USE OF WIND TURBINES TO GENERATE ELECTRICITY FOR HIGHWAY BUILDINGS

by

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SUMMARY

To determine the feasibility of using wind turbines to generate electrical power, measurements of wind speeds were made for a period of one year at three installations of the Virginia Department of Highways and Transportation. Unfortunately, the wind speeds were not sufficiently high to allow the economical use of a wind turbine at any location, and no further work is recommended.

ACKNOWLEDGEMENTS

The authors express appreciation to M. E. Wood, Jr., district engineer in Salem, J. L. Corley, district engineer in Bristol, and P. F. Cecchini, district engineer in Staunton, for their cooperation in this project. D. R. Collins, resident engineer at Christiansburg, was most helpful in providing facilities at his office, and J. D. Brugh, assistant resident engineer, and R. G. Stoots, now assistant resident engineer at Salem, were most helpful in collecting data at that site. Project inspectors Robert L. Hoffman and Robert C. Parks at the Route 77 rest area monitored the operation of the equipment while it was powered by batteries and assisted in the data collection in addition to their normal duties.

James W. French, materials technician supervisor at the Council, had charge of the collection and reduction of data for the study and made arrangements for the installation and continuing operation of the anemometers and recorders. These arrangements included climbing the antenna mast at Christiansburg to install the anemometer at a height of 58 feet on a particularly cold and windy day, a feat worthy of special thanks.

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INTRODUCTION

There is considerable interest in the use of wind power as a renewable and nonpolluting energy source. Spurred by the energy crisis, users ranging from individual home and farm owners to large corporations have evaluated the potential of wind turbines. Government programs through the Department of Energy gave impetus to the development and testing of machines ranging from small wind energy conversion systems (SWECS) with outputs of 100 kW or less to large turbines with capacities rated in megawatts.

In mid-1979, the Environmental Quality Division of the Virginia Department of Highways and Transportation requested that the Research Council undertake a study of the possible use of wind energy to generate electrical power at a rest area on Interstate Route 77 in Bland County. At the time the Federal Highway Administration's Region 15 Demonstration Project Division had under way its Project No. 52, "Solar Energy for Highway Uses", which included potential funding for wind energy applications if cost-effectiveness was indicated.(1) Michigan's Department of State Highways and Transportation had sponsored a feasibility study of the use of a wind turbine at a rest area which also utilized photovoltaic solar panels in a hybrid electrical generation system.(2) The development of a 20 kW pilot demonstration turbine system was recommended based on an economic and technical simulation study, although average wind speeds at the Michigan site were only 8.4 to 10.5 mph (3.8 to 4.7 m/s) in the summer, 10.5 to 14.9 mph (4.7 to 6.7 m/s) in the winter, and 10.2 to 10.6 mph (4.6 to 4.7 m/s) overall.

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It was recognized that wind speed would be a critical factor in the utilization of a wind turbine, since wind velocities over much of Virginia do not approach the 12 to 15 mile (5.4 to 6.7 m/s) average that is desirable. While areas in the mountains and along the coast generally offer sufficient wind speeds, it was necessary to obtain data at the Department's installations that might use the turbine to evaluate the effect of local terrain.

RELATIONSHIP BETWEEN WIND SPEED AND POWER

Wind power utilizes the kinetic energy of moving air, and kinetic energy is a function of mass and velocity. Thus,

$$KE = \tfrac{1}{2}\, mV^2,$$

where m is the mass of the moving air and V is its velocity.

The mass of the air is the product of its density, ρ, and its volume, which is the product of the velocity of the air, V, and the area, A, through which it passes. Thus,

$$m = \rho AV,$$

and

$$KE = \tfrac{1}{2}\, \rho AV^3.$$

This relationship is important in considering the use of wind energy because it indicates that for a given turbine, the kinetic energy and, in turn, the power varies as the cube of the velocity of the wind. Thus, a doubling of the wind speed, say from 7 to 14 mph (3.1 to 6.2 m/s) produces 8 times as much power.

PURPOSE AND SCOPE

The purpose of the subject study, which began as a joint effort of the Research Council and the Virginia Polytechnic Institute and State University, was to install wind speed recording systems at three sites and to use the data to estimate the potential for power generation by a selection of available SWECS.

The sites selected were Department installations at reasonably exposed sites in areas that appeared to offer the best wind speeds. All of the locations were in the mountains and valleys of upland Virginia. No sites on the coast, where wind speeds are generally high, were included. None of the Department's coastal sites were found to have sufficient exposure except for bridge-tunnel installations which have power requirements beyond the production of SWECS.

The wind speed recorders were located on the Department's property. No attempt was made to place anemometers at more promising locations, such as nearby ridge crests, on property owned by others.

Wind speeds were measured using a compilator which stored the length of time, in seconds, that the wind speed was within each of 31 bins of 2 mph (0.9 m/s) width.

The turbines included in the evaluation were selected from those available at the inception of the project, based on the experience of the research team. A variety of turbine sizes and types were included. Several of these units are no longer commercially available.

Details of the sites, instrumentation, data reduction procedures, and turbines are provided in succeeding sections of this report.

SITES

Wind speed recording systems were installed at the facilities shown in the map in Figure 1 and described below.

Site 1: Interstate Route 81 (NBL) Rest Area near Mt. Sidney, Augusta County

The anemometer was installed atop a commercially available television antenna mast attached to the chimney of the rest area building (Figure 2). The height of the anemometer is 35 ft. (10.7 m) above ground level, which is at an approximate elevation of 1,260 ft. (384 m). The rest area is located in the Shenandoah Valley, between the Blue Ridge and Appalachian mountain ranges. The area is generally described as plains with low mountains, with from 50 to 80 percent of the area gently sloping.(3) The rolling floor of the Valley extends to the east and south, and Mt. Sidney, whose elevation is 1,581 ft. (482 m), runs northeast approximately 1 mile (1,600 m) to the northwest of the site. Figure 3 shows a distance view of the site and Figure 4 is a map of the surrounding area. The site is exposed, but wind velocities in the Valley are generally low, less than 10 mph (4.5 m/s).

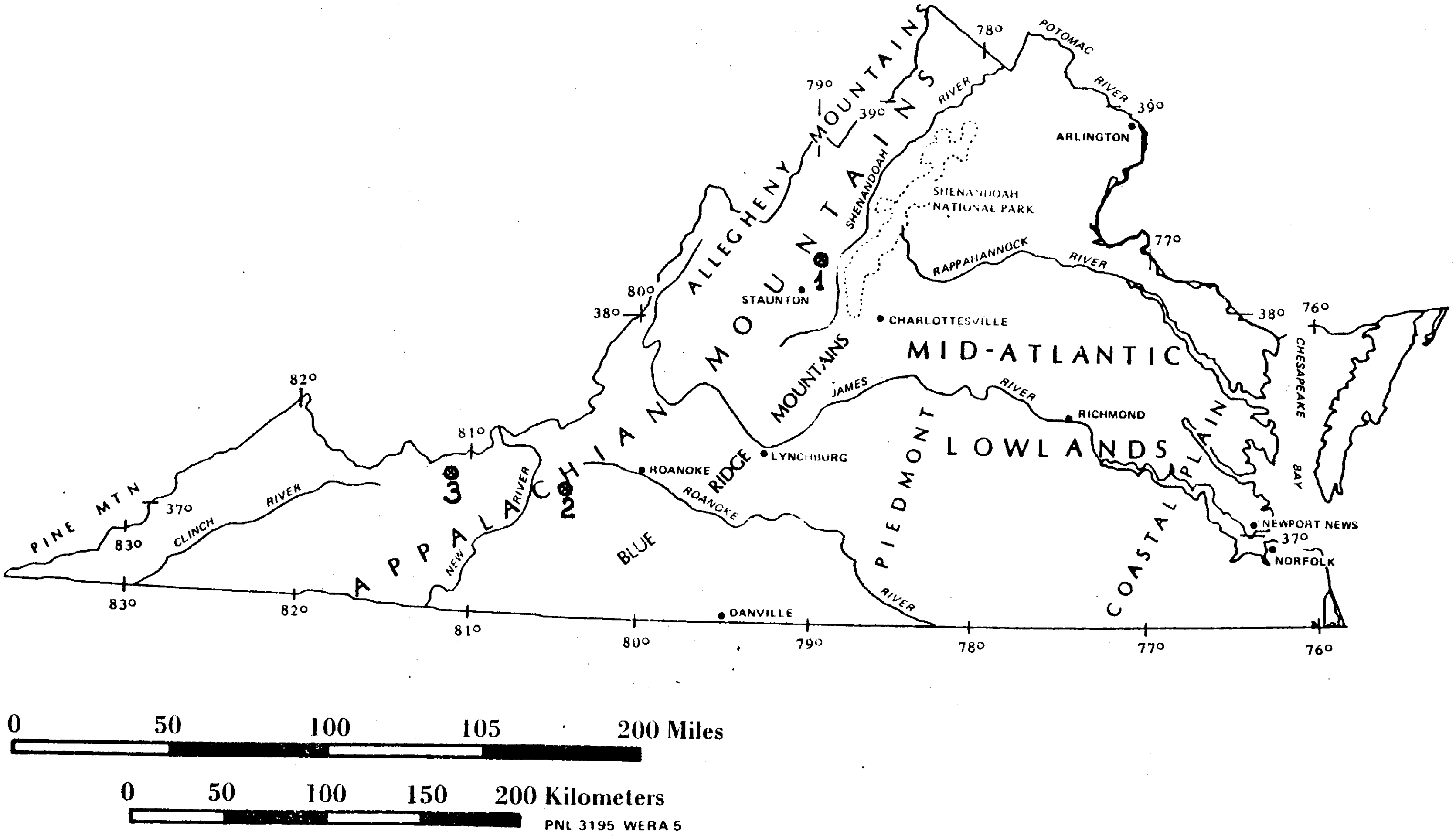

Figure 1. Location of the facilities at which wind speed recorders were installed, 1. rest area on I-81, 2. Christiansburg Residency, 3. rest area on I-77. (Reference 3)

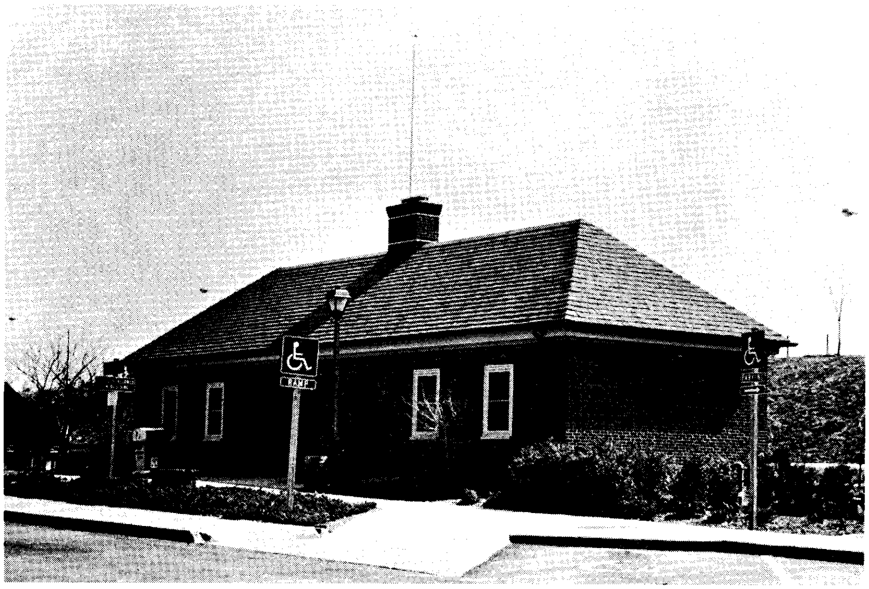

Figure 2. Rest area building with anemometer on I-81.

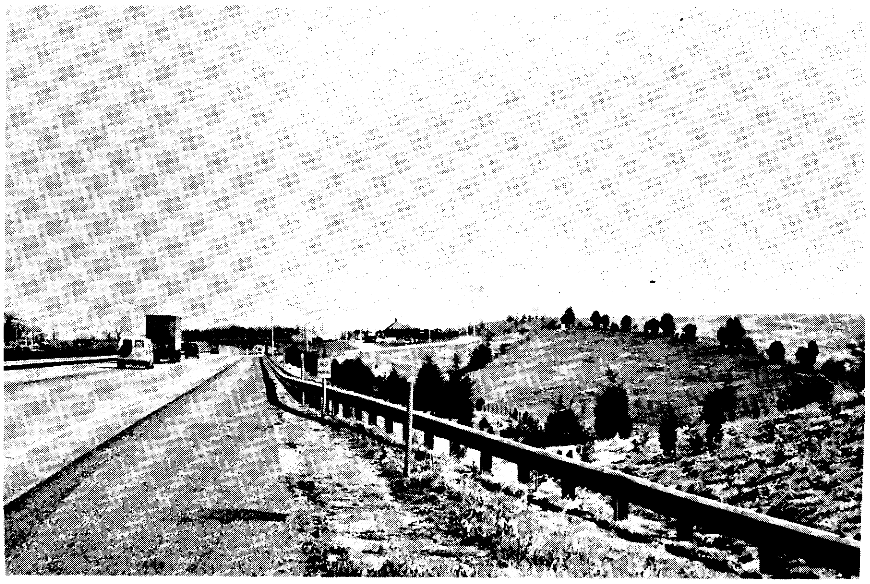

Figure 3. Distant view of I-81 rest area.

