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RIO VISTA WIND ENERGY PROJECT
FINAL DATA REPORT *FOR*
W. A. VACHON and ASSOCIATES

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May 2005

RIO VISTA WIND ENERGY PROJECT

FINAL REPORT

Prepared for:

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SECOR

May 2005

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1.0 INTRODUCTION

1.1 Project Overview

This report summarizes and documents operation of the doppler miniSODAR™ lower boundary layer wind monitoring system installed and operated at the Sacramento Municipal Utilities District (SMUD) Montezuma Hills Station. It also summarizes the data collected at the station during the period May 29 through June 28 of 2004. The goal of the project was to investigate the wind speed shear exponent (shear) at various heights above ground level (AGL) and the relation of those calculations to engineering construction options including turbine hub height and blade selection.

1.2 Instrumentation

SECOR was contracted by W. A. Vachon and Associates to provide measurements of the wind speed and calculated shear in the Montezuma Hills of central California. After a review of available instrumentation, an AeroVironment miniSODAR 4000 (Sound Operated Doppler Acoustic Radar) from AeroVironment, Inc., in Monrovia, CA, was chosen to make the measurements (Figures 1-1 and 1-2). The initial SODAR location was adjacent to a co-located instrumented meteorological tower with wind speed and direction sensors at 10 meter (m) intervals from 10 m to 50 m AGL.

Data from the meteorological tower were available from 10 – 50 m AGL in 10 m increments in miles per hour (statute miles). Ten-minute average data were referenced to the start of the time period (i.e., the period 1230 to 1240 was referenced as 1230).

SODAR data were available from 15 – 250 m in 5 m increments in meters per second. Ten-minute files were referenced to the start of a specific time period (i.e., the interval 1230 to 1240 was referenced as 1230).

A SODAR measures the doppler shift in received sound pulses that are transmitted upward in three orthogonal directions in sequence (Figure 1-3). The amount of doppler shift in the returned echoes from the three beams is related to the wind direction and speed aloft. "Bins" are created electronically which correspond to the returned signal from various heights aloft (set to 5 m increments for this project). The lowest sampling bin is located at 15 m AGL. For this project, the initial data collection configuration was from 15 – 150 m AGL.

The primary output consists of data tables generated at a user-selected interval containing relevant system information and processed return data (Tables 1-1 and 1-2). A binary output was available and archived, but not used, in this project. Copies of both datasets are on the CD-ROMs included with this report (Appendix C).

Directly comparing SODAR data with traditional data cannot be done without some degree of understanding of the sampling methods used. A SODAR provides results integrated over time (ten minutes for this project) of individual volumetric samples. These samples are also smoothed by data processing algorithms within the sensor. A cup anemometer is inherently a single point measurement in space (i.e., fixed platform meteorological tower) over a much smaller period of time (usually ~1 sec, but integrated into a 10-minute average value for this project). The physical mounting of the anemometer also provides a consistency in

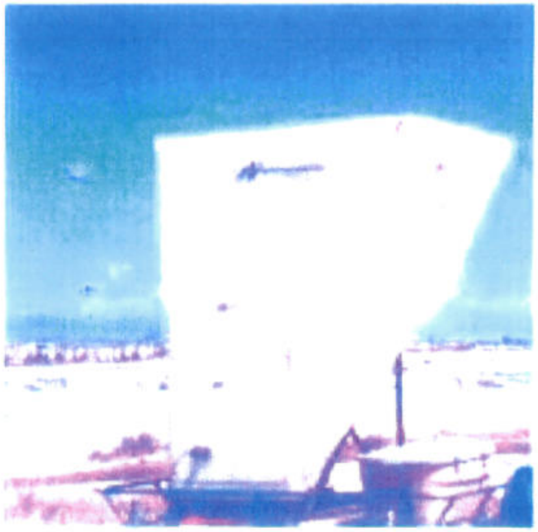


FIGURE 1-1: AEROVIRONMENT MINISODAR 4000

FIGURE 1-2: MINISODAR AT LOCATION #2.

(EXISTING SMUD TURBINES IN BACKGROUND)

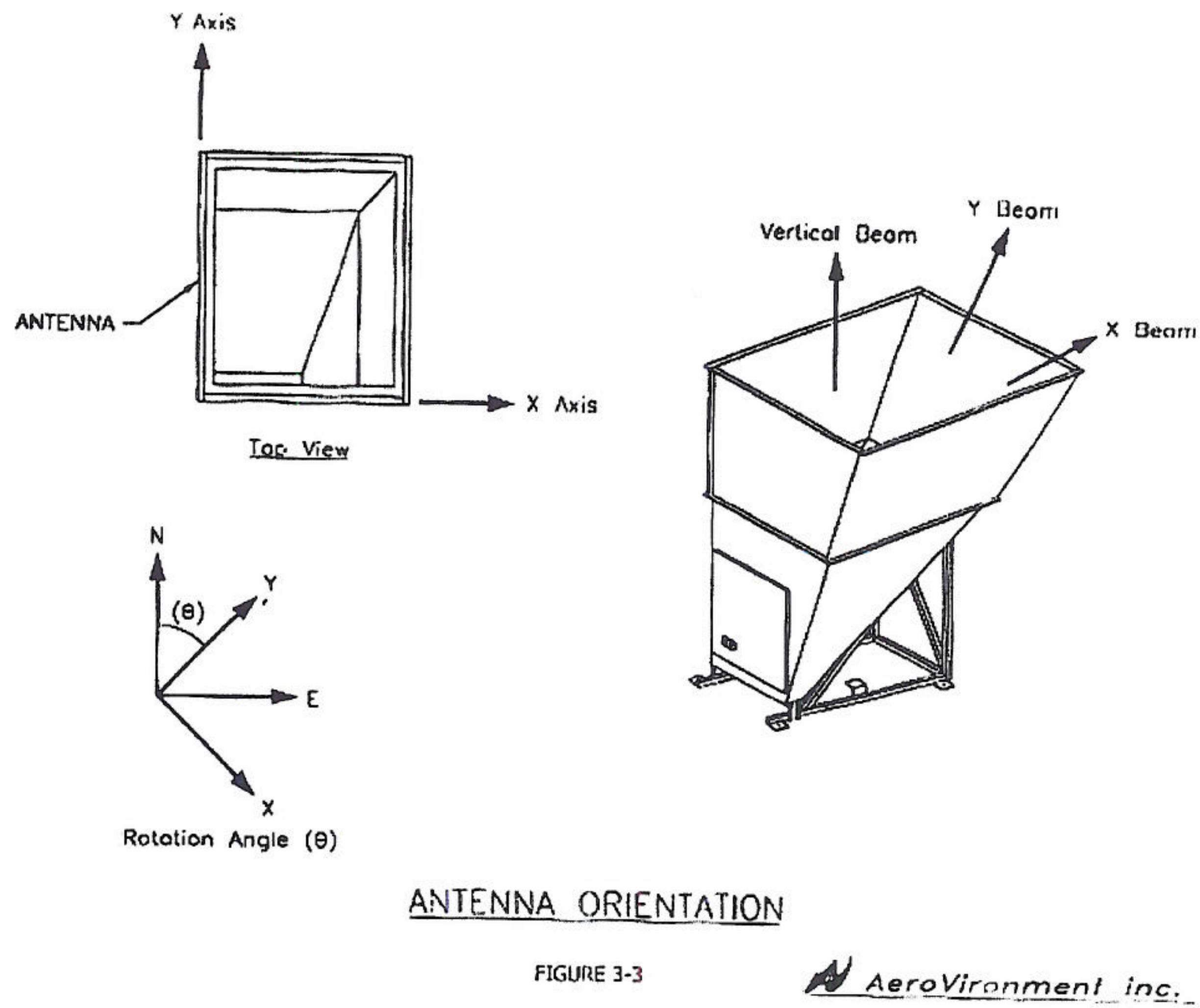


FIGURE 1-3: MINISODAR ANTENNA BEAM ORIENTATION

TABLE 1-1

SAMPLE TABLE OF SODAR DATA FROM JUNE 11, 2004

```
RVWP     06/11/2004 09:00:03 TO 06/11/2004 09:10:03 VR3.11  4500    800    100     50     10      0      0
600 5 15 8 -120 0 10 5 64 960 6 5 5 -800 800 -800 800 -400 400 1 10 187 500 68 1 49 7 0 0 0 10 2
3 COMPONENT 48HTS ZENITH 16-16 ARA 187 SEPANG 090 MXHT    0 UNOISE   151 VNOISE   164 WNOISE    98 ANTENNA
STATUS:FAULT AC STATUS: OFF BATTV  0.015
```

HT	SPD	DIR	W	SDW	IW	GSPD	GDIR	U	SDU	NU	IU	SNRU	V	SDV	NV	IV	SNRV	NW	SNRW
250	99.99	9999	99.99	99.99	95	99.99	9999	99.99	99.99	0	149	4	99.99	99.99	0	165	4	0	9

Intervening 5 meter levels removed to fit table to page.

