Wind Resource Assessment Report Waldron, AR

ARKANSAS ANEMOMETER LOAN PROGRAM

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Abstract and Summary Information

The measurement campaign had one year duration from 04/01/2011 to 03/31/2012 and was taken at 20m and 34m with NRG instrumentation. The data was analyzed weekly to check inconsistencies and validity and processed using Excel, Flexpro and Windographer standard Edition Version 2.04. The site analyzed is located in the Waldron, Arkansas in Scott County. It is an open site for most of the direction sectors with immediate roughness class of 1.5. It has seasonally directional winds, of which the most energetic come from the southern direction. The vertical wind profile shows moderate wind shear that varies by season as well.

<i>34m Meteorological Tower Data Synopsis</i>	(based on 1-yr measurements)
Data start date	April 1, 2011
Data finish data	March 31, 2012
Data recovery rate	99.7%
Site Coordinates	34.9785°N 94.1295°W
Average wind speed (20 meter)	3.3 m/s (Measured)
Average wind speed (34 meter)	4.1 m/s (Measured)
Average wind speed (50 meter)	4.9 m/s (Predicted)
Average wind speed (100 meter)	6.59 m/s (predicted)
C and K Weibull Parameters at 20m	c= 3.74m/s, k= 2.08
C and K Weibull Parameters at 34m	c=4.65m/s, k= 2.26
Mean wind power density (20 meter)	40 W/m ²
Mean wind power density (34 meter)	69 W/m ²
Mean wind power density (50 meter)	108 W/m ² - Class 1 (predicted)
Average Power law exponent Alpha	0.40
Mean Turbulence Intensity (34 meter) - IEC 3ed.	Insufficient data to calculate
Temp (Max, Avg, Min)	45.70, 19.1, -7.20 C°
Air density (Max, Avg, Min)	1.28, 1.16, 1.07 kg/m ³

1.0 Introduction

The Arkansas Anemometer Loan Program was established in the summer of 2009 with the objective to assist landowners in the state evaluate the wind energy potential of their property. The program is funded by DOE and the Arkansas Energy Office and is administered by the Renewable Energy Department at John Brown University. This report represents one of four final wind resource assessment reports produced as a result of this grant.

The sites chosen were based on different criteria such as accessibility, obstacle free, adequate cell phone coverage for remote data transfer and a clear statement of objectives from the landowner for the use of wind power. These sites are located in Waldron, Harrison, DeWitt, and Booneville. This report documents the finding at the Waldron Site.

The wind measurement system is installed for a period of one year to collect wind velocity and temperature values. The data is logged in 10 minute average values in a wind data acquisition system and sent via an internet modem to the renewable energy department at John Brown University for analysis. The data is monitored on a weekly basis and checked for sensor operation. During the measurement campaign quarterly reports are generated and upon completing the one-year period of data collection, the tower is removed from the site and a summary report of the wind resource is given to the tower borrower.

This report contains a collection of figures and values the analyst has generated using established analytical techniques that accurately reflect the wind resource. This report represents the final portion of the project and is designed to give the landowner the information necessary to make an informed choice about the role wind energy might play in their property.

This document is divided into several sections:

- This introduction which explains the origin, objective and scope of the program;
- Section 2 which describes the site terrain characteristics and topography;
- Section 3 which explains the measurement set-up and instrumentation used in the study;
- Section 4 which explains the wind characteristics and main calculated parameters;
- Section 5 which describes the wind power density characteristics;
- Section 6 which describes the energy production from the wind regime at the site in the context of eight small wind turbines and
- Section 7 which contains a short summary and discussion of the main findings.

2.0 Site Description

Site name:	J. Spencer, Waldron, AR
Coordinates:	34.9785°N 94.1295°W
Elevation:	2136ft. (651m)
Address:	3648 Poteau Mountain Road Waldron , AR
County:	Scott
Type of Sensors & Logger:	<ul style="list-style-type: none">• NRG Maximum #40 wind speed• NRG 200P Series wind vane• NRG 110S Temperature sensor• Symphonie Wind Data Logger
Type of Data:	10 min. avg/max/min/St.dev. wind speed 10 min. avg/max/min/St.dev. wind direction 10 min. avg/max/min/St dev .temperature data
Installation Date:	04/26/2011
Beginning of data collection	04/01/2011 00:00
End of data collection:	03/31/2012 23:50

2.1. Site Location

The location of the measurement tower is in Scott County outside Waldron city limits. The elevation is 321m with a flat terrain which has been cleared of trees for the most part for hay production. Wooded areas are found in the north, west and south directions at almost 900ft. The east section has scattered trees and a house about 350ft from the met tower position. A ground level panoramic view, aerial view and a topographical plan of the site are shown in Figure 1a, 1b and 1c respectively.

Figure 1a. Panoramic view of site

Figure 1b. Aerial view of site

Figure 1c. Topographic map site – 34.9785°N 94.1295°W Elevation 1,053 ft (321 m)

3.0 Measurement Set-up

3.1. General

The measurement set-up consists of a meteorological mast with wind speed, wind direction and temperature sensors and a data logger equipped with a wireless communications module. Wind speeds are measured at 34m and 20m and temperature is measured at ground level. The measurement values are recorded by the data logger and sent via internet to the Renewable Energy Department at John Brown University.

3.1.1 Meteorological Mast

Figure 2 depicts the arrangement of the mast and the instrumentation. The tower used was a 34m (110 ft) guy-supported tower from NRG. It is anchored at four different points with screw-in type anchors as well as drive-in type anchors where needed. The tower uses a gin-pole and helper gin-pole arrangement secured to an 8000lb 12V DC winch to be raised. The tower required no foundation work, only a leveled and flat area for the base which is secured with 36” steel pegs into the ground.

Figure 2. Sketch of meteorological mast and sensor arrangement

3.1.2 Wind Speed

The wind speed was measured at heights of 34m and 20m. For comparative and redundancy reasons two anemometers of the type NRG 40C were installed at the 34m height. The boom of one anemometer is located west and the second anemometer is oriented east. A third wind speed sensor was installed at 20 meters directed west. All instrumentation calibration values are listed in Table 1. The wind speed is recorded with 10 min. average, minimum, maximum and standard deviation values. Figure 3 shows the anemometer tower at the 34m and 20m level.

Figure 3. Met tower and sensors installed at the 34m and 20 m level

3.1.3 Wind Direction

A potentiometric NRG wind vane type 200P was installed at 34m height with its boom oriented north. The wind directions signals are recorded with 10 minute average, minimum, maximum and standard deviation values.

3.1.4 Data Logger

The data logger used was an NRG symphonie in conjunction with a GSM IPack communications module for remote data transfer. The data logger was powered by a 12-volt dc battery charged by a solar module attached to the front of the cabinet box used to protect it from the elements. It recorded the measured data with a sample frequency of 1 Hz. and the values were averaged directly in the logger to 10-minute mean values as well as 10-min extreme and 10-min standard deviation. The sensors for the wind speed give impulses that are counted by the logger; the temperature signal and wind direction are processed directly by the analogue/digital converters in the data logger and the measured data was transferred daily to John Brown University via electronic means. The table below contains the specifications of the logging equipment.

Sensor	Data Acquisition System		
Device	Data Logger	Sampling & Averaging Interval	1 Hz/ 10min
Type	NRG Symphonie – Internet enabled micropower wind energy data logger	Channels	15 (10 counter; 5 Analog)
Serial #:	309020260	I-Pack Option	Serial # 38605722 GSMA - Serial connection direct to IPack

3.1.5 Device Description

The measuring equipment was installed according to NRG specifications where applicable. All sensors were factory calibrated and checked for correct operation in lab before deployment. Table 1 lists all sensors and devices that were utilized during the measurement campaign.

Table 1. List of sensors used in the measurement campaign

Sensor	Wind Speed		
Device	Cup Anemometer	Measurement Range	1 to 96 m/s
Type	#40C	Resolution	.05 m/s
Serial #	63719	Accuracy	0.1 m/s
Calibration/ Transfer Function	$m/s = (Hz \times 0.760) + 0.38$	Height/Alignment	34 m West (270°)
		Distance Constant	3m
		Signals	Ave, max, min, St. Dev.
		DL channel	1
Sensor	Wind Speed		
Device	Cup Anemometer	Measurement Range	1 to 96 m/s
Type	40C	Resolution	.05 m/s
Serial #	63720	Accuracy	0.1 m/s
Calibration	$m/s = (Hz \times 0.757) + 0.44$	Height/Alignment	34 m East (90 °)
		Distance Constant	3m
		Signals	Ave, max, min, St. Dev.
		DL channel	2

Sensor	Wind Speed		
Device	Cup Anemometer	Measurement Range	1 to 96 m/s
Type	40C	Resolution	.05 m/s
Serial #	63721	Accuracy	0.1 m/s
Calibration	$m/s = (Hz \times 0.755) + 0.41$	Height/Alignment	20 m / West (270 °)
		Distance Constant	3m
		Signals	Ave, max, min, St. Dev.
		DL channel	3
Sensor	Wind Direction		
Device	Wind Vane	Measurement Range	0-360 degrees continuous
Type	200P 2001	Resolution	1 degree
Serial #	N/A	Accuracy	1%
Calibration	Slope: 0.351 Offset: 0 Analog DC voltage from conductive plastic potentiometer, 10K ohms	Height/Alignment	33 m / North (0°)
		Signals	Ave, max, min, St. dev.
		DL channel	7
Sensor	Temperature		
Device	NRG 110S	Measurement Range	-40 °C to 52.5 °C (-40 °F to 126.5 °F)
		Accuracy	+/- 1.1 °C
Serial #	3075		
Calibration/Transfer Function	Temp = 0.136 - 86.38	Height	1 m
		Signals	Ave, max, min, St. Dev.
		DL channel	9

4.0 Wind Characteristics

In the following sections, several characteristics of the wind at the site are graphically shown and discussed. The goals are to evaluate the characteristics that can help explain the physical processes at work at the site and to highlight the properties that are important in assessing the wind energy potential. These evaluations are done using raw data with 10 minute values of the average and extreme values as well as the standard deviation. Hourly, monthly and annual means of wind speed were constructed using the 10 minute values.

The time span analyzed was from April 01, 2011 to March 31, 2012. The data files were collected and uploaded into a Windographer standard Edition Version 2.04 software application. Summary tables and graphs were extracted into this report to show the main characteristics of the wind regime at the site.

4.1 Data Recovery

The amount of data recovered during an observation period is important to characterize the wind profile and should be examined to determine the confidence of other characteristics. The data recovery was 99.85% with no periods of missing data; however data for several hour periods was removed from the records because the effects of icing were detected. These times are from

02/13/2012 15:20–23:00; Table 2a and 2b shows these results as well as the average, extreme values (max and min), St. Dev. and the Weibull k and c parameters for wind distributions in the 20m and 34m measurements.

Table 2a. Data recovery rates and 34m means for every month during the duration of measurement

Month /Year	Possible Records	Valid Possible Records	Recovery Rate (%)	Mean (m/s)	Min (m/s)	Max (m/s)	Std.Dev. (m/s)	Weibull K	Weibul c (m/s)
Apr/11	4,320	4,320	100	5.2	0.4	12.6	2.33	2.37	5.88
May/11	4,464	4,464	100	5.0	0.4	12.2	1.89	2.83	5.55
Jun/11	4,320	4,320	100	4.0	0.4	11.9	1.79	2.37	4.54
July/11	4,464	4,464	100	3.4	0.4	11.3	1.21	3.06	3.81
Aug/11	4,464	4,464	100	3.7	0.4	12.6	1.41	2.74	4.10
Sep/11	4,320	4,320	100	3.4	0.4	9.9	1.47	2.48	3.87
Oct/11	4,464	4,464	100	3.9	0.4	14.0	1.76	2.34	4.40
Nov/11	4,320	4,320	100	4.8	0.4	11.9	2.02	2.51	5.35
Dec/11	4,464	4,464	100	3.7	0.4	13.1	1.75	2.17	4.13
Jan/12	4,464	4,464	100	4.4	0.4	13.9	2.22	2.04	4.95
Feb/12	4,176	4,098	98.13	3.8	0.4	12.9	1.94	2.02	4.27
Mar/12	4,464	4,464	100	4.3	0.4	11.5	1.80	2.54	4.84
All data	52,704	52,626	99.85	4.1	0.4	14.0	1.91	2.26	4.65
Mean of monthly means				4.1					

Table 2b. Data recovery rates and 20m means for every month during the duration of measurement

Month /Year	Possible Records	Valid Possible Records	Recovery Rate (%)	Mean (m/s)	Min (m/s)	Max (m/s)	St.Dev. (m/s)	Weibull K	Weibul c (m/s)
Apr/11	4,320	4,320	100	4.3	0.4	11.2	2.01	2.22	4.79
May/11	4,464	4,464	100	3.9	0.4	10.8	1.66	2.51	4.42
Jun/11	4,320	4,320	100	3.1	0.4	9.3	1.53	2.12	3.50
July/11	4,464	4,464	100	2.6	0.4	9.3	1.06	2.64	2.94
Aug/11	4,464	4,464	100	2.9	0.4	10.6	1.22	2.50	3.24
Sep/11	4,320	4,320	100	2.7	0.4	8.6	1.32	2.12	3.02
Oct/11	4,464	4,464	100	3.1	0.4	12.9	1.57	2.03	3.45
Nov/11	4,320	4,320	100	3.9	0.4	10.9	1.72	2.37	4.34
Dec/11	4,464	4,464	100	3.0	0.4	11.9	1.51	2.06	3.40
Jan/12	4,464	4,464	100	3.7	0.4	11.8	1.91	2.04	4.21
Feb/12	4,176	4,098	98.13	3.2	0.4	11.8	1.69	1.98	3.63
Mar/12	4,464	4,464	100	3.5	0.4	9.8	1.60	2.29	3.92
All data	52,704	52,626	99.85	3.3	0.4	12.9	1.66	2.08	3.74
Mean of monthly means				3.3					

4.2 Wind Speed Monthly Means

The monthly means, Figure 4, are often constructed and used to determine the seasonal behavior of the wind during the year and from the mean figures explain the overall strength of the winds during different periods of the year. Figure 4 shows the monthly behavior at the site for the 20m and 34m measurement.

The monthly mean wind speeds are low in terms of their wind energy content with April, May and November showing the highest potential. The highest monthly mean at 34m was observed during April 2011 with 5.02m/s. At 20m the highest mean wind speed was observed in April 2011 with 4.3m/s. We see a decrease from the 34m height to the 20m height measurement of almost 20%. The mean of monthly means is 4.1 m/s at 34m height and 3.3 m/s at 20m. There is a also a seasonal pattern observed from fall/winter/spring to the summer where the site shows higher mean wind speeds in the colder/cooler months than in the warmer/hotter months.

Figure 4. Monthly Mean wind speeds at 20m and 34m

4.3 Wind Speed Diurnal Means

The wind diurnal pattern is an important characteristic as well. It helps illuminate the mechanism responsible for the wind values, especially if there is a thermal effect in the area. In general for the site under investigation, the variation is very small at the 34m and even smaller at the 20m measurement. At the 34m height wind speeds seem to behave almost constant throughout the day with values between 4.4 and 3.9m/s but at the 20m measurement the pattern shows a wider range from 2.9 to 3.9m/s with typical lower wind speeds during night hours and higher wind speeds

during daylight hours. The magnitude builds up slowly starting at 8:00 AM until 13:00 hours and then drops down again for the night hours. Nevertheless, as a result of the low wind speeds in general, the diurnal pattern would play no significant role in meeting high or low energy peak periods. Figure 5 shows the average diurnal wind pattern in the site for the 34m and 20m measurements.

Figure 5. Mean wind speed according to hour of day

4.4 Measured Temperatures

The variability in temperature throughout the year results in a change in air density which has an effect in the power production of a wind turbine. The year under investigation had a very hot summer and an uncommon mild winter, which is depicted in Figure 6 where the temperature and the calculated density are plotted. Notice the inverse relationship of the temperature and density; density increases as temperature decreases. The average calculated density is 1.164 kg/m³.

Figure 6. Monthly Temperature means and Air density

4.5 Frequency Distribution

The frequency distribution is an indication of the wind resource potential of a site. It is a description of how the wind speed at a site is distributed over various wind speed categories. An ideal site would have winds that blow at a high rate for long periods. Figure 7 and 8 show a graphical representation of the annual wind distributions and Table 3 and 4 contain the tabulated values for the 20m and 34m measurement respectively. This distribution will determine in large part how much energy production is expected with a given turbine. These plots show the wind speeds in the horizontal axis and the frequency of occurrence in the vertical axis. The frequency is shown in number of hours per year with a total of 8760 hours per year. Each bar represents a binned wind speed with a lower and upper value; the value shown in the horizontal axis is the average of each bin.

Both distributions show similar shape but vary in the magnitude of the average values. For the wind speeds measured at 34m we see a skewed distribution showing a lower range of wind speeds with high occurrence, a peak centered around 3.75 m/s and a short tail at the upper end. This indicates that winds in the lower wind speed categories are frequent and in this case, the observed wind speeds **are below 5.0 m/s (11.2 miles/hr) about 70% of the time during the year.**

In general, the 30% frequency of the winds at the upper end of the range (above 5.0m/s) where power could potentially be produced suggests that the area may not prove feasible in terms of the wind resource. The upper end has a highest observable mean wind speed value of 13.75 m/s (31 miles/hr).

Figure 7. Annual Wind Speed Distribution for the 34m anemometer Mean= 4.13 m/s
Weibull Best-fit $k=2.26$ $c=4.65$ m/s

Table 3. Wind Speed Distribution values for the 34m measurement

Lower Bin m/s	Upper Bin m/s	Bin Avg.	% Frequency of occurrence	Hour Frequency	Cumulative Hours	Cumulative Frequency
0.0	0.5	0.25	1.602	140	140	1.60%
0.5	1.0	0.75	2.605	228	369	4.21%
1.0	1.5	1.25	3.029	265	634	7.24%
1.5	2.0	1.75	4.427	388	1022	11.66%
2.0	2.5	2.25	6.909	605	1627	18.57%
2.5	3.0	2.75	8.707	763	2390	27.28%
3.0	3.5	3.25	10.694	937	3326	37.97%
3.5	4.0	3.75	11.308	991	4317	49.28%
4.0	4.5	4.25	10.609	929	5246	59.89%
4.5	5.0	4.75	9.623	843	6089	69.51%
5.0	5.5	5.25	7.958	697	6786	77.47%
5.5	6.0	5.75	6.314	553	7340	83.79%
6.0	6.5	6.25	4.758	417	7756	88.54%
6.5	7.0	6.75	3.588	314	8071	92.13%
7.0	7.5	7.25	2.415	212	8282	94.55%
7.5	8.0	7.75	1.862	163	8445	96.41%
8.0	8.5	8.25	1.269	111	8557	97.68%
8.5	9.0	8.75	0.838	73	8630	98.52%
9.0	9.5	9.25	0.618	54	8684	99.13%
9.5	10.0	9.75	0.374	33	8717	99.51%
10.0	10.5	10.25	0.215	19	8736	99.72%
10.5	11.0	10.75	0.12	11	8746	99.84%
11.0	11.5	11.25	0.051	4	8751	99.89%
11.5	12.0	11.75	0.053	5	8755	99.95%
12.0	12.5	12.25	0.025	2	8757	99.97%
12.5	13.0	12.75	0.015	1	8759	99.99%
13.0	13.5	13.25	0.006	1	8759	99.99%
13.5	14.0	13.75	0.008	1	8760	100.00%

A similar skewed distribution is observed for the wind speeds measured at 20m but with lower overall values. This distribution shows a lower range of wind speeds with high hour occurrence, a peak centered around 2.75 m/s and again a short trailing tail at the upper end. Again this is an indication that winds in the higher wind speed categories are somewhat frequent but not enough for power production. In this case, the observed wind speeds **are above 5.0 m/s (11.2 miles/hr) about 15% of the time.**

The upper end shows a highest observable hourly wind speed value of 10.75m/s (24.0 miles/hr). This frequency of winds at the upper end of the range again plays a significant role since it is at higher wind speeds where most of the power could potentially be produced. Table 3 and 4 show the frequency distributions tabulated by hours and percentage for the 34m and 20m measurement respectively. The cells highlighted in red indicate the 5m/s bin.