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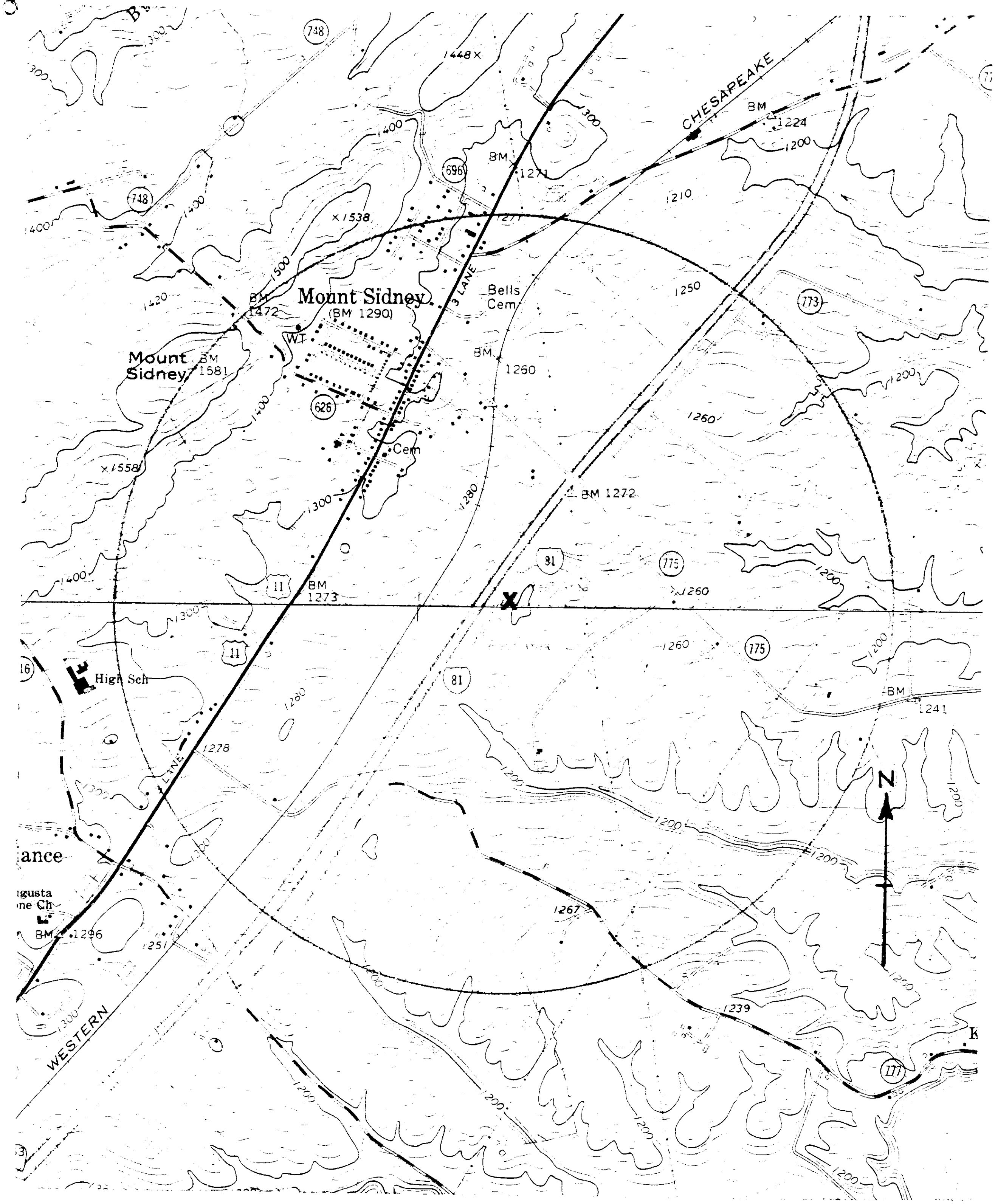

Figure 4. Map of terrain around the I-81 rest area. Circle has a radius of 1 mile (1609 m).

Site 2: Christiansburg Residency Office

The anemometer at this site was placed on an existing radio antenna mast 58 ft. (17.7 m) above ground level (Figures 5 and 6). The ground elevation is approximately 2,140 ft. (652 m) at the site, which, as shown in Figure 7, is a high point in an extensive area of plains with high hills, having from 50 to 80 percent of its surface gently sloping.(3) The closest dominant terrain feature is Price Mountain, with an elevation of 2,453 ft. (747 m), 3 miles (4,830 m) to the northwest.

Average wind speeds in the region are estimated to be 11.5 to 12.5 mph (5.1 to 5.6 m) at a height 33 ft. (10.1 m) above ridge crests, but the certainty of the estimate is considered low due to a lack of data.(3)

Site 3: Interstate Route I-77 (SBL) Rest Area and Information Center near Rocky Gap, Bland County

The anemometer was mounted at a height of 30 ft. (9.1 m) on a television antenna mast placed on the pump house in the rest area complex, Figures 8 and 9. The rest area is located at an elevation of 2,170 ft. (661 m) at the foot of Hogback Mountain, elevation 3,200 ft. (975 m), south of Rocky Gap. As shown in Figure 10, the ridge of Hogback runs south-southwest about 1.1 mile (1,750 m) south of the site, and Rich Mountain, 3,500 ft. (1,067 m), runs in a parallel direction 1.25 miles (2,000 m) north of the site.

The area is generally described as low, open mountains with from 20 to 50 percent of the surface being gently sloping.(3) The site, while somewhat sheltered, is windy. Average wind velocities 33 ft. (10.1 m) above the ridge crests are estimated at 11.5 to 12.5 mph (5.1 to 5.6 m/s), but there is much uncertainty about the estimate because of a lack of data and the complex terrain.

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Figure 5. Christiansburg residency office with anemometer mounted on antenna mast.

Figure 6. Distant view of Christiansburg residency complex. Anemometer is on pole to left of tower.

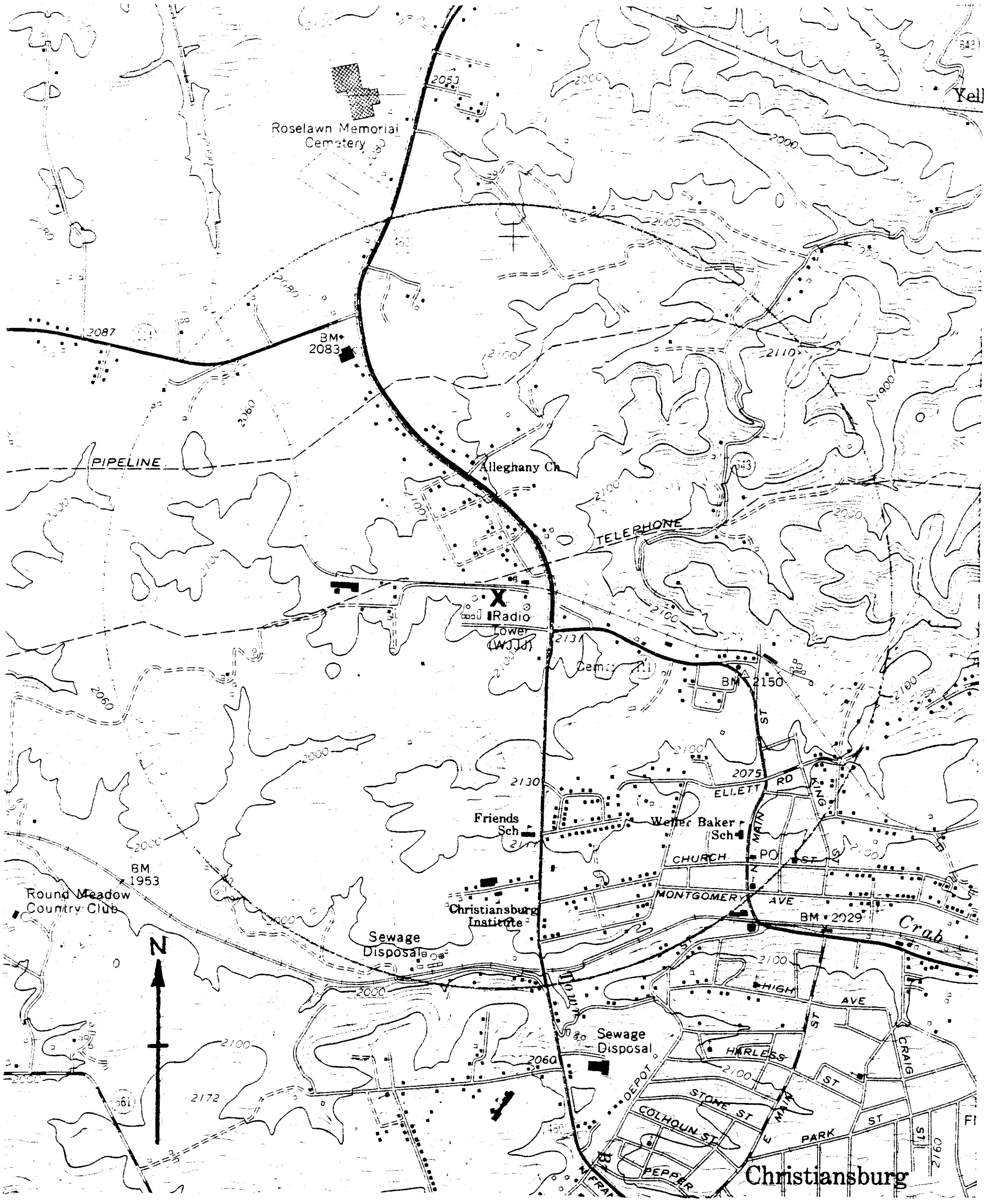

Figure 7. Map of terrain around the Christiansburg residency. Circle has a radius of 1 mile (1,609 m).

Figure 8. View of pump house, looking south, with Hogback Mountain in background.

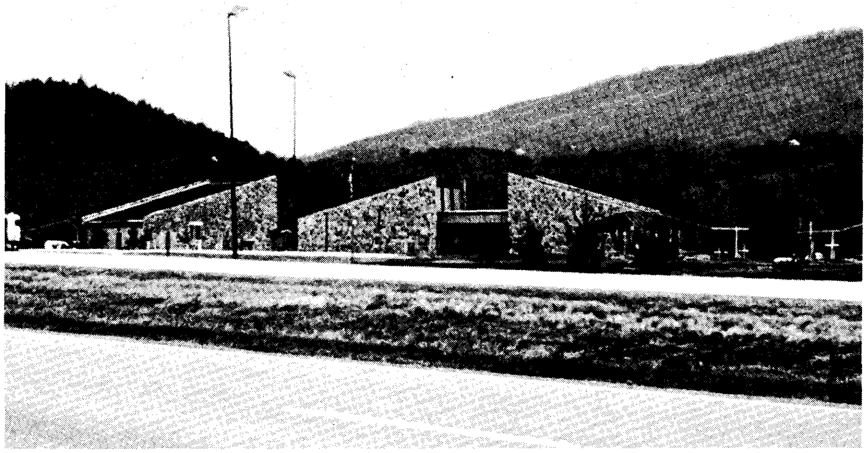

Figure 9. View of I-77 rest area, looking west, with crest of Rich Mountain in background.

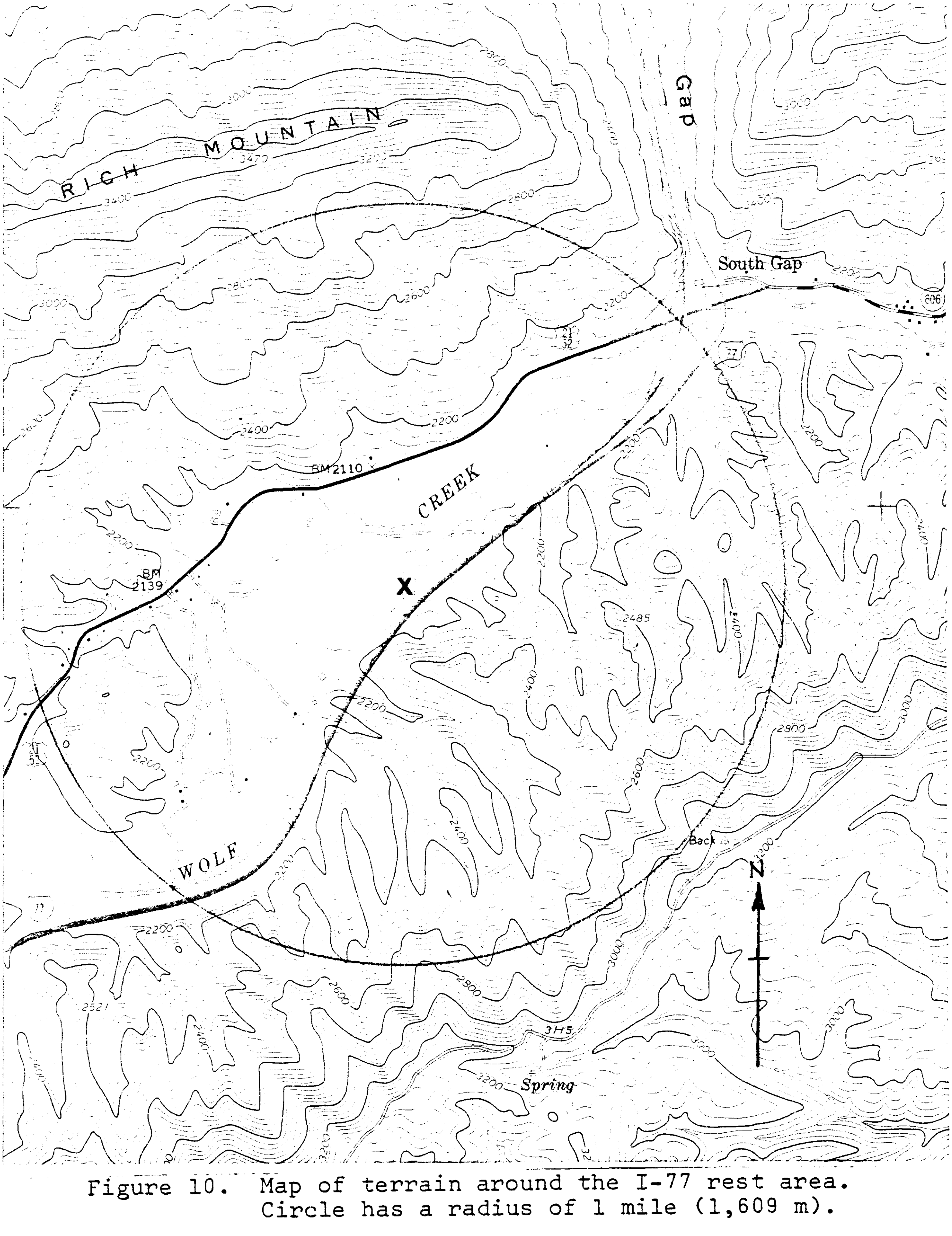

Figure 10. Map of terrain around the I-77 rest area. Circle has a radius of 1 mile (1,609 m).

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INSTRUMENTATION

The wind speed recording system consisted of a wind speed compilator manufactured by Natural Power, Incorporated, (Model A30-101), which received its input from a single 3-cup anemometer head (NPI Model A75-104). The compilator sampled the anemometer signal for 850 milliseconds and in the next 150 milliseconds assigned a count of 1 second to one of 32 memory bins having a bin width of 2 mph (0.9 m/s). Thus speeds were separated into increments of 0-2 mph (0-0.9 m/s) in bin 0, 2-4 mph (0.9-1.8 m/s) in bin 1, through bin 30. Bin 31 received any spillover. The output from the compilator consisted of the number of seconds of wind speed in each of the 2 mph (0.9 m/s) bins. These data were stored by the compilator, recorded manually at intervals, and reduced by a computer program described later to produce an average wind speed for the period and the amount of power, in kWh, that would have been produced by the wind turbines included in the study.

The compilator contained a crystal oscillator timer with an accuracy of ± 15 minutes/month, and the total number of seconds recorded in the bins always matched the length of the recording period with acceptable accuracy. The anemometer was specified as accurate to ± 1 mph (0.4 m/s) for wind speeds of 0-100 mph (0-44.7 m/s), and was considered suitable for unattended operation for periods of 1 year without recalibration. Lightning arrestors were included in the system circuits for additional protection. The system was capable of operating on either alternating or direct current.