HT	SPD	DIR	W	SDW	IW	GSPD	GDIR	U	SDU	NU	IU	SNRU	V	SDV	NV	IV	SNRV	NW	SNRW
150	7.01	272	0.53	1.05	141	14.29	269	-6.99	1.08	33	169	6	-0.56	0.87	20	159	6	12	4
145	7.46	273	0.54	1.07	151	13.06	260	-7.44	0.90	39	179	6	-0.50	0.87	22	168	6	22	4
140	7.49	274	0.47	0.95	163	13.43	281	-7.48	0.91	44	185	6	-0.37	0.91	25	173	6	27	4
135	7.97	270	0.30	1.09	166	14.41	265	-7.91	0.93	54	206	7	-1.00	0.99	32	189	7	28	5
130	8.05	267	0.32	1.06	174	19.23	269	-7.92	0.90	64	224	8	-1.43	1.09	36	193	8	33	5
125	8.09	264	0.15	1.12	193	17.64	264	-7.88	1.03	61	236	8	-1.84	1.09	44	217	8	41	6
120	8.00	261	0.15	0.99	221	14.59	255	-7.69	0.98	69	264	9	-2.19	0.97	51	226	9	48	7
115	8.25	262	0.05	0.99	245	16.36	261	-7.98	1.03	74	276	9	-2.10	1.05	57	247	9	52	7
110	8.25	264	0.08	0.97	264	15.13	260	-8.03	1.07	85	328	10	-1.89	0.99	60	262	10	57	8
105	8.26	264	-0.02	1.00	284	14.98	263	-8.05	0.98	91	374	11	-1.86	0.94	72	299	11	63	8
100	8.60	263	0.06	0.89	287	15.68	260	-8.35	0.96	94	410	12	-2.04	0.90	85	335	12	68	8
95	8.11	266	0.02	0.91	323	16.30	266	-7.96	0.97	99	425	12	-1.56	0.93	88	367	12	71	9
90	8.22	266	-0.03	0.91	373	17.05	249	-8.07	1.03	105	433	12	-1.58	0.97	94	393	12	79	10
85	8.35	266	-0.03	0.92	409	15.80	251	-8.21	0.99	113	478	13	-1.53	0.97	101	419	13	85	11
80	8.09	265	-0.05	0.94	446	14.36	255	-7.90	1.02	108	529	13	-1.74	0.95	97	447	13	92	12
75	8.25	265	0.00	0.96	461	15.69	248	-8.07	1.07	115	593	14	-1.74	0.94	103	497	14	94	12
70	7.89	266	-0.11	0.94	484	16.38	256	-7.75	1.10	116	655	14	-1.45	0.98	102	547	14	103	12
65	7.68	269	-0.13	0.91	523	16.14	259	-7.60	1.05	118	701	15	-1.13	0.96	108	576	15	110	13
60	7.46	270	-0.17	0.96	575	11.62	261	-7.40	0.98	117	750	16	-0.92	0.93	110	641	16	114	14
55	7.20	269	-0.15	0.94	667	12.98	274	-7.13	1.04	119	823	15	-0.99	0.99	114	750	15	111	14
50	7.34	269	-0.12	0.92	739	11.67	262	-7.26	0.99	121	912	17	-1.07	0.92	118	843	17	118	16
45	7.29	267	-0.14	0.91	788	11.27	254	-7.17	0.97	123	1012	17	-1.28	0.94	118	906	17	121	16
40	7.25	270	-0.17	0.86	882	11.07	276	-7.21	0.89	123	1196	18	-0.83	0.87	124	1008	18	119	15
35	7.10	272	-0.19	0.87	1033	11.16	256	-7.07	0.91	123	1451	16	-0.60	0.84	121	1199	16	120	16
30	6.98	274	-0.22	0.78	1314	10.20	252	-6.97	0.80	118	1824	17	-0.37	0.89	117	1548	17	120	16
25	7.11	274	-0.16	0.74	1691	14.33	250	-7.10	0.83	120	2342	17	-0.37	0.83	119	2054	17	120	16
20	7.22	272	-0.05	0.72	2263	11.81	261	-7.20	0.80	116	2866	16	-0.64	0.82	116	2683	16	115	15
15	6.82	269	0.00	0.67	2909	11.10	272	-6.76	0.69	115	3422	16	-0.90	0.79	112	3101	16	119	15
level	speed m/sec	dir deg	VWS m/sec	VWS std dev.		gust m/sec	gust dir deg	U-comp m/sec	U-comp std dev				V-comp m/sec	V-comp std dev					

TABLE 1-2

TABLE HEADER DECODING

AeroVironment Inc.

```
0500     10/10/2001 05:50:02 TO 10/10/2001 06:00:01 VR3.07  4500   800   100   50   10   0   0
600 5 15 7 -120 0 10 10 64 960 6 5 5 -800 800 -800 800 -300 300 1 10 108 300 68 1 40 7 0 2 0 10 4
3 COMPONENT 30HTS ZENITH 16-16 ARA 108 SEPANG 090 MXHT    0 UNOISE    51 VNOISE    38 WNOISE    43
 HT    SPD  DIR      W    SDW   IW   GSPD GDIR     U    SDU   NU   IU SNRU     V    SDV   NV   IV SNRV   NW SNRW
150
145
140
135
130
125
120
115
110
105
100
 95
 90
 85
 80
 75
 70
 65
 60
 55
 50
 45
 40
 35
 30
 25
 20
 15
```

I. Wind Table Header information:		II. Doppler SoDAR Wind Table Column Headers
Header Line 1	1. 8 character site name (site); 2. Sample start date (month/day/year); 3. Sample start time (hour/minute/second); 4. Sample end date (month/day/year); 5. Sample end time (hour/minute/second); 6. Doplmum+ version number; 7. Operating frequency (freq). 8. Analog filter bandwidth (bw); 9. Percentage of maximum pulse amplitude used(damp); 10. Length of the pulse in milliseconds (pulw); 11. Pulse amplitude taper time (rise); 12. Offset of the inphase signals (rofs); 13. Offset of the quadrature signal (iofs)	Abbreviation Meaning HT Sampling altitude [meters] SPD Horizontal wind speed [meters/sec] DIR Horizontal wind direction [degrees (adjusted with the ARA)] W Vertical wind velocity (z- axis velocity) [meters/second] SDW Standard deviation of the vertical wind velocity [meters/second] IW Signal intensity (in millivolts) measured by the vertical beam GSPD Wind gust horizontal wind speed (approx. the maximum 10 sec observation) [meters/second] GDIR Wind gust horizontal wind direction [degrees (adjusted with the ARA)] U U component velocity (x- axis velocity) [meters/second] SDU Standard deviation of the U component [meters/second] NU Number of valid samples in the U component estimates [count] IU Signal intensity (in millivolts) measured by the U beam SNRU Signal to noise ratio (average) for the U beam V V component velocity (y-axis velocity) [meters/second] SDV Standard deviation of the V component [meters/second] NV Number of valid samples in the V component estimates [count] IV Signal intensity (in millivolts) measured by the V beam SNRV Signal to noise ratio (average) for the V beam NW Number of valid samples in the W component estimates [count] SNRW Signal to noise ratio (average) for the W beam
Header Line 2	1. Averaging time in seconds (sec); 2. Spatial sampling distance in meters (avdst); 3. Amplitude acceptance threshold (amp); 4. Signal-to-noise ratio acceptance threshold (snr); 5. Adaptive noise threshold (back); 6. Time delay before taking noise sample (noms); 7. Time running average of background noise sample (nwt); 8. Minimum acceptable percentage of good samples (gd); 9. FFT size (nfft); 10. Digital sampling rate (srate); 11. Clutter rejection flag (clut); 12. Number of FFT bins used for Doppler shift (ubim); 13. Number of pulses used for Gust detection (ngav); 14. Minimum radial velocity (cm/sec) accepted for vertical beam (mincr); 15. Maximum radial velocity (cm/sec) accepted for the vertical beam (maxcr); 16. Minimum radial velocity (cm/sec) accepted for y beam (minbr); 17. Maximum radial velocity (cm/sec) accepted for the y beam (maxbr); 18. Minimum radial velocity (cm/sec) accepted for x beam (minar); 19. Maximum radial velocity (cm/sec) accepted for the x beam (maxar); 20. Watch dog timer flag (wdog); 21. Minimum amplitude change for mixing depth detection (maxdel); 22. Orientation wrt True North of the antenna enclosure (prdir); 23. Maximum accepted vertical velocity in cm/sec (wmax); 24. Spacing between the transducers in millimeters (phase); 25. Spacing between the recorded spectral data (speci); 26. Number of stored heights for the spectral data (specl); 27. Number of beams from which the spectral data is collected (specm); 28. Number of spectra averaged together (specn); 29. First gate from which the spectra are stored (specs); 30. Beam from which the DFS data is collected (cdin); 31. Number of data points averaged together for one DFS data point (cdnd); 32. Number of pulses averaged together (cdin)	

measurement. A SODAR also has different sensor response characteristics (e.g., starting thresholds, distance constants, etc.) than the anemometer. Together these limit the comparability of the datasets.

Background noise is also an important factor in SODAR data collection. A SODAR utilizes the frequency shift in reflected sound waves to derive wind speed and direction, therefore the site requires a high signal-to-noise ratio for better data collection performance. Noise caused by wind passing over the landscape, SODAR antenna and instrument trailer caused some data recovery difficulties. Wind speeds were generally at 8 - 15 meters per second (m/s) but frequently reached speeds of 25 m/s (or greater) for sustained periods, thereby occasionally affecting data recovery.

1.3 Station Location

The project resulted in two spatially disparate locations due to noise considerations. The wind energy site is significantly affected by a westerly flow off the north end of San Francisco Bay funneled by topography between San Pablo Bay and Suisun Bay, both northeast of San Francisco. This funneling of the regional flow provides a consistent wind speed and direction in this area resulting in an excellent environment for generation of electric power utilizing wind turbines. Approximately 500 turbines are located in the Montezuma Hills area west and southwest of Rio Vista, CA (Figure 1-4).

Station Location #1

The initial monitoring site selected was chosen to obtain wind measurements within an existing wind energy farm. After installation on May 3, 2004, preliminary data were found to be contaminated by reflections (i.e., fixed echoes) of the SODAR sound pulses off adjacent wind turbine towers. Telecommunication difficulties were also encountered. After attempts to minimize the reflections were unsuccessful, a subsequent review of available options resulted in the decision to relocate the SODAR on May 25th to a site away from existing towers but in an area planned for future turbine installation.

Station Location #2

The relocated site (Figure 1-5) was adjacent to an existing 50 meter meteorological tower (MET-2, instrumented at 10-m intervals from 10 m to 50 m), but far enough away to avoid any potential sound problems caused by fixed echoes or wind flowing across the tower guy wires. This site was approximately 3 km south of the first location. SODAR operation commenced on May 25th, with the first full day of data collection on May 26th. This site required power supplied by a bank of batteries. A second bank was acquired by enXco onsite technicians and swapped/recharged every 2 - 3 days. This proved to be an excellent alternative to other power options. The SODAR remained operational until June 29th when it was decommissioned and returned to AeroVironment. Thirty five continuous days of data were collected at this site.