Figure 8. Annual Wind Speed Distribution for the 20m anemometer Mean= 3.32 m/s Weibull Best-fit $k=2.08$ $c=3.74$ m/s

Table 4. Wind Speed Distribution values for the 20m measurement

Lower Bin m/s	Upper Bin m/s	Bin Avg.	Frequency of occurrence	Hour Frequency	Cumulative hours	Cumulative Frequency
0.0	0.5	0.25	2.84	249	249	2.84%
0.5	1.0	0.75	4.33	379	628	7.16%
1.0	1.5	1.25	5.19	454	1082	12.35%
1.5	2.0	1.75	7.80	683	1765	20.15%
2.0	2.5	2.25	10.91	956	2721	31.06%
2.5	3.0	2.75	13.00	1139	3860	44.06%
3.0	3.5	3.25	12.73	1115	4975	56.79%
3.5	4.0	3.75	11.55	1012	5986	68.34%
4.0	4.5	4.25	9.21	806	6793	77.54%
4.5	5.0	4.75	7.16	627	7420	84.70%
5.0	5.5	5.25	4.87	427	7847	89.57%
5.5	6.0	5.75	3.60	316	8162	93.18%
6.0	6.5	6.25	2.40	210	8373	95.58%
6.5	7.0	6.75	1.63	143	8515	97.21%
7.0	7.5	7.25	1.00	88	8603	98.21%
7.5	8.0	7.75	0.75	65	8668	98.95%
8.0	8.5	8.25	0.46	41	8709	99.42%
8.5	9.0	8.75	0.24	21	8730	99.66%
9.0	9.5	9.25	0.15	13	8743	99.81%
9.5	10.0	9.75	0.07	6	8749	99.88%
10.0	10.5	10.25	0.06	5	8754	99.93%
10.5	11.0	10.75	0.04	4	8758	99.97%
11.0	11.5	11.25	0.02	1	8759	99.99%
11.5	12.0	11.75	0.01	1	8760	100.00%

4.6 Wind Rose

How the wind varies in direction is also important in order to explain any natural flow as a direct consequence of the terrain or obstacles. Also in order to prevent the emergence of any obstacles such as high vegetation or even erecting any kind of structure that would be in the way of a predominant wind direction.

4.6.1 Frequency by Direction

The direction data has been plotted using radar and polar charts below. In this case 5% of the winds are of magnitude equal or less than 1 m/s and are considered “calms”. Figure 9 shows the frequency of the compass direction the wind speed at 34m has and Figure 10 shows this same information in a bar graph. The wind at the site is coming mostly from the SSE direction and to a lesser degree from the NW direction. The rest of the direction sectors are even less frequent. The annual predominant wind direction is also depicted in the aerial view of the site in Figure 1a.

Figure 9. Wind Direction Frequency

Figure 10. Wind Direction Frequency (bar graph)

4.6.2 Mean wind speed value direction

The *mean value by direction* graph shows a wind rose with the mean (average) values of a particular data column wind direction. The graphs below show the average wind speed at 34m and 20m measurement versus wind direction. Figure 11 indicates that the winds from the south and west tend to be the strongest, with an average wind speed of over 4.8 m/s. The easterly winds tend to be a little lighter averaging to 3.7m/s. Figure 12 shows the same behavior but with lesser magnitudes. The weakest winds come from the east and north east directions in general.

Figure 11. Mean wind speeds at 34m by direction

Figure 12. Mean wind speeds at 20m by direction

In order to better visualize the winds at the site during the different seasons, monthly polar plots are shown in Figure 13 and Figure 14. It is observed that in general the winds come from every direction, but the relatively stronger winds come from the south and western sectors. January, April, May and November 2011 for example, had winds slightly over 6.5m/s coming from the south and west direction.

Figure 13. Monthly plots showing mean wind speed values by direction for the 34m measurements

Figure 14. Monthly plots showing mean wind speed values by direction for the 20m measurements

4.7 Wind Profile and Wind Shear at the Site

The vertical wind speed profile is depicted in Figure 15. The average wind speeds measured at 20m and 34m along with the power law were used to calculate it, extrapolating up to a height of 100m. This formulation implies that there is a single parameter alpha (Power law fit $\alpha = 0.343$) describing the wind profile. The observations taken during this measurement campaign also show that the wind shear parameter alpha can take a range of values depending on the season and direction sector as depicted in Figure 16 and 17 respectively. The power density extrapolated to 50m showed a value of 108 W/m^2 , which is classified in Class 1 (poor) wind resources.

Figure 15. Vertical Wind Profile at the Site

Figure 16. Seasonal variation of wind shear at the site

Figure 17. Directional variation of wind shear at the site

4.8 Turbulence Intensity at the Site

Turbulence is an important characteristic in the wind as it determines the fatigue spectrum the turbine's rotor components are subject to during operation. It is quantified as turbulence intensity (TI) which is a dimensionless value defined as the standard deviation (STD) of the wind speed divided by the mean wind speed. The turbulence can vary by direction and is driven by thermal or mechanical factors, the latter being caused by wind blowing over the surface topography, vegetation and foliage and the former one being caused by convective instability of the atmosphere. Figure 18 shows the monthly mean values of TI and Figure 19 shows the mean values from all direction sectors from the 34m measurement. One can observe there to be greater convection during the summer months and this would lead to greater turbulence and less wind shear. Also during the warm season the vegetation is more foliated and this increases the surface roughness which would increase the turbulence intensity as well.

Figure 18. Monthly Mean values of Turbulence Intensity (TI)

Furthermore the 3rd edition of IEC 61400-1 defines four turbulence categories based on the representative TI which is the value below which 90% of the turbulence values fall (90th percentile). Since TI behaves with a normal distribution, the representative TI would be the mean value of TI plus 1.28 standard deviations. For the site under investigation the mean and the

representative TI at 15m/s could not be calculated as no wind speeds were observed with that magnitude, nevertheless Table 5 presents the TI values at the observed wind speeds.

Figure 19. Mean values of TI by Direction Sector

Table 5. Turbulence values with binned wind speed

Bin	Bin Midpoint (m/s)	Lower (m/s)	Upper (m/s)	Records in Bin	Mean TI	STD of TI	Representative TI	Peak TI
1	1	0.5	1.5	2,965	0.53	0.16	0.73	1.29
2	2	1.5	2.5	5,966	0.34	0.14	0.52	1.14
3	3	2.5	3.5	10,210	0.26	0.10	0.39	0.76
4	4	3.5	4.5	11,534	0.24	0.08	0.34	0.74
5	5	4.5	5.5	9,252	0.23	0.07	0.32	0.98
6	6	5.5	6.5	5,827	0.23	0.06	0.31	0.80
7	7	6.5	7.5	3,159	0.24	0.05	0.31	0.52
8	8	7.5	8.5	1,648	0.24	0.04	0.29	0.46
9	9	8.5	9.5	766	0.24	0.04	0.29	0.46
10	10	9.5	10.5	310	0.23	0.04	0.28	0.53
11	11	10.5	11.5	90	0.23	0.05	0.30	0.53
12	12	11.5	12.5	41	0.21	0.06	0.29	0.44
13	13	12.5	13.5	11	0.21	0.06	0.29	0.36
14	14	13.5	14.5	4	0.16	0.07	0.25	0.24
15	15	14.5	15.5	0				

5.0 Site Power Characteristics

In order to evaluate the wind power potential at this site the air density was calculated and power density quantities were derived thereafter. Calculations were done at heights of 20 and 34m and an average WPD was extrapolated to 50m (164 ft.). The values of power density (W/m^2) are plotted in the bar graph of Figure 20. The average annual power density for the site is 69 W/m^2 and 40 W/m^2 for 34 and 20 heights respectively (81% increase). Given a scale of 1 to 7, both are identified as Class 1 wind resource. Class 1 wind resources have wind power densities up to 200 W/m^2 meaning poor wind resources. The extrapolated wind power density at 50m was 108 W/m^2 which is considered still wind power class 1.

Figures 21a, 21b and 22a and 22b depict power density in relation to compass direction, in other words: where are the energetic winds coming from. We can observe that energy can be harnessed mostly from the S and W sectors. The rest of the sectors offer very little wind power. This corresponds to the fact that stronger winds come from those sectors as discussed in the previous sections.

Figure 20. Monthly wind power density @ 34m and 20m

Figure 21a. Energy at 34m vs Direction

Figure 21b. Energy at 20m vs Direction

Figure 22a. Energy at 34m vs Direction (Bar graph)

Figure 22b. Energy at 20m vs Direction (Bar graph)

6.0 Energy Calculation

This report is intended to provide assistance to Mr. John Spencer of Waldron, Arkansas by determining the site specific potential for harvesting wind energy. The information regarding the wind power characteristics at the site is presented with consideration of eight small wind turbines listed below. Their power curves which specify how much power the turbine produces at a given wind speed are depicted in Figures 23 and 24. These turbines are recognized in the industry with a history of successful applications and were selected based on turbine ratings and available wind resource. More information about these machines is found in their corresponding websites (www.windenergy.com, www.windspot.es, www.bergey.com, www.provenenergy.co.uk and www.endurancewindpower.com).

Lower range power turbines	Upper range power turbines
Whisper 200 from Southwest Wind Power	Bergey Excel-S 10kW from Bergey
Skystream 3.7 from Southwest Wind Power	Proven 15 kW from Proven Energy
Windspot 3.5 from Sonkyo Energy	35kW Endurance from Endurance Wind Power
7.5kW Endurance from Endurance Wind Power	55kW Endurance from Endurance Wind Power

Table 6 presents a summary containing the expected annual energy output and capacity factors (CF) for all eight turbines using the 20m and 30m wind distributions tabulated in section 4.5. The figures are based on 2.5% losses and conditions already detailed in the previous sections of this document.

From the results gathered, the 15kW turbine at 30m shows the highest capacity factor of 21.2% with an overall annual energy production of 27,818kWh. The capacity factor being the ratio of the amount of energy produced to the amount of energy that could be produced if a turbine ran at its rated capacity all the time. Usually a capacity factor between 20% and 30% is sought for a wind project to make economic sense. The rest of the turbines show a very small percentage of time producing at rated power which is equivalent to small CF's.

A summary of the estimated monthly energy productions and monthly performance values of all individual turbines is also presented in Tables 7a through 7h.

Figure 23. Power Curves for the Whisper 200, Skystream 2.4, Windspot 3.5 and Endurance 5kW

Figure 24. Power Curves for the Bergey 10kW, Proven 15kW and Endurance 35kW & 55kW

Table 6. Annual Energy Production for eight small wind turbines with a 20m &30m tower

Turbine Model	Hub Height (m/s)	Hub Height WS (m/s)	% Time At Zero output	% Time At Rated Output	Mean Net Power output (kW)	Mean Net Energy Output (kWh/yr.)	Net Capacity factor (%)
Whisper-200 1000 W	20	3.32	28.5	0.0	0.1	689	7.9
Skystream 3.7 2400 W	20	3.32	44.1	0.0	0.1	573	2.7
Windspot 3.5 3500 W	20	3.32	0.00	0.00	0.2	1980	6.5
Bergey Excel R 7.5kW	20	3.32	46.88	.02	0.4	3086	4.7
Bergey Excel-S 10kW	30	3.94	14.60	0.02	0.7	5957	6.8
Proven 15 kW	30	3.94	13.97	0.42	3.2	27,818	21.2
Endurance G3120 35 kW	30	3.94	17.05	0.01	5.0	43,730	14.3
Endurance E3120 55 kW	30	3.94	31.72	0.04	6.2	54,533	11.3

Table 7a. Energy output of the 200 whisper under the given wind regime at 20m hub height

Whisper 1000 W	20m Hub Height Wind Speed(m/s)	Time at zero Output (%)	Time at rated Output (%)	Mean Net Power Output (kW)	Mean Net energy output (kWh)	Net Capacity Factor (%)
Jan	3.74	23.97	0.00	0.1	92	12.4
Feb	3.23	30.62	0.00	0.1	50	7.5
Mar	3.48	24.42	0.00	0.1	65	8.8
Apr	4.25	17.18	0.00	0.2	123	17.1
May	3.94	17.38	0.00	0.1	92	12.4
Jun	3.11	33.01	0.00	0.1	40	5.6
Jul	2.62	38.98	0.00	0.0	11	1.5
Aug	2.89	31.83	0.00	0.0	24	3.2
Sep	2.69	40.25	0.00	0.0	17	2.4
Oct	3.06	33.18	0.02	0.1	43	5.8
Nov	3.86	19.79	0.00	0.1	90	12.5
Dec	3.02	31.79	0.00	0.1	40	5.4
Overall	3.32	28.53	0.00	0.1	689	7.9

Table 7b. Energy output of the 2.4kW Skystream under the given wind regime at 20m hub height

Skystream 3.7 2.4kW	20m Hub Height Wind Speed (m/s)	Time At Zero Output %	Time At rated Power %	Mean Net Power Output (kW)	Mean Net energy output (kWh)	Net Capacity Factor %
Jan	3.74	35.44	0.00	0.1	94	5.2
Feb	3.23	47.22	0.00	0.1	40	2.5
Mar	3.48	39.96	0.00	0.1	55	3.1
Apr	4.25	27.25	0.00	0.2	136	7.9
May	3.94	27.93	0.00	0.1	90	5.0
Jun	3.11	49.31	0.00	0.0	26	1.5
Jul	2.62	61.69	0.00	-0.0	-10	-0.5
Aug	2.89	51.59	0.00	0.0	7	0.4
Sep	2.69	57.64	0.00	-0.0	-3	-0.2
Oct	3.06	51.75	0.00	0.0	28	1.6
Nov	3.86	31.18	0.00	0.1	88	5.1
Dec	3.02	47.67	0.00	0.0	22	1.2
Overall	3.32	44.06	0.00	0.1	573	2.7

Table 7c. Energy output of the 3.5 kW WindSpot under the given wind regime at 20m hub height

WindSpot 3.5 kW	20m Hub Height Wind Speed (m/s)	Time At Zero Output %	Time At rated Power %	Mean Net Power Output (kW)	Mean Net energy output (kWh)	Net Capacity Factor %
Jan	3.74	0.00	0.00	0.3	230	8.8
Feb	3.23	0.00	0.00	0.2	149	6.4
Mar	3.48	0.00	0.00	0.2	174	6.7
Apr	4.25	0.00	0.00	0.4	282	11.2
May	3.94	0.00	0.00	0.3	216	8.3
Jun	3.11	0.00	0.00	0.2	134	5.3
Jul	2.62	0.00	0.00	0.1	92	3.5
Aug	2.89	0.00	0.00	0.1	110	4.2
Sep	2.69	0.00	0.00	0.1	100	4.0
Oct	3.06	0.00	0.02	0.2	143	5.5
Nov	3.86	0.00	0.00	0.3	215	8.5
Dec	3.02	0.00	0.00	0.2	137	5.2
Overall	3.32	0.00	0.00	0.2	1,980	6.5

Table 7d. Energy output of the 7.5kW Bergey Excel-R under the given wind regime at 20m hub height

Bergey 7.5kW	20m Hub Height Wind Speed(m/s)	Time at zero Output (%)	Time at rated Output (%)	Mean Net Power Output (kW)	Mean Net energy output (kWh)	Net Capacity Factor (%)
Jan	3.74	37.25	0.09	0.6	431	7.7
Feb	3.23	49.37	0.02	0.3	232	4.6
Mar	3.48	42.20	0.00	0.4	277	5.0
Apr	4.25	29.07	0.02	0.8	572	10.6
May	3.94	29.77	0.00	0.5	396	7.1
Jun	3.11	52.87	0.00	0.2	179	3.3
Jul	2.62	67.20	0.00	0.1	48	0.9
Aug	2.89	57.10	0.00	0.1	95	1.7
Sep	2.69	60.72	0.00	0.1	87	1.6
Oct	3.06	54.14	0.07	0.3	197	3.5
Nov	3.86	32.75	0.00	0.5	394	7.3
Dec	3.02	49.89	0.02	0.2	179	3.2
Overall	3.32	46.88	0.02	0.4	3,086	4.7

Table 7e. Energy output of the 10kW Bergey Excel-S under the given wind regime at 30m hub height

Bergey 10 kW	30m Hub Height Wind Speed(m/s)	Time at zero Output (%)	Time at rated Output (%)	Mean Net Power Output (kW)	Mean Net energy output (kWh)	Net Capacity Factor (%)
Jan	4.27	15.34	0.09	0.9	698	9.4
Feb	3.71	18.30	0.02	0.6	415	6.2
Mar	4.14	10.06	0.00	0.7	541	7.3
Apr	4.98	9.21	0.00	1.3	938	13.0
May	4.68	8.65	0.00	1.0	738	9.9
Jun	3.80	14.47	0.00	0.6	412	5.7
Jul	3.19	16.55	0.00	0.3	194	2.6
Aug	3.46	14.87	0.00	0.4	277	3.7
Sep	3.22	21.41	0.00	0.3	240	3.3
Oct	3.68	17.61	0.04	0.5	409	5.5
Nov	4.56	9.86	0.00	1.0	717	10.0
Dec	3.55	19.04	0.02	0.5	379	5.1
Overall	3.94	14.60	0.02	0.7	5,957	6.8

Table 7f. Energy output of the Proven 15kW under the given wind regime at 30m hub height

Proven 15kW	30m Hub Height Wind Speed (m/s)	Time at zero output (%)	Time at rated output (%)	Mean Net power output(kW)	Mean Net energy output (kWh)	Net capacity factor (%)
Jan	4.27	15.05	1.68	4.0	3,001	26.9
Feb	3.71	17.91	0.59	2.9	1,964	19.5
Mar	4.14	9.66	0.09	3.5	2,572	23.0
Apr	4.98	8.84	1.71	5.2	3,751	34.7
May	4.68	8.33	0.13	4.5	3,340	29.9
Jun	3.80	13.40	0.02	2.8	2,016	18.7
Jul	3.19	15.17	0.00	1.6	1,180	10.6
Aug	3.46	13.98	0.09	2.1	1,528	13.7
Sep	3.22	20.23	0.00	1.9	1,344	12.4
Oct	3.68	16.85	0.09	2.7	2,013	18.0
Nov	4.56	9.63	0.60	4.4	3,190	29.5
Dec	3.55	18.75	0.04	2.6	1,921	17.2
Overall	3.94	13.97	0.42	3.2	27,818	21.2

Table 7g. Energy output of the Endurance G3120 35kW under the given wind regime at 30m hub ht.

Endurance G3120 35 kW	30m Hub Height Wind Speed (m/s)	Time at zero output (%)	Time at rated output (%)	Mean Net power output(kW)	Mean Net energy output (kWh)	Net capacity factor (%)
Jan	4.27	29.46	0.16	6.9	5,135	19.7
Feb	3.71	37.26	0.00	4.5	3,000	12.8
Mar	4.14	25.74	0.00	5.5	4,060	15.6
Apr	4.98	19.49	0.00	9.6	6,915	27.4
May	4.68	18.66	0.00	7.7	5,740	22.0
Jun	3.80	34.00	0.00	4.2	3,057	12.1
Jul	3.19	41.67	0.00	1.6	1,168	4.5
Aug	3.46	35.91	0.00	2.5	1,847	7.1
Sep	3.22	44.14	0.00	2.3	1,626	6.5
Oct	3.68	36.00	0.00	4.0	2,982	11.5
Nov	4.56	21.67	0.00	7.6	5,490	21.8
Dec	3.55	36.87	0.00	3.7	2,717	10.4
Overall	3.94	31.72	0.01	5.0	43,730	14.3

Table 7h. Energy output of the Endurance E3120 55kW under the given wind regime at 30m hub ht.

Endurance E3120 55 kW	30m Hub Height Wind Speed (m/s)	Time at zero output (%)	Time at rated output (%)	Mean Net power output(kW)	Mean Net energy output (kWh)	Net capacity factor (%)
Jan	4.27	29.46	0.40	8.7	6,456	15.8
Feb	3.71	37.26	0.02	5.6	3,751	10.1
Mar	4.14	25.74	0.00	6.7	5,017	12.3
Apr	4.98	19.49	0.09	12.2	8,808	22.2
May	4.68	18.66	0.00	9.4	7,014	17.1
Jun	3.80	34.00	0.00	5.2	3,772	9.5
Jul	3.19	41.67	0.00	2.0	1,509	3.7
Aug	3.46	35.91	0.00	3.1	2,333	5.7
Sep	3.22	44.14	0.00	2.8	2,020	5.1
Oct	3.68	36.00	0.00	5.0	3,684	9.0
Nov	4.56	21.67	0.00	9.4	6,802	17.2
Dec	3.55	36.87	0.00	4.5	3,373	8.2
Overall	3.94	31.72	0.04	6.2	54,533	11.3

7.0 Summary and Discussion

1. The observed average annual wind speed at 34m height was 4.13m/s and 3.32m/s at the 20m measurement height. These results represent the period of measurement from 04/01/2011-03/31/2012. In order to obtain long term representative values, a correlation and adjustment are needed using a long term wind data.
2. The results indicate poor power density at the heights studied (20m and 34m). An estimation of the wind speed at 50m also resulted in Class 1 wind resource with a WPD=108 W/m².
3. The strongest winds come from the S directions and to a lesser degree from the west. The predominant wind direction sectors are mainly free of any obstruction giving the data more reliability.
4. The performance estimation of eight small turbines showed low capacity factors; between 22% (15kW Proven) and 3% (2.4kW Skystream), which indicate the wind resource at the site is not enough to make good utilization of the generator's capacity. Even though some energy production figures (mostly in the upper range capacity turbines) show sufficient energy production to serve a grid connection or stand-alone application, the cost-benefit would not make economic sense in these upper range turbine sizes (10kW-55kW).
5. The site does have the wind resources at the heights measured which in combination with the appropriate small wind turbine technology would have the potential to serve a stand-alone application. This application would require a battery bank arrangement and could meet different demands depending on the energy usage habits.

Wind Resource Assessment Report Dewitt, AR

ARKANSAS ANEMOMETER LOAN PROGRAM

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Abstract and Summary Information

The measurement campaign had one year duration from 05/01/2011 to 04/27/2012 and was taken at 20m and 34m with NRG instrumentation. The data was analyzed weekly to check inconsistencies and validity and processed using Excel, Flexpro and Windographer standard Edition Version 2.04. The site analyzed is located in the De Witt, Arkansas in Arkansas County. The site is completely unobstructed to the south and west with 1-story building in the immediate north. It has seasonally directional winds, of which the most energetic come from the southern direction. It has low turbulence values and small wind shear that varies by season as well.