DATA REDUCTION

The wind speed data for each recording period were reduced to provide the average wind speed and the theoretical energy output for selected turbines using a computer program, WINDANL, written by R. E. Akins. Documentation for the FORTRAN program, a listing of the program, and a sample data run for each of the 3 sites are appended to this report. The analysis follows procedures being considered for adoption by the American Wind Energy Association and the Department of Energy.(4)

Input for the program, which processes the data from one location at a time, consists of the description of the location, period of observation, the integer number of days in the period, the elevation of the anemometer, and the compilator data. Performance data taken from manufacturer's power curves can be entered for a maximum of 10 wind turbines. The 1/7 power law, shown below, was used to correct the measured probability density of wind speeds from the height of the anemometer to the reference height on which the power curve for each machine is based. The power law yields the increase in wind speed with increasing height through the relationship

$$\frac{Va}{Vr} = \left(\frac{Ha}{Hr}\right)^{a} ,$$

where

> Va is the wind speed recorded by the anemometer, Ha is the anemometer height, Vr is the new wind speed corresponding to the reference height, Hr, for the power curve, and a is an exponent taken as 1/7 for low surface roughness.

The machine data remained constant throughout the study. Details of the machines are provided in the next section of the report.

MACHINES EVALUATED

Nine turbines representing the range of sizes and types of machines available were included in the evaluation. The machines are listed below in order of increasing size. The number is the order in which they appear on the printout.

1.	Bergey Model BWC 100-S	1 kW
8.	Aero Power Starlite 1500	1.5 kW
6.	Northwind HR2	2 kW
4.	Fayette Winway 2027D	1-20 kW
2.	Gale 4000	4 kW
5.	Millville 10 kW	10 kW
7.	Jay Carter Model 25	25 kW
3.	Kaman 65 kW	65 kW
9.	ALCOA ALVAWT 835524-100 kW	100 kW

All of the turbines are horizontal axis machines in which the blades rotate about a horizontal axis (Figure 11), except for the ALCOA ALVAWT, which is a fairly large vertical axis, Darrieus type machine (Figure 12). Horizontal axis turbines are further described as upwind, meaning that a tail such as that on the Millville 10 kW in Figure 11 keeps the rotor upwind of the body of the turbine, or downwind. Both 2-blade and 3-blade machines were included in the study group, which is described below.

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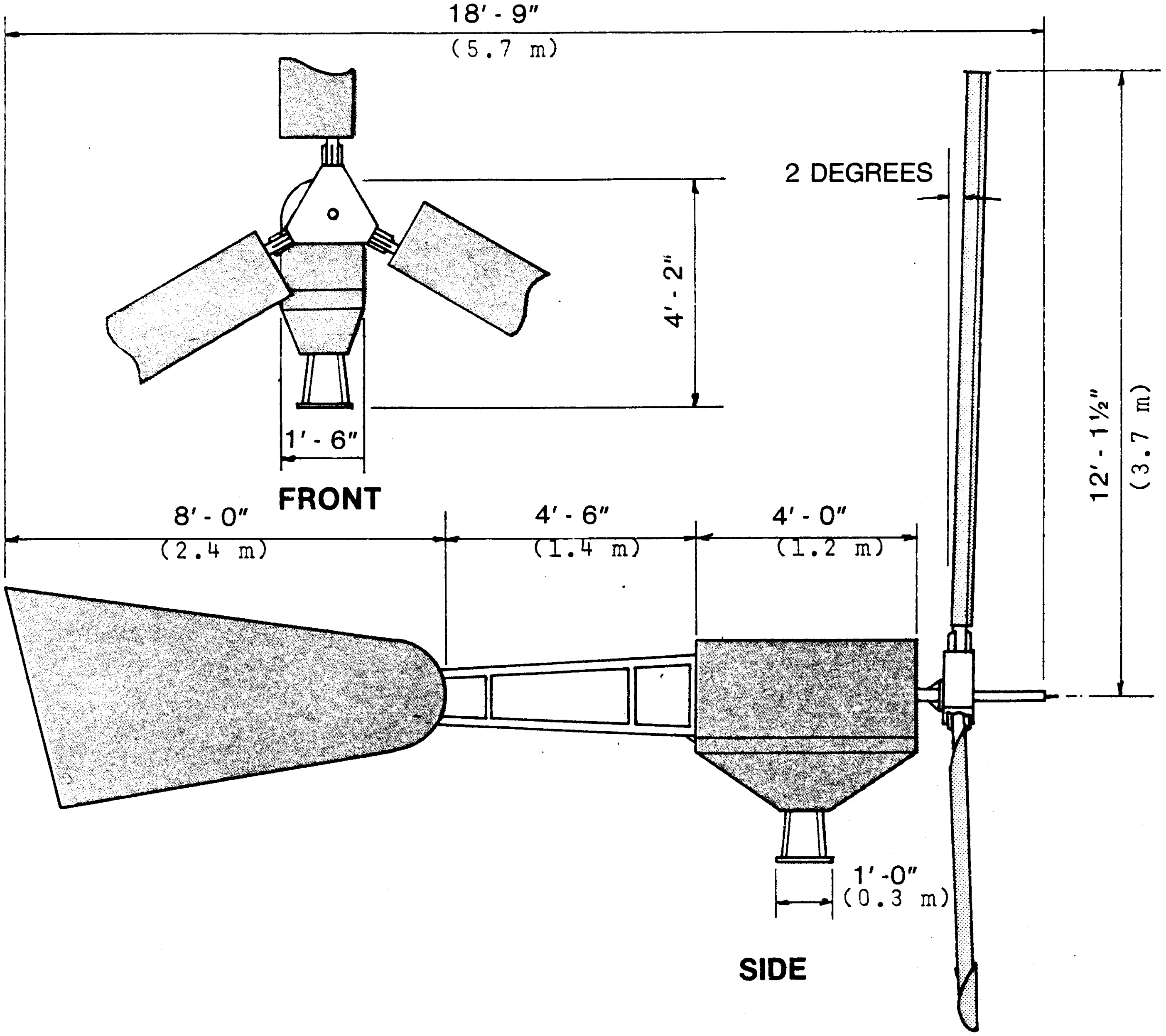

Figure 11. Millville Windmills' 10 kW mill, a horizontal axis, upwind turbine.

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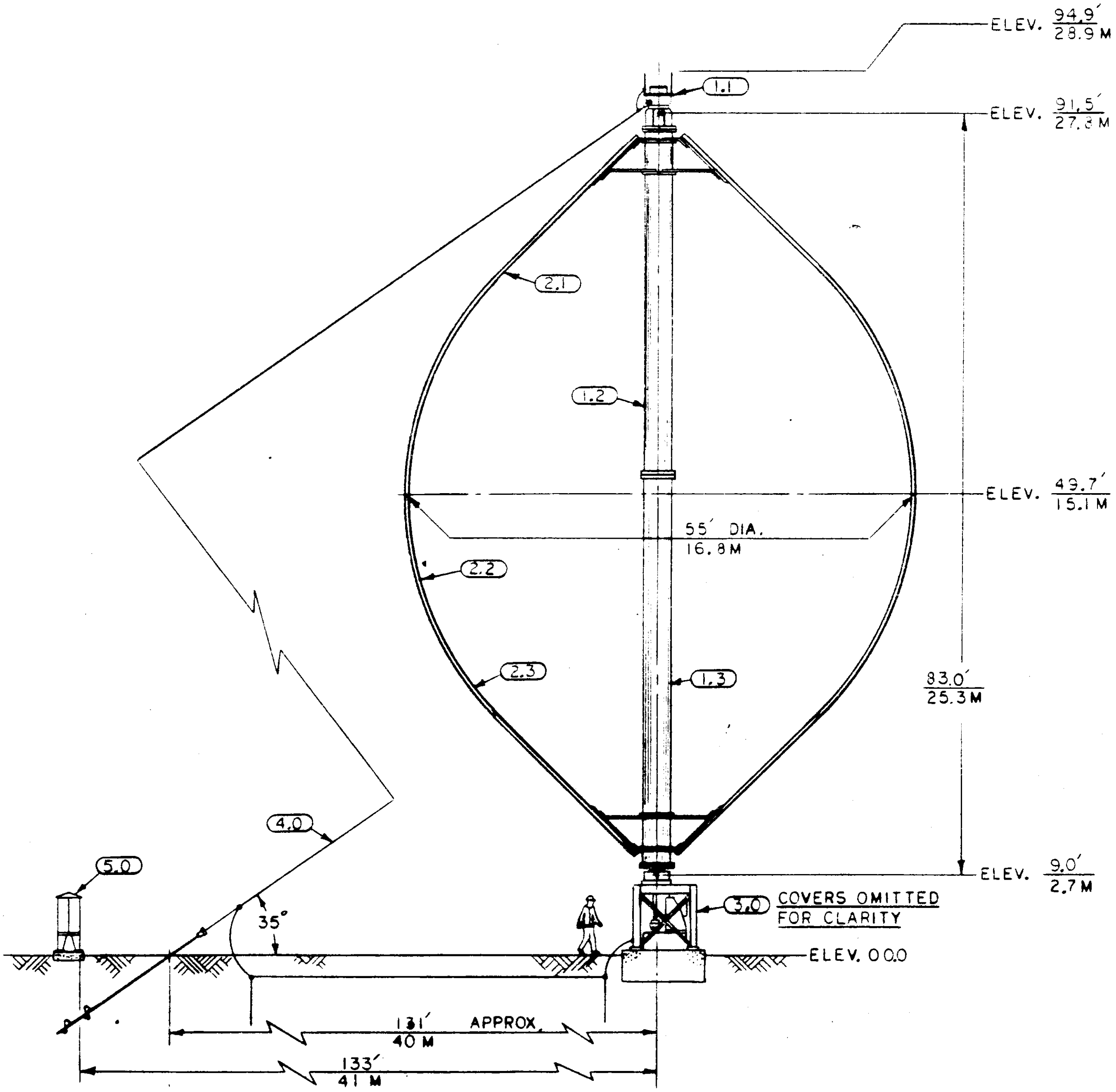

Figure 12. Alcoa vertical axis wind turbine. Model No. 835524-100 kW.

1. Bergey Windpower Model BWC 1000-S

The Model BWC 1000-S is a 3-blade, upwind turbine rated at 1000 W at a wind velocity of 25 mph (11.2 m/s). The cut-in speed, the wind velocity at which power generation begins, is 10 mph (4.5 m/s). The total power output is estimated to be 2,500 kWh per year at an average wind speed of 13 mph (5.8 m/s).

The rotor diameter is 2.6 meters, and a tower height of 50 to 80 ft. (15.2 to 24.4 m) is recommended. The cost of the turbine, exclusive of the tower and installation, was estimated at $2,995 in 1981. The smallest turbine in the study, the Bergey is intended for use by an individual, and it is too small for the uses examined in the subject study.

2. Gale 4000

The Gale 4000 is a 2-blade, downwind turbine with a large diameter rotor, 12 m, to enhance its performance at low wind velocities. The cut-in speed is 6 mph (2.7 m/s), and the machine is rated at 4 kW at speeds above 12.5 mph (5.6 m/s). The tower height is 60 ft. (18 m).

Estimated annual power outputs are 17,000 kWh at an average wind speed of 10 mph (4.5 m/s) and 21,000 kWh at 12 mph (5.4 m/s). The cost was estimated at $12,000.

3. Kaman 65 kW

One of the larger machines evaluated, the Kaman is a 2-blade, downwind turbine with a 65-ft. (20-m) diameter rotor and a hub 75 ft. (23 m) high. It is rated at 65 kW at a wind velocity of 26 mph (11.6 m/s). The cut-in speed is 10 mph (4.5 m/s), and at 12 mph (5.4 m/s) the estimated output is 7 kW.

The cost of a Kaman 65 kW, when in full production, was estimated at $33,000.

4. Fayette Manufacturing Corporation Winway 2027D

The Winway 2027D is a 3-blade, downwind turbine with a 27-ft. (8-m) diameter rotor. The cut-in speed is 8 mph (2.4 m/s), and the turbine produces a maximum output of 20 kW at 15 mph (15.2 m/s). Estimated outputs are 1 kW at 10 mph (4.5 m/s) and 2.1 kW at 12 mph (5.4 m/s). An average wind speed of 14 mph (6.3 m/s) will produce an estimated 22,776 kWh annually.

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5. Millville Windmills' 10 kW

The Millville 10 kW, Figure 11, is a 3-blade, upwind turbine with a 24.3-ft. (7.4-m) diameter rotor. Rated at 10 kW at a wind speed of 25 mph (11.2 m/s), the turbine cuts in at 9 mph (4.0 m/s) and produces approximately 1 kW at 12 mph (5.4 m/s).

The cost of the Millville 10 kW was given as approximately $11,000.

6. Northwind Power HR2

The HR2 is a 3-blade, upwind turbine with a 5-m diameter rotor. The turbine is rated at 2 kW (actually 2,000 W) at a wind speed of 20 mph (8.9 m/s). Its output is 760 W at 12 mph (5.4 m/s), and at that average speed its annual output is estimated to be 6,100 kWh. The cut-in speed is 8 mph (3.6 m/s).

The cost of the Northwind HR2 is estimated at $8,700, and that of a recommended 60 ft. (18.3 m) self-supporting tower is $2,600.

7. Jay Carter Model 25

The Jay Carter Model 25 is a 2-blade, downwind turbine with a 32-ft. (9.8-m) diameter rotor and is mounted on a 60-ft. (18.3-m) tower. The turbine is rated at a 25 kW output at a wind speed of 26 mph (11.6 m/s). The cut-in speed is 7.5 mph (3.4 m/s) and the maximum output, 30 kW, is attained at wind speeds in the 30 to 40 mph (13.4 to 17.9 m/s) range.

The cost of the Jay Carter Model 25 was estimated at $18,000.

8. Aero Power Starlite 1500

The Starlite 1500 is rated at 1,500 W at a wind speed of 22 mph (9.8 m/s). It is a 3-blade, upwind machine with a rotor 12 ft. (3.7 m) in diameter. The turbine cuts in at 7.5 mph (3.4 m/s), with a listed start-up speed of 10 mph (4.5 m/s). The machine will produce 3,190 kWh of electricity per year at a site with an average wind speed of 12 mph (5.4 m/s).

The cost of the Aero Power Starlite 1500 turbine was estimated at $3,600, that of a synchronous inventor at $1,950, and a 60 ft. (18.3 m) self-supporting tower at $2,800.

9. ALCOA ALVAWT 835524-100 kW

The ALCOA vertical axis wind turbine (ALVAWT) is a 2-blade Darrieus type machine, shown in Figure 12. Rated at a 95 kW capacity at a wind speed of 30 mph (13.4 m/s), the ALVAWT is at the upper end of the range of small wind energy conversion systems, and was considered too large for the Virginia sites. It was also noted that the turbine was designed for economical use under wind speeds in the 14 to 20 mph (6.3 to 8.9 m/s) range. At sites with an average wind speed of 14 mph (6.3 m/s), the estimated annual output would be 165,000 kWh.