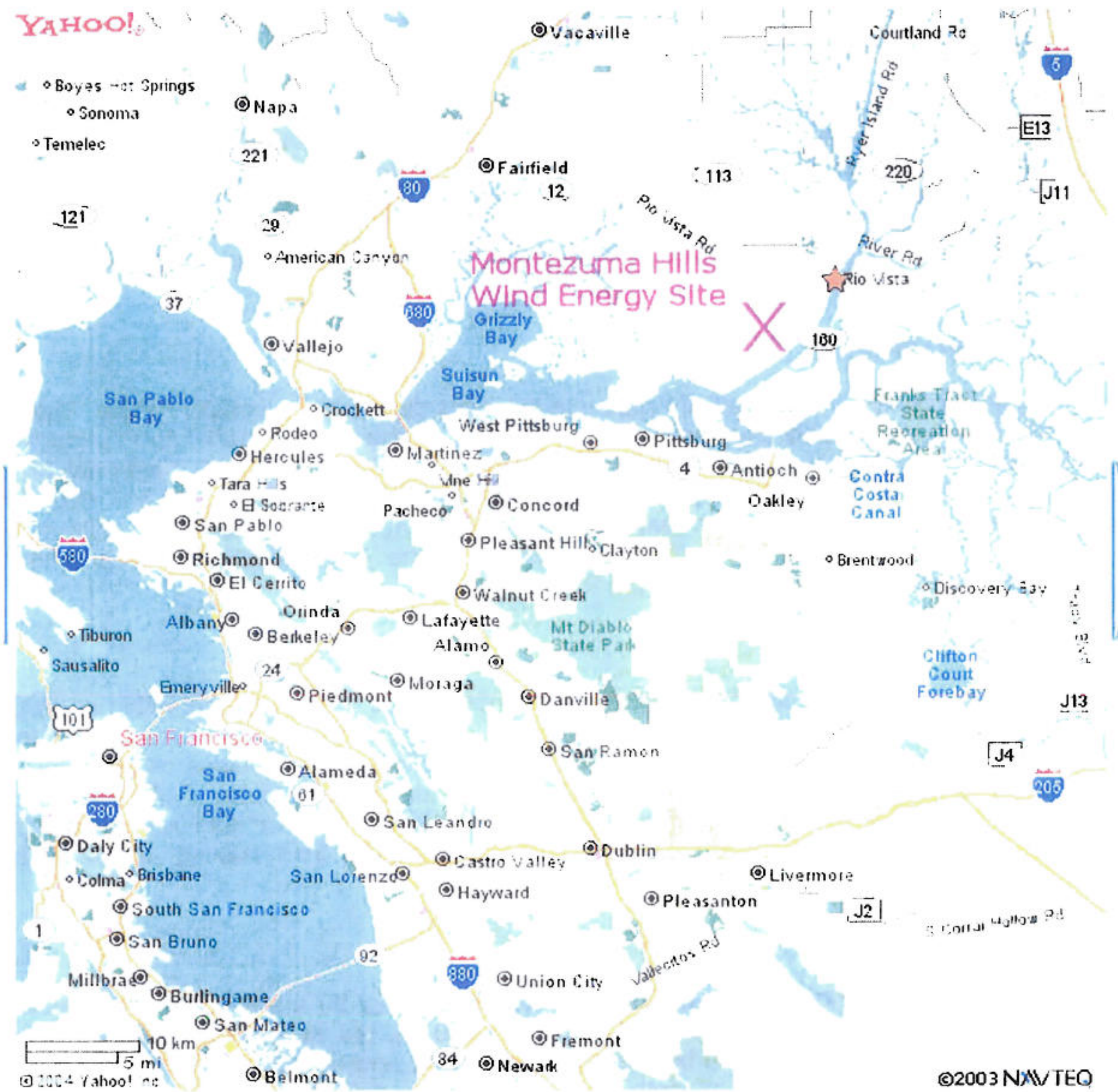


FIGURE 1-4: REGIONAL MAP OF RIO VISTA AREA SHOWING MONTEZUMA HILLS WIND ENERGY SITE

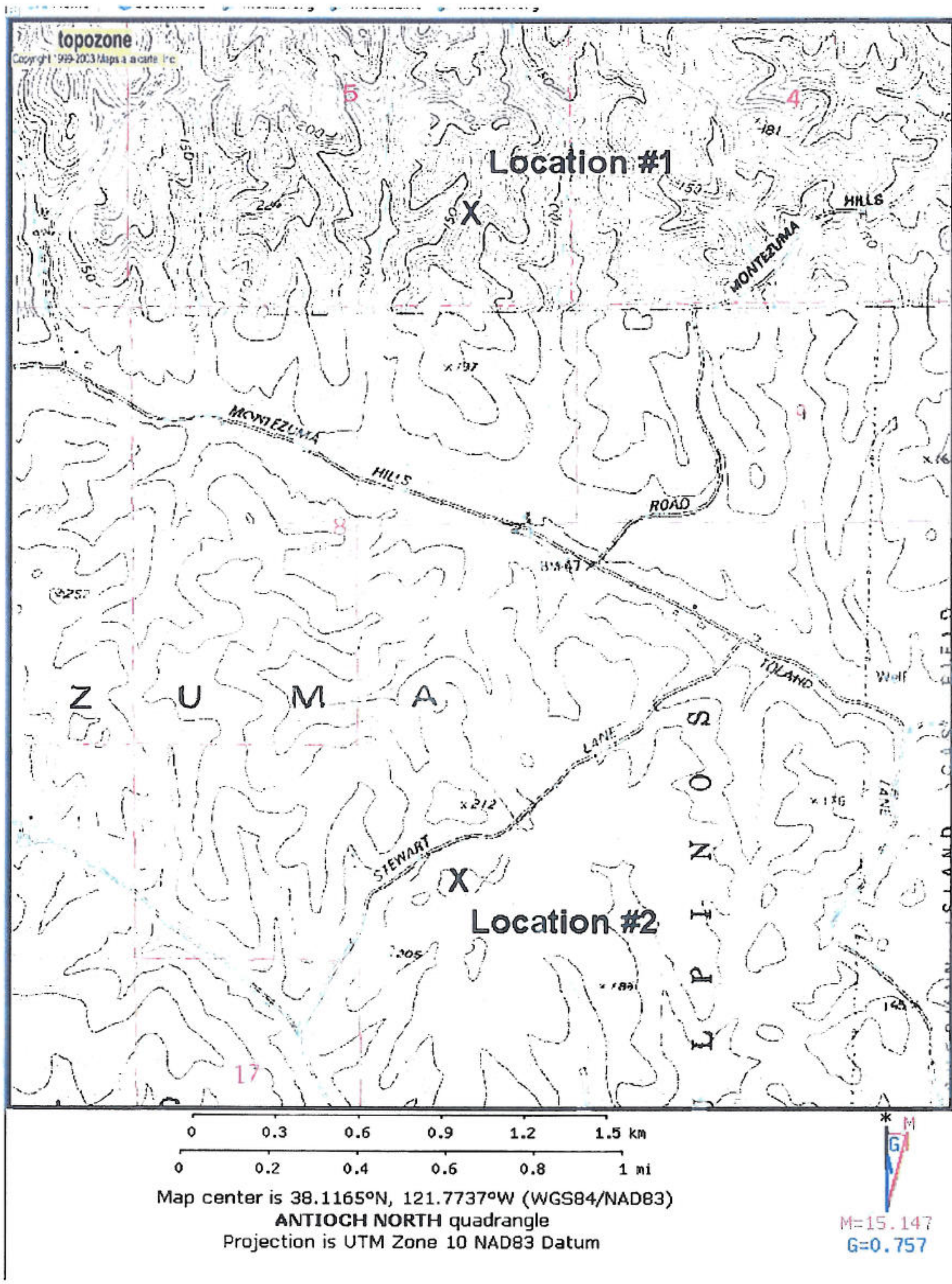


FIGURE 1-5: SITE MAP SHOWING BOTH SODAR LOCATIONS

2.0 STATION PERFORMANCE SUMMARY

This chapter presents a summary of events significant to SODAR performance and contributing to data completeness and accuracy. There were no specific goals for data recovery other than a maximum height of 150 m relating to the top of the proposed turbine blades.

2.1 Significant Project Events

The project involved specification, installation, and operation of an AeroVironment miniSODAR 4000. Initial setup and operation occurred without problems except for telecommunications. A cellular access data modem was used as a conventional phone line was not available at either station location.

Station Location #1 proved to be inappropriate despite repeated attempts to minimize sound reflections off of adjacent wind turbine towers approximately 50 m distant. Throughout mid-May, options were discussed and a relocation of the SODAR to a different location within the SMUD property was performed on May 25th.

Station Location #2 proved to be acceptably quiet with good data returns during the setup and checkout period (24 - 27 May, 2004). Telecommunications were adequate and data recovery was nominal. There were several periods of computer problems at the end of May and early June which resulted in data loss for those days only.

2.2 Missing, Invalid, and Adjusted Data

Missing SODAR data occurred during periods of computer malfunction or excessive noise caused by high wind speeds. The Maximum Return Height (MRH) data show the time periods with no data recovery. A spreadsheet, described in Appendix B, contains the MRH data. SODAR time periods are 10-minute intervals (144 per day) chosen to match MET-2 data.

Invalid SODAR data consisted of several types. First are data which are clearly invalid in the tables due to computer or communication difficulties. Second are data which occur above the first reported invalid level (denoted by a -99.99 or -999 data value in the SODAR output tables). Although data recovery may occur above an invalid level, the recommended methodology (from AeroVironment) is to invalidate all data above the first level not recovered as these are generally spurious in nature. These data are denoted by yellow shading in the SODAR spreadsheet daily data pages (See Appendix B).

Since the SODAR data were recorded in Pacific Standard Time (PST), and the Meteorological tower data were in Pacific Daylight Time (PDT), most of the spreadsheets have been matched in time to enable valid, time-correlated comparisons of data. The pages are clearly marked as either PST, PDT, or Time Adjusted as necessary.

A normal correction to the SODAR wind direction orientation was made to adjust the antenna orientation relative to true north. No other data adjustments were made to the data.

Forty-two (42) 10-minute time intervals were invalidated in the MET-2 data received from SMUD. These are detailed in Table 2-1 (below). The values were anomalously low compared to data before and after listed times. Shear exponents were greater than 1 for some of these data. Therefore they were deleted from the analysis dataset (Met-Speeds page in the spreadsheet) but are retained in the archived data.

TABLE 2-1

INVALIDATED MET-2 DATA

Date	Time Interval (PDT)	Heights	Total Periods [1]
June 1	0840 – 0910	40 M	4
June 2	1040 – 1100	30 M	3 (7)
June 8	1130	ALL	5 (12)
June 9	0720 - 0800	20 M	5 (17)
June 13	1110 – 1310	30 M	13 (30)
June 14	1650 – 1740	50 M	6 (36)
June 15	1350	ALL	5 (41)
June 28	1010	30 M	1 (42)

[1] Figures in parenthesis are cumulative values.

There were no other data losses, invalidations, or adjustments.

2.3 Data Recovery

Data recovery percentages for the data have been calculated based on the total number of hours of valid data collected versus the total number of possible hours in the period (See Appendix A, section A.1).

SODAR data recovery for the entire project at Location #2 was 65%. This is for data collected that that had an MRH of at least 150 m AGL as indicated in the 10-minute tables. The percentage goes up to 85% at 120 m AGL. Data recovery by day is shown in Figure 2-1, and data recovery by height is shown in Figure 2-2.

For MET-2, the equivalent data recovery was 99.8% (for all levels).