<i>34m Meteorological Tower Data Synopsis</i>	(based on 1-yr measurements)
Data start date	May 01, 2011
Data finish data	April 27, 2012
Data recovery rate	100.0%
Site Coordinates	34.2724°N 91.3482°W
Average wind speed (20 meter)	4.1 m/s (Measured)
Average wind speed (34 meter)	4.8 m/s (Measured)
Average wind speed (50 meter)	5.4 m/s (Predicted)
Average wind speed (100 meter)	6.58 m/s (predicted)
C and K Weibull Parameters at 20m	c= 4.62m/s, k= 1.87
C and K Weibull Parameters at 34m	c=5.35m/s, k= 2.03
Mean wind power density (20 meter)	86 W/m ²
Mean wind power density (34 meter)	125 W/m ²
Mean wind power density (50 meter)	159 W/m ² - Class 1 (predicted)
Average Power law exponent Alpha	0.295
Mean Turbulence Intensity (34 meter) - IEC 3ed.	0.141 Class C
Temp (Max, Avg, Min)	42.30, 18.41, -4.70 C°
Air density (Max, Avg, Min)	1.30, 1.11, 1.20 kg/m ³

1.0 Introduction

The Arkansas Anemometer Loan Program was established in the summer of 2009 with the objective to assist landowners in the state evaluate the wind energy potential of their property. The program is funded by DOE and the Arkansas Energy Office and is administered by the Renewable Energy Department at John Brown University. This report represents one of four final wind resource assessment reports produced as a result of this grant.

The sites chosen were based on different criteria such as accessibility, obstacle free, adequate cell phone coverage for remote data transfer and a clear statement of objectives from the landowner for the use of wind power. These sites are located in Waldron, Harrison, DeWitt, and Booneville. This report documents the findings at the DeWitt Site.

The wind measurement system is installed for a period of one year to collect wind velocity and temperature values. The data is logged in 10 minute average values in a wind data acquisition system and sent via an internet modem to the renewable energy department at John Brown University for analysis. The data is monitored on a weekly basis and checked for sensor operation. During the measurement campaign quarterly reports are generated and upon completing the one-year period of data collection, the tower is removed from the site and a summary report of the wind resource is given to the tower borrower.

This report contains a collection of figures and values the analyst has generated using established analytical techniques that accurately reflect the wind resource. This report represents the final portion of the project and is designed to give the landowner the information necessary to make an informed choice about the role wind energy might play in their property.

This document is divided into several sections:

- This introduction which explains the origin, objective and scope of the program;
- Section 2 which describes the site terrain characteristics and topography;
- Section 3 which explains the measurement set-up and instrumentation used in the study;
- Section 4 which explains the wind characteristics and main calculated parameters;
- Section 5 which describes the wind power density characteristics;
- Section 6 which describes the energy production from the wind regime at the site in the context of eight small wind turbines and
- Section 7 which contains a short summary and discussion of the main findings.

2.0 Site Description

Site name:	Phillips Community College – Terry Turner
Coordinates:	34.2724°N 91.3482°W
Elevation:	197ft. (61m)
Address:	1210 Rice Belt Avenue, De Witt, AR 72042
County:	Arkansas
Type of Sensors & Logger:	<ul style="list-style-type: none">• NRG Maximum #40 wind speed• NRG 200P Series wind vane• NRG 110S Temperature sensor• Symphonie Wind Data Logger
Type of Data:	10 min. avg/max/min/St.dev. wind speed 10 min. avg/max/min/St.dev. wind direction 10 min. avg/max/min/St dev .temperature data
Installation Date:	04/24/2011
Beginning of data collection	05/01/2011 00:00
End of data collection:	04/27/2012 23:50

2.1. Site Location

The location of the measurement tower is in Arkansas County on the south border of the city of De Witt, Arkansas. The site is mostly flat with an elevation of 61m asl. The areas south and west of the measurement are unobstructed and used for rice crops. The north and east sectors have 1-story buildings located almost 200ft and 500ft respectively. A ground level panoramic view, aerial view and a topo map of the site are shown in Figure 1a, 1b and 1c respectively.

Figure 1a. Panoramic view of site

Figure 1b. Aerial view of site (From Google Earth)

Figure 1c. Topographic map site 34.2724°N 91.3482°W Elevation 197 ft (60 m)

3.0 Measurement Set-up

3.1. General

The measurement set-up consists of a meteorological mast with wind speed, wind direction and temperature sensors and a data logger equipped with a wireless communications module. Wind speeds are measured at 34m and 20m and temperature is measured at ground level. The measurement values are recorded by the data logger and sent via internet to the Renewable Energy Department at John Brown University.

3.1.1 Meteorological Mast

Figure 2 depicts the arrangement of the mast and the instrumentation. The tower used was a 34m (110 ft) guy-supported tower from NRG. It is anchored at four different points with screw-in type anchors as well as drive-in type anchors where needed. The tower uses a gin-pole and helper gin-pole arrangement secured to an 8000lb 12V DC winch to be raised. The tower required no foundation work, only a leveled and flat area for the base which is secured with 36” steel pegs into the ground.

Figure 2. Sketch of meteorological mast and sensor arrangement

3.1.2 Wind Speed

The wind speed was measured at heights of 34m and 20m. For comparative and redundancy reasons two anemometers of the type NRG 40C were installed at the 34m height. The boom of one anemometer is located west and the second anemometer is oriented east. A third wind speed sensor was installed at 20 meters directed west. All instrumentation calibration values are listed in Table 1. The wind speed is recorded with 10 min. average, minimum, maximum and standard deviation values. Figure 3 shows the anemometer tower at the 34m and 20m level.

Figure 3. Met tower and sensors installed at the 34m and 20 m level

3.1.3 Wind Direction

A potentiometric NRG wind vane type 200P was installed at 34m height with its boom oriented north. The wind directions signals are recorded with 10 minute average, minimum, maximum and standard deviation values.

3.1.4 Data Logger

The data logger used was an NRG symphonie in conjunction with a GSM IPack communications module for remote data transfer. The data logger was powered by a 12-volt dc battery charged by a solar module attached to the front of the cabinet box used to protect it from the elements. It recorded the measured data with a sample frequency of 1 Hz. and the values were averaged directly in the logger to 10-minute mean values as well as 10-min extreme and 10-min standard deviation. The sensors for the wind speed give impulses that are counted by the logger; the temperature signal and wind direction are processed directly by the analogue/digital converters in the data logger and the measured data was transferred daily to John Brown University via electronic means. The table below contains the specifications of the logging equipment.

Sensor	Data Acquisition System		
Device	Data Logger	Sampling & Averaging Interval	1 Hz/ 10min
Type	NRG Symphonie – Internet enabled micropower wind energy data logger	Channels	15 (10 counter; 5 Analog)
Serial #:	309020344	I-Pack Option	Serial # 38605722 GSMA - Serial connection direct to IPack

3.1.5 Device Description

The measuring equipment was installed according to NRG specifications where applicable. All sensors were factory calibrated and checked for correct operation in lab before deployment. Table 1 lists all sensors and devices that were utilized during the measurement campaign.

Table 1. List of sensors used in the measurement campaign

Sensor	Wind Speed		
Device	Cup Anemometer	Measurement Range	1 to 96 m/s
Type	#40C	Resolution	.05 m/s
Serial #	63717	Accuracy	0.1 m/s
Calibration/ Transfer Function	$m/s = (Hz \times 0.756) + 0.42$	Height/Alignment	34 m West (270°)
		Distance Constant	3m
		Signals	Ave, max, min, St. Dev.
		DL channel	1
Sensor	Wind Speed		
Device	Cup Anemometer	Measurement Range	1 to 96 m/s
Type	40C	Resolution	.05 m/s
Serial #	63718	Accuracy	0.1 m/s
Calibration	$m/s = (Hz \times 0.757) + 0.46$	Height/Alignment	34 m East (90 °)
		Distance Constant	3m
		Signals	Ave, max, min, St. Dev.
		DL channel	2

Sensor	Wind Speed		
Device	Cup Anemometer	Measurement Range	1 to 96 m/s
Type	40C	Resolution	.05 m/s
Serial #	66367	Accuracy	0.1 m/s
Calibration	$m/s = (Hz \times 0.757) + 0.37$	Height/Alignment	20 m / (120°)
		Distance Constant	3m
		Signals	Ave, max, min, St. Dev.
		DL channel	3
Sensor	Wind Direction		
Device	Wind Vane	Measurement Range	0-360 degrees continuous
Type	200P 2001	Resolution	1 degree
Serial #	N/A	Accuracy	1%
Calibration	Slope: 0.351 Offset: 0 Analog DC voltage from conductive plastic potentiometer, 10K ohms	Height/Alignment	33 m / North (0°)
		Signals	Ave, max, min, St. dev.
		DL channel	7
Sensor	Temperature		
Device	NRG 110S	Measurement Range	-40 °C to 52.5 °C (-40 °F to 126.5 °F)
		Accuracy	+/- 1.1 °C
Serial #	3075		
Calibration/Transfer Function	$Temp = 0.136 - 86.38$	Height	1 m
		Signals	Ave, max, min, St. Dev.
		DL channel	9

4.0 Wind Characteristics

In the following sections, several characteristics of the wind at the site are graphically shown and discussed. The goals are to evaluate the characteristics that can help explain the physical processes at work at the site and to highlight the properties that are important in assessing the wind energy potential. These evaluations are done using raw data with 10 minute values of the average and extreme values as well as the standard deviation. Hourly, monthly and annual means of wind speed were constructed using the 10 minute values.

The time span analyzed was from May 1, 2011 to April 27, 2012. The data files were collected and uploaded into a Windographer standard Edition Version 2.04 software application. Summary tables and graphs were extracted into this report to show the main characteristics of the wind regime at the site.

4.1 Data Recovery

The amount of data recovered during an observation period is important to characterize the wind profile and should be examined to determine the confidence of other characteristics. The data recovery was 100.00% with no periods of missing data. Table 2a and 2b shows these results as

well as the average, extreme values (max and min), St. Dev. and the Weibull k and c parameters for wind measurement at the 20m and 34m heights.

Table 2a. Data recovery rates and 34m means for every month during the duration of measurement

Month /Year	Possible Records	Valid Possible Records	Recovery Rate (%)	Mean (m/s)	Min (m/s)	Max (m/s)	Std.Dev. (m/s)	Weibull K	Weibul c (m/s)
May/11	1,440	1,440	100.00	7.32	1.3	19.7	2.98	2.61	8.25
Jun/11	4,464	4,464	100.00	5.86	0.5	15.3	2.40	2.57	6.58
July/11	4,320	4,320	100.00	4.67	0.5	15.9	2.31	2.11	5.27
Aug/11	4,464	4,464	100.00	3.28	0.5	18.2	1.43	2.38	3.69
Sep/11	4,464	4,464	100.00	3.58	0.5	14.4	1.66	2.23	4.02
Oct/11	4,320	4,320	100.00	4.16	0.5	13.4	2.02	2.16	4.70
Nov/11	4,464	4,464	100.00	4.42	0.5	13.0	1.98	2.32	4.96
Dec/11	4,320	4,320	100.00	5.94	0.5	15.9	2.53	2.50	6.69
Jan/12	4,464	4,464	100.00	4.35	0.5	15.4	2.19	2.08	4.90
Feb/12	4,464	4,464	100.00	5.70	0.5	18.1	2.47	2.43	6.43
Mar/12	4,176	4,176	100.00	4.98	0.5	14.2	2.38	2.22	5.63
Apr/12	4,464	4,464	100.00	6.01	0.5	19.6	2.53	2.53	6.78
All data	52,704	52,704	100.00	4.89	0.5	19.7	2.44	2.11	5.52
Mean of monthly means				4.89					

Table 2b. Data recovery rates and 20m means for every month during the duration of measurement

Month /Year	Possible Records	Valid Possible Records	Recovery Rate (%)	Mean (m/s)	Min (m/s)	Max (m/s)	St.Dev. (m/s)	Weibull K	Weibul c (m/s)
May/11	4,464	4,464	100	5.13	4.90	0.40	14.60	2.39	2.24
Jun/11	4,320	4,320	100	4.05	3.80	0.40	14.00	2.18	1.92
July/11	4,464	4,464	100	2.70	2.60	0.40	16.90	1.28	2.17
Aug/11	4,464	4,464	100	2.84	2.70	0.40	12.80	1.48	2.00
Sep/11	4,320	4,320	100	3.42	3.00	0.40	12.40	1.92	1.88
Oct/11	4,464	4,464	100	3.65	3.40	0.40	12.00	1.89	2.02
Nov/11	4,320	4,320	100	5.05	4.90	0.40	14.40	2.41	2.19
Dec/11	4,464	4,464	100	3.61	3.40	0.40	13.60	2.05	1.80
Jan/12	4,464	4,464	100	4.90	4.60	0.40	16.50	2.31	2.23
Feb/12	4,176	4,176	100	4.26	3.90	0.40	13.50	2.30	1.94
Mar/12	4,464	4,464	100	5.20	4.80	0.40	17.80	2.47	2.23
Apr/12	3,742	3,742	100	4.38	4.00	0.40	15.80	2.47	1.87
All data	52,126	52,126	100	4.10	3.70	0.40	17.80	2.28	1.87
Mean of monthly means				4.10					

4.2 Wind Speed Monthly Means

The monthly means, Figure 4, are often constructed and used to determine the seasonal behavior of the wind during the year and from the mean figures explain the overall strength of the winds

during different periods of the year. Figure 4 shows the monthly behavior at the site for the 20m and 34m measurement.

The monthly mean wind speeds are low, especially during the summer months with a lowest mean of 3.28m/s and 2.70m/s. In terms of their wind energy content with May/11, November/11 and March/12 showed the highest potential. The highest monthly mean at 34m and 20m was observed during March 2011 with 6.01m/s and 5.20m/s. On average there is a 16% decrease in wind speed from the 34m height to the 20m height. The mean of monthly means is 4.83 m/s at 34m height and 4.10 m/s at 20m. There is a also a seasonal pattern observed from fall/winter/spring to the summer where the site shows higher mean wind speeds in the colder/cooler months than in the warmer/hotter months.

Figure 4. Monthly Mean wind speeds at 20m and 34m

4.3 Wind Speed Diurnal Means

The wind diurnal pattern is an important characteristic as well. It helps illuminate the mechanism responsible for the wind values, especially if there is a thermal effect in the area. In general for the site under investigation a thermal effect is seen especially at the 20m measurement where the variation almost doubles in comparison to the 34m measurement. The night hours have the typical lower wind speeds that start to build up in magnitude at 8:00 peaking at 14:00 and then decreasing again for the evening hours. Nevertheless, as a result of the low wind speeds in

general, the diurnal pattern would play no significant role in meeting high or low energy peak periods. Figure 5 shows the average diurnal wind pattern in the site for the 34m and 20m measurements.

Figure 5. Mean wind speed according to hour of day

4.4 Measured Temperatures

The variability in temperature throughout the year results in a change in air density which has an effect in the power production of a wind turbine. The year under investigation had a very hot summer and an uncommon mild winter. This is depicted in Figure 6 where the temperature and the calculated density are plotted simultaneously. Notice the inverse relationship of the temperature and density; density increases as temperature decreases. The average calculated density is 1.202 kg

Figure 6. Monthly Temperature means and Air density

4.5 Frequency Distribution

The frequency distribution is an indication of the wind resource potential of a site. It is a description of how the wind speed at a site is distributed over various wind speed categories. An ideal site would have winds that blow at a high rate for long periods. Figure 7 and 8 show a graphical representation of the annual wind distributions and Table 3 and 4 contain the tabulated values for the 20m and 34m measurement respectively. This distribution will determine in large part how much energy production is expected with a given turbine. The plots show the wind speeds in the horizontal axis and the frequency of occurrence in the vertical axis. The frequency is shown in number of hours per year with a total of 8760 hours. Each bar represents a binned wind speed with a lower and upper value; the value shown in the horizontal axis is the average of each bin.

Both distributions show similar shape but vary in the magnitude of the average values. For the wind speeds measured at 34m we see a skewed distribution showing a lower range of wind speeds with high occurrence, a peak centered around 3.75 m/s and a short tail at the upper end. This indicates that winds in the lower wind speed categories are frequent and in this case, the observed wind speeds **are below 5.0 m/s (11.2 miles/hr) about 60% of the time during the year.**

In general, the 40% frequency of the winds at the upper end of the range (above 5.0m/s) where power could potentially be produced suggests that the area may be marginally feasible in terms of the wind resource. The upper end has a highest observable mean wind speed value of 18.25 m/s (40 miles/hr).

Figure 7. Annual Wind Speed Distribution for the 34m anemometer Mean= 4.83 m/s
Weibull Best-fit $k=2.03$ $c=5.35$ m/s

Table 3. Wind Speed Distribution values for the 34m measurement

Lower Bin m/s	Upper Bin m/s	Bin Avg.	% Frequency of occurrence	Hour Frequency	Cumulative Hours	Cumulative Frequency
0.0	0.5	0.25	1.481	130	130	1.48%
0.5	1.0	0.75	1.978	173	303	3.46%
1.0	1.5	1.25	2.814	247	550	6.27%
1.5	2.0	1.75	4.176	366	915	10.45%
2.0	2.5	2.25	5.690	498	1414	16.14%
2.5	3.0	2.75	7.486	656	2070	23.63%
3.0	3.5	3.25	8.612	754	2824	32.24%
3.5	4.0	3.75	9.652	845	3669	41.89%
4.0	4.5	4.25	9.005	789	4458	50.89%
4.5	5.0	4.75	8.368	733	5191	59.26%
5.0	5.5	5.25	7.294	639	5830	66.56%
5.5	6.0	5.75	6.175	541	6371	72.73%
6.0	6.5	6.25	5.514	483	6854	78.25%
6.5	7.0	6.75	4.591	402	7256	82.84%
7.0	7.5	7.25	3.795	332	7589	86.63%
7.5	8.0	7.75	3.304	289	7878	89.93%
8.0	8.5	8.25	2.312	203	8081	92.25%
8.5	9.0	8.75	1.777	156	8236	94.02%
9.0	9.5	9.25	1.395	122	8359	95.42%
9.5	10.0	9.75	1.134	99	8458	96.55%
10.0	10.5	10.25	0.869	76	8534	97.42%
10.5	11.0	10.75	0.719	63	8597	98.14%
11.0	11.5	11.25	0.516	45	8642	98.66%
11.5	12.0	11.75	0.411	36	8678	99.07%
12.0	12.5	12.25	0.301	26	8705	99.37%
12.5	13.0	12.75	0.201	18	8722	99.57%
13.0	13.5	13.25	0.148	13	8735	99.72%
13.5	14.0	13.75	0.111	10	8745	99.83%
14.0	14.5	14.25	0.054	5	8750	99.88%
14.5	15.0	14.75	0.050	4	8754	99.93%
15.0	15.5	15.25	0.025	2	8756	99.96%
15.5	16.0	15.75	0.013	1	8757	99.97%
16.0	16.5	16.25	0.012	1	8758	99.98%
16.5	17.0	16.75	0.008	1	8759	99.99%
17.0	17.5	17.25	0.004	0	8759	99.99%
17.5	18.0	17.75	0.002	0	8759	99.99%
18.0	18.5	18.25	0.004	0	8760	100.00%

A similar skewed distribution is observed for the wind speeds measured at 20m but with lower overall values. This distribution shows a lower range of wind speeds with high hour occurrence, a peak centered around 2.75 m/s and again a short trailing tail at the upper end. Again this is an

indication that winds in the higher wind speed categories are not sufficient for a sizable energy generation. In this case, the observed wind speeds **are above 5.0 m/s (11.2 miles/hr) about 30% of the time.**

The upper end shows a highest observable hourly wind speed value of 16.25m/s (36 miles/hr). This frequency of winds at the upper end of the range again plays a significant role since it is at higher wind speeds where most of the power could potentially be produced. Table 3 and 4 show the frequency distributions tabulated by hours and percentage for the 34m and 20m measurement respectively. The cells highlighted in red indicate the 5m/s bin.