The ALVAWT was the largest turbine evaluated in the study. Its rotor height is 83 ft. (25.3 m) and its rotor diameter is 55 ft. (16.8 m). The machine would be difficult to place at a highway site because ALCOA recommends there be no buildings within a distance of 6 diameters from the machine. In spite of its size the ALVAWT was included to allow evaluation of a Darrieus type, vertical axis turbine. Cost data were not available.

RESULTS

Measurements of wind speeds for periods of one year indicated no potential for the use of wind energy conversion systems to generate electricity at any of the three sites. Wind speeds were not sufficiently high. As shown in Table 1, which displays the average wind velocities, the annual average wind speed was above the least cut-in speed for any of the turbines evaluated only at the Christiansburg Residency. In fact, wind velocities at the I-81 rest area exceeded 7 mph (3.1 m/s) during only one evaluation period in the spring of the year. None of the sites had an annual average wind speed that approached the low 12.5 mph (5.6 m/s) rated speed of the 4 kW Gale 4000 turbine, which was designed to operate at low wind speeds.

The average speeds for each period for the three sites are plotted on Figure 13, which also indicates the cut-in speeds for the 9 turbines. Although the average wind speeds were often below the cut-in speeds, some power was generated by each machine in each period by higher than average winds. However, annual wind frequency diagrams, Figures 14-16, indicate that the periods of higher wind velocities were of insufficient length to allow significant power generation.

The data presented previously indicate that the Christiansburg Residency is the best of the three sites. The Route I-81 rest area near Mt. Sidney, while offering good exposure, is in an area with lower wind speeds. The difference between the wind velocities measured at the Christiansburg Residency and those at the Route I-77 rest area is probably due to the effect of local terrain features. The residency complex is prominently exposed,

Table 1

Average Wind Velocities ($\overline{V}$) in mph For Each Recording Period and Annually (1 mph = 0.45 m/s)

Site 1
Route I-81 (NBL) Rest Area

PERIOD	NO. DAYS	$\overline{V}$
8/20-9/18	29	3.6
9/18-10/8	20	5.9
10/8-11/9	32	3.8
11/9-11/20	NO DATA	
11/20-12/8	18	5.8
12/8-12/15	7	5.9
12/15-1/7/82	22	5.8
1/7-2/10	34	6.4
2/10-4/8	57	7.4
4/8-5/13	35	5.4
5/13-6/4	22	3.7
6/4-7/7	33	4.2
7/7-8/4	28	2.2
8/4-8/12	8	3.1

ANNUAL $\overline{V}$ = 4.9

Site 2
Christiansburg Residency

PERIOD	NO. DAYS	$\overline{V}$
10/12/81-10/16	4	6.6
10/16-11/16	31	7.3
11/16-12/1	15	9.8
12/1-12/17	16	10.7
12/17-1/4/82	18	7.4
1/4-1/19	15	12.1
1/19-2/1	13	10.5
2/1-2/16	15	6.8
2/16-3/2	14	9.6
3/2-3/16	14	8.8
3/16-3/31	15	8.9
3/31-4/16	16	13.3
4/16-6/16	61	6.6
6/16-7/6	20	6.5
7/6-7/21	15	4.1
7/21-7/30	9	4.5
7/30-8/17	18	4.6
8/17-10/4	48	5.2
10/4-10/18	14	5.8

ANNUAL $\overline{V}$ = 7.5

Site 3
Route I-77 (SBL) Rest Area

PERIOD	NO. DAYS	$\overline{V}$
10/12/81-10/22	10	5.2
10/22-11/2	11	4.7
11/2-11/9	7	5.3
11/9-11/30	21	5.9
11/30-12/8	8	8.3
12/8-1/7/82	30	6.5
1/7-2/10	34	8.3
2/10-3/11	29	6.3
3/11-3/24	13	6.5
3/24-4/1	8	7.0
4/1-4/8	7	11.8
4/8-4/15	7	7.8
4/15-5/4	19	4.8
5/4-5/13	9	4.4
5/13-6/1	19	3.4
6/1-6/15	14	4.6
6/15-7/1	16	4.6
7/1-7/15	14	5.7
7/15-8/17	NO DATA	
8/17-8/20	3	3.1
8/20-8/31	11	4.4
8/31-9/30	30	2.3
9/30-10/15	15	3.2

ANNUAL $\overline{V}$ = 5.7

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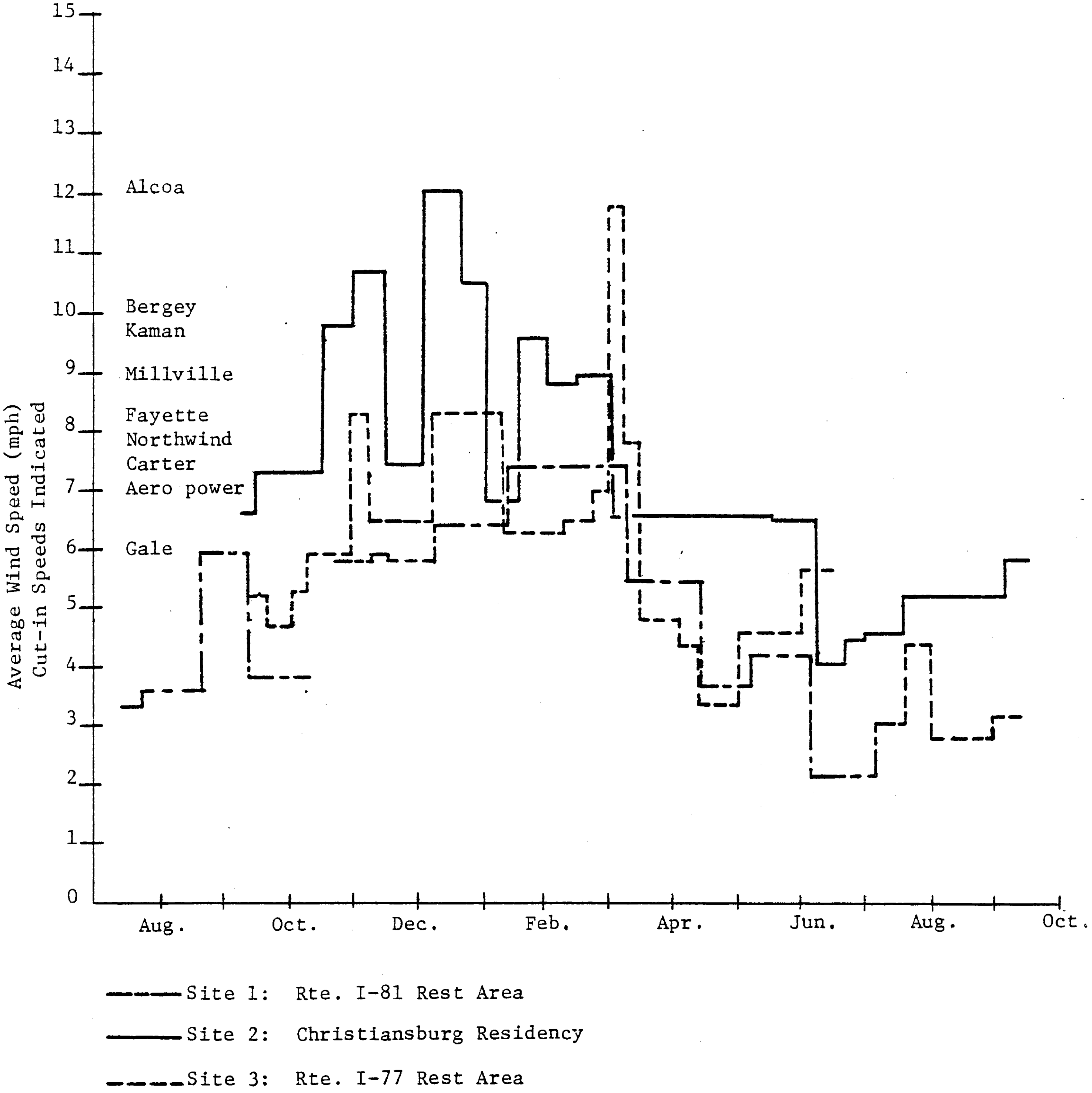


1 mph = 0.45 m/s

Figure 13. Plot of average wind velocity for each period with cut-in speeds for studied wind turbines.

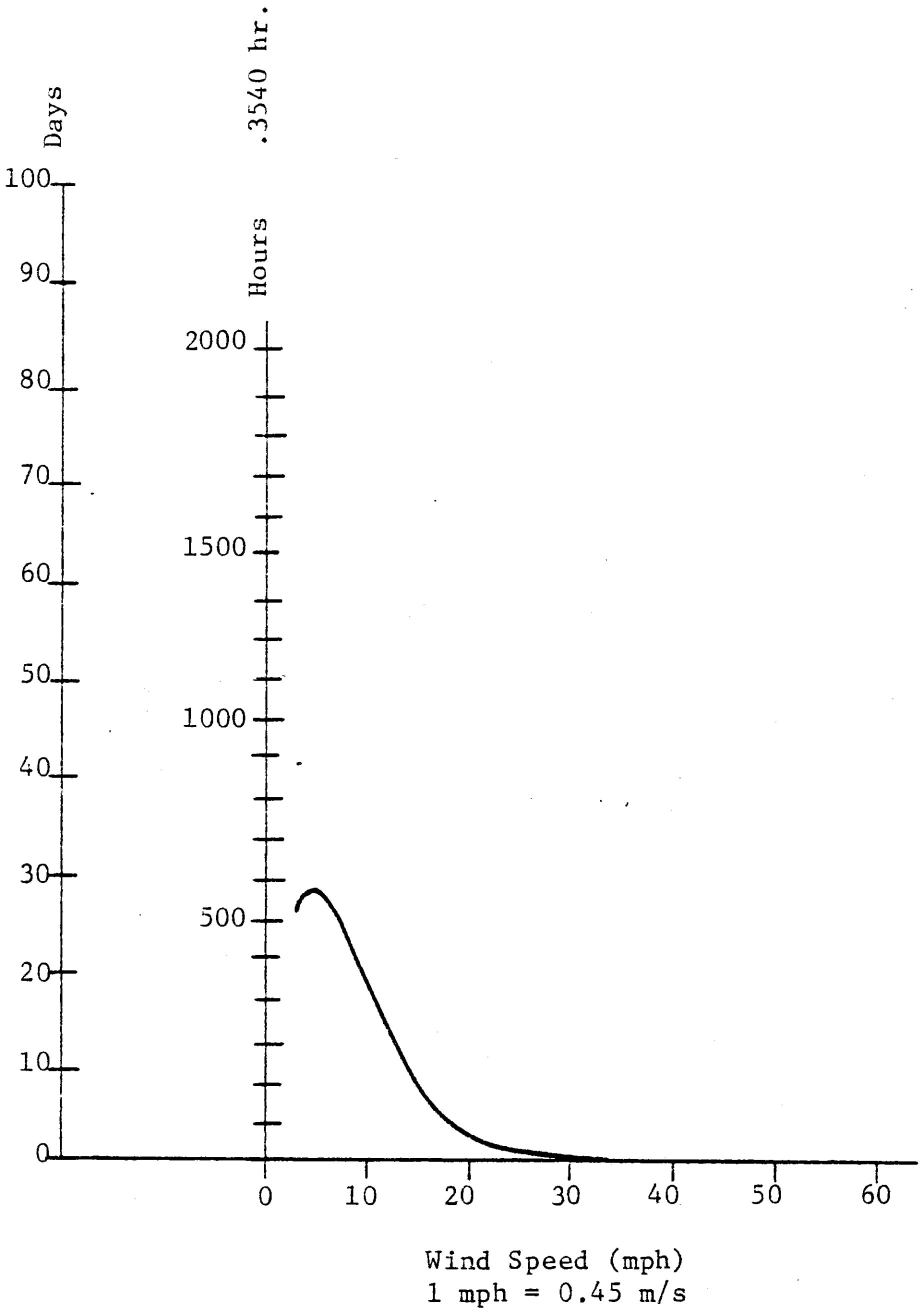
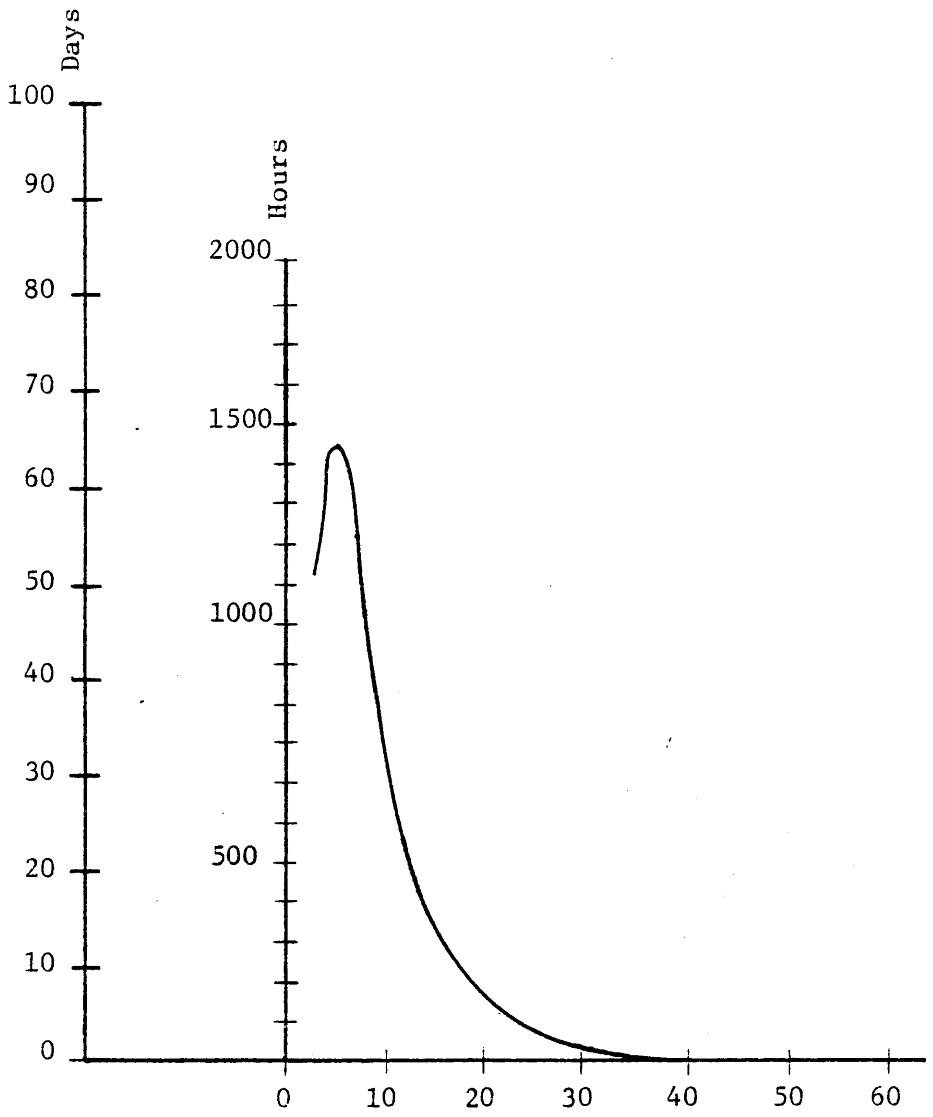


Figure 14. Wind frequency diagram, Route I-81 rest area, 8/20/81 - 8/12/82.