The MRH (Maximum Return Height) of the SODAR data appears to be related to wind speed induced noise contamination. Figure 2-3 shows a plot of MET-2 10 m wind speed vs the MRH. The 10 m height is the lowest available during this project, and best suited to relate speed near the surface to background noise at the SODAR antenna location. There is a general trend that the higher the wind speed, the lower the MRH. However, there is enough variation shown in the width of the horizontal lines (points) to show that there are other potential factors (e.g., humidity, turbulence, density layers, etc.) also involved in SODAR data recovery.

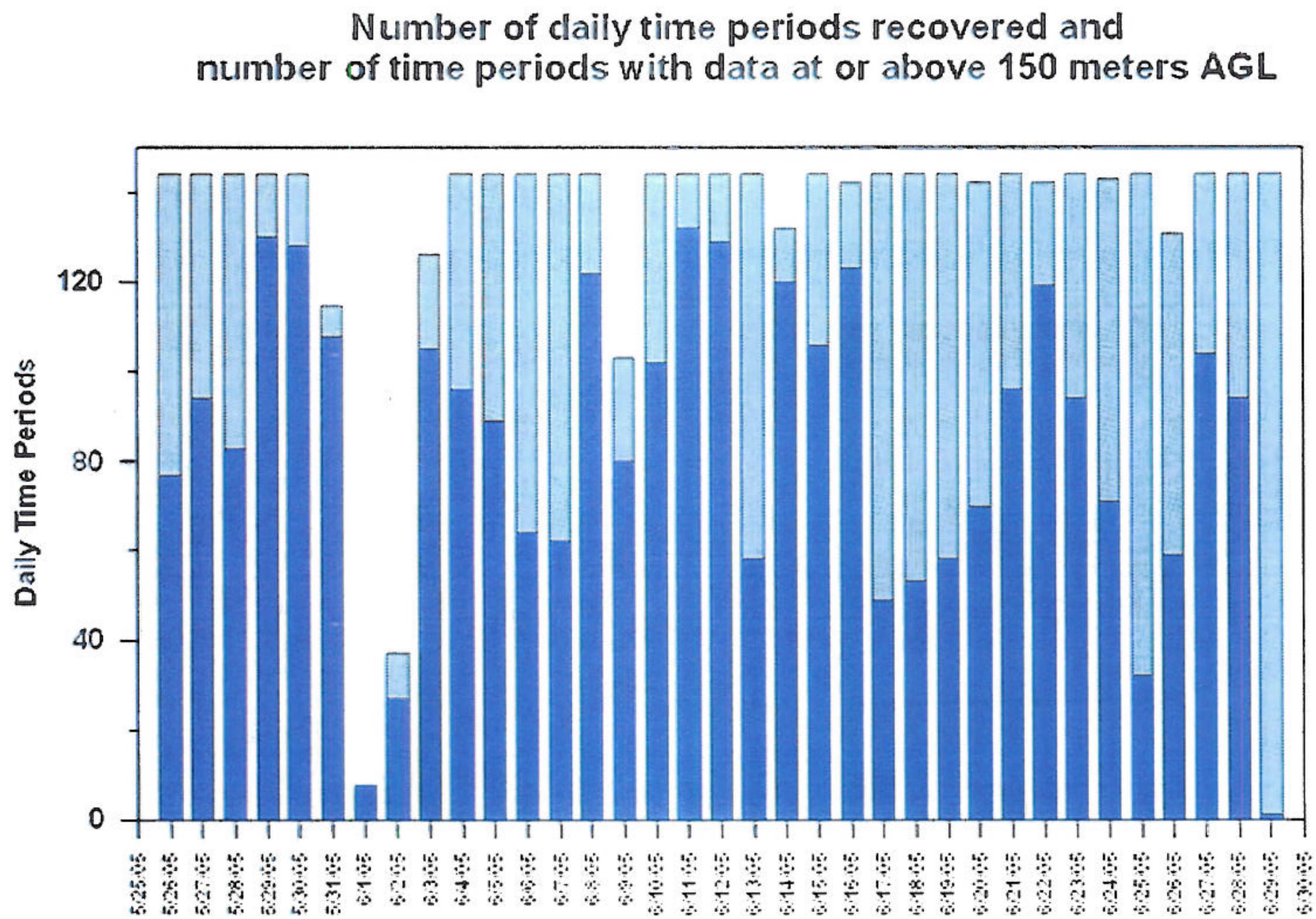


FIGURE 2-1: DAILY DATA RECOVERY, ALL DAILY TIME PERIODS (GREEN) AND DATA TO 150 METERS AGL (BLUE).