Figure 8. Annual Wind Speed Distribution for the 20m anemometer Mean= 4.10m/s Weibull Best-fit $k=1.87$ $c=4.62$ m/s

Table 4. Wind Speed Distribution values for the 20m measurement

Lower Bin m/s	Upper Bin m/s	Bin Avg.	Frequency of occurrence	Hour Frequency	Cumulative hours	Cumulative Frequency
0.0	0.5	0.25	2.413	211	211	2.41%
0.5	1.0	0.75	2.596	227	439	5.01%
1.0	1.5	1.25	4.178	366	805	9.19%
1.5	2.0	1.75	6.599	578	1383	15.79%
2.0	2.5	2.25	8.959	785	2168	24.75%
2.5	3.0	2.75	10.503	920	3088	35.25%
3.0	3.5	3.25	10.148	889	3977	45.40%
3.5	4.0	3.75	8.994	788	4765	54.39%
4.0	4.5	4.25	8.023	703	5467	62.41%
4.5	5.0	4.75	7.121	624	6091	69.53%
5.0	5.5	5.25	6.087	533	6624	75.62%
5.5	6.0	5.75	5.090	446	7070	80.71%
6.0	6.5	6.25	4.263	373	7444	84.97%
6.5	7.0	6.75	3.553	311	7755	88.53%
7.0	7.5	7.25	2.905	254	8009	91.43%
7.5	8.0	7.75	2.009	176	8185	93.44%
8.0	8.5	8.25	1.621	142	8327	95.06%
8.5	9.0	8.75	1.266	111	8438	96.33%
9.0	9.5	9.25	1.009	88	8527	97.34%
9.5	10.0	9.75	0.775	68	8595	98.11%
10.0	10.5	10.25	0.553	48	8643	98.67%
10.5	11.0	10.75	0.365	32	8675	99.03%
11.0	11.5	11.25	0.313	27	8702	99.34%
11.5	12.0	11.75	0.230	20	8723	99.57%
12.0	12.5	12.25	0.134	12	8734	99.71%
12.5	13.0	12.75	0.123	11	8745	99.83%
13.0	13.5	13.25	0.058	5	8750	99.89%
13.5	14.0	13.75	0.046	4	8754	99.93%
14.0	14.5	14.25	0.033	3	8757	99.97%
14.5	15.0	14.75	0.013	1	8758	99.98%
15.0	15.5	15.25	0.008	1	8759	99.99%
15.5	16.0	15.75	0.006	1	8759	99.99%
16.0	16.5	16.25	0.002	0	8760	100.00%

4.6 Wind Rose

How the wind varies in direction is also important in order to explain any natural flow as a direct consequence of the terrain or obstacles. Also in order to prevent the emergence of any obstacles

such as high vegetation or even erecting any kind of structure that would be in the way of a predominant wind direction.

4.6.1 Frequency by Direction

The direction data has been plotted using radar and polar charts below. In this case 4% of the winds are of magnitude equal or less than 1 m/s and are considered “calms”. Figure 9 shows the frequency of the compass direction the wind speed at 34m has and Figure 10 shows this same information in a bar graph. The wind at the site is coming mostly from the south direction. The rest of the direction sectors are very similar in frequency. The annual predominant wind direction is also depicted in the aerial view of the site in Figure 1a.

Figure 9. Wind Direction Frequency

Figure 10. Wind Direction Frequency (bar graph)

4.6.2 Mean wind speed value direction

The *mean value by direction* graph shows a wind rose with the mean (average) values of a particular data column wind direction. The graphs below show the average wind speed at 34m and 20m measurement versus wind direction. Figure 11 indicates that the winds from the south and northwest tend to be the strongest, with average wind speeds between 5 and 6 m/s. The easterly winds tend to be a little lighter averaging between 3.5 and 4.0m/s. Figure 12 shows the same behavior but with lesser magnitudes. In average, the weakest winds come from the east and north east directions.

Figure 11. Mean wind speeds at 34m by direction

Figure 12. Mean wind speeds at 20m by direction

In order to better visualize the winds at the site during the different seasons, monthly polar plots are shown in Figure 13 and Figure 14. It is observed that in general the winds come from every direction, but the relatively stronger winds come from the south and northwestern sectors. January through May shows wind speeds up to 7m/s coming from the south directions, April, May and November 2011 for example had winds up to 8.0m/s coming from the south as well.

Figure 13. Monthly plots showing mean wind speed values by direction for the 34m measurements

Figure 14. Monthly plots showing mean wind speed values by direction for the 20m measurements

4.7 Wind Profile and Wind Shear at the Site

The vertical wind speed profile is depicted in Figure 15. The average wind speeds measured at 20m and 34m along with the power law were used to calculate the profile, extrapolating up to a height of 100m. This formulation implies that there is a single parameter alpha (Power law fit $\alpha = 0.295$) describing the wind profile. The observations taken during this measurement campaign also show that the wind shear parameter alpha can take a range of values depending on the season and direction sector as depicted in Figure 16 and 17 respectively. The power density extrapolated to 50m showed a value of 108 W/m^2 , which is still classified in Class 1 (poor) wind resources.

Figure 15. Vertical Wind Profile at the Site

Figure 16. Seasonal variation of wind shear at the site

Figure 17. Directional variation of wind shear at the site

4.8 Turbulence Intensity at the Site

Turbulence is an important characteristic in the wind as it determines the fatigue spectrum the turbine's rotor components are subject to during operation. It is quantified as turbulence intensity (TI) which is a dimensionless value defined as the standard deviation (STD) of the wind speed divided by the mean wind speed. The turbulence can vary by direction and is driven by thermal or mechanical factors, the latter being caused by wind blowing over the surface topography, (complex terrain, forests) and building structures and the former one being caused by convective instability of the atmosphere. Figure 18 shows the monthly mean values of TI and Figure 19 shows the mean values from all direction sectors from the 34m measurement. One can observe there to be very little variation on turbulence. At this particular site, the terrain being flat with no forests or dense vegetation causes rather low turbulence values. The turbulence is higher from the north which could possibly be a result of the school building structure in that direction. One can observe there to be greater convection during the summer months and this would lead to greater turbulence and less wind shear during the hot months.

Figure 18. Monthly Mean values of Turbulence Intensity (TI)

Furthermore the 3rd edition of IEC 61400-1 defines four turbulence categories based on the representative TI which is the value below which 90% of the turbulence values fall (90th percentile). Since TI behaves with a normal distribution, the representative TI would be the mean value of TI plus 1.28 standard deviations. For the site under investigation the mean TI and the

representative TI at 15m/s resulted in 0.11 and 0.14 respectively as shown in Table 5, categorizing the site as C (Mean TI at <0.12).

Figure 19. Mean values of TI by Direction Sector

Table 5. Turbulence values with binned wind speed

Bin	Bin Midpoint (m/s)	Lower (m/s)	Upper (m/s)	Records in Bin	Mean TI	STD of TI	Representative TI	Peak TI
4	4	3.5	4.5	9,725	0.121	0.068	0.207	0.923
5	5	4.5	5.5	8,164	0.113	0.059	0.189	0.878
6	6	5.5	6.5	6,093	0.113	0.056	0.184	0.594
7	7	6.5	7.5	4,371	0.115	0.052	0.182	0.528
8	8	7.5	8.5	2,927	0.116	0.046	0.175	0.500
9	9	8.5	9.5	1,653	0.114	0.04	0.165	0.611
10	10	9.5	10.5	1,044	0.118	0.041	0.17	0.719
11	11	10.5	11.5	644	0.114	0.036	0.159	0.387
12	12	11.5	12.5	371	0.118	0.04	0.17	0.474
13	13	12.5	13.5	182	0.121	0.034	0.164	0.284
14	14	13.5	14.5	86	0.12	0.032	0.16	0.252
15	15	14.5	15.5	39	0.114	0.021	0.141	0.182
16	16	15.5	16.5	13	0.121	0.026	0.154	0.173
17	17	16.5	17.5	6	0.137	0.037	0.185	0.181
18	18	17.5	18.5	3	0.178	0.068	0.265	0.246

5.0 Site Power Characteristics

In order to evaluate the wind power potential at this site the air density was calculated and power density quantities were derived thereafter. Calculations were done at heights of 20 and 34m and an average WPD was extrapolated to 50m (164 ft.). The values of power density (W/m^2) are plotted in the bar graph of Figure 20. The average annual power density for the site is 69 W/m^2 and 40 W/m^2 for 34 and 20 heights respectively (81% increase). Given a scale of 1 to 7, both are identified as Class 1 wind resource. Class 1 wind resources have wind power densities up to 200 W/m^2 meaning poor wind resources. The extrapolated wind power density at 50m was 108 W/m^2 which is considered still wind power class 1.

Figures 21a, 21b and 22a and 22b depict power density in relation to compass direction, in other words: where are the energetic winds coming from. We can observe that energy can be harnessed mostly from the south winds. The rest of the sectors offer very little wind power. This corresponds to the fact that stronger winds come from those sectors as discussed in the previous sections.

Figure 20. Monthly wind power density @ 34m and 20m

Figure 21a. Energy at 34m vs Direction

Figure 21b. Energy at 20m vs Direction

Figure 22a. Energy at 34m vs Direction (Bar graph)

Figure 22b. Energy at 20m vs Direction (Bar graph)

6.0 Energy Calculation

This report is intended to provide assistance to Mr. Terry Turner of Phillips Community College in De Witt, Arkansas by determining the site specific potential for harvesting wind energy. The information regarding the wind power characteristics at the site is presented with consideration of eight small wind turbines listed below. Their power curves which specify how much power the turbine produces at a given wind speed are depicted in Figures 23 and 24. These turbines are recognized in the industry with a history of successful applications and were selected based on turbine ratings and available wind resource. More information about these machines is found in their corresponding websites (www.windenergy.com, www.windspot.es, www.bergey.com, www.provenenergy.co.uk and www.endurancewindpower.com).

Lower range power turbines	Upper range power turbines
Whisper 200 from Southwest Wind Power	Bergey Excel-S 10kW from Bergey
Skystream 3.7 from Southwest Wind Power	Proven 15 kW from Proven Energy
Windspot 3.5 from Sonkyo Energy	35kW Endurance from Endurance Wind Power
7.5kW Endurance from Endurance Wind Power	55kW Endurance from Endurance Wind Power

Table 6 presents a summary containing the expected annual energy output and capacity factors (CF) for all eight turbines using the 20m and 30m wind distributions tabulated in section 4.5. The figures are based on 2.0% losses and conditions already detailed in the previous sections of this document.

From the results gathered, the 15kW turbine at 30m shows the highest capacity factor of 30% with an overall annual energy production of 40,067kWh. The capacity factor being the ratio of the amount of energy produced to the amount of energy that could be produced if a turbine ran at its rated capacity all the time. Usually a capacity factor between 20% and 30% is sought for a wind project to make economic sense. The rest of the turbines show a very small percentage of time producing at rated power which is equivalent to small CF's.

A summary of the estimated monthly energy productions and monthly performance values of all individual turbines is also presented in Tables 7a through 7h.

Figure 23. Power Curves for the Whisper 200, Skystream 2.4, Windspot 3.5 and Endurance 5kW

Figure 24. Power Curves for the Bergey 10kW, Proven 15kW and Endurance 35kW & 55kW

Table 6. Annual Energy Production for eight small wind turbines with a 20m & 30m tower

Turbine Model	Hub Height (m/s)	Hub Height WS (m/s)	% Time At Zero output	% Time At Rated Output	Mean Net Power output (kW)	Mean Net Energy Output (kWh/yr.)	Net Capacity factor (%)
Whisper-200 1000 W	20	4.10	36.77	0.14	0.1	1,231	14.1
Skystream 3.7 2400 W	20	4.10	35.25	0.02	0.2	1,760	8.4
Windspot 3.5 3500 W	20	4.10	0.01	0.22	0.4	3,626	11.8
Bergey Excel R 7.5kW	20	4.10	36.78	0.82	0.8	7,413	11.3
Bergey Excel-S 10kW	30	4.60	11.91	0.46	1.2	10,417	11.9
Proven 15 kW	30	4.60	11.66	3.72	4.6	40,067	30.5
Endurance G3120 35 kW	30	4.60	26.67	0.27	8.2	71,567	23.3
Endurance E3120 55 kW	30	4.60	26.67	0.46	10.6	92,852	19.3

Table 7a. Energy output of the 200 whisper under the given wind regime at 20m hub height

Whisper 1000 W	20m Hub Height Wind Speed(m/s)	Time at zero Output (%)	Time at rated Output (%)	Mean Net Power Output (kW)	Mean Net energy output (kWh)	Net Capacity Factor (%)
Jan	4.90	18.73	0.25	0.2	154	20.7
Feb	4.26	33.50	0.14	0.2	107	15.9
Mar	5.20	18.59	0.34	0.2	175	23.5
Apr	4.38	34.05	0.40	0.2	119	16.5
May	5.13	18.53	0.43	0.2	168	22.6
Jun	4.05	37.27	0.05	0.1	94	13.1
Jul	2.70	64.61	0.00	0.0	16	2.2
Aug	2.84	60.10	0.00	0.0	26	3.5
Sep	3.42	50.46	0.00	0.1	58	8.0
Oct	3.65	42.36	0.00	0.1	72	9.6
Nov	5.05	20.72	0.07	0.2	167	23.2
Dec	3.61	41.58	0.04	0.1	77	10.4
Overall	4.10	36.77	0.14	0.1	1,231	14.1

Table 7b. Energy output of the 2.4kW Skystream under the given wind regime at 20m hub height

Skystream 3.7 2.4kW	20m Hub Height Wind Speed (m/s)	Time At Zero Output %	Time At rated Power %	Mean Net Power Output (kW)	Mean Net energy output (kWh)	Net Capacity Factor %
Jan	5.60	13.28	0.54	0.5	341	19.1
Feb	4.86	23.71	0.02	0.3	222	13.8
Mar	5.91	9.81	0.09	0.5	384	21.5
Apr	5.01	20.47	0.00	0.3	249	14.4
May	5.81	11.36	0.00	0.5	350	19.6
Jun	4.62	25.67	0.00	0.3	192	11.1
Jul	3.22	43.68	0.00	0.0	31	1.7
Aug	3.47	38.15	0.00	0.1	59	3.3
Sep	4.10	29.33	0.00	0.2	128	7.4
Oct	4.35	25.47	0.00	0.2	153	8.6
Nov	5.88	12.78	0.05	0.5	378	21.9
Dec	4.27	27.89	0.13	0.2	165	9.2
Overall	4.75	23.51	0.07	0.3	2,649	12.6

Table 7c. Energy output of the 3.5 kW WindSpot under the given wind regime at 20m hub height

WindSpot 3.5 kW	20m Hub Height Wind Speed (m/s)	Time At Zero Output %	Time At rated Power %	Mean Net Power Output (kW)	Mean Net energy output (kWh)	Net Capacity Factor %
Jan	4.90	0.02	0.47	0.6	426	16.4
Feb	4.26	0.00	0.17	0.5	306	13.0
Mar	5.20	0.02	0.69	0.7	486	18.7
Apr	4.38	0.00	0.45	0.5	348	13.8
May	5.13	0.00	0.56	0.6	460	17.7
Jun	4.05	0.00	0.05	0.4	274	10.9
Jul	2.70	0.02	0.07	0.1	103	4.0
Aug	2.84	0.00	0.02	0.2	124	4.8
Sep	3.42	0.00	0.00	0.3	197	7.8
Oct	3.65	0.00	0.00	0.3	221	8.5
Nov	5.05	0.00	0.16	0.6	451	17.9
Dec	3.61	0.00	0.04	0.3	236	9.1
Overall	4.10	0.01	0.22	0.4	3,626	11.8

Table 7d. Energy output of the 7.5kW Bergey Excel-R under the given wind regime at 20m hub height

Bergey 7.5kW	20m Hub Height Wind Speed(m/s)	Time at zero Output (%)	Time at rated Output (%)	Mean Net Power Output (kW)	Mean Net energy output (kWh)	Net Capacity Factor (%)
Jan	4.90	18.73	1.34	1.3	937	16.8
Feb	4.26	33.50	0.79	1.0	643	12.8
Mar	5.20	18.59	2.20	1.5	1,084	19.4
Apr	4.38	34.10	1.79	1.0	734	13.6
May	5.13	18.55	1.81	1.4	1,027	18.4
Jun	4.05	37.27	0.42	0.8	554	10.3
Jul	2.70	64.61	0.04	0.1	88	1.6
Aug	2.84	60.10	0.11	0.2	146	2.6
Sep	3.42	50.46	0.16	0.5	343	6.4
Oct	3.65	42.38	0.04	0.6	410	7.3
Nov	5.05	20.79	0.97	1.4	1,013	18.8
Dec	3.61	41.58	0.29	0.6	450	8.1
Overall	4.10	36.78	0.82	0.8	7,413	11.3

Table 7e. Energy output of the 10kW Bergey Excel-S under the given wind regime at 30m hub height

Bergey 10 kW	30m Hub Height Wind Speed(m/s)	Time at zero Output (%)	Time at rated Output (%)	Mean Net Power Output (kW)	Mean Net energy output (kWh)	Net Capacity Factor (%)
Jan	5.44	6.38	0.94	1.7	1,284	17.3
Feb	4.73	11.49	0.29	1.3	867	12.9
Mar	5.75	3.18	1.37	1.9	1,438	19.3
Apr	4.87	9.17	0.91	1.4	980	13.6
May	5.65	5.44	1.05	1.8	1,336	18.0
Jun	4.49	13.43	0.25	1.1	770	10.7
Jul	3.10	22.51	0.04	0.3	218	2.9
Aug	3.32	21.73	0.13	0.4	310	4.2
Sep	3.94	13.68	0.05	0.7	537	7.5
Oct	4.18	13.42	0.02	0.8	628	8.4
Nov	5.69	6.64	0.35	1.9	1,383	19.2
Dec	4.12	15.34	0.20	0.9	680	9.1
Overall	4.60	11.91	0.46	1.2	10,417	11.9

Table 7f. Energy output of the Proven 15kW under the given wind regime at 30m hub height

Proven 15kW	30m Hub Height Wind Speed (m/s)	Time at zero output (%)	Time at rated output (%)	Mean Net power output(kW)	Mean Net energy output (kWh)	Net capacity factor (%)
Jan	5.44	6.41	8.22	6.3	4,652	41.7
Feb	4.73	11.57	4.00	5.0	3,351	33.2
Mar	5.75	3.16	8.38	6.6	4,927	44.1
Apr	4.87	8.95	4.68	4.9	3,539	32.8
May	5.65	5.42	4.10	6.5	4,826	43.2
Jun	4.49	13.01	1.44	4.3	3,095	28.7
Jul	3.10	21.39	0.04	1.6	1,215	10.9
Aug	3.32	20.95	0.54	2.1	1,546	13.9
Sep	3.94	13.26	1.83	3.2	2,301	21.3
Oct	4.18	13.19	0.54	3.8	2,851	25.5
Nov	5.69	6.64	9.05	6.8	4,907	45.4
Dec	4.12	15.46	1.99	3.9	2,881	25.8
Overall	4.60	11.66	3.72	4.6	40,067	30.5

Table 7g. Energy output of the Endurance G3120 35kW under the given wind regime at 30m hub ht.

Endurance G3120 35 kW	30m Hub Height Wind Speed (m/s)	Time at zero output (%)	Time at rated output (%)	Mean Net power output(kW)	Mean Net energy output (kWh)	Net capacity factor (%)
Jan	5.44	14.45	1.84	11.7	8,689	33.4
Feb	4.73	25.91	0.24	9.1	6,115	26.0
Mar	5.75	11.74	0.38	12.7	9,420	36.2
Apr	4.87	24.05	0.00	8.9	6,392	25.4
May	5.65	13.35	0.00	12.4	9,256	35.5
Jun	4.49	28.13	0.00	7.7	5,519	21.9
Jul	3.10	47.80	0.00	1.8	1,363	5.2
Aug	3.32	43.44	0.00	2.7	2,040	7.8
Sep	3.94	34.03	0.00	5.1	3,659	14.5
Oct	4.18	30.00	0.02	6.4	4,782	18.4
Nov	5.69	14.14	0.51	13.2	9,496	37.7
Dec	4.12	32.44	0.25	6.6	4,882	18.7
Overall	4.60	26.67	0.27	8.2	71,567	23.3

Table 7h. Energy output of the Endurance E3120 55kW under the given wind regime at 30m hub ht.

Endurance E3120 55 kW	30m Hub Height Wind Speed (m/s)	Time at zero output (%)	Time at rated output (%)	Mean Net power output(kW)	Mean Net energy output (kWh)	Net capacity factor (%)
Jan	5.44	14.45	2.28	15.3	11,400	27.9
Feb	4.73	25.91	0.43	11.8	7,900	21.4
Mar	5.75	11.74	0.96	16.8	12,529	30.6
Apr	4.87	24.05	0.24	11.7	8,425	21.3
May	5.65	13.35	0.13	16.1	11,983	29.3
Jun	4.49	28.13	0.00	9.8	7,050	17.8
Jul	3.10	47.80	0.00	2.3	1,737	4.2
Aug	3.32	43.44	0.00	3.5	2,599	6.4
Sep	3.94	34.03	0.00	6.5	4,705	11.9
Oct	4.18	30.00	0.04	7.9	5,905	14.4
Nov	5.69	14.14	0.88	17.4	12,494	31.6
Dec	4.12	32.44	0.52	8.3	6,202	15.2
Overall	4.60	26.67	0.46	10.6	92,852	19.3

7.0 Summary and Discussion

1. The observed average annual wind speed at 34m height was 4.8m/s and 4.1m/s at the 20m measurement height. These results represent the period of measurement from 05/01/2011-04/27/2012. In order to obtain long term representative values, a correlation and adjustment are needed using a long term wind data.
2. The predominant wind and the most energetic winds come from the south.
3. The results indicate relative poor power density at 20 and 34m heights. An estimation of the power density at 50m also resulted in Class1 resource with a WPD=159 W/m².
4. The performance estimation of eight small turbines showed a wide range of capacity factors; between 8% (3.7kW Skystream) and 30% (15kW Proven), which indicates different degrees of utilization values and therefore different feasibilities depending on the turbine project. Even though some energy production figures (mostly in the upper range capacity turbines) show sufficient energy production to serve a net metering agreement, the cost-benefit would have to be evaluated based in the cost of replaced energy.
5. This particular site, being a college campus offering a RE program would definitely benefit from the installation of a wind turbine. The site measured does have enough wind resources to have a small wind turbine operating above 60% of the time, serving an academic purpose.

