	75	67	19	6	1	0	92	84	73	64

	SEPTEMBER								OCTOBER								NOVEMBER								DECEMBER							
THRESHOLD	.GE. THRESH DAYS				.LT. THRESH DAYS				.GE. THRESH DAYS				.LT. THRESH DAYS				.GE. THRESH DAYS				.LT. THRESH DAYS				.GE. THRESH DAYS				.LT. THRESH DAYS			
	2	3	5	7	2	3	5	7	2	3	5	7	2	3	5	7	2	3	5	7	2	3	5	7	2	3	5	7	2	3	5	7
60	59	36	10	2	74	55	30	19	49	20	4	1	77	60	37	24	48	21	4	1	81	65	39	24	44	14	2	0	82	68	48	34
100	45	19	4	0	80	64	40	27	42	14	2	1	84	71	51	36	41	17	2	1	86	73	52	37	38	13	2	0	86	73	53	39
140	32	14	2	1	85	73	51	36	37	10	2	1	87	76	59	46	32	11	0	0	89	77	59	44	33	11	1	0	88	78	60	47
160	27	10	2	1	89	80	61	47	30	8	2	1	90	81	66	55	21	4	0	0	91	83	66	52	29	8	1	0	90	81	66	54
220	17	4	2	1	91	83	67	54	23	5	0	0	91	83	71	61	19	3	0	0	93	86	71	59	29	8	0	0	92	85	73	62

Table 3. Percent of hours and average wind power available when speeds are in the low range of 1 - 10 mph -- January, July, and annual for NTS stations, BJY and Rainier Mesa.

	% of Hours (1957 - 1969)		Average Wind Power (watts/m²) (1957 - 1964)	
	BJY	Rainier Mesa	BJY	Rainier Mesa
January	56	34	12	12
July	48	32	13	9
Annual	47	34	14	11