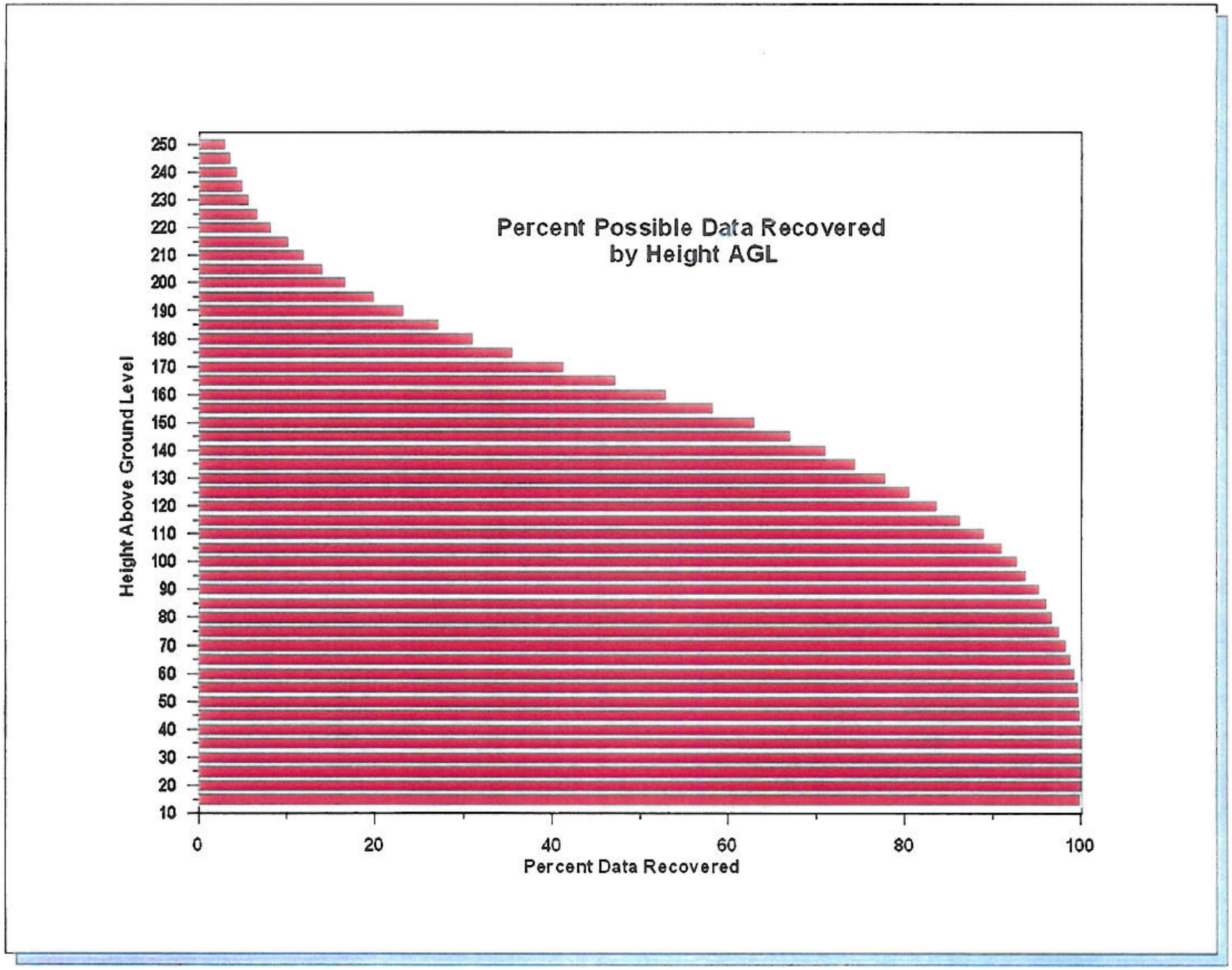


FIGURE 2-2: DATA RECOVERY PERCENTAGE BY HEIGHT ABOVE GROUND LEVEL

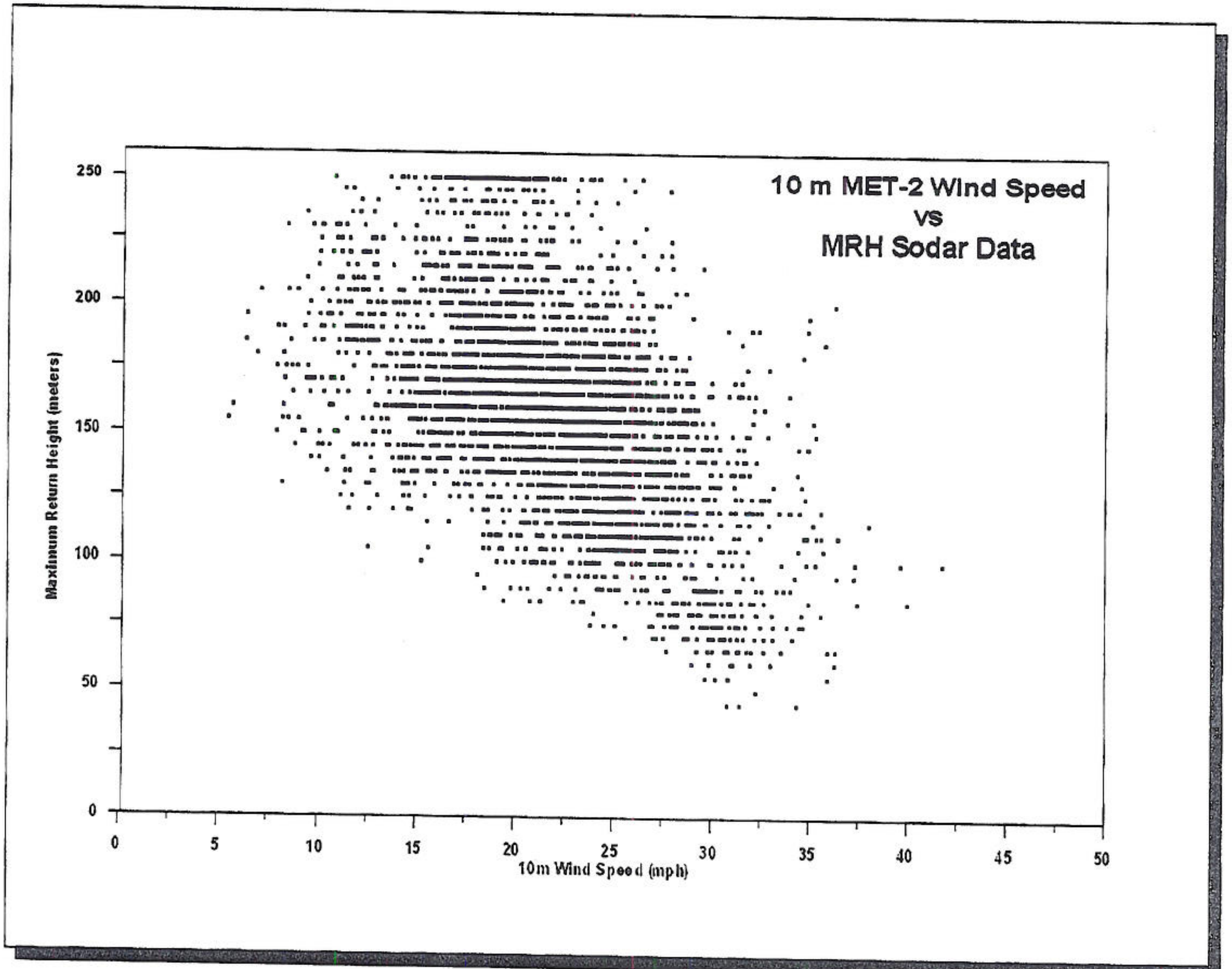


FIGURE 2-3: 10 m MET-2 WIND SPEED AND MAXIMUM RETURN HEIGHT FROM SODAR DATA

3.0 DATA ANALYSIS AND SUMMARY

This chapter provides a summary of the data collected from both the SODAR and MET-2 instrumented meteorological tower and calculated shear values.

Data used for this analysis were derived from data tables generated by the SODAR and data received from the on-site instrumented meteorological tower, MET-2. The goal of the project was to investigate the shear exponent at various heights AGL and the relation of those calculations to options for turbine hub height and blade selection. Meteorological conditions during the project were consistently clear and windy. A front did go through the area in mid-June which switched wind to the north temporarily. Occasional cloudy conditions were encountered, but they were rare. No significant precipitation was observed at Location #2 during the project. Typically, this period is warm to hot, dry and very windy, and 2004 was no exception. A study of this type is typically a climatology of wind sampled over a specific period. Table 3-1 compares the 50 m wind speed data from both MET-2 and the SODAR.

To facilitate a reasonable analysis, wind speed was the parameter analyzed, along with the derived wind speed shear exponent and descriptive statistics.

The formulation for the shear exponent is described in Appendix A. SODAR data showed the shear exponent averaged 0.115 for the duration of the project (using the height range spanning 15 m to 150 m), but with extremes of -0.405 to 0.660. The average value is smaller than the 1/7th power law factor (0.142) that is widely used as a first guess, indicating somewhat less actual shear. However, this comment is relating an average to an average. Shear values over a shorter period will vary, as noted with the extremes above. This variation generally reflects atmospheric stability conditions as a function of time of day.

3.1 Comparisons

A comparison of MET-2 and SODAR 50 m wind speed shows a bias towards higher speeds with the SODAR, but still a general near-linear bias (Figure 3-1). For the overall dataset at 50 m AGL (equivalent to the height of a turbine hub), the average SODAR wind was biased 111% of the wind measured at MET-2 (Table 3-1). Maximum wind speed was 122%. Overall, the SODAR values were higher than those of the MET-2 Tower data. Wind rose diagrams from both sites are shown in Figures 3-2 (MET-2) and 3-3 (SODAR). These diagrams also include a numerical breakdown of the wind speed distribution by direction.

The data plots of wind speed vs. time (Figures 3-4 (SODAR) and 3-5 (MET-2)) show the diurnal pattern. Most locations have a diurnal wind pattern, with increasing wind speed from dawn to mid-afternoon during daylight and early evening hours, followed by a period of decreasing velocity overnight. This was the case at Montezuma Hills. The datasets plotted are not matched, but utilize all available data. Overall, they display similar trend, wind speed value differences notwithstanding.

Early in the project preparation period, a dataset from a met tower near Location #1 was received with a frequency distribution of the wind speed in 1 mph increments. A similar distribution for data from the met tower near Location #2 is plotted in Figure 3-6, which shows the frequency data as vertical bars. The four panels correspond to the four datasets (MET-2 at

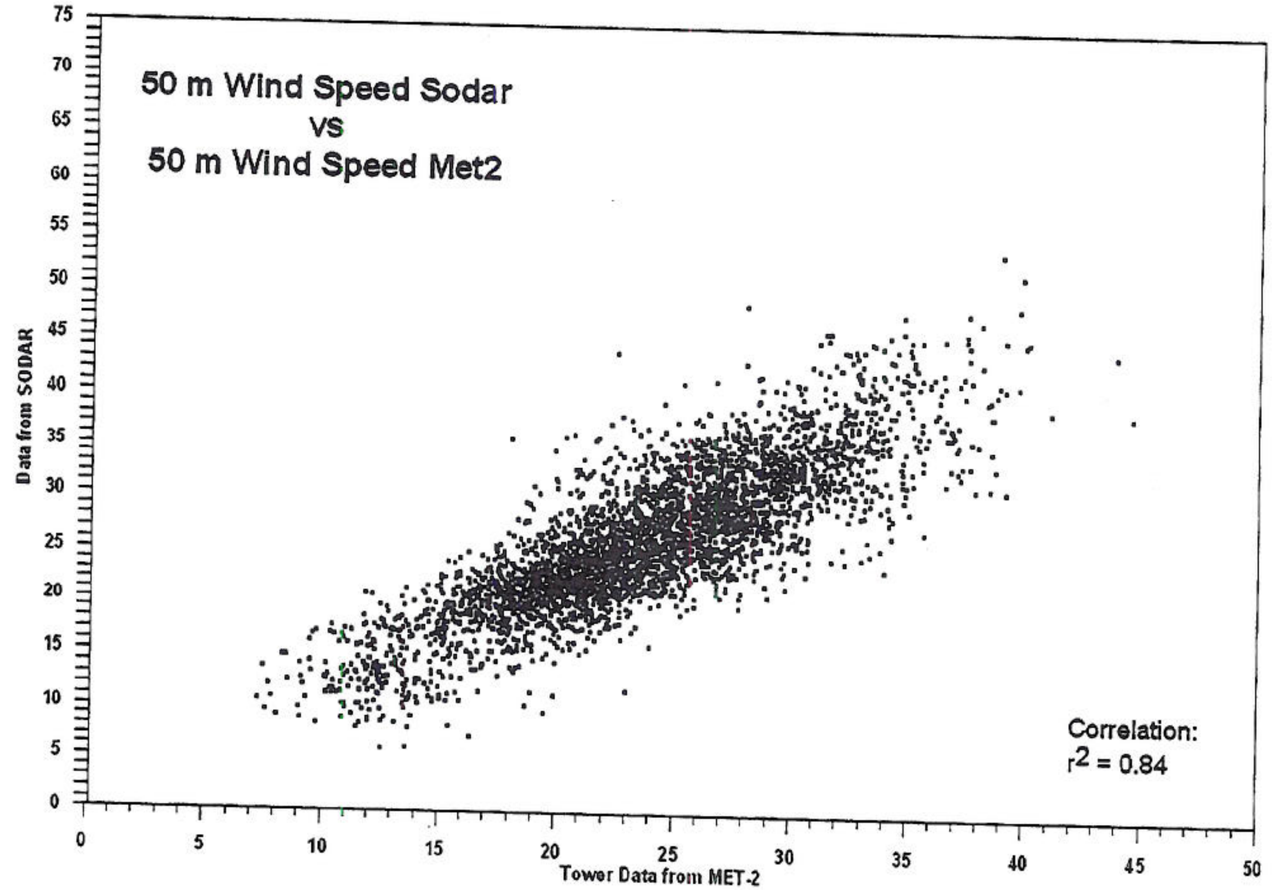


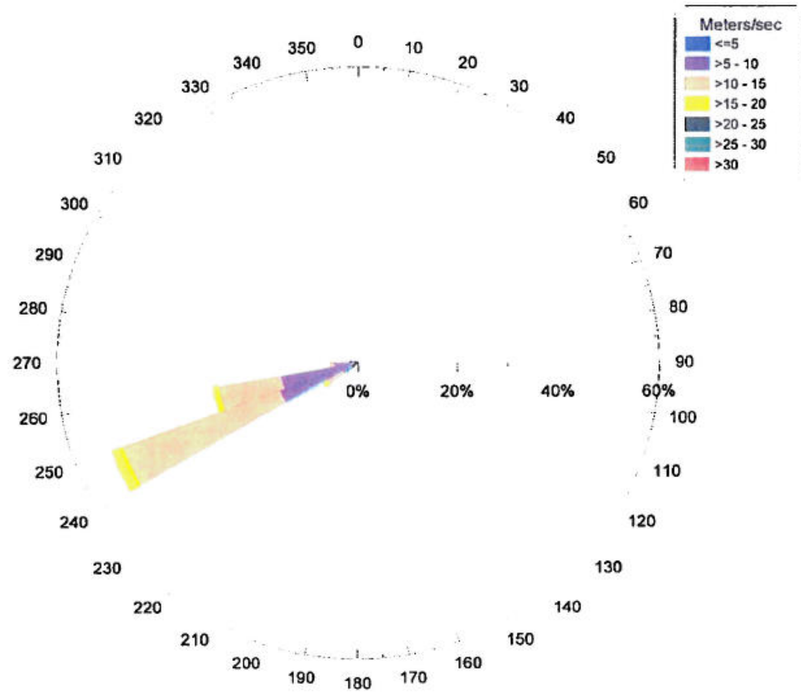
FIGURE 3-1: SODAR 50 m WIND SPEED PLOTTED AGAINST MET-2 50 m WIND SPEED (ALL DATA)