Wind Speed (mph)
1 mph = 0.45 m/s

Figure 15. Wind frequency diagram, Christiansburg Residency, 10/12/81 - 10/18/82.

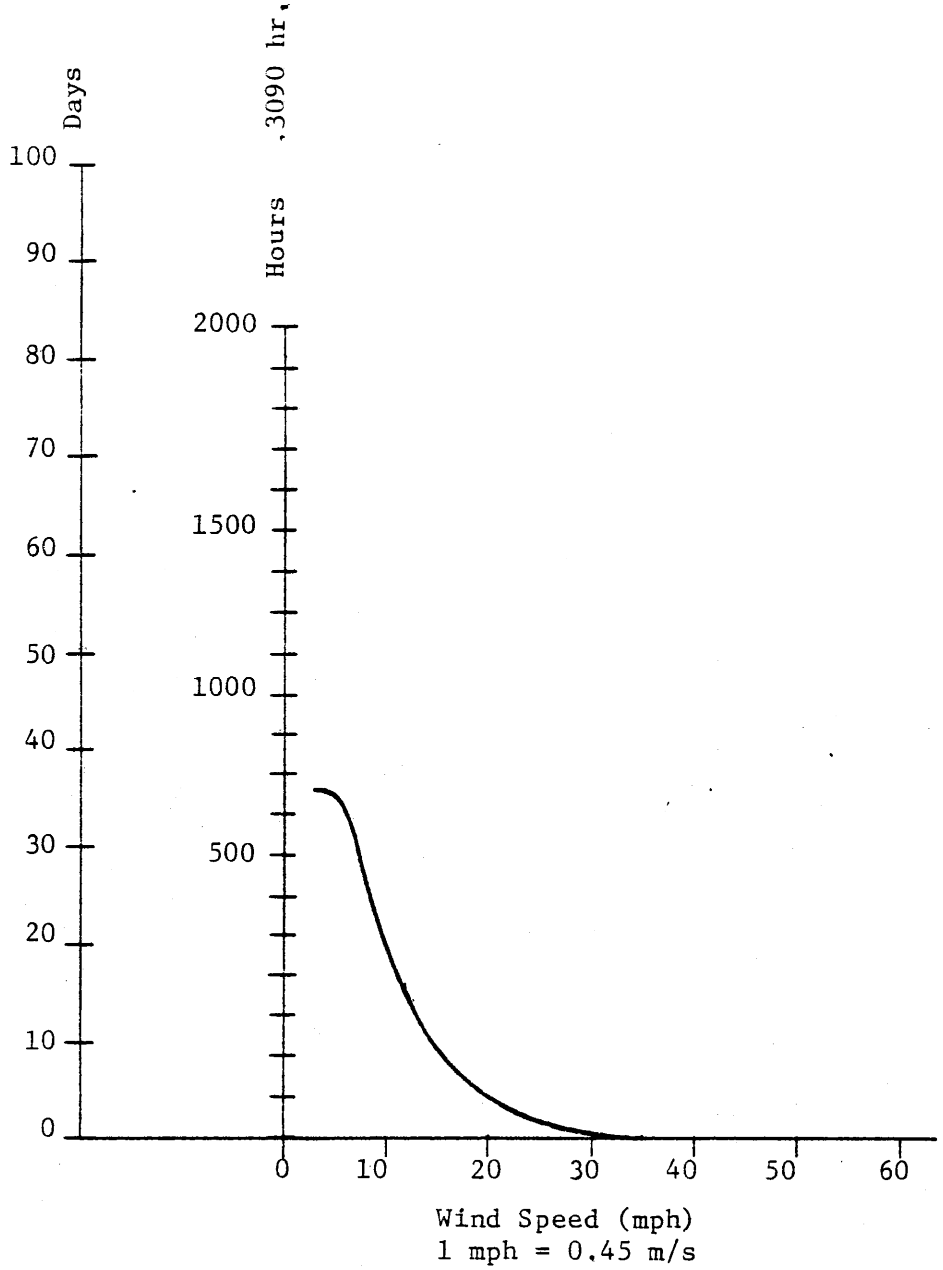


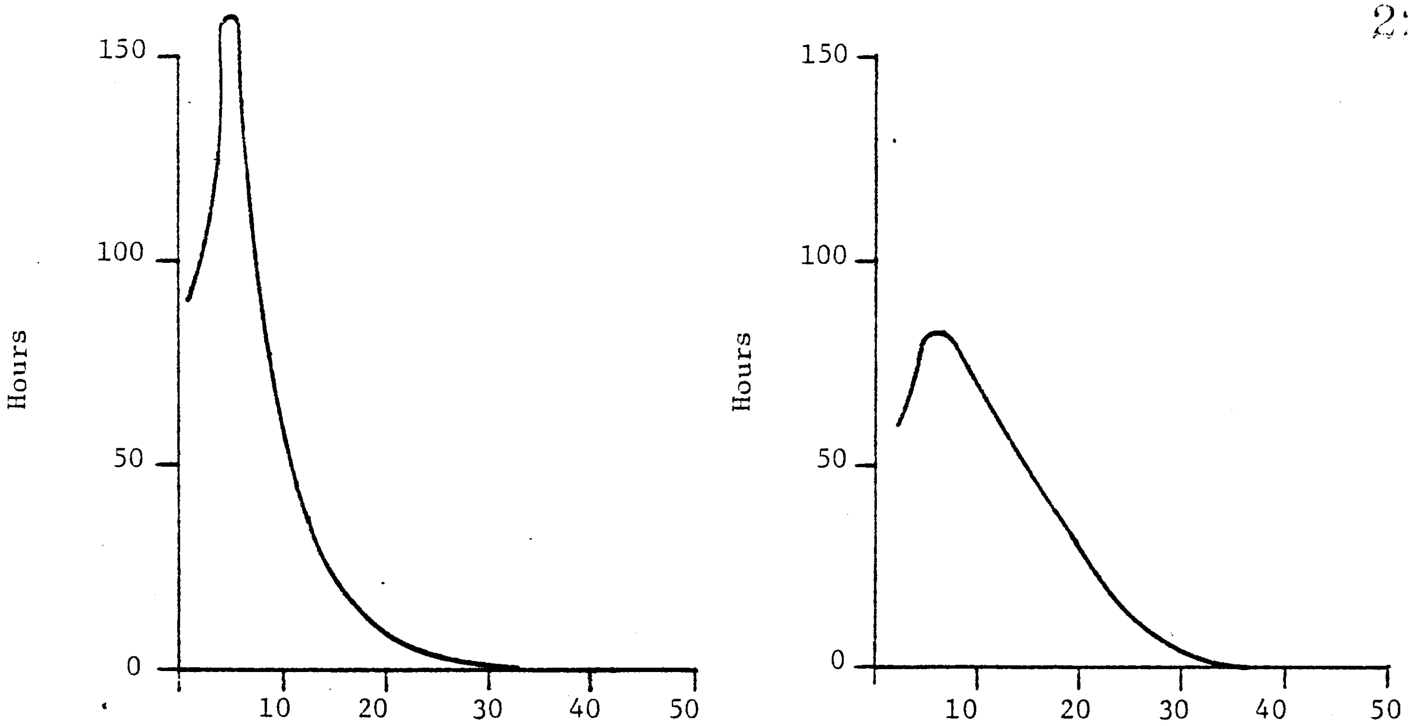
Figure 16. Wind frequency diagram, Route I-77 rest area, 10/12/81 - 10/15/82.

while the rest area lies between relatively high ridges. The effect of the differing anemometer heights, 58 versus 30 ft. (17.7 vs. 9.1 m), is relatively slight, about 0.6 mph (0.3 m/s), if the 1/7 power law is assumed valid. The remaining discussion will concentrate on the Christiansburg site.

Wind frequency diagrams for the Christiansburg site, Figure 17 a-j, show the wind distribution over the year's evaluation period. The most favorable winds occurred during the period from mid-November through mid-April, during which time the area beneath the curve in the critical 10 to 30 mph (4.5 to 13.4 m/s) range increased. In contrast, the diagrams for the summer months indicate calm conditions.

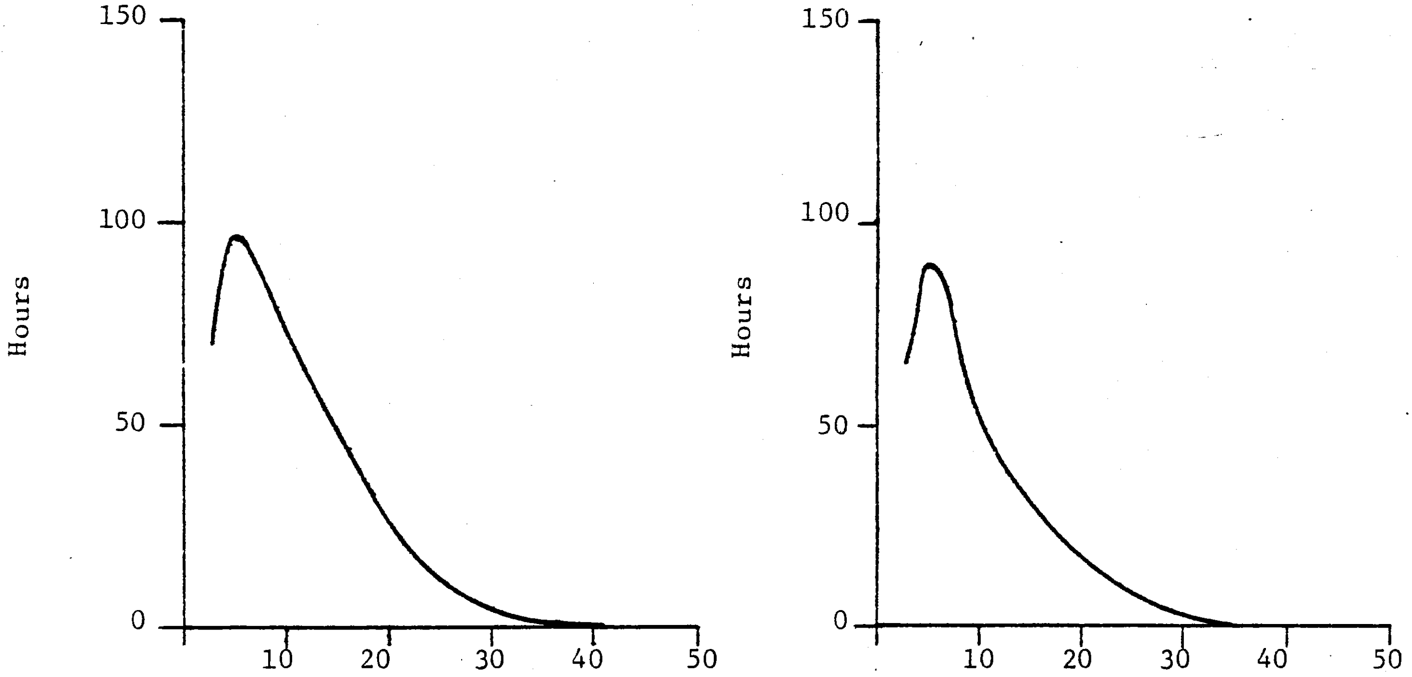
Figure 18 compares the power generated by each of the 9 turbines in each evaluation period with the electrical demand of the Christiansburg Residency complex. At first glance it would appear that the two largest machines, the Kaman 65 kW and the ALCOA 100 kW, provided adequate service, but it must be realized that these machines are oversized for the site. At the low measured wind speeds, the Kaman outperforms the larger ALCOA, which is being used at speeds often below its cut-in velocity and far less than its intended operating range. Had the wind speeds been higher, it is likely that the 25 kW Jay Carter turbine might have effectively filled a portion of the residency's electrical needs. The actual power usage by the residency during the year's evaluation period was 72,200 kWh. It is projected that at an average wind speed of 12 mph (5.4 m/s), the Carter turbine would produce approximately 40,000 kWh annually according to the manufacturer's data. The inability of the turbines to meet the electrical needs under the low measured wind speeds is indicated by the data in Appendix B.