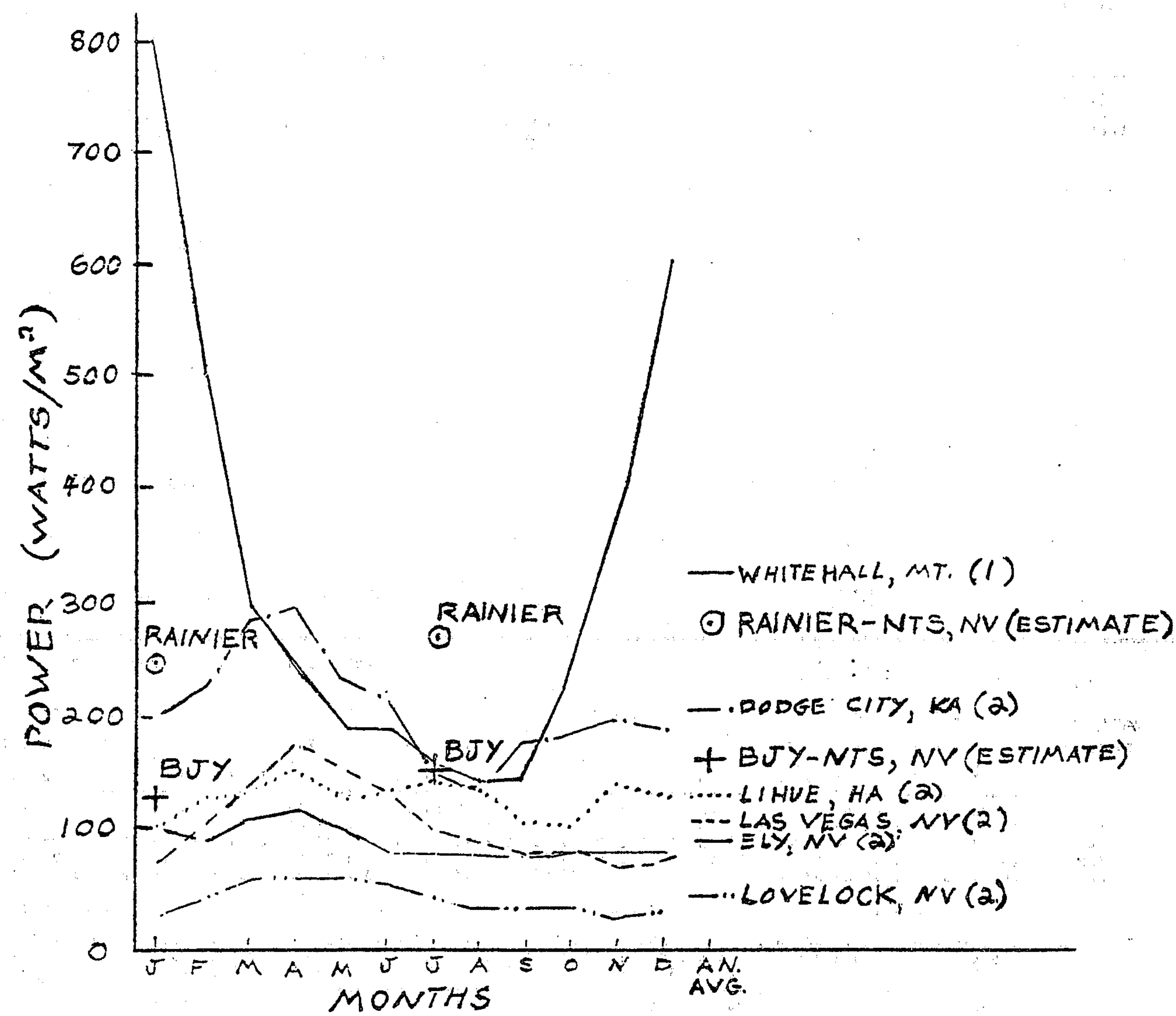

Figure 1. Daily average wind power, by month and annual, for selected Nevada stations and others of interest. Available point values for NTS stations, BJY and Rainier Mesa, have been plotted.

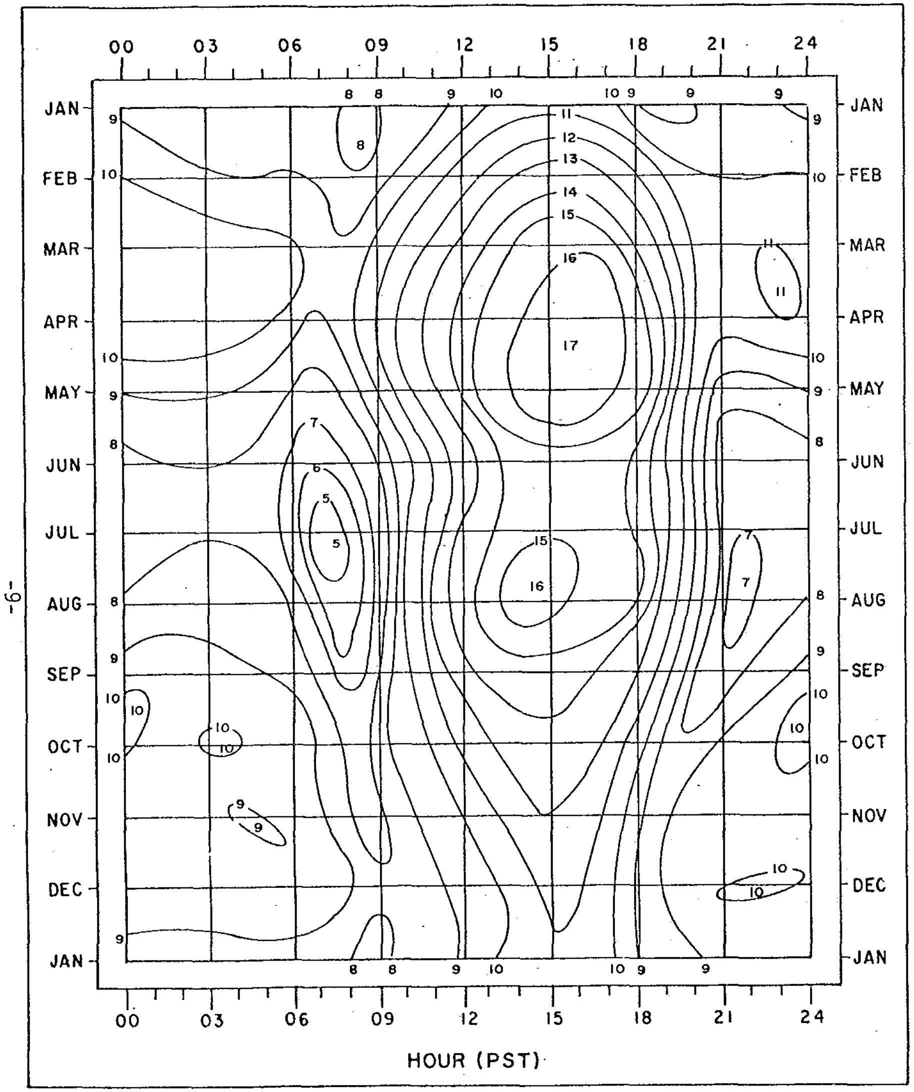

Figure 2. Average wind speed in miles per hour as a function of time of day.
Station: BJY