Wind Resource Assessment Report

Booneville USDA Site

ARKANSAS ANEMOMETER LOAN PROGRAM

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1.0 Introduction

The Arkansas Anemometer Loan Program was established in the summer of 2009 with the objective to assist landowners in the state evaluate the wind energy potential of their property. The program is funded by DOE and the Arkansas Energy Office and is administered by the Renewable Energy Department at John Brown University. This report represents one of four final wind resource assessment reports produced as a result of this grant.

The sites chosen were based on different criteria such as accessibility, obstacle free, adequate cell phone coverage for remote data transfer and a clear statement of objectives from the landowner for the use of wind power. These sites are located in Booneville, Waldron, Harrison and DeWitt. This report documents the finding at the Booneville Site.

The wind measurement system is installed for a period of one year to collect wind velocity and temperature values. The data is logged in 10 minute average values in a wind data acquisition system and sent via an internet modem to the renewable energy department at John Brown University for analysis. The data is monitored on a weekly basis and checked for sensor operation. During the measurement campaign quarterly reports are generated and upon completing the one-year period of data collection, the tower is removed from the site and a summary report of the wind resource is given to the tower borrower.

The summary report is a collection of figures and values the analyst has generated using established analytical techniques that accurately reflect the wind resource. This report represents the final portion of the project and is designed to give the landowner the information necessary to make an informed choice about the role wind energy might play in their property.

This document is divided into several sections:

- This introduction which explains the origin, objective and scope of the program;
- Section 2 which describes the site terrain characteristics and topography;
- Section 3 which explains the measurement set-up and instrumentation used in the study;
- Section 4 which explains the wind characteristics and main calculated parameters;
- Section 5 which describes the energy production from the wind regime at the site in the context of eight small wind turbines and a case analysis of a water pumping application using the wind resources at the site.
- Section 6 which contains a short summary of the wind characteristics and production capabilities and
- Section 7 which contains a summary and discussion of the findings.

2.0 Site Description

Site name:	Booneville-USDA Dale Bumpers Research Farm
UTM Coordinates:	Zone 15 409629E 3881926N
Elevation:	526 ft.
Address:	6883 S State HWY 23 Booneville, AR 72927
County:	Logan
Type of Sensors & Logger:	<ul style="list-style-type: none">• NRG Maximum #40 wind speed• NRG 200P Series wind vane• NRG 110S Temperature sensor• Symphonie Wind Data Logger
Type of Data:	10 min. avg/max/min/st. dev. wind speed 10 min. avg/max/min/St. dev. wind direction 10 min. avg/max/min/st dev .temperature data
Installation Date:	03/01/2011
Beginning of data collection	04/1/2011 00:00
End of data collection:	03/31/2012 23:50

2.1. Site Location

The location of the measurement is in Logan County outside Booneville city limits. The terrain is mostly flat with differences of 25 or less feet in a radius of 1.5 miles. It is predominantly foot high grass or being used to plant crops for research purposes. Several trees of 15-25 ft. tall are found in the eastern directions at approximately 350ft which offer no effect to the current measurement. The elevation of the site is the 526 ft. asl and there are no drastic changes in the immediate site topography. A ground level panoramic view, aerial view and a topographical plan of the site are shown in Figure 1a, 1b and 1c respectively.

Figure 1a. Panoramic view of site

Figure 1b. Aerial view of site

**Figure 1c. Topographic map of anemometer site center UTM Zone 15 409629E 3881926N
Elevation at tower point: 525 feet (160 meters)**

3.0 Measurement Set-up

3.1. General

The measurement set-up consists of a meteorological mast with wind speed, wind direction and temperature sensors and a data logger equipped with a wireless communications module. Wind speeds are measured at 34m and 20m and temperature is measured at ground level. The measurement values are recorded by the data logger and sent via internet to the Renewable Energy Department at John Brown University.

3.1.1 Meteorological Mast

Figure 2 depicts the arrangement of the mast and the instrumentation. The tower used was a 34m (110 ft) guy-supported tower from NRG. It is anchored at four different points with screw-in type anchors as well as drive-in type anchors where needed. The tower uses a gin-pole and helper gin-pole arrangement secured to an 8000lb 12V DC winch to be raised. The tower required no foundation work, only a leveled and flat area for the base which is secured with 36" steel pegs into the ground.

Figure 2. Sketch of meteorological mast and sensor arrangement

3.1.2 Wind Speed

The wind speed was measured at heights of 34m and 20m. For comparative and redundancy reasons two anemometers of the type NRG 40C were installed at the 34m height. The boom of one anemometer is located east and the second anemometer is oriented west. A third wind speed sensor was installed at 20 meters directed west. All instrumentation calibration values are listed in the Table 1. The wind speed is recorded with 10 min. average, minimum, maximum and standard deviation values. Figure 3 shows the anemometer tower at the 34m and 20m level.

Figure 3. Met tower and sensors installed at the 34 and 20 m level

3.1.3 Wind Direction

A potentiometric NRG wind vane type 200P was installed at 34m height with its boom oriented north. The wind directions signals are recorded with 10 minute average, minimum, maximum and standard deviation values.

3.1.4 Data Logger

The data logger used was an NRG symphonie in conjunction with a CDMA IPack communications module for remote data transfer. The symphonie data logger was powered by a 12-volt dc battery charged by a solar module attached to the front of the cabinet box used to protect it from the elements. The logger recorded the measured data with a sample frequency of 1 Hz. and the values were averaged directly in the logger to 10-minute mean values as well as 10-min extreme and 10-min standard deviation. The sensors for the wind speed give impulses that are counted by the logger; the temperature signal and wind direction are processed directly by the analogue/digital converters in the data logger and the measured data was transferred daily to John Brown University via electronic means. Table 1 shows the specifications of the logging equipment.

Table 1. Data Acquisition System Main Specifications

Sensor	Data Acquisition System		
Device	Data Logger	Sampling & Averaging Interval	1 Hz/ 10min
Type	NRG Symphonie – Internet enabled micropower wind energy data logger	Channels	15 (10 counter; 5 Analog)
Serial #:	309020392	I_Pack Option	Serial # 38605722 CDMA - Serial connection direct to IPack

3.1.5 Device Description

The measuring equipment was installed according to NRG specifications where applicable. All sensors were factory calibrated and checked for correct operation in lab before deployment. Table 2 lists all sensors and devices that were utilized during the measurement campaign.

Table 2. List of sensors used in the measurement campaign

Sensor	Wind Speed		
Device	Cup Anemometer	Measurement Range	1 to 96 m/s
Type	#40C	Resolution	.05 m/s
Serial #	3705	Accuracy	0.1 m/s
Calibration/ Transfer Function	$m/s = (Hz \times 0.758) + 0.43$	Height/Alignment	34 m West (270°)
		Distance Constant	3m
		Signals	Ave, max, min, St. Dev.
		DL channel	1
Sensor	Wind Speed		
Device	Cup Anemometer	Measurement Range	1 to 96 m/s
Type	40C	Resolution	.05 m/s
Serial #	3706	Accuracy	0.1 m/s
Calibration	$m/s = (Hz \times 0.756) + 0.40$	Height/Alignment	34 m East (90 °)
		Distance Constant	3m
		Signals	Ave, max, min, St. Dev.
		DL channel	2

Sensor	Wind Speed		
Device	Cup Anemometer	Measurement Range	1 to 96 m/s
Type	40C	Resolution	.05 m/s
Serial #	3707	Accuracy	0.1 m/s
Calibration	$m/s = (Hz \times 0.759) + 0.43$	Height/Alignment	20 m / West (270 °)
		Distance Constant	3m
		Signals	Ave, max, min, St. Dev.
		DL channel	3
Sensor	Wind Direction		
Device	Wind Vane	Measurement Range	0-360 degrees continuous
Type	200P 2001	Resolution	1 degree
Serial #	N/A	Accuracy	1%
Calibration	Slope: 0.351 Offset: 0 Analog DC voltage from conductive plastic potentiometer, 10K ohms	Height/Alignment	33 m / North (0°)
		Signals	Ave, max, min, St. dev.
		DL channel	7
Sensor	Temperature		
Device	NRG 110S	Measurement Range	-40 °C to 52.5 °C (-40 °F to 126.5 °F)
		Accuracy	+/- 1.1 °C
Serial #	3075		
Calibration/Transfer Function	Temp = 0.136 - 86.38	Height	1 m
		Signals	Ave, max, min, St. Dev.
		DL channel	9

4.0 Wind Characteristics

In the following sections, several characteristics of the wind at the site are graphically shown and discussed. The goals are to evaluate the characteristics that can help explain the physical processes at work at the site and to highlight the properties that are important in assessing the wind energy potential. These evaluations are done using raw data with 10 minute values of the average and extreme values as well as the standard deviation. Hourly, monthly and annual means were constructed using the 10 minute values.

The time span analyzed was from April 1, 2011 to March 31, 2012. The data files were collected and uploaded into a Windographer standard Edition Version 2.04 software application. Summary tables and graphs were extracted into this report to show the main characteristics of the wind regime at the site.

4.1 Data Recovery

The amount of data recovered during an observation period is important to characterize the wind profile and should be examined to determine the confidence of other characteristics. For this campaign the data recovery is 100%. Data was collected from April 1, 2011 to March 31, 2012. Table 3 shows these results as well as the extreme values (max and min), standard deviation of

the data and the Weibull k and c parameters that characterize a wind distribution. These parameters can be taken by a wind turbine distributor and used to calculate energy production.

Table 3. Data recovery rates and 34m means for every month during the duration of measurement

Month /Year	Possible Records	Valid Possible Records	Recovery Rate (%)	Mean (m/s)	Min (m/s)	Max (m/s)	Std.Dev. (m/s)	Weibull K	Weibul c (m/s)
Apr/11	4,320	4,320	100	4.43	4.2	0.4	16	3.17	1.29
May/11	4,464	4,464	100	4.31	4.2	0.4	14.5	2.33	1.88
Jun/11	4,320	4,320	100	3.40	3	0.4	18.7	2.46	1.34
July/11	4,464	4,464	100	2.66	2.5	0.4	17.5	1.78	1.49
Aug/11	4,464	4,464	100	2.81	2.7	0.4	12	1.80	1.57
Sep/11	4,320	4,320	100	2.48	2.1	0.4	14.6	1.83	1.37
Oct/11	4,464	4,464	100	2.85	2.4	0.4	11.8	2.15	1.31
Nov/11	4,320	4,320	100	4.35	4.1	0.4	14.3	2.66	1.68
Dec/11	4,464	4,464	100	2.65	2.3	0.4	10.8	1.97	1.35
Jan/12	4,464	4,464	100	3.87	3.5	0.4	14.6	2.69	1.43
Feb/12	4,176	4,176	100	3.35	3	0.4	13	2.26	1.48
Mar/12	4,464	4,464	100	3.81	3.5	0.4	13.2	2.59	1.44
All data	52,704	52,704	100	3.41	3	0.4	18.7	2.44	1.39
Mean of monthly means				3.41					

4.2 Monthly Means

The monthly means, Figure 4, are often constructed and used to determine the seasonal behavior of the wind during the year and from the mean figures explain the overall strength of the winds during different periods of the year. Figure 4 shows the monthly behavior at the site for the 20m and 34m measurement.

The monthly mean wind speeds are low in terms of their wind energy content; April, May and November show the highest potential. We see a natural increase from the 20m height to the 34m height measurement of 16%. The highest monthly mean at 34m was observed during April 2011 with 4.43 m/s. At 20m the highest mean wind speed was observed in April 2011 with 4.35 m/s. There is a clear seasonal pattern observed from winter/spring to summer/fall months where the site had higher mean wind speeds in the colder/cooler months to the warmer/hotter months. This increase was in the order of 20%. However in terms of wind energy content these mean values are low and are not in the range to produce a sizable amount of electrical energy from a small turbine. The mean of monthly means is 3.41 m/s at 34m height.

Figure 4. Monthly Mean wind speeds

4.3 Diurnal Means

The diurnal pattern is an important characteristic as well. It helps illuminate the mechanism responsible for the wind values, especially if there is a thermal effect in the area. In the site in question we see a clear pattern where winds are very light during night hours and begin to pick up in the morning hours around 8:00 AM. The magnitude builds up slowly until 3:00 PM to 4:00 PM and then drops down again. In general the energy producing hours, although rather low, range from 9:00 AM to 5:00 PM. Figure 5 shows the average diurnal wind pattern in the site for the 34m and 20m measurements.

Figure 5. Mean wind speed according to hour of day

4.4 Frequency Distribution

The frequency distribution is an indication of the wind resource potential of a site. It is a description of how the wind speed at a site is distributed over various wind speed categories. An ideal site would have winds that blow at a high rate for long periods. Figure 6 and 7 show a graphical representation of the annual wind distribution in the site during the measurement period for the 34m and 20m measurement respectively. This distribution will determine in large part how much energy production is expected with a given turbine. These plots show the wind speeds in the horizontal axis and the frequency of occurrence in the vertical axis. The frequency is shown in number of hours per year with a total of 8760 hours per year. Each bar represents a binned wind speed with a lower and upper value; the value shown in the horizontal axis is the average of each bin.

Both distributions show similar shape but vary in the magnitude of the average values. For the wind speeds measured at 34m we see a skewed distribution showing a lower range of wind speeds with high hour occurrence, a peak centered around 3.41 m/s and a trailing tail at the upper end. This indicates that winds in the higher wind speed categories are infrequent and in this case, the observed wind speeds **are above 5.0 m/s (11.2 miles/hr) about 22% of the time.**

The upper end is low in occurrence with a highest observable mean wind speed value at 15.75 m/s (35 miles/hr). This low occurrence suggests that there is a low frequency of winds at the upper end of the range. If they happen, it is mostly attributed to windy days caused by low pressure fronts coming into the area. This is significant because it is at higher wind speeds where most of the power could potential be produced.

Figure 6. Annual Wind Speed Distribution for the 34m anemometer Mean= 3.41 m/s
Weibull Best-fit $k=1.39$ $c=3.73$ m/s

Table 4. Wind Speed Distribution values for the 34m measurement

Lower Bin m/s	Upper Bin m/s	Bin Avg.	Frequency of occurrence	Hour Frequency	Cumulative Hours	Cumulative Frequency
0.0	0.50	0.25	8.97%	786	786	8.97%
0.5	1.00	0.75	9.18%	804	1590	18.16%
1.0	1.50	1.25	7.62%	668	2258	25.78%
1.5	2.00	1.75	7.94%	696	2954	33.72%
2.0	2.50	2.25	7.59%	665	3619	41.31%
2.5	3.00	2.75	7.48%	655	4274	48.79%
3.0	3.50	3.25	7.37%	646	4920	56.16%
3.5	4.00	3.75	7.05%	617	5537	63.21%
4.0	4.50	4.25	6.54%	573	6110	69.75%
4.5	5.00	4.75	5.75%	503	6614	75.50%
5.0	5.50	5.25	4.92%	431	7045	80.42%
5.5	6.00	5.75	4.16%	365	7409	84.58%
6.0	6.50	6.25	3.54%	310	7720	88.12%
6.5	7.00	6.75	2.87%	251	7971	91.00%
7.0	7.50	7.25	2.19%	192	8163	93.19%
7.5	8.00	7.75	1.73%	152	8315	94.92%
8.0	8.50	8.25	1.30%	114	8429	96.22%
8.5	9.00	8.75	1.02%	89	8518	97.24%
9.0	9.50	9.25	0.72%	63	8581	97.96%
9.5	10.00	9.75	0.60%	53	8634	98.57%
10.0	10.50	10.25	0.39%	34	8668	98.95%
10.5	11.00	10.75	0.30%	26	8694	99.25%
11.0	11.50	11.25	0.24%	21	8715	99.49%
11.5	12.00	11.75	0.19%	17	8732	99.68%
12.0	12.50	12.25	0.13%	11	8743	99.81%
12.5	13.00	12.75	0.08%	7	8750	99.89%
13.0	13.50	13.25	0.05%	4	8755	99.94%
13.5	14.00	13.75	0.03%	2	8757	99.97%
14.0	14.50	14.25	0.01%	1	8758	99.98%
14.5	15.00	14.75	0.01%	1	8759	99.99%
15.0	15.50	15.25	0.01%	1	8759	99.99%
15.5	16.00	15.75	0.01%	1	8760	100.00%

A similar skewed distribution is observed for the wind speeds measured at 20m but with lower overall values. This distribution shows a lower range of wind speeds with high hour occurrence, a peak centered around 2.75 m/s and a trailing tail at the upper end. Again this is an indication that winds in the higher wind speed categories are infrequent and in this case, the observed wind speeds **are above 5.0 m/s (11.2 miles/hr) about 15% of the time.**

The upper end is low in occurrence and the highest observable hourly wind speed value observed was 14.0 m/s (31.3 miles/hr). This low frequency of winds at the upper end of the range again plays a significant role since it is at higher wind speeds where most of the powers could potential

be produced. Table 4 and 5 show the frequency distributions tabulated by hours and percentage for the 34m and 20m measurement respectively. The cells highlighted in red indicate the 5m/s bin.

Figure 7. Annual Wind Speed Distribution for the 20m anemometer Mean= 2.92 m/s Weibull Best-fit $k = 1.20$ $c = 3.11$ m/s

Table 5. Wind Speed Distribution values for the 20m measurement

Lower Bin m/s	Upper Bin m/s	Bin Avg.	Frequency of occurrence	Hour Frequency	Cumulative hours	Cumulative Frequency
0.0	0.5	0.25	15.58%	1364	1364	15.58%
0.5	1.0	0.75	12.48%	1094	2458	28.06%
1.0	1.5	1.25	7.99%	700	3158	36.05%
1.5	2.0	1.75	7.37%	646	3804	43.43%
2.0	2.5	2.25	7.32%	641	4446	50.75%
2.5	3.0	2.75	7.11%	623	5069	57.86%
3.0	3.5	3.25	6.75%	591	5659	64.61%
3.5	4.0	3.75	6.05%	530	6190	70.66%
4.0	4.5	4.25	5.23%	458	6648	75.89%
4.5	5.0	4.75	4.46%	391	7039	80.35%
5.0	5.5	5.25	4.04%	354	7393	84.39%
5.5	6.0	5.75	3.45%	302	7695	87.84%
6.0	6.5	6.25	2.82%	247	7942	90.66%
6.5	7.0	6.75	2.29%	200	8142	92.95%
7.0	7.5	7.25	1.79%	156	8299	94.73%
7.5	8.0	7.75	1.34%	117	8416	96.07%
8.0	8.5	8.25	1.04%	91	8507	97.11%
8.5	9.0	8.75	0.80%	70	8577	97.91%
9.0	9.5	9.25	0.62%	54	8631	98.53%
9.5	10.0	9.75	0.44%	38	8669	98.96%
10.0	10.5	10.25	0.30%	27	8696	99.27%
10.5	11.0	10.75	0.22%	20	8715	99.49%
11.0	11.5	11.25	0.21%	18	8734	99.70%
11.5	12.0	11.75	0.13%	12	8745	99.83%
12.0	12.5	12.25	0.07%	6	8752	99.91%
12.5	13.0	12.75	0.05%	5	8756	99.96%
13.0	13.5	13.25	0.03%	2	8758	99.98%
13.5	14.0	13.75	0.01%	1	8759	99.99%
14.0	14.5	14.25	0.00%	1	8760	100.00%

4.5 Wind Rose

How the wind varies in direction is also important in order to explain any natural flow as a direct consequence of the terrain or obstacles. Also in order to prevent the emergence of any obstacles such as high vegetation or even erecting any kind of structure that would be in the way of a predominant wind direction.

In this case 30% of the winds are of magnitude equal or less than 1 m/s and are considered “calms”. The direction data has been plotted using radar and polar charts below. Figure 8 shows the frequency of the compass direction the 34m and Figure 9 shows this same information in a bar graph. The wind at the site is coming mostly from the SSW direction and less frequent from the west and eastern direction sectors as shown below.

Figure 8. Wind Direction Frequency

Figure 9. Wind Direction Frequency (bar graph)

The *mean value by direction* graph shows a wind rose with the mean (average) values of a particular data column wind direction. The graphs below show the average wind speed at 20m and 34m versus wind direction. Figure 10 indicates that the winds from the south direction tend to be the strongest, with an average wind speed of over 4 m/s. The WNW winds and easterly winds tend to be a little lighter averaging to 4 m/s. Mean wind speeds outside these direction sectors are lower and less effective for energy production. Figure 11 shows the same behavior but with lesser magnitudes. The weakest winds come from the east and north east directions in general. The annual predominant wind direction is also depicted in the aerial view of the site in Figure 1a.

Figure 10. Graph showing mean wind speeds at 20m by direction

Figure 11. Graph showing mean wind speeds at 34m by direction

In order to better visualize the winds at the site during the different seasons, monthly polar plots are shown in Figure 12 and Figure 13. It is observed that in general the winds come from every direction, but the relatively stronger winds come from the north-western and south western sectors.