TABLE 3-1

COMPARISON OF AVERAGE 50 m WIND (MPH) SPEED BY DAY

Date	MET-2 Tower Data	SODAR Data	MET-2 Tower Data	SODAR Data
	Average 50 m		Standard Dev.	
May 31 [1]	23.5	15.9	1.7	2.8
June 1 [1]	20.5	25.3	5.3	2.0
June 2 [1]	22.2	28.6	4.4	2.3
June 3	25.3	28.1	3.6	2.2
June 4	25.7	27.7	5.4	2.7
June 5	25.3	28.4	4.1	2.8
June 6	30.1	33.6	6.8	3.6
June 7	25.2	28.3	4.0	2.5
June 8	18.4	19.7	2.8	1.5
June 9	19.8	24.4	6.1	2.7
June 10	18.9	20.6	4.3	2.4
June 11	19.8	21.2	4.1	2.0
June 12	20.5	22.1	5.9	3.1
June 13	25.3	29.2	3.4	2.2
June 14	18.4	21.5	4.3	2.7
June 15	16.1	17.2	4.1	2.3
June 16	24.0	25.7	7.3	3.4
June 17	26.9	30.4	2.9	1.7
June 18	25.9	28.2	4.5	2.3
June 19	28.1	31.9	4.8	3.2
June 20	26.1	29.7	4.9	3.0
June 21	25.9	29.1	4.3	2.5
June 22	22.3	24.2	3.6	1.7
June 23	25.2	27.5	4.3	2.4
June 24	25.2	27.9	3.4	2.0
June 25	27.2	30.2	4.6	2.7
June 26	25.9	29.2	3.3	2.1
June 27	18.5	20.3	4.2	2.5
June 28	20.7	26.3	4.1	3.6
All Data	23.3	25.9	5.7	4.0

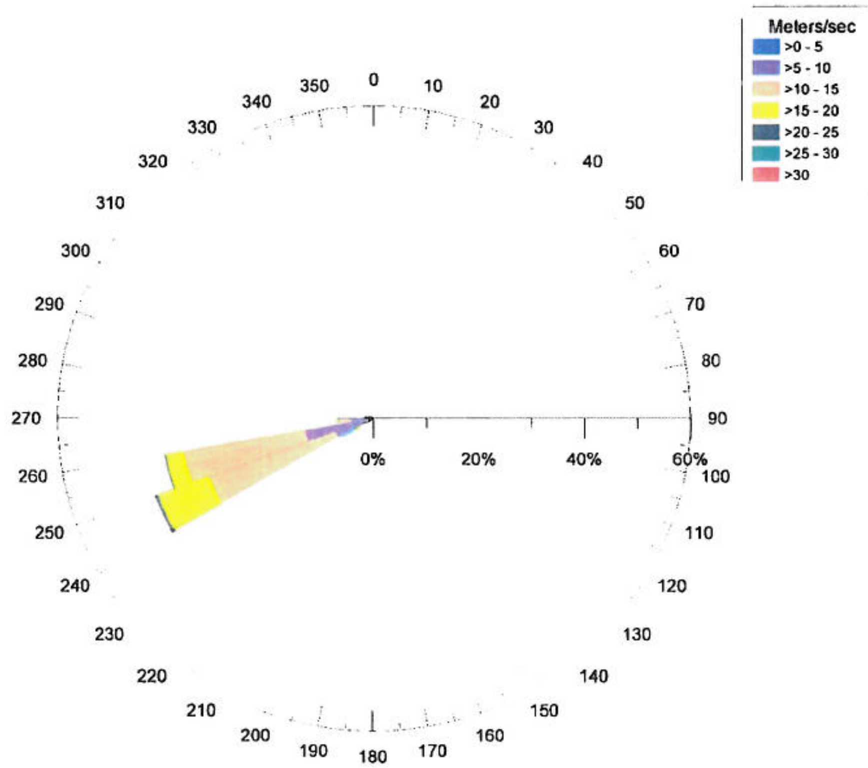
[1] These days have less than 50% data recovery. Results may not be representative.



Rio Vista Wind Energy Project - Rio Vista, CA
WIND ROSE ANALYSIS (PERCENT)
6/ 1/00 through 6/28/17
MET-2 Data All Hours

WIND DIRECTION	WIND SPEED (M/S) <= 1.5	<= 3.1	<= 5.1	<= 8.2	<=10.8	>10.8	TOTAL	AVG SPEED
N	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NNE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ENE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
E	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ESE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SSE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S	0.00	0.00	0.15	0.00	0.00	0.00	0.15	4.90
SSW	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SW	0.00	0.00	0.00	0.90	1.65	0.75	3.31	9.30
WSW	0.00	0.00	0.60	10.83	34.14	41.95	87.52	10.78
W	0.00	0.00	0.75	3.91	2.71	0.45	7.82	7.80
WNW	0.00	0.00	0.00	0.45	0.15	0.00	0.60	6.35
NW	0.00	0.00	0.15	0.15	0.00	0.00	0.30	5.30
NNW	0.00	0.00	0.00	0.15	0.15	0.00	0.30	7.15
CALM	0.00						0.00	
TOTAL	0.00	0.00	1.65	16.39	38.80	43.16	100.00	

FIGURE 3-2: 50 m AGL WIND ROSE FOR MET-2 DATA



Rio Vista Wind Energy Project - Rio Vista, CA
WIND ROSE ANALYSIS (PERCENT)
6/ 1/00 through 6/28/17
SODAR Data All Hours

WIND DIRECTION	WIND SPEED (M/S) <= 1.5	<= 3.1	<= 5.1	<= 8.2	<=10.8	>10.8	TOTAL	AVG SPEED
N	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NNE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ENE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
E	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ESE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SSE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S	0.00	0.00	0.16	0.00	0.00	0.00	0.16	4.50
SSW	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SW	0.00	0.00	0.00	0.49	0.33	1.48	2.30	10.67
WSW	0.00	0.00	0.33	5.74	25.74	55.25	87.05	12.10
W	0.00	0.00	0.49	1.64	4.43	1.80	8.36	9.21
WNW	0.00	0.00	0.33	1.15	0.16	0.00	1.64	6.49
NW	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NNW	0.00	0.00	0.16	0.16	0.16	0.00	0.49	6.70
CALM	0.00						0.00	
TOTAL	0.00	0.00	1.48	9.18	30.82	58.52	100.00	

FIGURE 3-3: 50 m AGL WIND ROSE FOR SODAR DATA

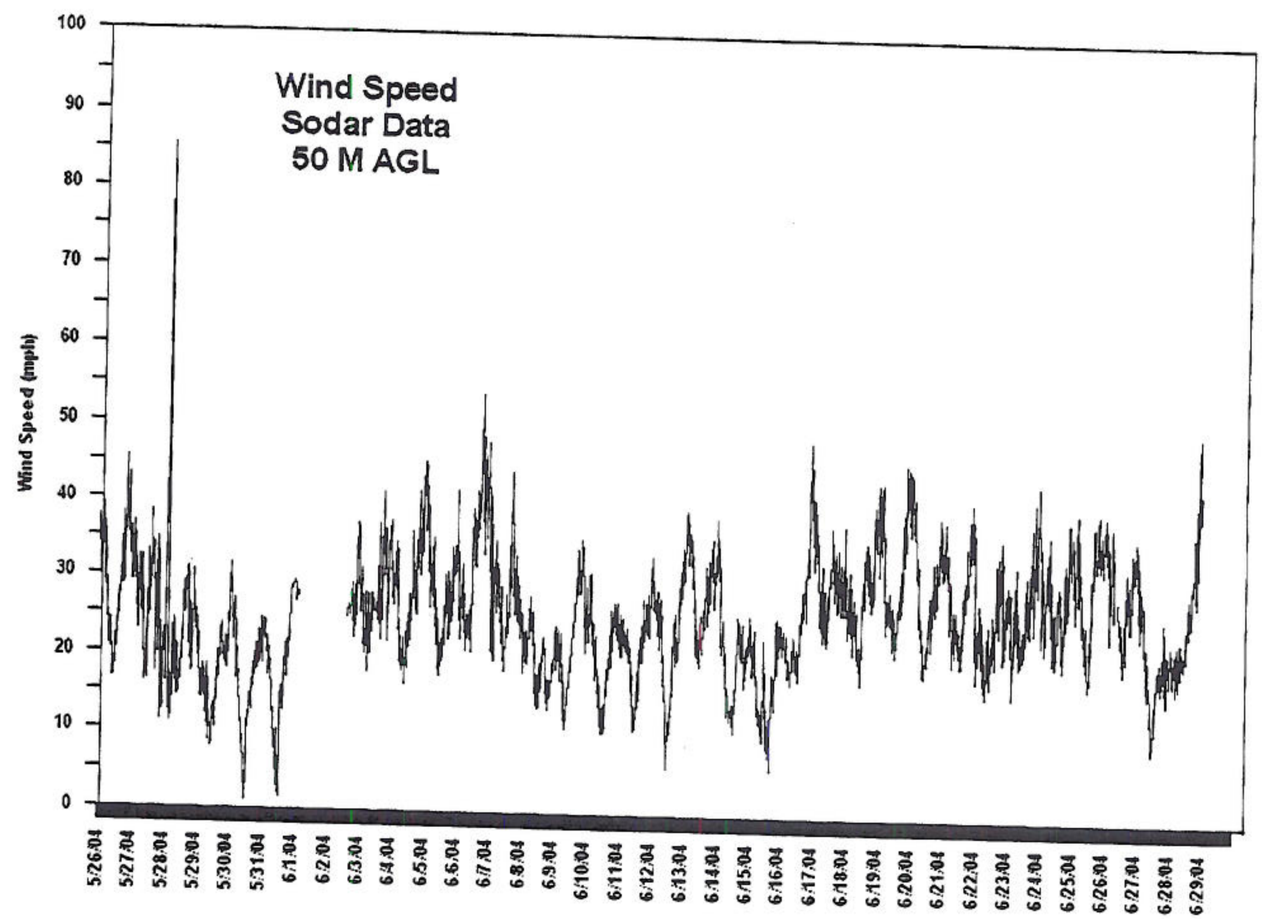


FIGURE 3-4: SODAR 50 m WIND SPEED (ALL DATA)