2217



a) Wind speed, mph
Oct. 16 - Nov. 16, 1981
31 days

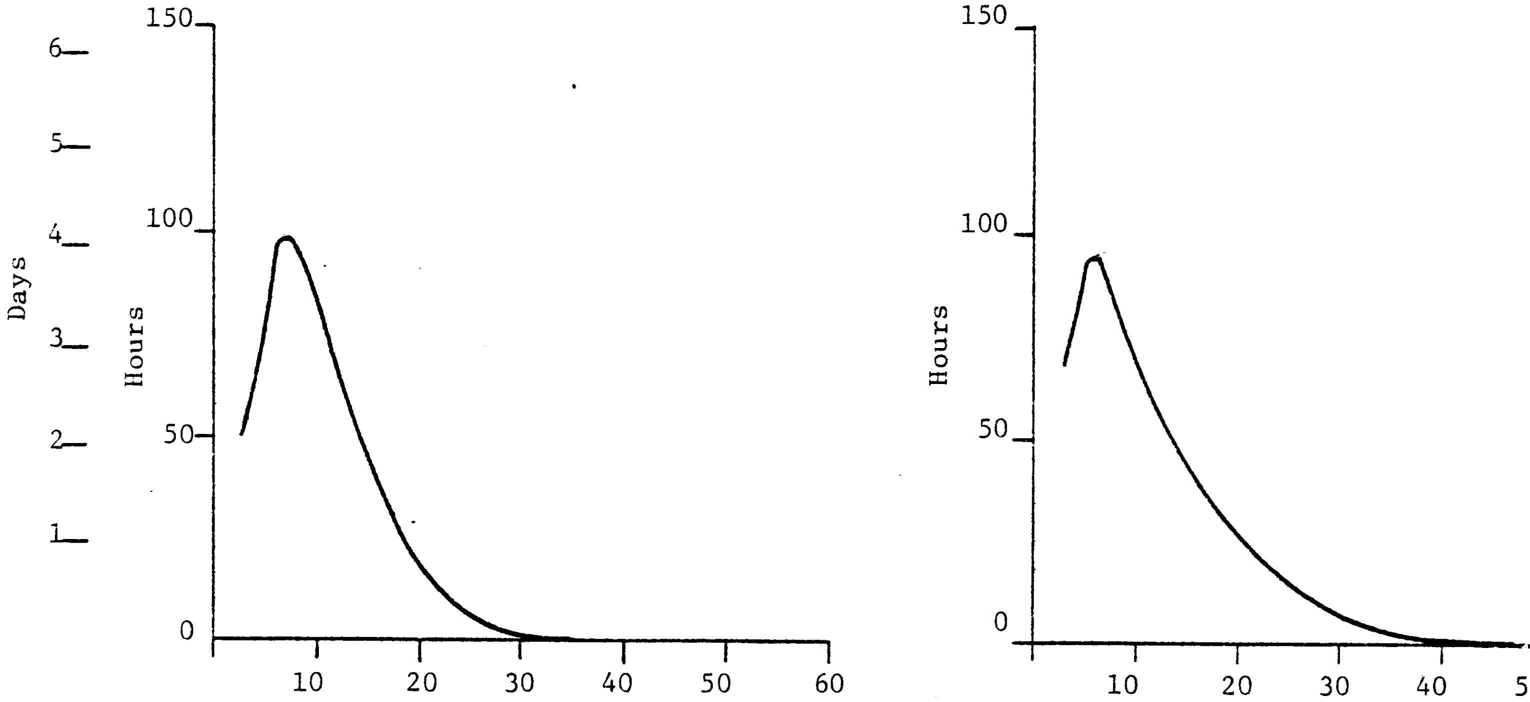
b) Wind speed, mph
Nov. 16 - Dec. 17, 1981
31 days



c) Wind speed, mph
Dec. 17, 1981 - Jan. 19,
1982, 33 days

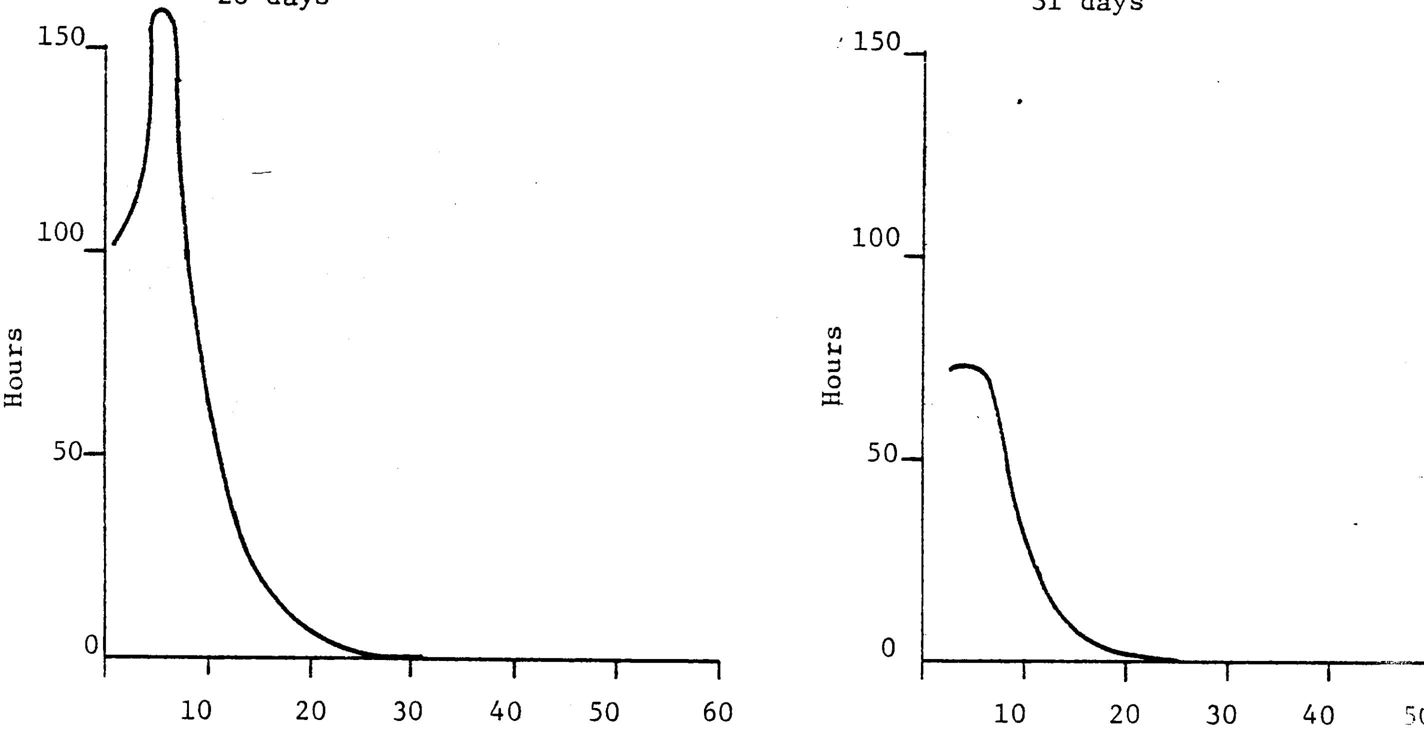
d) Wind speed, mph
Jan. 19 - Feb. 16, 1982
28 days

Figure 17. Wind frequency diagrams, Christiansburg Residency (1 mph = 0.45 m/s).



e) Wind speed, mph
Feb. 16 - Mar. 16, 1982
28 days

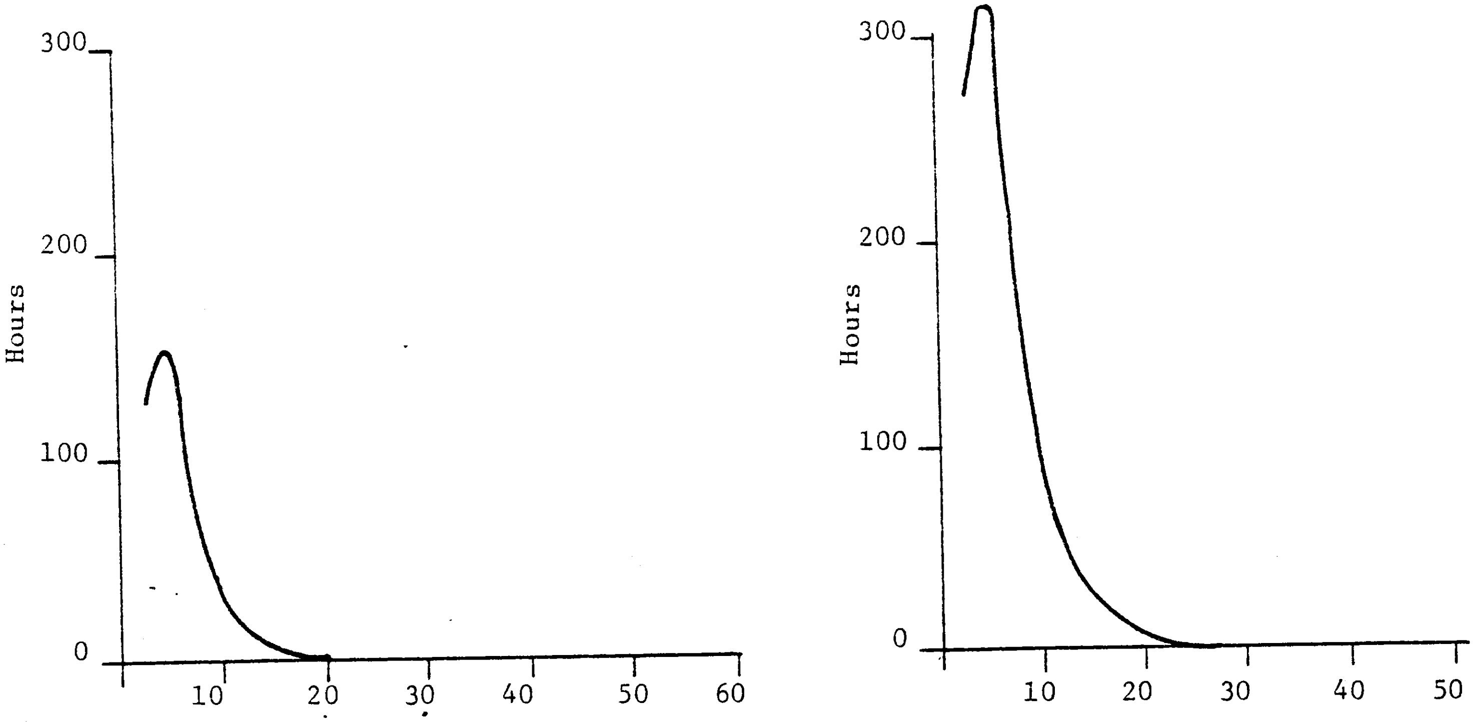
f) Wind speed, mph
Mar. 16 - Apr. 16, 1982
31 days



g) Wind speed, mph
Apr. 16 - June 16, 1982
61 days

h) Wind speed, mph
June 16 - July 21
35 days

Figure 17 continued. (1 mph = 0.45 m/s)



i) Wind speed, mph
July 21 - Aug. 17, 1982
27 days

j) Wind speed, mph
Aug. 17 - Oct. 18, 1982
62 days

Figure 17 continued. (1 mph = 0.45 m/s).

2200

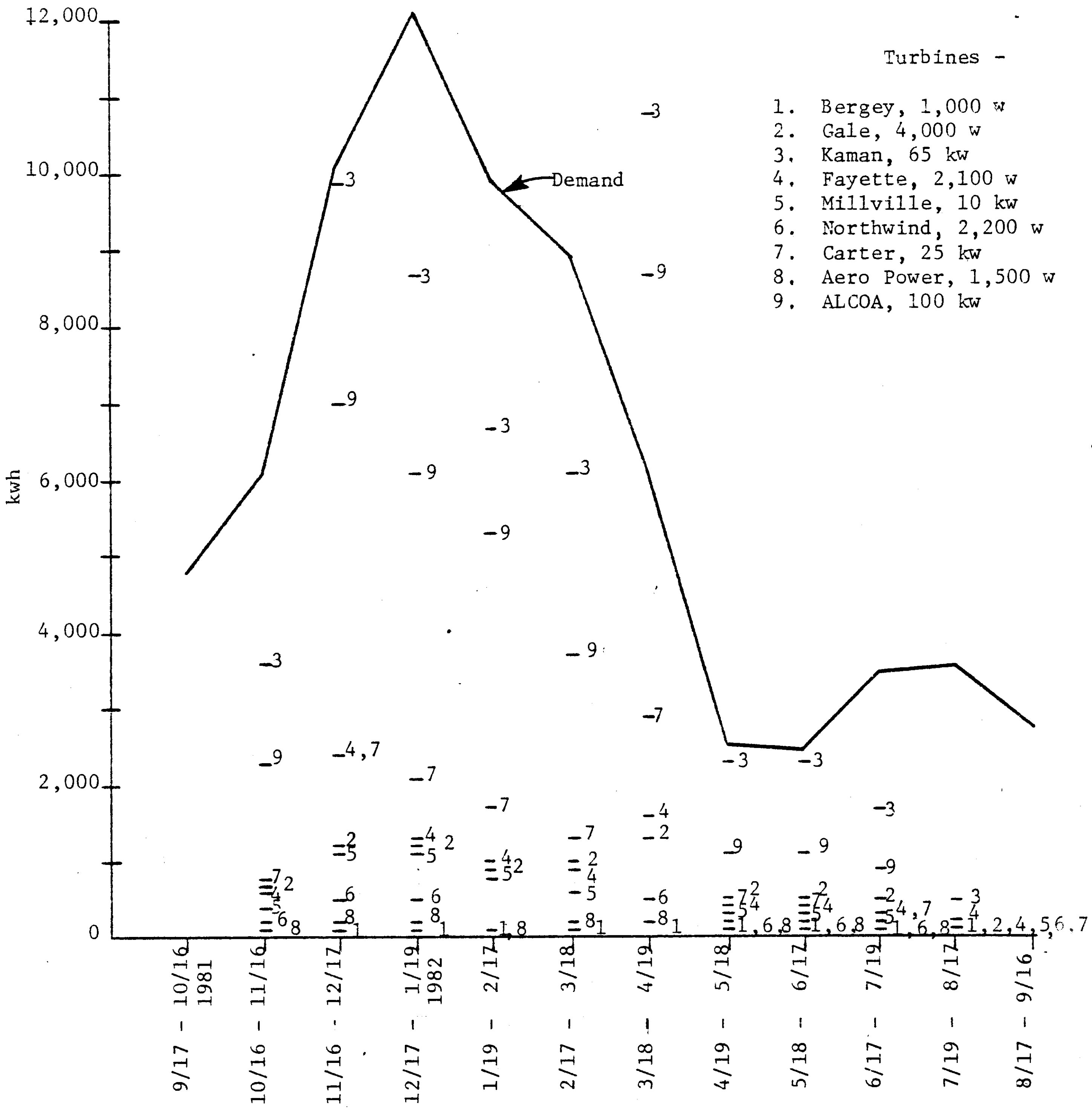


Figure 18. Output of study turbines versus electrical demand, Christiansburg Residency.

CONCLUSIONS AND RECOMMENDATIONS

Wind speeds at the three sites included in this study were not sufficiently high to allow the economical generation of electricity by wind turbines. It seems doubtful that other sites in the interior of Virginia would be more favorable, and no further work is recommended.

There is a likelihood that better wind conditions would be found at some of the Department's coastal bridge-tunnel locations, but these would require the installation of larger turbines to meet a high electrical demand.

Further work in this area, if desired, should be limited to gathering wind speed data using available equipment. If average wind speeds were of sufficient magnitude,a more thorough study could be started.

REFERENCES

1. Demonstration Projects Division, "Work Plan, Demonstration Project No. 52, Solar Energy for Highway Uses", Federal Highway Administration, Region 15, Arlington, Virginia, 1978.

2. Zapp, R. H., J. Asmussen, D. Reinhard, G. Anderson, and N. Arora, "Highway Department Demonstration of Solar and Wind Energy", Division of Engineering Research, Michigan State University, East Lansing, Michigan, 1978.

3. Brode, R., R. Stoner, D. L. Elliott, W. R. Barchet, and R. L. George, <u>Wind Energy Resource Atlas: Volume 5 — The East Central Region</u>, PNL-3195 WERA-5, VC-60, Pacific Northwest Laboratory, Richland, Washington 99352 (available from National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22151).

4. Akins, R. E., "Performance Evaluation of Wind Turbines", <u>Transportation Engineering Journal</u>, ASCE, January 1980, TEL, pp. 19-29.

APPENDIX A

Program WINDANL Description and Input Parameters

by

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May 19, 1981

Prepared under contract with the Virginia Highway and Transportation Research Council.