Figure 12. Monthly plots showing mean wind speed values by direction for the 34m measurements

Figure 13. Monthly plots showing mean wind speed values by direction for the 20m measurements

5.0 Site Power Characteristics

This report is intended to provide assistance to Dr. Randy Raper of The Dale Bumpers USDA Research Center in Boonville, AR by determining the site specific potential for harvesting wind energy. The information regarding the site power characteristics at the site is presented with consideration of eight small wind turbines with 20 and 30m hub height and their expected annual energy output.

In order to evaluate the wind power potential at this site a number of quantities were computed using the collected wind speed and temperature. Air density, wind speeds and power density up to a height of 100m (328 ft.) were calculated. These values are summarized in the following power density graphs (W/m^2) and consolidated in tables within Figure 16.

Figure 14a, 14b and 15a and 15b depict where the energetic winds are coming from, in other words the total amount of wind energy coming from each direction sector. We can observe that energy can be harnessed mostly from the SSW and to a lesser degree from the WNW sector. The rest of the sectors offer very little wind power. This obeys the fact that stronger winds come from those sectors as discussed in the previous sections.

The last power density graph, Figure 16 shows monthly power density bars at 34 and 20m. The annual power density for the site is 69 W/m^2 and 54 W/m^2 for 34 and 20 heights respectively. Given a scale of 1 to 7, both are identified as Class 1 wind resource. Class 1 wind resources have wind power densities up to 200 W/m^2 meaning poor wind resources.

Figure 14a. Energy at 34m vs Direction

Figure 14b. Energy at 34m vs Direction

Figure 15a. Energy at 20m vs Direction

Figure 15b. Energy at 20m vs Direction

Figure 16. Monthly wind power density @ 34m and 20m

The vertical wind speed profile is depicted in Figure 17. The wind speeds were extrapolated up to 100m using the power law and log law as labeled in the corresponding figure. As can be seen, the wind speed values are still relatively low at 50, 70, and 100m. The power density extrapolated to 50m showed a value of 80 W/m^2 , which is still classified as Class 1 wind resource. Power law fit ($\alpha = 0.293$); Log law fit ($z_0 = 0.850 \text{ m}$).

Figure 17. Vertical Wind Profile at the Site

5.1 Energy Calculation

Eight turbines were used to calculate an annual energy production at this site. Their capacities fall into two ranges; from 1 to 5 kW and from 10-50kW and their power curves are depicted in Figures 18 and 19. The lower range capacity turbines chosen were the following:

- *the Whisper 200 from Southwest Wind Power*
- *the Skystream 3.7 from Southwest Wind Power*
- *the Windspot 3.5 from Sonkyo Energy,*
- *the 5kW Endurance from Endurance Wind Power*

The upper range capacity turbines chosen were:

- *the Bergey Excel-S 10kW from Bergey,*
- *the Proven 15 kW from Proven Energy*
- *the 35kW Endurance from Endurance Wind Power*
- *the 55kW Endurance from Endurance Wind Power*

These are recognized in the industry with a history of successful applications and were selected based on turbine ratings and available wind resource. More information about these machines is found in their corresponding websites (www.windenergy.com, www.windspot.es, www.bergey.com, www.provenenergy.co.uk and www.endurancewindpower.com).

Smaller turbines are design for lower resources with the intent to serve small loads, which is the case for this site. Each turbine presents a unique and characteristic power curve, specifying how much power it will produce at a given windspeed. Table 6 presents the estimated annual energy production and capacity factors of the turbines based on 2% losses and on the wind distributions at 20 and 34m hub height and conditions already detailed in the previous sections of this document. The capacity factor is the ratio of the amount of energy produced to the amount of energy that could be produced if a turbine ran at its rated capacity all the time. In all eight cases the resulting capacity factors were low. Usually a capacity factor above between 20% and 30% is sought for a wind project to make economic sense. The small range wind turbines resulted in a capacity factor less than 10%. The upper range wind performed better, but still exhibit capacity factors below 20%. Table 6 show these results.

A summary of the estimated annual energy production and performance figures of all eight turbines is also presented in Table 6. Tables 7a through 7h present the expected monthly production figures for all eight turbines models based on the wind regime at the site.

In addition to the calculated energy production, Appendix A contains an analysis of the *Whisper 200 turbine being utilized for a water pumping application. This application would be of particular interest to the USDA Dale Bumpers Research Farm. Pump graphs and specification sheets are included in this section as well.*

Figure 18. Power Curves for the Whisper 200, Skystream 2.4, Windspot 3.5 and Endurance 5kW

Figure 19. Power Curves for the Bergey 10kW, Proven 15kW and Endurance 35kW & 55kW

Table 6. Annual Energy Production for eight small wind turbines with a 20m & 30m tower

Turbine Model	Hub Height (m/s)	Hub Height WS (m/s)	% Time At Zero output	% Time At Rated Output	Mean Net Power output (kW)	Mean Net Energy Output (kWh/yr)	Net Capacity factor (%)
Whisper-200 1000 W	20	2.92	49.32	0.09	0.1	713	8.1
Skystream 3.7 2400 W	20	2.92	57.86	0.00	0.1	705	3.4
Windspot 3.5 3500 W	20	2.92	0.00	0.07	0.3	2,423	7.9
Bergey ExcelR 7.5kW	20	2.92	59.27	0.41	0.5	4,604	7.0
Bergey Excel-S 10kW	30	3.25	38.92	0.13	0.7	5,923	6.8
Proven 15 kW	30	3.25	38.65	1.78	2.7	24,020	18.3
Endurance G3120 35 kW	30	3.25	52.68	0.00	4.7	41,492	13.5
Endurance E3120 55 kW	30	3.25	52.68	0.26	6.1	53,279	11.1

Table 7a. Energy output of the 200 whisper under the given wind regime at 20m hub height

Whisper 1000 W	20m Hub Height Wind Speed(m/s)	Time at zero Output (%)	Time at rated Output (%)	Mean Net Power Output (kW)	Mean Net energy output (kWh)	Net Capacity Factor (%)
Jan	3.23	45.27	0.31	0.1	85	11.4
Feb	2.73	50.98	0.02	0.1	43	6.4
Mar	3.30	44.24	0.07	0.1	88	11.8
Apr	4.35	32.27	0.23	0.2	162	22.5
May	3.73	31.47	0.13	0.1	102	13.7
Jun	2.88	51.30	0.02	0.1	59	8.2
Jul	2.24	58.27	0.02	0.0	8	1.1
Aug	2.34	54.86	0.00	0.0	13	1.8
Sep	2.03	64.10	0.00	0.0	2	0.2
Oct	2.27	60.80	0.00	0.0	22	2.9
Nov	3.75	36.30	0.28	0.2	111	15.4
Dec	2.20	61.65	0.00	0.0	15	2.0
Overall	2.92	49.32	0.09	0.10	713	8.1

Table 7b. Energy output of the 2.4kW Skystream under the given wind regime at 20m hub height

Skystream 3.7 2.4kW	20m Hub Height Wind Speed (m/s)	Time At Zero Output %	Time At rated Power %	Mean Net Power Output (kW)	Mean Net energy output (kWh)	Net Capacity Factor %
Jan	3.23	52.49	0.00	0.1	100	5.6
Feb	2.73	60.20	0.00	0.0	33	2.0
Mar	3.30	51.72	0.00	0.1	100	5.6
Apr	4.35	38.15	0.00	0.3	224	12.9
May	3.73	40.32	0.00	0.2	113	6.3
Jun	2.88	57.75	0.00	0.1	56	3.2
Jul	2.24	67.94	0.00	-0.0	-17	-0.9
Aug	2.34	67.25	0.00	-0.0	-10	-0.6
Sep	2.03	73.98	0.00	-0.0	-25	-1.4
Oct	2.27	68.93	0.00	0.0	1	0.0
Nov	3.75	44.24	0.00	0.2	140	8.1
Dec	2.20	70.95	0.00	-0.0	-8	-0.5
Overall	2.92	57.86	0.00	0.1	705	3.4

Table 7c. Energy output of the 3.5 kW Windspot under the given wind regime at 20m hub height

WindSpot 3.5 kW	20m Hub Height Wind Speed (m/s)	Time At Zero Output %	Time At rated Power %	Mean Net Power Output (kW)	Mean Net energy output (kWh)	Net Capacity Factor %
Jan	3.23	0.00	0.16	0.3	260	10.0
Feb	2.73	0.00	0.00	0.2	159	6.8
Mar	3.30	0.00	0.04	0.3	257	9.9
Apr	4.35	0.00	0.21	0.6	418	16.6
May	3.73	0.00	0.13	0.4	265	10.2
Jun	2.88	0.02	0.07	0.3	199	7.9
Jul	2.24	0.00	0.02	0.1	103	4.0
Aug	2.34	0.00	0.00	0.1	110	4.2
Sep	2.03	0.00	0.02	0.1	94	3.7
Oct	2.27	0.00	0.00	0.2	134	5.1
Nov	3.75	0.00	0.21	0.4	304	12.1
Dec	2.20	0.00	0.00	0.2	121	4.6
Overall	2.92	0.00	0.07	0.3	2,423	7.9

Table 7d. Energy output of the 7.5kW Bergey Excel-R under the given wind regime at 20m hub height

Bergey 7.5kW	20m Hub Height Wind Speed(m/s)	Time at zero Output (%)	Time at rated Output (%)	Mean Net Power Output (kW)	Mean Net energy output (kWh)	Net Capacity Factor (%)
Jan	3.23	53.72	0.92	0.7	531	9.5
Feb	2.73	61.93	0.05	0.4	285	5.6
Mar	3.30	53.09	0.31	0.7	523	9.4
Apr	4.35	39.14	1.71	1.3	937	17.4
May	3.73	41.76	0.47	0.7	533	9.6
Jun	2.88	59.07	0.09	0.5	387	7.2
Jul	2.24	69.53	0.04	0.2	124	2.2
Aug	2.34	68.91	0.00	0.2	138	2.5
Sep	2.03	75.21	0.02	0.2	113	2.1
Oct	2.27	70.34	0.00	0.3	219	3.9
Nov	3.75	45.49	1.34	0.9	640	11.8
Dec	2.20	72.67	0.00	0.2	177	3.2
Overall	2.92	59.27	0.41	0.5	4,604	7.0

Table 7e. Energy output of the 10kW Bergey Excel-S under the given wind regime at 30m hub height

Bergey 10 kW	30m Hub Height Wind Speed(m/s)	Time at zero Output (%)	Time at rated Output (%)	Mean Net Power Output (kW)	Mean Net energy output (kWh)	Net Capacity Factor (%)
Jan	3.66	35.04	0.34	0.9	686	9.2
Feb	3.15	39.44	0.02	0.6	393	5.8
Mar	3.65	34.23	0.07	0.9	647	8.7
Apr	4.37	31.81	0.35	1.4	1,002	13.9
May	4.15	21.35	0.20	1.0	709	9.5
Jun	3.22	41.16	0.09	0.7	490	6.8
Jul	2.52	45.41	0.04	0.3	208	2.8
Aug	2.67	41.29	0.00	0.3	231	3.1
Sep	2.34	52.25	0.02	0.3	190	2.6
Oct	2.65	49.84	0.00	0.4	314	4.2
Nov	4.17	26.37	0.42	1.1	803	11.2
Dec	2.50	48.81	0.00	0.3	252	3.4
Overall	3.25	38.92	0.13	0.7	5,923	6.8

Table 7f. Energy output of the Proven 15kW under the given wind regime at 30m hub height

Proven 15kW	30m Hub Height Wind Speed (m/s)	Time at zero output (%)	Time at rated output (%)	Mean Net power output(kW)	Mean Net energy output (kWh)	Net capacity factor (%)
Jan	3.66	34.83	3.63	3.4	2,558	22.9
Feb	3.15	39.15	0.53	2.6	1,725	17.1
Mar	3.65	33.94	2.44	3.4	2,546	22.8
Apr	4.37	31.44	6.64	4.7	3,419	31.7
May	4.15	21.15	1.70	3.9	2,936	26.3
Jun	3.22	41.00	1.16	2.8	2,036	18.9
Jul	2.52	45.12	0.16	1.4	1,077	9.7
Aug	2.67	41.04	0.22	1.6	1,187	10.6
Sep	2.34	51.90	0.07	1.3	957	8.9
Oct	2.65	49.55	0.16	1.9	1,450	13.0
Nov	4.17	26.13	4.51	4.1	2,939	27.2
Dec	2.50	48.45	0.20	1.6	1,195	10.7
Overall	3.25	38.65	1.78	2.7	24,020	18.3

Table 7g. Energy output of the Endurance G3120 35kW under the given wind regime at 30m hub ht.

Endurance G3120 35 kW	30m Hub Height Wind Speed (m/s)	Time at zero output (%)	Time at rated output (%)	Mean Net power output(kW)	Mean Net energy output (kWh)	Net capacity factor (%)
Jan	3.66	46.24	0.00	6.2	4,619	17.7
Feb	3.15	52.99	0.00	4.3	2,920	12.4
Mar	3.65	46.37	0.00	6.2	4,594	17.6
Apr	4.37	40.46	0.00	9.2	6,655	26.4
May	4.15	34.30	0.00	6.9	5,167	19.8
Jun	3.22	52.99	0.00	5.0	3,586	14.2
Jul	2.52	63.60	0.00	1.9	1,431	5.5
Aug	2.67	59.66	0.00	2.2	1,603	6.2
Sep	2.34	68.29	0.00	1.9	1,350	5.4
Oct	2.65	62.30	0.00	3.2	2,373	9.1
Nov	4.17	38.06	0.00	7.5	5,367	21.3
Dec	2.50	66.55	0.00	2.5	1,837	7.1
Overall	3.25	52.68	0.00	4.7	41,492	13.5

Table 7h. Energy output of the Endurance E3120 55kW under the given wind regime at 30m hub ht.

Endurance E3120 55 kW	30m Hub Height Wind Speed (m/s)	Time at zero output (%)	Time at rated output (%)	Mean Net power output(kW)	Mean Net energy output (kWh)	Net capacity factor (%)
Jan	3.66	46.24	0.74	8.1	6,053	14.8
Feb	3.15	52.99	0.02	5.4	3,660	9.9
Mar	3.65	46.37	0.20	8.0	5,936	14.5
Apr	4.37	40.46	1.02	12.3	8,886	22.4
May	4.15	34.30	0.27	8.8	6,517	15.9
Jun	3.22	52.99	0.07	6.3	4,542	11.5
Jul	2.52	63.60	0.02	2.4	1,776	4.3
Aug	2.67	59.66	0.00	2.7	2,000	4.9
Sep	2.34	68.29	0.00	2.3	1,671	4.2
Oct	2.65	62.30	0.00	3.9	2,926	7.2
Nov	4.17	38.06	0.81	9.8	7,047	17.8
Dec	2.50	66.55	0.00	3.1	2,281	5.6
Overall	3.25	52.68	0.26	6.1	53,279	11.1

6.0 Water Pumping Application

For the low wind regime found at this site, water pumping applications may still be feasible and therefore worthwhile investigating. The average measured wind speed at 20m is 2.92m/s, but the wind is blowing above 4m/s approximately 30% of the time at which adequate volume but of water could be pumped to satisfy various needs. Figure 20a and 20b show two typical water pumping configurations that could be implemented. One has a reservoir at ground level and the other one has an elevated tank arrangement. Both use a prepackaged system consisting of a Whisper 200 turbine and a Grundfos SQFlex water pump plus accessories.

Figure 20a Wind power pumping applications WT with elevated tank. Figure taken from the Grundfos Operating Manual

Figure, 20b. Wind power pumping applications: WT w/ground level reservoir. Figure taken from the Grundfos Operating Manual

Figure 21 shows the water pumping production curves from the Grundfos SQF pumps models at different wind speeds. Based on the site's mean diurnal wind values (Figure 7 repeated below), and the monthly wind distributions at 20m hub height, Figure 22, the wind is blowing above 4m/s approximately 30% of time. This represents a considerable number of hours throughout the year with enough wind power for the pumping system to operate.

The red shaded area in Figure 21 accounts for volumetric flow rates encompassing several combinations of heads and wind speeds between 4 and 5 m/s. . The pump and accessories are complete systems that can be purchased of the shelf from the brand Grundfos (<http://us.grundfos.com/>) in combination with a Whisper 200 turbine from Southwest Wind Power.

Figure 21. Pump production curves (taken from Grundfos Operating Manual)

Figure 7. Mean wind speed according to hour of day (Repeated)

Figure 22. Monthly wind speed Distributions at 20m hub height

The expected monthly volumes in cubic meters pumped based on the monthly wind speed distributions at 20m height for heads of 100, 150, 200 and 250 ft. are presented in Table 8 and plotted in Figure 23. The user can determine for his specific situation if the quantity of water meets any specific demand at the site (irrigation, livestock hydration , etc.). For calculation purposes only the times the winds speeds are above 5 m/s are taken into account to build Table 8.

Table 8. Monthly volumes (cubic meters) pumped at different heads based on times when wind speed is above 5 m/s

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Hours (% of month)	149 (20.0)	95 (14.1)	157 (21.2)	252 (35.0)	173 (23.3)	125 (17.3)	30 (4.1)	36 (5.0)	37 (4.9)	77 (10.4)	177 (24.6)	59 (7.9)	1367 (15.7)
100'	176	112	186	298	205	147	36	42	43	91	209	70	1617
150'	141	90	149	239	164	118	29	34	35	73	167	56	1294
200'	115	73	122	195	134	96	23	28	28	60	137	46	1057
250'	94	60	99	159	109	79	19	22	23	49	112	37	862

Figure 23. Data from Table 8 plotted showing monthly water production. Arrangement consists of a Whisper 200 turbine with a Grundfos 2SQ-6 pump at 4 heads (100', 150', 200' and 250')

7.0 Summary and Discussion

1. The observed average annual wind speed at 34m height was 3.41 m/s (7.62 miles/hr) and 2.92 m/s (6.52 miles/hr) at 20m measurement height.
2. The analysis of the data indicates a low power density at the heights studied (20m and 34m) and therefore little energy production possibility for a grid connected application or to provide power to a sizable load. An estimation of the wind speed at 50m using the power law and log law was still considered under Class 1 wind resource. (80 W/m^2)
3. The strongest winds come from the southern and northern western directions. The predominant wind direction sectors are mainly free of any obstruction giving the data more reliability.
4. The site does not to have a significant wind energy resource which in combination with the current wind turbine technology would allow for independence in terms of power production. The estimation of the energy production generated by eight small turbines showed low capacity factors which are equivalent to a low feasibility. These capacity factors vary depending on the turbine and month, but overall they are relatively small with the highest annual CF of 18% (Proven 15kW).
5. Even though the average measured wind speed at 20m is 2.92m/s, the wind is blowing above 4m/s approximately 30% of the time at which adequate volumes of water could be pumped to satisfy various needs. The site does seem to offer enough daily wind energy to implement a water pumping application supplying enough water to keep a specific number of livestock hydrated. An estimation shows with a Whisper 200 turbine combines with a Grundfos SQflex and 100ft of head the capacity varies monthly and ranges from 36 cubic meters in July to 298 cubic meters in April. These quantities could be of use depending on the water demand and application.

Wind Resource Assessment Report Harrison, AR

ARKANSAS ANEMOMETER LOAN PROGRAM

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Abstract and Summary Information

The measurement campaign had one year duration from 04/01/2011 to 03/31/2012 and was taken at 20m and 34m with NRG instrumentation. The data was analyzed weekly to check inconsistencies and validity and processed using Windographer software and excel applications.

The site analyzed is located in the Harrison, Arkansas, in the Ozarks region. It is an open site for most of the direction sectors with roughness class of 2. It benefits from a high elevation with wind power development with a Class 1 at 34m. It has seasonally directional winds, of which the most energetic come from the SSW sector. The vertical wind profile shows moderate wind shear that varies by season as well.

<i>34m Meteorological Tower Data Synopsis</i>	(based on 1-yr measurements)
Data start date	April 1, 2011
Data finish data	March 31, 2012
Data recovery rate	99.7%
Site UTM Coordinates	Zone 15 -- 476934E 4000636N
Average wind speed (20 meter)	4.60 m/s (Measured)
Average wind speed (34 meter)	5.54 m/s (Measured)
Average wind speed (50 meter)	6.29 m/s (Predicted)
Average wind speed (100 meter)	7.98 m/s (predicted)
C and K Weibull Parameters at 20m	c= 5.20m/s, k= 2.05
C and K Weibull Parameters at 34m	c=6.26 m/s, k= 2.27
Mean wind power density (20 meter)	105 W/m ²
Mean wind power density (34 meter)	167 W/m ²
Mean wind power density (50 meter)	228 W/m ² - Class 1 (predicted)
Average Power law exponent Alpha	0.343
Mean Turbulence Intensity (34 meter) - IEC 3ed.	0.17 @ 15m/s - Category S
Temp (Max, Avg, Min)	43.5, 16.4, -12.10 C°
Air density (Max, Avg, Min)	1.25,1.13, 1.03 kg/m ³

1.0 Introduction

The Arkansas Anemometer Loan Program was established in the summer of 2009 with the objective to assist landowners in the state evaluate the wind energy potential of their property. The program is funded by DOE and the Arkansas Energy Office and is administered by the Renewable Energy Department at John Brown University. This report represents one of four final wind resource assessment reports produced as a result of this grant.