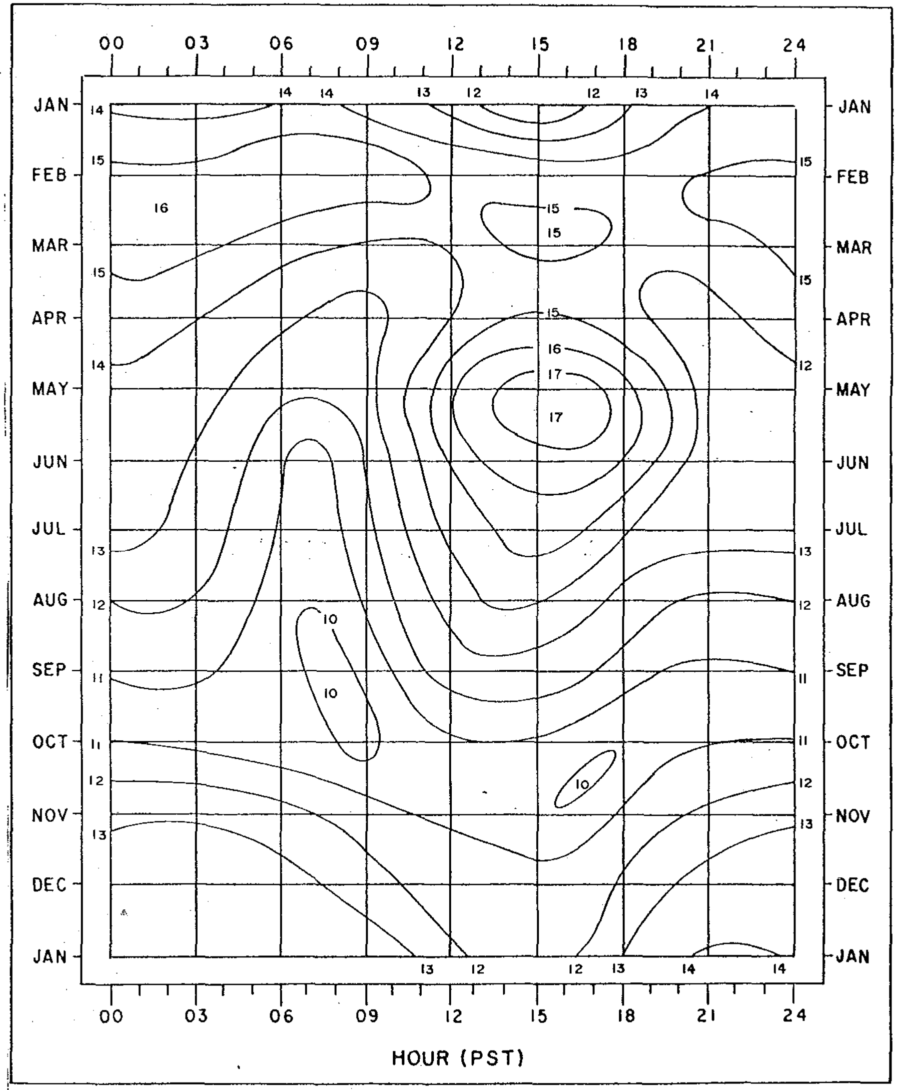

Figure 3. Average wind speed in miles per hour as a function of time of day.
Station: Rainier Mesa (Area 12)