TABLE OF CONTENTS

1. Introduction

This program was written to analyze data collected from the Natural Power Wind Compilators and predict energy output of specific machines at the location. The program is capable of processing the data from only one location at a time and can consider up to 10 possible turbines at a location. This Appendix describes the basic logic of the program and the sequence of input parameters, and includes a listing of the FORTRAN program.

2. Program Description

The initial comments in the program contain an alphabetic list of major program variables. Lines 7-11 contain the input data for the particular location. Lines 12-14 input the performance data for the particular machines which will be used to predict an energy yield at a particular location.

The DO50 loop, which begins at line 17 and continues to line 54, is the main computational portion of the program. This loop is processed NMACH times, or once for each machine whose output is to be computed. The first calculation is to correct the measured probability density of wind speeds from the height of the reference anemometer to the reference height used in the specification of the power curve for the particular machine. This correction is based on a "1/7 power law" which is appropriate for exposed open terrain. The wind speed axis of the probability density is corrected to correspond to wind speeds at the reference level (usually hub height) of the particular turbine. The values of the probability density corresponding to wind speeds of 1,3,5,... mph are then interpolated or extrapolated from the input readings (array PDF) and placed into array CPDF. The last reading of array PDF corresponds to wind speeds greater than 60 mph and is carried over to array CPDF directly in line 38. This value is not used in the calculation of the energy production. The total number of hours in the observation period is calculated in the DO 22 loop in lines 40, 41. This value, SUM, will be used later in the calculations. In lines 44-47, the array of the corrected probability density function is normalized.

The actual energy calculation is carried out in lines 48-51. The corrected normalized probability density function is integrated over the full range of wind speeds in the DO 30 loop. This quantity is then multiplied by the number of hours in the observation period to obtain kWhrs.

The final data for each machine at the candidate site are output in lines 57-59.

2228

3. Input Sequence

This section describes the input data and the format of the input cards required to properly execute the program. Each input quantity will be related to an input card number, a line number in the program, and a format statement.

Card 1 — line 7 — Format 100-(110)

NMACH — number of machines to be considered at a location. Must be between 1 and 10.

Card 2 — line 8 — Format 101-(20A4)

SITEA — alphanumeric array of 80 characters to describe the location.

Card 3 — line 9 — Format 102 — (20A4).

SITEP — alphanumeric array of 80 characters to describe the period of observation.

Card 4 — line 10 — Format 103 — (2F10.0)

SITED — floating point array — element 1 is the integer number of days in the observation period and element 2 is the elevation of the aneomometer in ft.

Card 5-8 — line 11 — Format 104 — (8F10.0)

PDF — array with actual readings for the analysis period from the Natural Power Compilator. Numbers must be right-justified and may be input as the difference between values on the most recent two readings.

The remaining inputs will have a set for each machine. The example will contain only one set as if NMACH was equal to 1.

Card 9 — line 13 — Format 105 — (20A4)

MACHA (I, 20) — alphanumeric array describing machine I,80 characters.

Card 10-14 — line 11 — Format 106 — (8F10.0)

MACHD (I,33) — performance data on machine I. The first element (I,1) is the reference elevation at which the wind speed used in the power curve of this machine is specified. (I,2 - I,33) Output power is kW of machine starting at 1 mph and continuing at 2 mph increments 3,4,7,9,....

These 6 cards will be repeated for each machine up to a total of 10.

2230

```
      PROGRAM WINDANL(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
C      PROGRAM WINDANL
C
C      WRITTEN 2/81 BY R.E. AKINS, VA TECH FOR THE VA HRC TO
C      ANALYZE MONTHLY DATA FROM THE NATURAL POWER SYSTEMS
C      THE PROGRAM IS CONFIGURED TO ANALYZE THE DATA FROM
C      ONE OF THE LOCATIONS AT A TIME
C
C      THE FOLLOWING IS AN ALPHABETICAL LIST OF MAJOR VARIABLES IN
C      THE PROGRAM
C
C         CORR-SHEAR CORRRECTION TO CORRECT PDF TO HUB HEIGHT
C         CPDF-PROBABILITY DENSITY OF WIND SPEEDS CORRECTED TO HUB
C              HEIGHT
C         CVEL-VELOCITIES OF INITIAL PDF CORRECTED FOR SHEAR
C         ITEMP-COUNTER USED IN INTERPOLATION FOR SHEAR CORREC
C         MACA(I,J)-ALPHANUMMERIC DESCRIPTION OF MACHINE I
C         MACD(I,33)-I=1 HUB HEIGHT OF MACHINE I
C             I=2,33 OUTPUT POWER (KW) AT 1,3,5,7,9,..MPH
C         NMACH-NUMBER OF MACHINES
C         PDF-MEASURED PROBABILITY DENSITY-FROM NATURAL POWER
C         PWR(I)-OUTPUT IN KWHRS FOR MACHINE I
C         SITEA-ALPHANUMERIC DESCRIPTION OF SITE
C         SITED-I=1 PERIOD DAYS, I=2 ANEMOMETER HEIGHT FT
C         SITEP-PERIOD OF OBSERVATION - HOURS
C         SUM-TOTAL OBSERVATION PERIOD - HOURS - FROM PDF
C         T1 - LOWER LIMIT IN INTERPOLATION
C         T2 - UPPER LIMIT IN INTERPOLATION
C
      DIMENSION SITEA(20),SITEP(20),SITED(2),PDF(32),CPDF(32)
      DIMENSION MACA(10,20),MACD(10,33)
      DIMENSION PWR(10),CVEL(32)
      REAL MACD, VTOT, VSUM, VBAR, X
      INTEGER SITEA, SITEP, I, NMATCH
      DATA CPDF/32*0./
C
C         INPUT MACHINE DATA
C
      READ(5,100)NMACH
      DO 10 I=1,NMACH
      READ(5,105)(MACA(I,J),J=1,20)
   10 READ(5,106)(MACD(I,J),J=1,33)
   11 CONTINUE
C
C         INPUT SITE DATA
C
      READ (5,101,END=99) (SITEA(J),J=1,20)
      READ(5,102)(SITEP(J),J=1,20)
      READ(5,103)(SITED(J),J=1,2)
      READ(5,104)(PDF(J),J=1,32)
C
C     CALCULATE AVERAGE WIND SPEED FOR PERIOD
C
      VSUM = 0.0
      VTOT = 0.0
```

```
      DO 12 I = 1, 32
      VTOT = VTOT + PDF(I)
      X = FLOAT(2*I) - 1.0
      VSUM = VSUM + X * PDF(I)
   12 CONTINUE

      VBAR = VSUM/VTOT
      WRITE(6,200)SITEA,SITEP,SITED,PDF
      WRITE (6,205) VBAR
  205 FORMAT (1H0,5X,"MEAN WIND SPEED FOR THIS PERIOD ",F10.1)
      WRITE(6,201)
C
C        CALCULATE POWER OUTPUT OF EACH TURBINE FOR PERIOD
C        OF OBSERVATION
C
      DO 50 I=1,NMACH
C
C        CORRECT PDF TO REFERENCE HEIGHT FOR THE MACHINE
C
      CORR=(MACD(I,1)/SITED(2))**0.143
      DO 15 J=1,32
   15 CVEL(J)=FLOAT(2*J-1)*CORR
C
C        INTERPOLATE TO OBTAIN NEW SITE PDF CORRECTED FOR TO HUB
C        HEIGHT OF MACHINE
C
      IT=1
      DO 20 J=1,31
   16 T1=FLOAT(J*2-1)
      T2=T1+2.
      IF(T1.LT.CVEL(IT))GO TO 19
      IF(T1.GT.CVEL(IT+1))GO TO 18
C
C     T1 IS IN RANGE CVEL(IT) TO CVEL(IT+1)
C
      CPDF(J)=PDF(IT)+(PDF(IT+1)-PDF(IT))*
     1((T1-CVEL(IT))/(CVEL(IT+1)-CVEL(IT)))
      IF(T2.LT.CVEL(IT+1))GO TO 20
      IT=IT+1
      GO TO 20
C
C        EXTRAPOLATE FOR LAST POINT
C
C
C        CORRECT RANGE FOR INTERPOLATION
C
   18 IF(IT.LT.31)IT=IT+1
      IF(IT.LT.31)GO TO 16
      CPDF(J)=PDF(IT)+(PDF(IT)-PDF(IT-1))*
     1((T1-CVEL(IT))/(CVEL(IT)-CVEL(IT-1)))
      GO TO 20
C
C        EXTRAPOLATE FOR FIRST POINT IF NECESSARY
C
   19 CPDF(J)=PDF(IT)*T1/CVEL(J)
```

```
   20 CONTINUE
      CPDF(32)=PDF(32)
CC
C         CALCULATE THE NUMBER OF HOURS IN PERIOD
C
      SUM=0.
      DO 22 J=1,32
   22 SUM=SUM+PDF(J)
      SUM=SUM/3600.
      SUM1=0.
      DO 23 J=1,32
   23 SUM1=SUM1+CPDF(J)
      DO 24 J=1,32
   24 CPDF(J)=CPDF(J)/SUM1
C
C         CPDF HAS NOW BEEN NORMALIZED
C
C         CALCULATE MACHINE OUTPUT
C
      PWR(I)=0.
      DO 30 J=1,31
      K=J+1
   30 PWR(I)=PWR(I)+CPDF(J)*MACD(I,K)
      PWR(I)=PWR(I)*SUM
      WRITE(6,204)(MACA(I,J),J=1,20),MACD(I,1),CPDF
   50 CONTINUE
C
C         OUTPUT THE RESULTS OF THE CALCULATIONS
C
      DO 60 I=1,NMACH
      WRITE(6,202)(MACA(I,J),J=1,20)
   60 WRITE(6,203)PWR(I)
      GO TO 11
   99 CONTINUE
      STOP
C
C         FORMAT STATEMENTS
C
  100 FORMAT(I10)
  101 FORMAT(20A4)
  102 FORMAT(20A4)
  103 FORMAT(2F10.0)
  104 FORMAT((8F10.0))
  105 FORMAT(20A4)
  106 FORMAT((8F10.0))
  200 FORMAT(1H1,5X,"FEASIBILITY OF USING WIND TURBINES TO GENERATE ",
     1"ELECTRICITY FOR HIGHWAY FACILITIES",//,6X,"LOCATION ",20A4,//,
     26X,"PERIOD ",2X,20A4,//,6X,"INPUT NUMBER OF DAYS",F10.0,10X,
     3"HEIGHT OF ANEMOMETER",F10.0,2X,"FT",
     4//,6X,"INPUT PDF",/,(5X,8F10.0))
  201 FORMAT(1H0,5X,"DATA FOR EACH MACHINE FOR THIS PERIOD")
  202 FORMAT(1H0,5X,"TURBINE - ",20A4)
  203 FORMAT(6X,"OUTPUT FOR THIS PERIOD",F10.1, " KWHRS")
  204 FORMAT(1H0,6X,"CORRECTED PDF FOR ",20A4,/,6X,"REFERENCE  ",
     1"HEIGHT",F10.2,/,(5X,8F10.5))
      END
```

APPENDIX B

Sample Outputs
(1 ft. = 0.30 m and 1 mph = 0.45 m/s)

Site 1

```
FEASIBILITY OF USING WIND TURBINES TO GENERATE ELECTRICITY FOR HIGHWAY FACILITIES

LOCATION                 INTERSTATE 81 REST AREA

PERIOD          AUGUST 20, 1981  TO  AUGUST 12, 1982

INPUT NUMBER OF DAYS        345.            HEIGHT OF ANEMOMETER        35.  FT

INPUT PDF
12745304.   2210907.   2431549.   2193392.   1787197.   1378766.    993393.    664392.
  423894.    261772.    164392.    105881.     70097.     46985.     32202.     22511.
   15566.     10959.      7239.      4793.      2901.      1819.      1050.       636.
     369.       212.       141.        66.        45.        22.         3.        12.

MEAN WIND SPEED FOR THIS PERIOD          4.9

DATA FOR EACH MACHINE FOR THIS PERIOD

 CORRECTED PDF FOR      BERGEY WIND POWER MODEL BWC 1000-S
REFERENCE  HEIGHT      50.00
    .45646     .11294     .09061     .08423     .07078     .05617     .04213     .02966
    .01981     .01275     .00811     .00525     .00348     .00236     .00162     .00113
    .00080     .00056     .00040     .00027     .00018     .00011     .00007     .00004
    .00003     .00002     .00001     .00001     .00000     .00000     .00000     .00000

 CORRECTED PDF FOR      GALE COMPANY GALE 4000
REFERENCE  HEIGHT      30.00
    .50210     .08820     .09615     .08595     .06943     .05294     .03760     .02482
    .01563     .00959     .00599     .00385     .00253     .00169     .00116     .00080
    .00055     .00038     .00025     .00016     .00010     .00006     .00003     .00002
    .00001     .00001     .00000     .00000     .00000     .00000     .00000     .00000

 CORRECTED PDF FOR      KAMAN AEROSPACE KAMAN 65KW
REFERENCE  HEIGHT      75.00
    .41405     .13921     .08603     .08258     .07158     .05835     .04536     .03330
    .02300     .01524     .00998     .00662     .00445     .00305     .00212     .00149
    .00106     .00077     .00055     .00040     .00028     .00019     .00013     .00008
    .00005     .00003     .00002     .00001     .00001     .00001     .00000     .00000

 CORRECTED PDF FOR      FAYETTE MANUFACTURING WINDWAY MODEL 20270
REFERENCE  HEIGHT      50.00
    .45646     .11294     .09061     .08423     .07078     .05617     .04213     .02966
    .01981     .01275     .00811     .00525     .00348     .00236     .00162     .00113
    .00080     .00056     .00040     .00027     .00018     .00011     .00007     .00004
    .00003     .00002     .00001     .00001     .00000     .00000     .00000     .00000

 CORRECTED PDF FOR      MILLVILLE  10 KW
REFERENCE  HEIGHT      40.00
    .48201     .09675     .09333     .08516     .07023     .05479     .04012     .02741
    .01783     .01121     .00708     .00457     .00303     .00204     .00140     .00098
    .00068     .00048     .00033     .00022     .00014     .00009     .00005     .00003
    .00002     .00001     .00001     .00000     .00000     .00000     .00000     .00000

 CORRECTED PDF FOR      NORTHWIND POWER  HR2
REFERENCE  HEIGHT      60.00
    .43690     .12526     .08851     .08350     .07119     .05722     .04366     .03138
    .02131     .01392     .00890     .00577     .00382     .00260     .00180     .00127
    .00091     .00065     .00047     .00033     .00022     .00015     .00009     .00006
    .00004     .00002     .00001     .00001     .00001     .00000     .00000     .00000

 CORRECTED PDF FOR      JAY CARTER MODEL 25
REFERENCE  HEIGHT      30.00
```