The sites chosen were based on different criteria such as accessibility, obstacle free, adequate cell phone coverage for remote data transfer and a clear statement of objectives from the landowner for the use of wind power. These sites are located in Harrison, Waldron, DeWitt, and Booneville. This report documents the finding at the Harrison Site.

The wind measurement system is installed for a period of one year to collect wind velocity and temperature values. The data is logged in 10 minute average values in a wind data acquisition system and sent via an internet modem to the renewable energy department at John Brown University for analysis. The data is monitored on a weekly basis and checked for sensor operation. During the measurement campaign quarterly reports are generated and upon completing the one-year period of data collection, the tower is removed from the site and a summary report of the wind resource is given to the tower borrower.

This report contains a collection of figures and values the analyst has generated using established analytical techniques that accurately reflect the wind resource. This report represents the final portion of the project and is designed to give the landowner the information necessary to make an informed choice about the role wind energy might play in their property.

This document is divided into several sections:

- This introduction which explains the origin, objective and scope of the program;
- Section 2 which describes the site terrain characteristics and topography;
- Section 3 which explains the measurement set-up and instrumentation used in the study;
- Section 4 which explains the wind characteristics and main calculated parameters;
- Section 5 which describes the energy production from the wind regime at the site in the context of eight small wind turbines and
- Section 6 which contains a short summary of the wind characteristics and production capabilities and
- Section 7 which lists conclusions and summary.

2.0 Site Description

Site name:	3996 Hilltop Rd, Harrison, AR
UTM Coordinates:	Zone 15 -- 476934E 4000636N
Elevation:	2136ft. (651m)
Address:	3996 Hilltop Rd , Harrison, AR
County:	Boone
Type of Sensors & Logger:	<ul style="list-style-type: none">• NRG Maximum #40 wind speed• NRG 200P Series wind vane• NRG 110S Temperature sensor• Symphonie Wind Data Logger
Type of Data:	10 min. avg/max/min/St.dev. wind speed 10 min. avg/max/min/St.dev. wind direction 10 min. avg/max/min/St dev .temperature data
Installation Date:	04/26/2011
Beginning of data collection	04/01/2011 00:00
End of data collection:	03/31/2012 23:50

2.1. Site Location

The location of the measurement tower is in Boone County outside Harrison city limits. The terrain is semi-flat with an elevation of 2136ft. with changes of ± 75 ft. from the met tower position in a radius of $\frac{1}{2}$ mile. Several trees of 15-25 ft. tall are situated approximately at 262ft. in the WSW direction at a lower elevation (20ft) and a line of shorter trees is situated across the NE perimeter at approximately at 250 ft. Another line of short trees is located in the northern perimeter at approximately at 300ft. A ground level panoramic view, aerial view and a topographical plan of the site are shown in Figure 1a, 1b and 1c respectively.

Figure 1a. Panoramic view of site

Figure 1b. Aerial view of site

Figure 1c. Topographic map site – UTM Zone 15 476934E 4000636N Elevation at tower: 2,136 feet (651 meters)

3.0 Measurement Set-up

3.1. General

The measurement set-up consists of a meteorological mast with wind speed, wind direction and temperature sensors and a data logger equipped with a wireless communications module. Wind speeds are measured at 34m and 20m and temperature is measured at ground level. The measurement values are recorded by the data logger and sent via internet to the Renewable Energy Department at John Brown University.

3.1.1 Meteorological Mast

Figure 2 depicts the arrangement of the mast and the instrumentation. The tower used was a 34m (110 ft) guy-supported tower from NRG. It is anchored at four different points with screw-in type anchors as well as drive-in type anchors where needed. The tower uses a gin-pole and helper gin-pole arrangement secured to an 8000lb 12V DC winch to be raised. The tower required no foundation work, only a leveled and flat area for the base which is secured with 36" steel pegs into the ground.

Figure 2. Sketch of meteorological mast and sensor arrangement

3.1.2 Wind Speed

The wind speed was measured at heights of 34m and 20m. For comparative and redundancy reasons two anemometers of the type NRG 40C were installed at the 34m height. The boom of one anemometer is located west and the second anemometer is oriented east. A third wind speed sensor was installed at 20 meters directed west. All instrumentation calibration values are listed in the Table 1. The wind speed is recorded with 10 min. average, minimum, maximum and standard deviation values. Figure 3 shows the anemometer tower at the 34m and 20m level.

Figure 3. Met tower and sensors installed at the 34m and 20 m level

3.1.3 Wind Direction

A potentiometric NRG wind vane type 200P was installed at 34m height with its boom oriented north. The wind directions signals are recorded with 10 minute average, minimum, maximum and standard deviation values.

3.1.4 Data Logger

The data logger used was an NRG symphonie in conjunction with a CDMA IPack communications module for remote data transfer. The symphonie data logger was powered by a 12-volt dc battery charged by a solar module attached to the front of the cabinet box used to protect it from the elements. The logger recorded the measured data with a sample frequency of 1 Hz. and the values were averaged directly in the logger to 10-minute mean values as well as 10-min extreme and 10-min standard deviation. The sensors for the wind speed give impulses that are counted by the logger; the temperature signal and wind direction are processed directly by the analogue/digital converters in the data logger and the measured data was transferred daily to John Brown University via electronic means. The table below contains the specifications of the logging equipment.

Sensor	Data Acquisition System		
Device	Data Logger	Sampling & Averaging Interval	1 Hz/ 10min
Type	NRG Symphonie – Internet enabled micropower wind energy data logger	Channels	15 (10 counter; 5 Analog)
Serial #:	309020258	I-Pack Option	Serial # 38605722 CDMA - Serial connection direct to IPack

3.1.5 Device Description

The measuring equipment was installed according to NRG specifications where applicable. All sensors were factory calibrated and checked for correct operation in lab before deployment. Table 1 lists all sensors and devices that were utilized during the measurement campaign.

Table 1. List of sensors used in the measurement campaign

Sensor	Wind Speed		
Device	Cup Anemometer	Measurement Range	1 to 96 m/s
Type	#40C	Resolution	.05 m/s
Serial #	63722	Accuracy	0.1 m/s
Calibration/ Transfer Function	$m/s = (Hz \times 0.759) + 0.42$	Height/Alignment	34 m West (270°)
		Distance Constant	3m
		Signals	Ave, max, min, St. Dev.
		DL channel	1
Sensor	Wind Speed		
Device	Cup Anemometer	Measurement Range	1 to 96 m/s
Type	40C	Resolution	.05 m/s
Serial #	63723	Accuracy	0.1 m/s
Calibration	$m/s = (Hz \times 0.758) + 0.40$	Height/Alignment	34 m East (90 °)
		Distance Constant	3m
		Signals	Ave, max, min, St. Dev.
		DL channel	2

Sensor	Wind Speed		
Device	Cup Anemometer	Measurement Range	1 to 96 m/s
Type	40C	Resolution	.05 m/s
Serial #	63724	Accuracy	0.1 m/s
Calibration	$m/s = (Hz \times 0.755) + 0.43$	Height/Alignment	20 m / West (270 °)
		Distance Constant	3m
		Signals	Ave, max, min, St. Dev.
		DL channel	3
Sensor	Wind Direction		
Device	Wind Vane	Measurement Range	0-360 degrees continuous
Type	200P 2001	Resolution	1 degree
Serial #	N/A	Accuracy	1%
Calibration	Slope: 0.351 Offset: 0 Analog DC voltage from conductive plastic potentiometer, 10K ohms	Height/Alignment	33 m / North (0°)
		Signals	Ave, max, min, St. dev.
		DL channel	7
Sensor	Temperature		
Device	NRG 110S	Measurement Range	-40 °C to 52.5 °C (-40 °F to 126.5 °F)
		Accuracy	+/- 1.1 °C
Serial #	3075		
Calibration/Transfer Function	$Temp = 0.136 - 86.38$	Height	1 m
		Signals	Ave, max, min, St. Dev.
		DL channel	9

4.0 Wind Characteristics

In the following sections, several characteristics of the wind at the site are graphically shown and discussed. The goals are to evaluate the characteristics that can help explain the physical processes at work at the site and to highlight the properties that are important in assessing the wind energy potential. These evaluations are done using raw data with 10 minute values of the average and extreme values as well as the standard deviation. Hourly, monthly and annual means of wind speed were constructed using the 10 minute values.

The time span analyzed was from April 01, 2011 to March 31, 2012. The data files were collected and uploaded into a Windographer standard Edition Version 2.04 software application. Summary tables and graphs were extracted into this report to show the main characteristics of the wind regime at the site.

4.1 Data Recovery

The amount of data recovered during an observation period is important to characterize the wind profile and should be examined to determine the confidence of other characteristics. The data recovery was 99.7% with no periods of missing data; however data for several hour periods was removed from the records because the effects of icing were detected. These times are:

12/23/2011 07:00–09:00; 12/26/2012 14:00–19:00; 02/13/2012 15:20–23:00; 02/14/2012 00:00–11:00. Table 2a and 2b shows these results as well as the average, extreme values (max and min), St. Dev. and the Weibull k and c parameters for wind distributions in the 20m and 34m measurements.

Table 2a. Data recovery rates and 34m means for every month during the duration of measurement

Month /Year	Possible Records	Valid Possible Records	Recovery Rate (%)	Mean (m/s)	Min (m/s)	Max (m/s)	Std.Dev. (m/s)	Weibull K	Weibul c (m/s)
Apr/11	4,320	4,320	100	7.05	0.4	19.0	3.05	2.5	8.0
May/11	4,464	4,464	100	6.19	0.4	18.1	2.32	2.9	6.9
Jun/11	4,320	4,320	100	5.21	0.4	14.4	1.98	2.8	5.8
July/11	4,464	4,464	100	3.98	0.4	10.0	1.29	3.3	4.4
Aug/11	4,464	4,464	100	4.36	0.4	12.4	1.76	2.6	4.9
Sep/11	4,320	4,320	100	4.38	0.4	11.3	1.57	3.0	4.9
Oct/11	4,464	4,464	100	4.82	0.4	11.8	1.98	2.6	5.4
Nov/11	4,320	4,320	100	6.81	0.4	17.3	3.14	2.3	7.6
Dec/11	4,464	4,420	99.01	5.22	0.4	15.3	2.40	2.3	5.9
Jan/12	4,464	4,464	100	6.70	0.4	17.4	2.92	2.4	7.5
Feb/12	4,176	4,057	97.15	5.48	0.4	16.0	2.72	2.1	6.2
Mar/12	4,464	4,464	100	6.36	0.4	16.3	2.52	2.7	7.2
All data	52,704	52,541	99.69	5.54	0.4	19.0	2.58	2.3	6.3
Mean of monthly means				5.54					

Table 2b. Data recovery rates and 20m means for every month during the duration of measurement

Month /Year	Possible Records	Valid Possible Records	Recovery Rate (%)	Mean (m/s)	Min (m/s)	Max (m/s)	St.Dev. (m/s)	Weibull K	Weibul c (m/s)
Apr/11	4,320	4,320	100	6.07	0.4	17.0	2.81	2.30	6.86
May/11	4,464	4,464	100	5.19	0.4	15.2	2.09	2.68	5.82
Jun/11	4,320	4,320	100	4.27	0.4	12.3	1.81	2.50	4.81
July/11	4,464	4,464	100	3.14	0.4	9.1	1.15	2.90	3.52
Aug/11	4,464	4,464	100	3.46	0.4	10.2	1.58	2.32	3.90
Sep/11	4,320	4,320	100	3.39	0.4	9.7	1.41	2.56	3.81
Oct/11	4,464	4,464	100	3.85	0.4	10.7	1.77	2.31	4.35
Nov/11	4,320	4,320	100	5.84	0.4	15.3	2.84	2.13	6.56
Dec/11	4,464	4,420	99.01	4.35	0.4	13.7	2.17	2.11	4.91
Jan/12	4,464	4,464	100	5.65	0.4	14.3	2.67	2.23	6.37
Feb/12	4,176	4,057	97.15	4.56	0.4	14.0	2.48	1.89	5.12
Mar/12	4,464	4,464	100	5.44	0.4	14.6	2.33	2.48	6.13
All data	52,704	52,541	99.69	4.60	0.4	17.0	2.37	2.05	5.20
Mean of monthly means				4.60					

4.2 Wind Speed Monthly Means

The monthly means, Figure 4, are often constructed and used to determine the seasonal behavior of the wind during the year and from the mean figures explain the overall strength of the winds during different periods of the year. Figure 4 shows the monthly behavior at the site for the 20m and 34m measurement.

The monthly mean wind speeds are low and moderate in terms of their wind energy content; April, May and November show the highest potential. We see a decrease from the 34m height to the 20m height measurement of 18%. The highest monthly mean at 34m was observed during April 2011 with 7.05m/s. At 20m the highest mean wind speed was observed in April 2011 with 6.07m/s. There is a clear seasonal pattern observed from fall/winter/spring to the summer where the site shows had higher mean wind speeds in the colder/cooler months than in the warmer/hotter months. The mean of monthly means is 5.54 m/s at 34m height and 4.60 m/s at 20m.

Figure 4. Monthly Mean wind speeds at 20m and 34m

4.3 Wind Speed Diurnal Means

The wind diurnal pattern is an important characteristic as well. It helps illuminate the mechanism responsible for the wind values, especially if there is a thermal effect in the area. In general for the site under investigation, the variation is very small at the 20m and even smaller at the 34m measurement. At the 34m height wind speeds seem to behave almost constant throughout the day with a value above 5.5m/s but at the 20m measurement the pattern tends to show some similitude to the typical lower wind speeds during night hours and higher wind speeds during daylight

hours. The magnitude builds up slowly starting at 8:00 AM, it remains almost constant until 4:00 PM and then drops down again for the night hours. Nevertheless, as a result of the small variation, (STD of 0.18 m/s) the diurnal pattern would play no significant role in meeting high or low energy peak periods. Figure 5 shows the average diurnal wind pattern in the site for the 34m and 20m measurements.

Figure 5. Mean wind speed according to hour of day

4.4 Measured Temperatures

The variability in temperature throughout the year results in a change in air density which has an effect in the power production of a wind turbine. The year under investigation had a very hot summer and an uncommon mild winter, which is depicted in Figure 6 where temperature and the calculated density are plotted. Notice the inverse relationship of the temperature and density; density increases as temperature decreases. The average calculated density is 1.130 kg/m^3 .

Figure 6. Monthly Temperature means and Air density

4.5 Frequency Distribution

The frequency distribution is an indication of the wind resource potential of a site. It is a description of how the wind speed at a site is distributed over various wind speed categories. An ideal site would have winds that blow at a high rate for long periods. Figure 7 and 8 show a graphical representation of the annual wind distributions and Table 3 and 4 contain the tabulated values for the 20m and 34m measurement respectively. This distribution will determine in large part how much energy production is expected with a given turbine. These plots show the wind speeds in the horizontal axis and the frequency of occurrence in the vertical axis. The frequency is shown in number of hours per year with a total of 8760 hours per year. Each bar represents a binned wind speed with a lower and upper value; the value shown in the horizontal axis is the average of each bin.

Both distributions show similar shape but vary in the magnitude of the average values. For the wind speeds measured at 34m we see a skewed distribution showing a lower range of wind speeds with low hour occurrence, a peak centered around 4.25 m/s and a thick tail at the upper end. This indicates that winds in the higher wind speed categories are frequent and in this case, the observed wind speeds **are above 5.0 m/s (11.2 miles/hr) about 53% of the time during the year**. The upper end has a highest observable mean wind speed value of 18.75 m/s (42 miles/hr). In general the high occurrence (53% of the time) of winds at the upper end of the range suggests that the area may prove feasible in terms of the wind resource. This is significant because it is at higher wind speeds where most of the power could potential be produced.

Figure 7. Annual Wind Speed Distribution for the 34m anemometer Mean= 5.54 m/s
Weibull Best-fit $k=2.27$ $c=6.26$ m/s

Table 3. Wind Speed Distribution values for the 34m measurement

Lower Bin m/s	Upper Bin m/s	Bin Avg.	Frequency of occurrence	Hour Frequency	Cumulative Hours	Cumulative Frequency
0.0	0.5	0.25	0.4435	39	39	0.44%
0.5	1.0	0.75	0.8812	77	116	1.32%
1.0	1.5	1.25	1.3361	117	233	2.66%
1.5	2.0	1.75	2.0061	176	409	4.67%
2.0	2.5	2.25	3.5382	310	719	8.21%
2.5	3.0	2.75	4.979	436	1155	13.18%
3.0	3.5	3.25	7.2286	633	1788	20.41%
3.5	4.0	3.75	8.6028	754	2542	29.02%
4.0	4.5	4.25	9.2423	810	3351	38.26%
4.5	5.0	4.75	8.8864	778	4130	47.14%
5.0	5.5	5.25	8.1479	714	4844	55.29%
5.5	6.0	5.75	7.4075	649	5492	62.70%
6.0	6.5	6.25	6.237	546	6039	68.94%
6.5	7.0	6.75	5.1446	451	6490	74.08%
7.0	7.5	7.25	4.5622	400	6889	78.64%
7.5	8.0	7.75	4.0445	354	7243	82.69%
8.0	8.5	8.25	3.5192	308	7552	86.21%
8.5	9.0	8.75	2.893	253	7805	89.10%
9.0	9.5	9.25	2.6608	233	8038	91.76%
9.5	10.0	9.75	2.0137	176	8215	93.77%
10.0	10.5	10.25	1.4922	131	8345	95.27%
10.5	11.0	10.75	1.1705	103	8448	96.44%
11.0	11.5	11.25	0.8907	78	8526	97.33%
11.5	12.0	11.75	0.7442	65	8591	98.07%
12.0	12.5	12.25	0.5063	44	8635	98.58%
12.5	13.0	12.75	0.3464	30	8666	98.92%
13.0	13.5	13.25	0.3559	31	8697	99.28%
13.5	14.0	13.75	0.2455	22	8719	99.53%
14.0	14.5	14.25	0.1808	16	8734	99.71%
14.5	15.0	14.75	0.1275	11	8746	99.83%
15.0	15.5	15.25	0.0628	6	8751	99.90%
15.5	16.0	15.75	0.0419	4	8755	99.94%
16.0	16.5	16.25	0.0266	2	8757	99.97%
16.5	17.0	16.75	0.0076	1	8758	99.97%
17.0	17.5	17.25	0.0095	1	8759	99.98%
17.5	18.0	17.75	0.0038	0	8759	99.99%
18.0	18.5	18.25	0.0038	0	8759	99.99%
18.5	19.0	18.75	0.0076	1	8760	100.00%

A similar skewed distribution is observed for the wind speeds measured at 20m but with lower overall values. This distribution shows a lower range of wind speeds with low hour occurrence, a peak centered around 3.25 m/s and again a thick short trailing tail at the upper end. Again this is an indication that winds in the higher wind speed categories are somewhat frequent and in this case, the observed wind speeds **are above 5.0 m/s (11.2 miles/hr) about 37% of the time**.

The upper end is moderate occurrence and the highest observable hourly wind speed value observed was 16.75 m/s (37.45 miles/hr). This frequency of winds at the upper end of the range again plays a significant role since it is at higher wind speeds where most of the power could potentially be produced. Table 3 and 4 show the frequency distributions tabulated by hours and percentage for the 34m and 20m measurement respectively. The cells highlighted in red indicate the 5m/s bin.

Figure 8. Annual Wind Speed Distribution for the 20m anemometer Mean= 4.6 m/s Weibull Best-fit $k=2.05$ $c=5.20$ m/s

Table 4. Wind Speed Distribution values for the 20m measurement

Lower Bin m/s	Upper Bin m/s	Bin Avg.	Frequency of occurrence	Hour Frequency	Cumulative hours	Cumulative Frequency
0.0	0.5	0.25	0.752	66	66	0.75%
0.5	1.0	0.75	1.915	168	234	2.67%
1.0	1.5	1.25	2.741	240	474	5.41%
1.5	2.0	1.75	4.699	412	885	10.11%
2.0	2.5	2.25	6.875	602	1488	16.98%
2.5	3.0	2.75	9.170	803	2291	26.15%
3.0	3.5	3.25	10.219	895	3186	36.37%
3.5	4.0	3.75	9.530	835	4021	45.90%
4.0	4.5	4.25	8.919	781	4802	54.82%
4.5	5.0	4.75	8.022	703	5505	62.84%
5.0	5.5	5.25	6.450	565	6070	69.29%
5.5	6.0	5.75	5.424	475	6545	74.72%
6.0	6.5	6.25	4.600	403	6948	79.32%
6.5	7.0	6.75	4.277	375	7323	83.59%
7.0	7.5	7.25	3.517	308	7631	87.11%
7.5	8.0	7.75	3.161	277	7908	90.27%
8.0	8.5	8.25	2.539	222	8130	92.81%
8.5	9.0	8.75	1.958	172	8302	94.77%
9.0	9.5	9.25	1.330	117	8418	96.10%
9.5	10.0	9.75	1.079	95	8513	97.18%
10.0	10.5	10.25	0.796	70	8582	97.97%
10.5	11.0	10.75	0.541	47	8630	98.51%
11.0	11.5	11.25	0.438	38	8668	98.95%
11.5	12.0	11.75	0.337	30	8698	99.29%
12.0	12.5	12.25	0.291	25	8723	99.58%
12.5	13.0	12.75	0.179	16	8739	99.76%
13.0	13.5	13.25	0.122	11	8750	99.88%
13.5	14.0	13.75	0.051	4	8754	99.93%
14.0	14.5	14.25	0.030	3	8757	99.96%
14.5	15.0	14.75	0.010	1	8758	99.97%
15.0	15.5	15.25	0.013	1	8759	99.99%
15.5	16.0	15.75	0.004	0	8759	99.99%
16.0	16.5	16.25	0.004	0	8759	99.99%
16.5	17.0	16.75	0.006	1	8760	100.00%

4.6 Wind Rose

How the wind varies in direction is also important in order to explain any natural flow as a direct consequence of the terrain or obstacles. Also in order to prevent the emergence of any obstacles such as high vegetation or even erecting any kind of structure that would be in the way of a predominant wind direction.