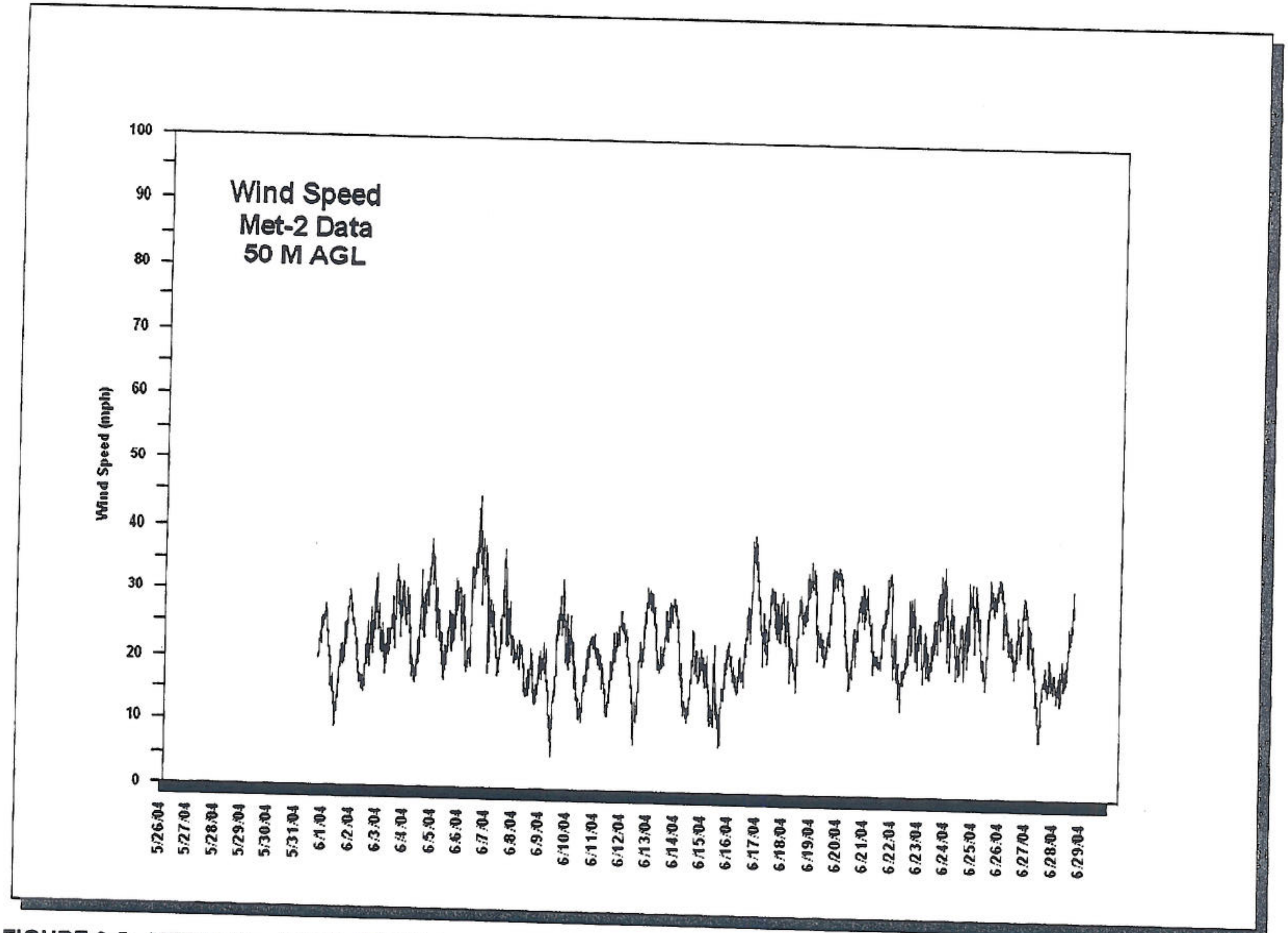


FIGURE 3-5: MET-2 50 m WIND SPEED (ALL DATA)

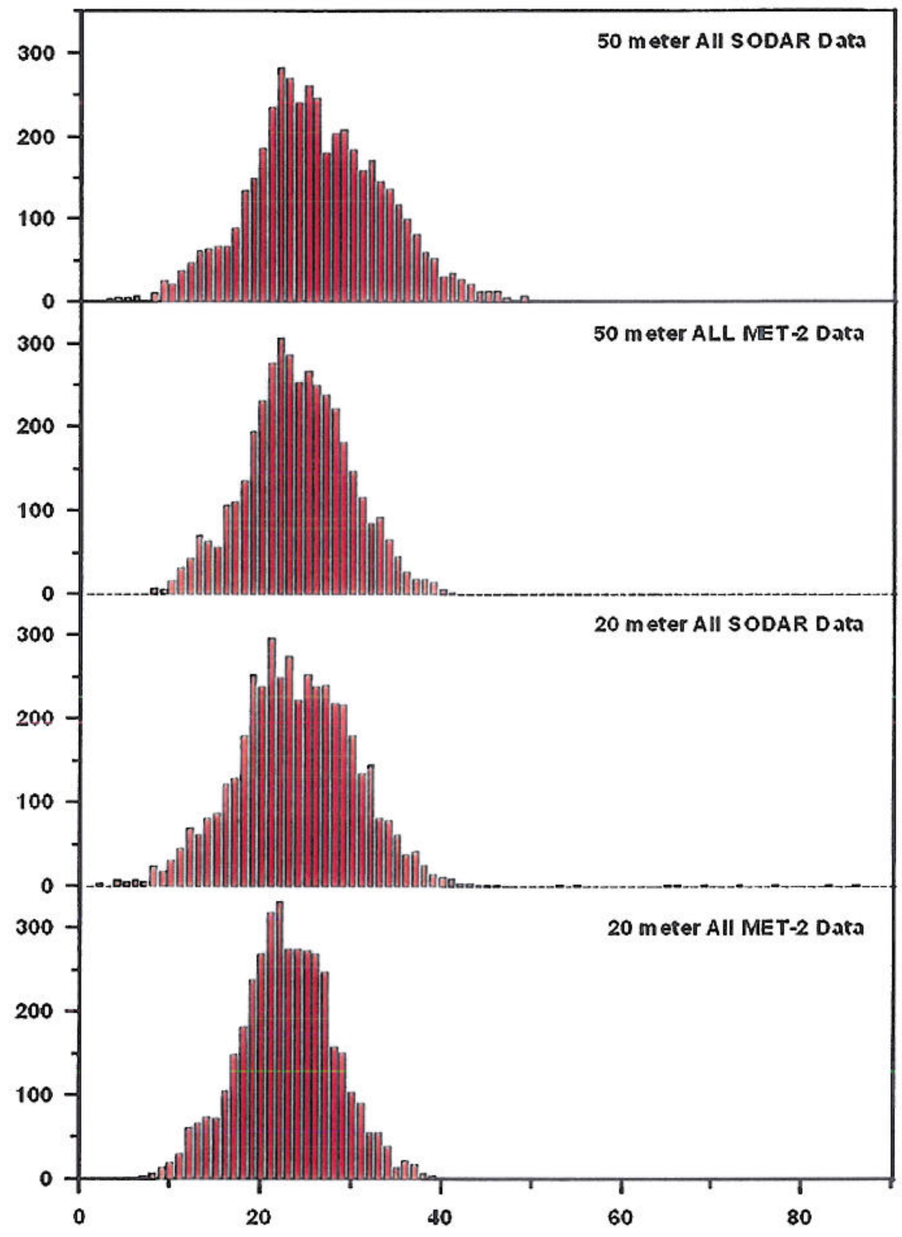


FIGURE 3-6: FREQUENCY DISTRIBUTION OF 20 m AND 50 m WIND SPEED DATA, MET-2 AND SODAR

20 and 50 m, and SODAR at 20 and 50 m). Both of the SODAR datasets are slightly more dispersed than the corresponding MET-2 data, as indicated by a slight horizontal stretching of the graph.

3.2 Analysis

The formulation for the wind speed shear exponent is described in Appendix A. The goal of the project was to investigate the shear exponent at various heights AGL and the relation of those calculations to options for turbine hub height and blade selection.

Meteorological data were available from 10 – 50 m AGL in 10 m increments. SODAR data were available from 15 – 250 m AGL in 5-m increments. This resulted in the span of 20 m to 50 m AGL as the largest vertical range that could be directly compared in the two datasets. A comparison of the 20 to 50 m wind speed shear and the 50 m wind from the same dataset are shown in Figures 3-7 and 3-8. MET-2 data are rather tightly clustered with respect to the shear exponent, indicating the wind shear exponent does not vary greatly with wind speed. SODAR data cluster the other way, indicating significantly greater variation in wind shear as a function of wind speed. 20 to 50 meter shear exponent values exceeded the $1/7^{th}$ power law exponent of 0.142 in the 20 to 50 m SODAR dataset 19.7% of the time and in the MET-2 dataset, 1.3%.

Above 50 m, a similar comparison was made for SODAR data only, using the 100 m wind. Figure 3-9 shows that the data are dispersed, with data clustering roughly above and below the 0.142 value.

A comparison of all 50 to 150 m shear exponent data by time of day (Figure 3-10) shows a diurnal pattern related to the effect of solar heading and mixing. The exponent is high overnight until near local sunrise when the heating and mixing effects start to be seen. During mid-day and into late afternoon the shear exponent actually goes negative for a few hours indicating that the wind speed is higher near the surface than aloft.

Analysis of all the SODAR data in 10-m layers in Figure 3-11 indicates the shear exponent increases to a height of approximately 100 m AGL, then decreases. Since these data are plotted by layer, the effects of time-of-day are not shown. Comparing this figure with Figure 3-10 gives an indication of the time-of-day of maximum shear and the level at which that shear may occur.

Extrapolation of these data into a meaningful example is shown in Figure 3-12 where an 80 meter hub was paired with a 90 meter blade diameter. This gives a lower height of 35 meters and an upper height of 125 meters. The shear exponent values varied from -0.572 to +1.073 at the extremes, with an average of 0.155 for the entire dataset. The large positive value is a result of a near 3:1 difference in wind speed from 35 meters to 125 meters recorded at one time period. It appears the high-speed layer is oscillating in height and this happened to catch one of the peaks at that level. Removing that data point from the set gives a max value of 0.615. A more modest set of values between 0.35 and -0.05 contains > 90% of the data points. This is for the entire dataset, and as the figure shows, this varies both diurnally and over a period of time due to varying synoptic conditions.

Investigation of additional scenarios is possible through the use of the spreadsheet described in Appendix B.