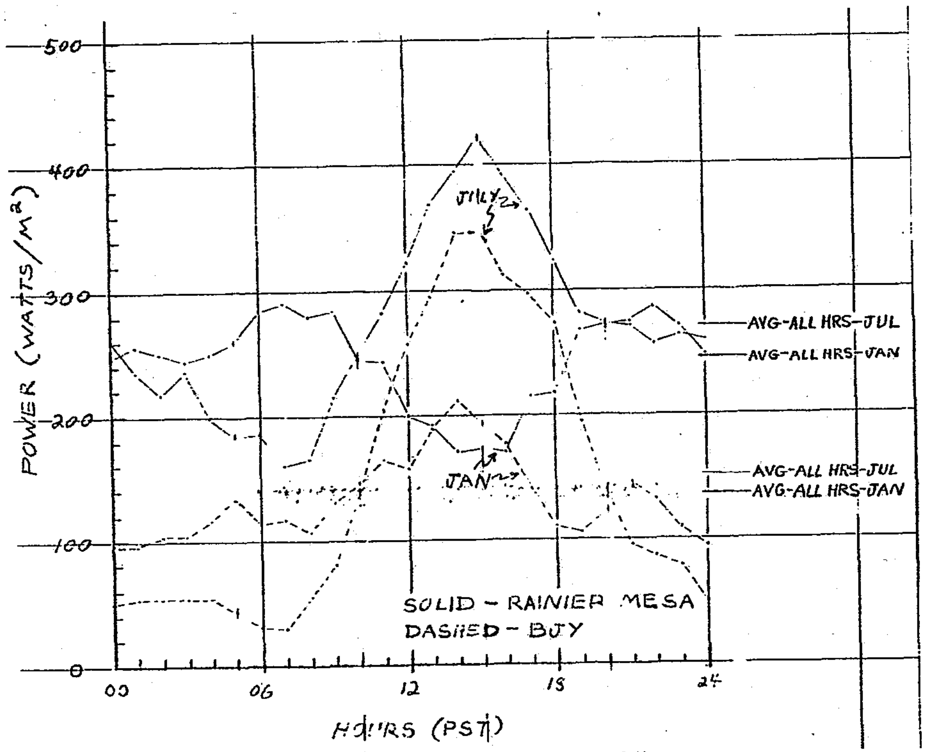

Figure 4. The diurnal average wind power availability profile for NTS stations, BJY and Rainier Mesa, for July and January, with daily average wind power for each curve indicated.

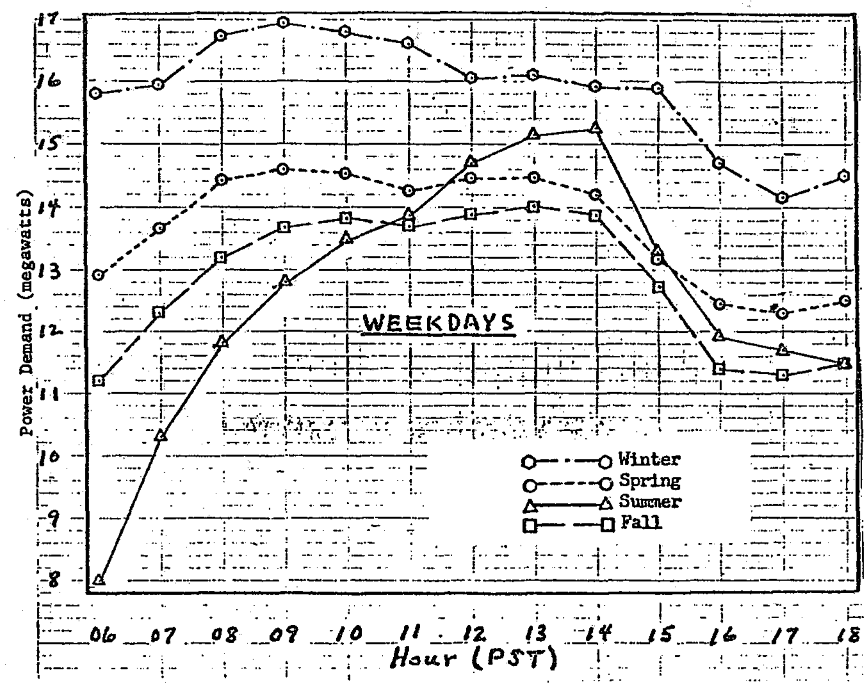

Figure 5. Nevada Test Site power demand during weekday daytime hours, by season.

121 Climatological Prediction of Cumulonimbus Clouds in the Vicinity of the Yucca Flat Weather Station. R. F. Quiring, June 1977. (PB-271-704/AS)
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129 Fire Whirls. David W. Goens, May 1978. (PB-283-866/AS)
130 Flash-Flood Procedure. Ralph C. Hatch and Gerald Williams, May 1978. (PB-286-014/AS)
131 Automated Fire-Weather Forecasts. Mark A. Mollner and David E. Olsen, September 1978. (PB-289-916/AS)
132 Estimates of the Effects of Terrain Blocking on the Los Angeles WSR-74C Weather Radar. R. G. Pappas, R. Y. Lee, B. W. Finke, October 1978.(PB289767/AS)
133 Spectral Techniques in Ocean Wave Forecasting. John A. Jannuzzi, October 1978. (PB291317/AS)
134 Solar Radiation. John A. Jannuzzi, November 1978. (PB291195/AS).
135 Application of a Spectrum Analyzer in Forecasting Ocean Swell in Southern California Coastal Waters. Lawrence P. Kierulff, January 1979. (PB292716/AS)
136 Basic Hydrologic Principles. Thomas L. Dietrich, January 1979. (PB292247/AS)
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