4.6.1 Frequency by Direction

The direction data has been plotted using radar and polar charts below. In this case 3% of the winds are of magnitude equal or less than 1 m/s and are considered “calms”. Figure 9 shows the frequency of the compass direction the wind speed at 34 m has and Figure 10 shows this same information in a bar graph. The wind at the site is coming mostly from the SSW direction and less frequent from the rest of the direction sectors as shown below. The annual predominant wind direction is also depicted in the aerial view of the site in Figure 1a.

Figure 9. Wind Direction Frequency

Figure 10. Wind Direction Frequency (bar graph)

4.6.2 Mean wind speed value direction

The *mean value by direction* graph shows a wind rose with the mean (average) values of a particular data column wind direction. The graphs below show the average wind speed at 34m and 20m measurement versus wind direction. Figure 11 indicates that the winds from the south and south west tend to be the strongest, with an average wind speed of over 6.5 m/s. The easterly winds tend to be a little lighter averaging to 4 m/s. Figure 12 shows the same behavior but with lesser magnitudes. The weakest winds come from the east and north east directions in general.

Figure 11. Mean wind speeds at 34m by direction

Figure 12. Mean wind speeds at 20m by direction

In order to better visualize the winds at the site during the different seasons, monthly polar plots are shown in Figure 13 and Figure 14. It is observed that in general the winds come from every direction, but the relatively stronger winds come from the south and western sectors. July and August 2011 for example, had light winds coming from every direction as oppose to November 2011 that had strong winds averaging 9.5 m/s coming from the SW direction.

Figure 13. Monthly plots showing mean wind speed values by direction for the 34m measurements

Figure 14. Monthly plots showing mean wind speed values by direction for the 20m measurements

4.7 Wind Profile and Wind Shear at the Site

The vertical wind speed profile is depicted in Figure 15. The average wind speeds measured at 20m and 34m along with the power law were used to calculate it, extrapolating up to a height of 100m. This formulation implies that there is a single parameter alpha (Power law fit $\alpha = 0.343$) describing the wind profile. The observations taken during this measurement campaign show that the wind shear parameter alpha can take a range of values depending on the season and direction sector as depicted in Figure 16 and 17 respectively. The power density extrapolated to 50m showed a value of 228 W/m^2 , which is classified as Class 2 wind resources.

Figure 15. Vertical Wind Profile at the Site

Figure 16. Seasonal variation of wind shear at the site

Figure 17. Directional variation of wind shear at the site

4.8 Turbulence Intensity at the Site

Turbulence is an important characteristic in the wind as it determines the fatigue spectrum the turbine's rotor components are subject to during operation. It is quantified as turbulence intensity (TI) which is a dimensionless value defined as the standard deviation (STD) of the wind speed divided by the mean wind speed. The turbulence can vary by direction and is driven by thermal or mechanical factors, the latter being caused by wind blowing over the surface topography, vegetation and foliage and the former one being caused by convective instability of the atmosphere. Figure 18 shows the monthly mean values of TI and Figure 19 shows the mean values from all direction sectors. One can observe there to be greater convection during the summer months and this would lead to greater turbulence and less wind shear. Also during the warm season the vegetation is more foliated and this increases the surface roughness which would increase the turbulence intensity as well.

Figure 18. Monthly Mean values of TI

Furthermore the 3rd edition of IEC 61400-1 defines four turbulence categories based on the representative TI which is the value below which 90% of the turbulence values fall (90th percentile). Since TI behaves with a normal distribution, the representative TI would be the mean value of TI plus 1.28 standard deviations. For the site under investigation the mean TI and the representative TI at 15m/s resulted in 0.17 and 0.20 respectively as shown in Table 5, categorizing the site as S (Mean TI at 15m/s >0.16).

Figure 19. Mean values of TI by Direction Sector

Table 5. Turbulence values with binned wind speed

Bin	Bin Midpoint (m/s)	Lower (m/s)	Upper (m/s)	Records in Bin	Mean TI	STD of TI	Representative TI	Peak TI
1	1	0.5	1.5	1,165	0.47	0.16	0.68	1.07
2	2	1.5	2.5	2,913	0.30	0.15	0.49	0.96
3	3	2.5	3.5	6,414	0.20	0.10	0.33	0.75
4	4	3.5	4.5	9,376	0.17	0.08	0.26	0.76
5	5	4.5	5.5	8,950	0.16	0.06	0.24	0.75
6	6	5.5	6.5	7,169	0.17	0.05	0.23	0.58
7	7	6.5	7.5	5,100	0.18	0.05	0.23	0.66
8	8	7.5	8.5	3,974	0.18	0.04	0.22	0.62
9	9	8.5	9.5	2,918	0.18	0.04	0.22	0.36
10	10	9.5	10.5	1,842	0.17	0.04	0.22	0.39
11	11	10.5	11.5	1,083	0.18	0.03	0.22	0.47
12	12	11.5	12.5	657	0.17	0.03	0.21	0.28
13	13	12.5	13.5	369	0.17	0.03	0.20	0.28
14	14	13.5	14.5	224	0.17	0.03	0.22	0.51
15	15	14.5	15.5	100	0.17	0.02	0.20	0.22
16	16	15.5	16.5	36	0.17	0.02	0.20	0.23
17	17	16.5	17.5	9	0.18	0.02	0.20	0.21
18	18	17.5	18.5	4	0.18	0.03	0.22	0.23
19	19	18.5	19.5	5	0.16	0.02	0.18	0.19
20	20	19.5	20.5	0				

5.0 Site Power Characteristics

In order to evaluate the wind power potential at this site the air density was calculated and power density quantities were derived thereafter. Calculations were done at heights of 20 and 34m and extrapolated to 50m (164 ft.). The values of power density (W/m^2) are plotted in the bar graph of Figure 20. The average annual power density for the site is 167 W/m^2 and 105.3 W/m^2 for 34 and 20 heights respectively (67% increase). Given a scale of 1 to 7, both are identified as Class 1 wind resource. Class 1 wind resources have wind power densities up to 200 W/m^2 meaning poor wind resources. Nevertheless the extrapolated wind power density at 50m was 228 W/m^2 which is considered wind power class 2 (Marginal).

Figures 21a, 21b and 22a and 22b depict power density in relation to compass direction, in other words: where are the energetic winds coming from. We can observe that energy can be harnessed mostly from the SSW and to a lesser degree from the WNW sector. The rest of the sectors offer very little wind power. This corresponds to the fact that stronger winds come from those sectors as discussed in the previous sections.

Figure 20. Monthly wind power density @ 34m and 20m

Figure 21a. Energy at 34m vs Direction

Figure 21b. Energy at 20m vs Direction

Figure 22a. Energy at 34m vs Direction (Bar graph)

Figure 22b. Energy at 20m vs Direction (Bar graph)

6.0 Energy Calculation

This report is intended to provide assistance to Randy English of Harrison, Arkansas by determining the site specific potential for harvesting wind energy. The information regarding the site power characteristics at the site is presented with consideration of eight small wind turbines with 20 and 30m hub height and their expected annual energy output. Their capacities fall into two ranges; from 1 to 5 kW and from 10-50kW and their power curves are depicted in Figures 23 and 24. The lower range capacity turbines chosen were the following:

- *the Whisper 200 from Southwest Wind Power*
- *the Skystream 3.7 from Southwest Wind Power*
- *the Windspot 3.5 from Sonkyo Energy,*
- *the 5kW Endurance from Endurance Wind Power*

The upper range capacity turbines chosen were:

- *the Bergey Excel-S 10kW from Bergey,*
- *the Proven 15 kW from Proven Energy*
- *the 35kW Endurance from Endurance Wind Power*
- *the 55kW Endurance from Endurance Wind Power*

These are recognized in the industry with a history of successful applications and were selected based on turbine ratings and available wind resource. More information about these machines is found in their corresponding websites (www.windenergy.com, www.windspot.es, www.bergey.com, www.provenenergy.co.uk and www.endurancewindpower.com).

Smaller turbines are design for lower resources with the intent to serve small loads, which is the case for this site. Each turbine presents a unique and characteristic power curve, specifying how much power it will produce at a given wind speed. Table 6 presents the estimated annual energy production and capacity factors of the turbines based on 2.5% losses and on the wind distributions at 20 and 34m hub height and conditions already detailed in the previous sections of this document. The capacity factor is the ratio of the amount of energy produced to the amount of energy that could be produced if a turbine ran at its rated capacity all the time.

The 15kW, 35kW and 55kW turbine chosen show estimations of good capacity factors; 36%, 29% and 34% respectively. The rest of the turbines result in capacity factors below 20%. Usually a capacity factor between 20% and 30% is sought for a wind project to make economic sense. Table 6 shows these results.

A summary of the estimated annual energy production and performance values of all eight turbines is also presented in Table 6. Tables 7a through 7h present the expected monthly production figures for all eight turbines models based on the wind regime at the site.

Figure 23. Power Curves for the Whisper 200, Skystream 2.4, Windspot 3.5 and Endurance 5kW

Figure 24. Power Curves for the Bergey 10kW, Proven 15kW and Endurance 35kW & 55kW

Table 6. Annual Energy Production for eight small wind turbines with a 20m & 30m tower

Turbine Model	Hub Height (m/s)	Hub Height WS (m/s)	% Time At Zero output	% Time At Rated Output	Mean Net Power output (kW)	Mean Net Energy Output (kWh/yr)	Net Capacity factor (%)
Whisper-200 1000 W	20	4.6	16.64	.34	0.2	1815	20.7
Skystream 3.7 2400 W	20	4.6	26.15	0.0	0.3	2302	10.9
Windspot 3.5 3500 W	20	4.6	0.01	0.27	0.5	4325	14.1
Bergey ExcelR 7.5kW	20	4.6	29.09	1.16	1.0	9167	14.0
Bergey Excel-S 10kW	30	5.27	6.76	0.85	1.5	13,469	15.4
Proven 15 kW	30	5.27	6.30	1.93	5.4	47,566	36.2
Endurance G3120 35 kW	30	5.27	17.05	0.02	10.0	88,791	29.0
Endurance E3120 55 kW	30	5.27	17.05	0.06	13.4	117,415	24.4

Table 7a. Energy output of the 200 whisper under the given wind regime at 20m hub height

Whisper 1000 W	20m Hub Height Wind Speed(m/s)	Time at zero Output (%)	Time at rated Output (%)	Mean Net Power Output (kW)	Mean Net energy output (kWh)	Net Capacity Factor (%)
Jan	5.65	8.53	0.67	0.3	249	33.5
Feb	4.56	19.50	0.76	0.2	143	21.3
Mar	5.44	6.21	0.58	0.3	216	29.1
Apr	6.07	6.30	1.02	0.4	266	36.9
May	5.19	9.79	0.02	0.3	198	26.6
Jun	4.27	14.05	0.00	0.2	110	15.3
Jul	3.14	24.80	0.00	0.0	33	4.4
Aug	3.46	26.90	0.00	0.1	58	7.8
Sep	3.39	22.18	0.00	0.1	50	6.9
Oct	3.85	20.43	0.00	0.1	92	12.4
Nov	5.84	13.47	0.90	0.4	263	36.6
Dec	4.35	15.66	0.18	0.2	136	18.2
Overall	4.60	15.64	0.34	0.2	1,815	20.7

Table 7b. Energy output of the 2.4kW Skystream under the given wind regime at 20m hub height

Skystream 3.7 2.4kW	20m Hub Height Wind Speed (m/s)	Time At Zero Output %	Time At rated Power %	Mean Net Power Output (kW)	Mean Net energy output (kWh)	Net Capacity Factor %
Jan	5.65	14.36	0.00	0.5	352	19.7
Feb	4.56	27.56	0.00	0.3	180	11.2
Mar	5.44	12.79	0.00	0.4	287	16.1
Apr	6.07	11.55	0.00	0.5	391	22.6
May	5.19	15.64	0.00	0.3	237	13.3
Jun	4.27	24.63	0.00	0.2	119	6.9
Jul	3.14	44.89	0.00	0.0	19	1.1
Aug	3.46	40.68	0.00	0.1	50	2.8
Sep	3.39	39.54	0.00	0.1	39	2.3
Oct	3.85	35.57	0.00	0.1	91	5.1
Nov	5.84	18.15	0.00	0.5	373	21.6
Dec	4.35	28.26	0.00	0.2	163	9.1
Overall	4.60	26.15	0.00	0.3	2,302	10.9

Table 7c. Energy output of the 3.5 kW Windspot under the given wind regime at 20m hub height

WindSpot 3.5 kW	20m Hub Height Wind Speed (m/s)	Time At Zero Output %	Time At rated Power %	Mean Net Power Output (kW)	Mean Net energy output (kWh)	Net Capacity Factor %
Jan	5.65	0.00	0.56	0.8	588	22.6
Feb	4.56	0.00	0.54	0.5	342	14.5
Mar	5.44	0.00	0.45	0.7	492	18.9
Apr	6.07	0.07	0.93	0.9	638	25.3
May	5.19	0.00	0.02	0.6	423	16.3
Jun	4.27	0.00	0.00	0.3	251	10.0
Jul	3.14	0.00	0.00	0.2	119	4.6
Aug	3.46	0.00	0.00	0.2	163	6.3
Sep	3.39	0.00	0.00	0.2	144	5.7
Oct	3.85	0.00	0.00	0.3	222	8.5
Nov	5.84	0.00	0.69	0.9	620	24.6
Dec	4.35	0.00	0.09	0.4	322	12.4
Overall	4.60	0.01	0.27	0.5	4,325	14.1

Table 7d. Energy output of the 7.5kW Bergey Excel-R under the given wind regime at 20m hub height

Bergey 7.5kW	20m Hub Height Wind Speed(m/s)	Time at zero Output (%)	Time at rated Output (%)	Mean Net Power Output (kW)	Mean Net energy output (kWh)	Net Capacity Factor (%)
Jan	5.65	15.66	3.05	1.8	1,347	24.1
Feb	4.56	29.31	1.70	1.1	736	14.6
Mar	5.44	14.29	1.66	1.5	1,105	19.8
Apr	6.07	12.73	4.03	2.1	1,482	27.4
May	5.19	17.05	0.13	1.3	945	16.9
Jun	4.27	28.31	0.05	0.7	486	9.0
Jul	3.14	52.58	0.00	0.2	114	2.0
Aug	3.46	45.77	0.00	0.3	247	4.4
Sep	3.39	43.98	0.00	0.3	197	3.7
Oct	3.85	39.25	0.00	0.5	403	7.2
Nov	5.84	19.21	2.94	2.0	1,445	26.8
Dec	4.35	30.57	0.52	0.9	659	11.8
Overall	4.60	29.09	1.16	1.0	9,167	14.0

Table 7e. Energy output of the 10kW Bergey Excel-S under the given wind regime at 30m hub height

Bergey 10 kW	30m Hub Height Wind Speed(m/s)	Time at zero Output (%)	Time at rated Output (%)	Mean Net Power Output (kW)	Mean Net energy output (kWh)	Net Capacity Factor (%)
Jan	6.40	4.64	1.99	2.5	1,861	25.0
Feb	5.20	10.43	1.58	1.6	1,063	15.8
Mar	6.11	2.37	1.25	2.1	1,530	20.6
Apr	6.78	3.26	2.78	2.8	1,982	27.5
May	5.92	4.37	0.07	1.8	1,371	18.4
Jun	4.95	4.56	0.05	1.1	794	11.0
Jul	3.74	8.47	0.00	0.4	312	4.2
Aug	4.09	11.22	0.00	0.7	488	6.6
Sep	4.08	8.75	0.00	0.6	446	6.2
Oct	4.54	8.24	0.00	0.9	699	9.4
Nov	6.54	8.94	2.08	2.7	1,934	26.9
Dec	4.96	6.18	0.48	1.3	989	13.3
Overall	5.27	6.76	0.85	1.5	13,469	15.4

Table 7f. Energy output of the Proven 15kW under the given wind regime at 30m hub height

Proven 15kW	30m Hub Height Wind Speed (m/s)	Time at zero output (%)	Time at rated output (%)	Mean Net power output(kW)	Mean Net energy output (kWh)	Net capacity factor (%)
Jan	6.40	4.50	8.04	7.7	5,729	51.3
Feb	5.20	10.11	2.76	5.6	3,750	37.2
Mar	6.11	2.17	1.48	6.9	5,152	46.2
Apr	6.78	3.13	3.84	7.9	5,702	52.8
May	5.92	4.17	0.07	6.8	5,058	45.3
Jun	4.95	3.98	0.00	4.6	3,329	30.8
Jul	3.74	7.12	0.00	2.3	1,719	15.4
Aug	4.09	10.19	0.00	3.1	2,332	20.9
Sep	4.08	8.13	0.00	3.1	2,235	20.7
Oct	4.54	7.84	0.00	4.1	3,071	27.5
Nov	6.54	8.59	5.49	8.0	5,786	53.6
Dec	4.96	5.95	1.63	5.0	3,698	33.1
Overall	5.27	6.30	1.93	5.4	47,566	36.2

Table 7g. Energy output of the Endurance G3120 35kW under the given wind regime at 30m hub ht.

Endurance G3120 35 kW	30m Hub Height Wind Speed (m/s)	Time at zero output (%)	Time at rated output (%)	Mean Net power output(kW)	Mean Net energy output (kWh)	Net capacity factor (%)
Jan	6.40	9.61	0.22	15.4	11,436	43.9
Feb	5.20	21.76	0.00	10.6	7,138	30.3
Mar	6.11	7.53	0.00	13.5	10,023	38.5
Apr	6.78	7.85	0.00	15.9	11,472	45.5
May	5.92	10.84	0.00	13.4	9,942	38.2
Jun	4.95	14.56	0.00	8.1	5,862	23.3
Jul	3.74	26.77	0.00	2.9	2,160	8.3
Aug	4.09	27.98	0.00	4.9	3,664	14.1
Sep	4.08	22.80	0.00	4.6	3,309	13.1
Oct	4.54	21.80	0.00	7.1	5,288	20.3
Nov	6.54	14.91	0.00	16.5	11,852	47.0
Dec	4.96	18.39	0.00	8.9	6,634	25.5
Overall	5.27	17.05	0.02	10.1	88,791	29.0

Table 7h. Energy output of the Endurance E3120 55kW under the given wind regime at 30m hub ht.

Endurance E3120 55 kW	30m Hub Height Wind Speed (m/s)	Time at zero output (%)	Time at rated output (%)	Mean Net power output(kW)	Mean Net energy output (kWh)	Net capacity factor (%)
Jan	6.40	9.61	0.58	21.1	15,675	38.3
Feb	5.20	21.76	0.07	13.9	9,353	25.3
Mar	6.11	7.53	0.00	17.9	13,306	32.5
Apr	6.78	7.85	0.00	22.1	15,922	40.2
May	5.92	10.84	0.00	17.2	12,822	31.3
Jun	4.95	14.56	0.00	10.3	7,398	18.7
Jul	3.74	26.77	0.00	3.6	2,703	6.6
Aug	4.09	27.98	0.00	6.1	4,517	11.0
Sep	4.08	22.80	0.00	5.7	4,074	10.3
Oct	4.54	21.80	0.00	8.9	6,587	16.1
Nov	6.54	14.91	0.00	22.7	16,313	41.2
Dec	4.96	18.39	0.00	11.7	8,731	21.3
Overall	5.27	17.05	0.06	13.4	117,415	24.4

7.0 Summary and Discussion

1. The observed average annual wind speed at 34m height was 5.54m/s and 4.60 m/s at 20m measurement height. These results represent the period of measurement from 04/01/2011-03/31/2012. In order to obtain long term representative values, a correlation and adjustment are needed using a long term wind data.
2. The analysis of the data indicates a marginal power density at the heights studied (20m and 34m). An estimation of the wind speed at 50m using the power law resulted in a Class 2 wind resource ($WPD = 228 \text{ W/m}^2$).
3. The strongest winds come from the SW directions. The predominant wind direction sectors are mainly free of any obstruction giving the data more reliability.
4. The 34m and 20m measurement showed wind speeds distributions above 5.0 m/s 53% and 39% of the time respectively. These wind resources in combination with the appropriate small wind turbine technology would allow for a sizable power production as shown in the tables in section 6. The performance estimation of the eight small turbines showed capacity factors between 14% (3.5kW Windspot) and 36% (15kW Proven) which can lead to a feasible project, depending on the energy demand, price and net metering arrangement.