2224

Site 1, cont.

```
        .50210     .08820     .09615     .08595     .06943     .05294     .03760     .02482
        .01563     .00959     .00599     .00385     .00253     .00169     .00116     .00080
        .00055     .00038     .00025     .00016     .00010     .00006     .00003     .00002
        .00001     .00001     .00000     .00000     .00000     .00000     .00000     .00000

     CORRECTED PDF FOR      AERO POWER SYSTEMS STARLITE 1500
    REFERENCE  HEIGHT      60.00
        .43690     .12526     .08851     .08350     .07119     .05722     .04366     .03138
        .02131     .01392     .00890     .00577     .00382     .00260     .00180     .00127
        .00091     .00065     .00047     .00033     .00022     .00015     .00009     .00006
        .00004     .00002     .00001     .00001     .00001     .00000     .00000     .00000

     CORRECTED PDF FOR      ALCOA  ALVAWT 835524-100KW
    REFERENCE  HEIGHT      30.00
        .50210     .08820     .09615     .08595     .06943     .05294     .03760     .02482
        .01563     .00959     .00599     .00385     .00253     .00169     .00116     .00080
        .00055     .00038     .00025     .00016     .00010     .00006     .00003     .00002
        .00001     .00001     .00000     .00000     .00000     .00000     .00000     .00000

    TURBINE -      BERGEY WIND POWER MODEL BWC 1000-S
    OUTPUT FOR THIS PERIOD      479.7 KWHRS

    TURBINE -      GALE COMPANY GALE 4000
    OUTPUT FOR THIS PERIOD     4915.2 KWHRS

    TURBINE -      KAMAN AEROSPACE KAMAN 65KW
    OUTPUT FOR THIS PERIOD    29627.7 KWHRS

    TURBINE -      FAYETTE MANUFACTURING WINDWAY MODEL 20270
    OUTPUT FOR THIS PERIOD     4542.6 KWHRS

    TURBINE -      MILLVILLE  10 KW
    OUTPUT FOR THIS PERIOD     3124.0 KWHRS

    TURBINE -      NORTHWIND POWER  HR2
    OUTPUT FOR THIS PERIOD     1588.7 KWHRS

    TURBINE -      JAY CARTER MODEL 25
    OUTPUT FOR THIS PERIOD     6205.0 KWHRS

    TURBINE -      AERO POWER SYSTEMS STARLITE 1500
    OUTPUT FOR THIS PERIOD      753.4 KWHRS

    TURBINE -      ALCOA  ALVAWT 835524-100KW
    OUTPUT FOR THIS PERIOD    18267.0 KWHRS
 09.43.54.UCLP, AAB11LP  ,       0.486KLNS.
```

Site 2

```
FEASIBILITY OF USING WIND TURBINES TO GENERATE ELECTRICITY FOR HIGHWAY FACILITIES

LOCATION                    CHRISTIANSBURG RESIDENCY

PERIOD           OCTOBER 12, 1981  TO  OCTOBER 18, 1982

INPUT NUMBER OF DAYS        371.             HEIGHT OF ANEMOMETER        58.  FT

INPUT PDF
 5855173.  4355479.  5500535.  4739167.  3213433.  2236289.  1649558.  1218358.
  904175.   641873.   472427.   332398.   222645.   153004.   101731.   129160.
   44080.    29004.    19046.    12774.     7995.     5030.     3014.     1825.
    1039.      517.      219.      108.       36.       17.        4.        3.

MEAN WIND SPEED FOR THIS PERIOD          7.5

DATA FOR EACH MACHINE FOR THIS PERIOD

 CORRECTED PDF FOR      BERGEY WIND POWER MODEL BWC 1000-S
REFERENCE  HEIGHT      50.00
    .18697    .14065    .17482    .14808    .09988    .06939    .05089    .03739
    .02742    .01945    .01412    .00978    .00653    .00442    .00353    .00323
    .00124    .00081    .00053    .00035    .00021    .00013    .00008    .00005
    .00002    .00001    .00000    .00000    .00000    .00000    .00000    .00000

 CORRECTED PDF FOR      GALE COMPANY GALE 4000
REFERENCE  HEIGHT      30.00
    .19914    .15589    .18300    .14507    .09572    .06605    .04728    .03395
    .02355    .01663    .01131    .00734    .00485    .00382    .00318    .00124
    .00078    .00050    .00030    .00018    .00010    .00006    .00003    .00001
    .00001    .00000    .00000    .00000    .00000    .00000    .00000    .00000

 CORRECTED PDF FOR      KAMAN AEROSPACE KAMAN 65KW
REFERENCE  HEIGHT      75.00
    .17158    .13488    .16408    .14700    .10522    .07388    .05433    .04059
    .03042    .02225    .01631    .01187    .00827    .00568    .00391    .00346
    .00288    .00117    .00078    .00052    .00035    .00022    .00014    .00009
    .00005    .00003    .00002    .00001    .00000    .00000    .00000    .00000

 CORRECTED PDF FOR      FAYETTE MANUFACTURING WINDWAY MODEL 2027D
REFERENCE  HEIGHT      50.00
    .18697    .14065    .17482    .14808    .09988    .06939    .05089    .03739
    .02742    .01945    .01412    .00978    .00653    .00442    .00353    .00323
    .00124    .00081    .00053    .00035    .00021    .00013    .00008    .00005
    .00002    .00001    .00000    .00000    .00000    .00000    .00000    .00000

 CORRECTED PDF FOR      MILLVILLE  10 KW
REFERENCE  HEIGHT      40.00
    .19206    .14697    .17827    .14692    .09822    .06805    .04944    .03600
    .02585    .01830    .01296    .00870    .00579    .00381    .00408    .00189
    .00101    .00064    .00042    .00026    .00015    .00009    .00005    .00003
    .00001    .00001    .00000    .00000    .00000    .00000    .00000    .00000

 CORRECTED PDF FOR      NORTHWIND POWER  HR2
REFERENCE  HEIGHT      50.00
    .18215    .13649    .17151    .14855    .10149    .07072    .05214    .03857
    .02867    .02044    .01504    .01063    .00717    .00493    .00329    .00397
    .00159    .00095    .00062    .00042    .00026    .00017    .00010    .00006
    .00004    .00002    .00001    .00000    .00000    .00000    .00000    .00000

 CORRECTED PDF FOR      JAY CARTER MODEL 25
REFERENCE  HEIGHT      30.00
```

Site 2, cont.

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     .19914     .15589     .18300     .14507     .09572     .06605     .04728     .03395
     .02355     .01663     .01131     .00734     .00485     .00382     .00318     .00124
     .00078     .00050     .00030     .00018     .00010     .00006     .00003     .00001
     .00001     .00000     .00000     .00000     .00000     .00000     .00000     .00000

  CORRECTED PDF FOR       AERO POWER SYSTEMS STARLITE 1500
 REFERENCE  HEIGHT       60.00
     .18215     .13649     .17151     .14855     .10149     .07072     .05214     .03857
     .02867     .02044     .01504     .01063     .00717     .00493     .00329     .00397
     .00159     .00095     .00062     .00042     .00026     .00017     .00010     .00006
     .00004     .00002     .00001     .00000     .00000     .00000     .00000     .00000

  CORRECTED PDF FOR       ALCOA  ALVAWT 835524-100KW
 REFERENCE  HEIGHT       30.00
     .19914     .15589     .18300     .14507     .09572     .06605     .04728     .03395
     .02355     .01663     .01131     .00734     .00485     .00382     .00318     .00124
     .00078     .00050     .00030     .00018     .00010     .00006     .00003     .00001
     .00001     .00000     .00000     .00000     .00000     .00000     .00000     .00000

 TURBINE -      BERGEY WIND POWER MODEL BWC 1000-S
 OUTPUT FOR THIS PERIOD      903.6 KWHRS

 TURBINE -      GALE COMPANY GALE 4000
 OUTPUT FOR THIS PERIOD     8734.6 KWHRS

 TURBINE -      KAMAN AEROSPACE KAMAN 65KW
 OUTPUT FOR THIS PERIOD    55730.5 KWHRS

 TURBINE -      FAYETTE MANUFACTURING WINDWAY MODEL 2027D
 OUTPUT FOR THIS PERIOD     8364.6 KWHRS

 TURBINE -      MILLVILLE  10 KW
 OUTPUT FOR THIS PERIOD     6139.2 KWHRS

 TURBINE -      NORTHWIND POWER  HR2
 OUTPUT FOR THIS PERIOD     2853.2 KWHRS

 TURBINE -      JAY CARTER MODEL 25
 OUTPUT FOR THIS PERIOD    12757.0 KWHRS

 TURBINE -      AERO POWER SYSTEMS STARLITE 1500
 OUTPUT FOR THIS PERIOD     1395.6 KWHRS

 TURBINE -      ALCOA  ALVAWT 835524-100KW
 OUTPUT FOR THIS PERIOD    38067.6 KWHRS
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Site 3

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FEASIBILITY OF USING WIND TURBINES TO GENERATE ELECTRICITY FOR HIGHWAY FACILITIES

LOCATION                ROUTE I77 REST AREA IN BLAND COUNTY, VIRGINIA

PERIOD          OCTOBER 12, 1981  TO  OCTOBER 15, 1982

INPUT NUMBER OF DAYS        335.             HEIGHT OF ANEMOMETER          30.  FT

INPUT PDF
11122506.  3101524.  3095430.  2614444.  2012888.  1497433.  1090326.   791033.
  574439.   410658.   289572.   203518.   141471.    94819.    63775.    43564.
   28881.    19050.    12698.     8487.     5410.     3505.     2329.     1439.
     555.      535.      311.      180.      118.       45.       25.       23.

MEAN WIND SPEED FOR THIS PERIOD          5.7

DATA FOR EACH MACHINE FOR THIS PERIOD

 CORRECTED PDF FOR      BERGEY WIND POWER MODEL BWC 1000-S
REFERENCE  HEIGHT      50.00
   .35942    .13729    .10765    .09501    .07661    .05900    .04438    .03300
   .02448    .01809    .01318    .00950    .00682    .00484    .00333    .00232
   .00163    .00112    .00077    .00052    .00036    .00024    .00016    .00011
   .00007    .00005    .00003    .00002    .00001    .00001    .00000    .00000

 CORRECTED PDF FOR      GALE COMPANY GALE 4000
REFERENCE  HEIGHT      30.00
   .40845    .11390    .11367    .09601    .07392    .05499    .04004    .02905
   .02109    .01508    .01063    .00747    .00520    .00348    .00234    .00160
   .00106    .00070    .00047  - .00031    .00020    .00013    .00009    .00005
   .00003    .00002    .00001    .00001    .00000    .00000    .00000    .00000

 CORRECTED PDF FOR      KAMAN AEROSPACE KAMAN 65KW
REFERENCE  HEIGHT      75.00
   .32509    .15258    .10320    .09400    .07815    .06150    .04716    .03554
   .02680    .02034    .01526    .01131    .00832    .00607    .00437    .00306
   .00215    .00155    .00110    .00076    .00053    .00037    .00026    .00017
   .00012    .00008    .00006    .00004    .00002    .00002    .00001    .00000

 CORRECTED PDF FOR      FAYETTE MANUFACTURING WINDWAY MODEL 2027D
REFERENCE  HEIGHT      50.00
   .35942    .13729    .10765    .09501    .07661    .05900    .04438    .03300
   .02448    .01809    .01318    .00950    .00682    .00484    .00333    .00232
   .00163    .00112    .00077    .00052    .00036    .00024    .00015    .00011
   .00007    .00005    .00003    .00002    .00001    .00001    .00000    .00000

 CORRECTED PDF FOR      MILLVILLE  10 KW
REFERENCE  HEIGHT      40.00
   .37980    .12761    .11016    .09544    .07550    .05735    .04259    .03136
   .02308    .01684    .01213    .00866    .00615    .00428    .00291    .00200
   .00138    .00092    .00062    .00042    .00028    .00018    .00012    .00008
   .00005    .00003    .00002    .00001    .00001    .00000    .00000    .00000

 CORRECTED PDF FOR      NORTHWIND POWER  HR2
REFERENCE  HEIGHT      60.00
   .34361    .14453    .10564    .09460    .07738    .06021    .04571    .03421
   .02552    .01902    .01397    .01023    .00747    .00541    .00382    .00267
   .00187    .00131    .00090    .00062    .00042    .00029    .00020    .00013
   .00009    .00006    .00004    .00002    .00002    .00001    .00001    .00000

 CORRECTED PDF FOR      JAY CARTER MODEL 25
REFERENCE  HEIGHT      30.00
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2238

Site 3, cont.

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       .40845    .11390    .11367    .09601    .07392    .05499    .04004    .02905
       .02109    .01508    .01063    .00747    .00520    .00348    .00234    .00160
       .00106    .00070    .00047    .00031    .00020    .00013    .00009    .00005
       .00003    .00002    .00001    .00001    .00000    .00000    .00000    .00000

      CORRECTED PDF FOR      AERO POWER SYSTEMS STARLITE 1500
     REFERENCE  HEIGHT     60.00
       .34361    .14453    .10564    .09460    .07738    .06021    .04571    .03421
       .02552    .01902    .01397    .01023    .00747    .00541    .00382    .00267
       .00187    .00131    .00090    .00062    .00042    .00029    .00020    .00013
       .00009    .00006    .00004    .00002    .00002    .00001    .00001    .00000

      CORRECTED PDF FOR      ALCOA  ALVAWT 835524-100KW
     REFERENCE  HEIGHT     30.00
       .40845    .11390    .11367    .09601    .07392    .05499    .04004    .02905
       .02109    .01508    .01063    .00747    .00520    .00348    .00234    .00160
       .00106    .00070    .00047    .00031    .00020    .00013    .00009    .00005
       .00003    .00002    .00001    .00001    .00000    .00000    .00000    .00000

     TURBINE -      BERGEY WIND POWER MODEL BWC 1000-S
     OUTPUT FOR THIS PERIOD      716.8 KWHRS

     TURBINE -      GALE COMPANY GALE 4000
     OUTPUT FOR THIS PERIOD    6376.9 KWHRS

     TURBINE -      KAMAN AEROSPACE KAMAN 65KW
     OUTPUT FOR THIS PERIOD   44979.2 KWHRS

     TURBINE -      FAYETTE MANUFACTURING WINDWAY MODEL 20270
     OUTPUT FOR THIS PERIOD    6700.0 KWHRS

     TURBINE -      MILLVILLE  10 KW
     OUTPUT FOR THIS PERIOD    4973.7 KWHRS

     TURBINE -      NORTHWIND POWER  HR2
     OUTPUT FOR THIS PERIOD    2275.3 KWHRS

     TURBINE -      JAY CARTER MODEL 25
     OUTPUT FOR THIS PERIOD   10313.3 KWHRS

     TURBINE -      AERO POWER SYSTEMS STARLITE 1500
     OUTPUT FOR THIS PERIOD    1112.7 KWHRS

     TURBINE -      ALCOA  ALVAWT 835524-100KW
     OUTPUT FOR THIS PERIOD   30822.1 KWHRS
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