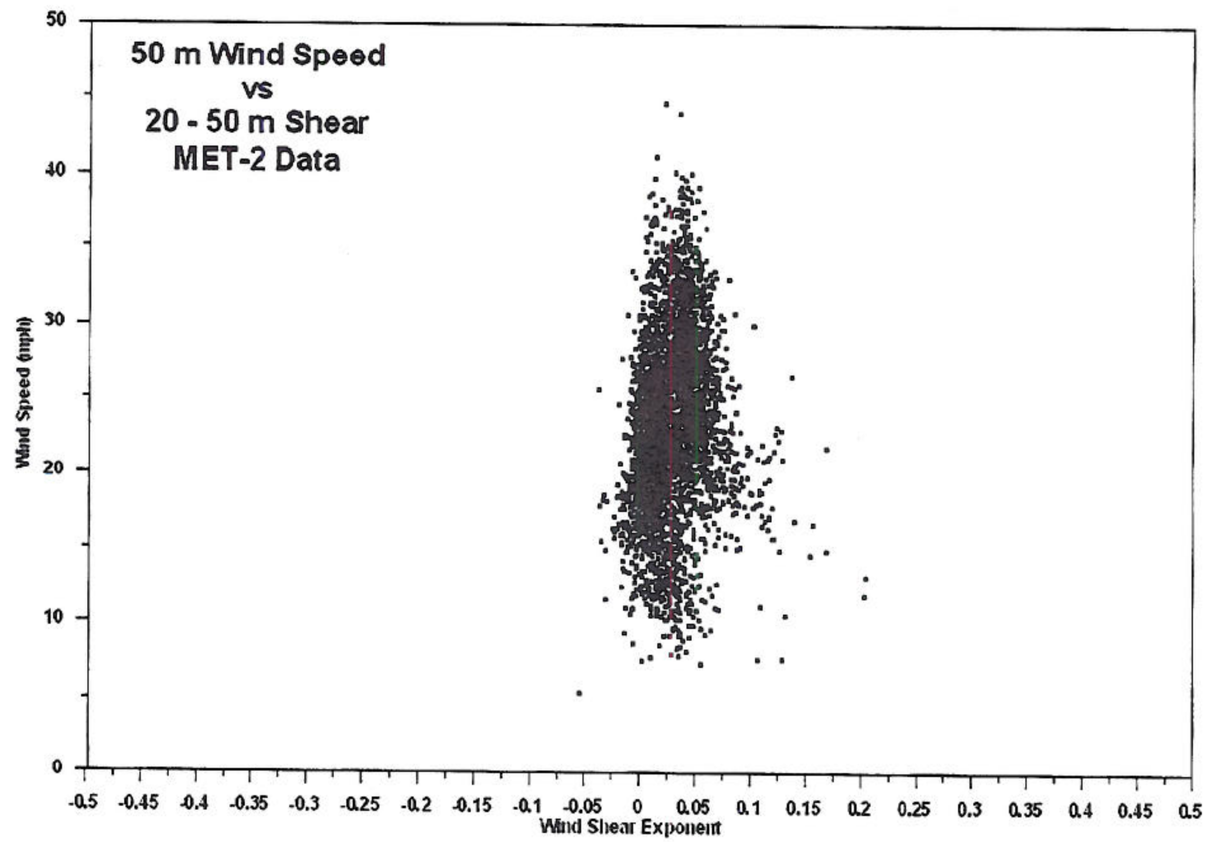


FIGURE 3-7: COMPARISON OF 50 m WIND SPEED AND 20 TO 50 m SHEAR EXPONENT – MET-2 DATA

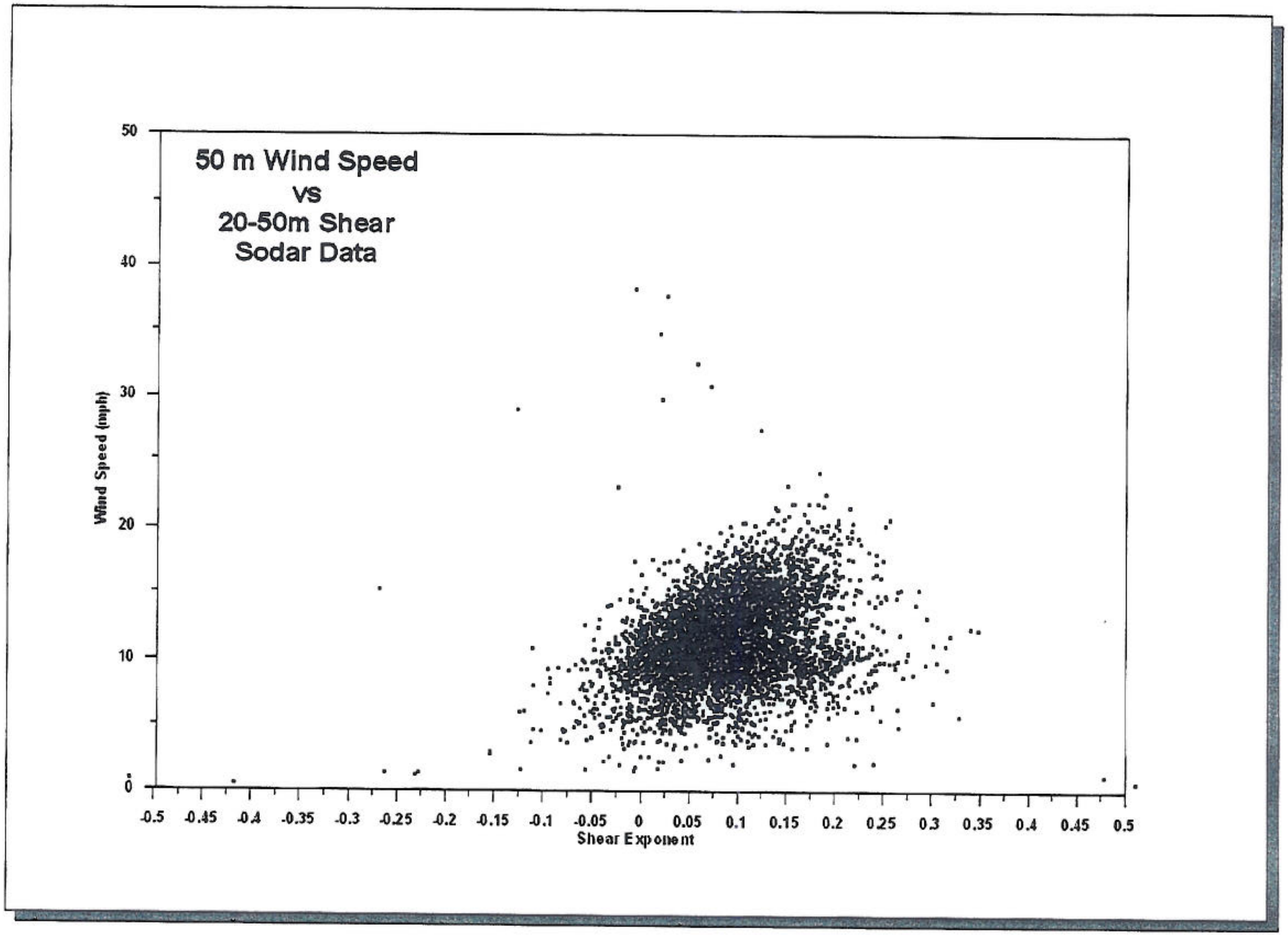


FIGURE 3-8: COMPARISON OF 50 m WIND SPEED AND 20 TO 50 m SHEAR EXPONENT – SODAR DATA

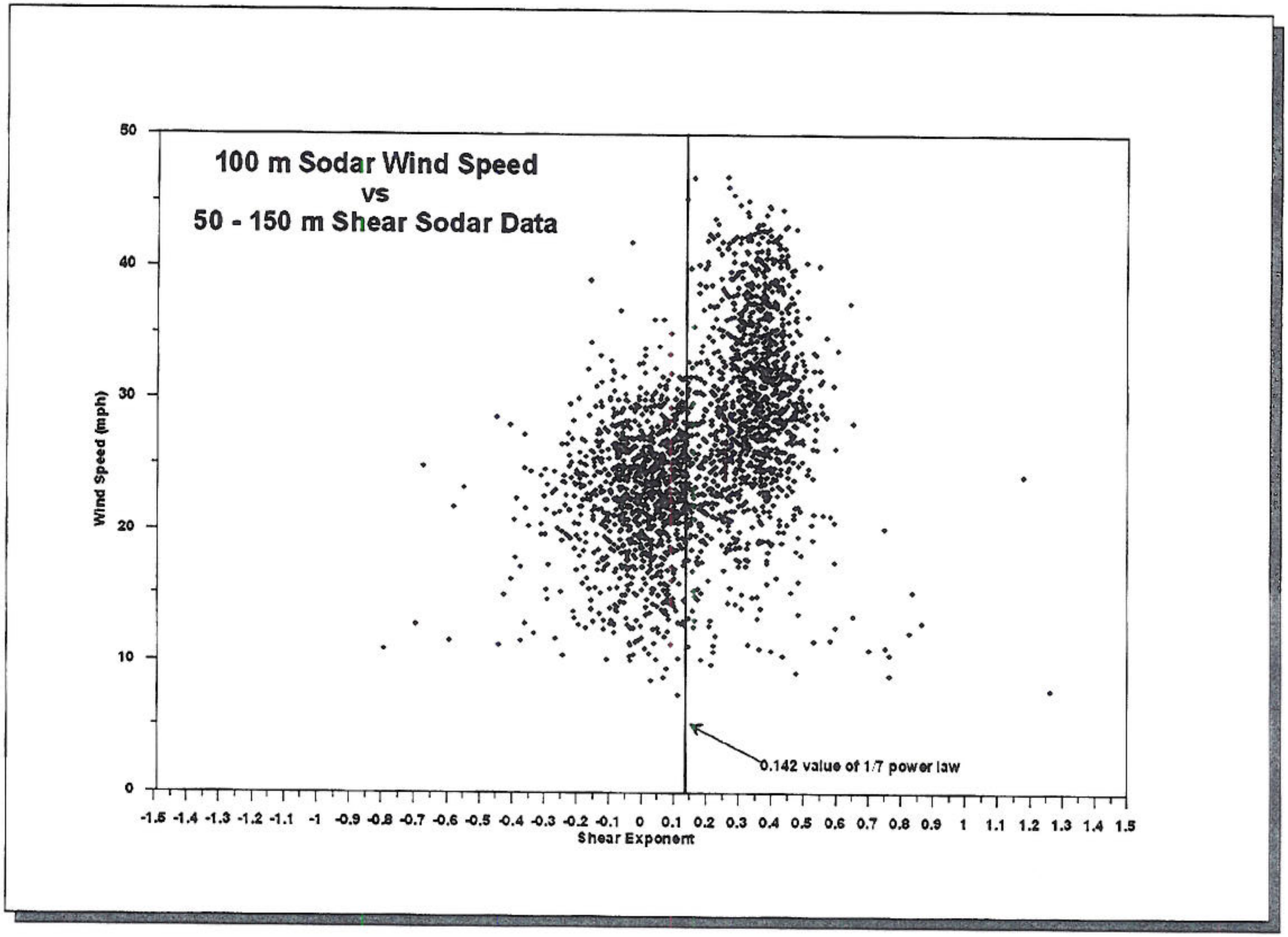


FIGURE 3-9: 100 m SODAR WIND SPEED AND 50 TO 150 m WIND SPEED SHEAR EXPONENT

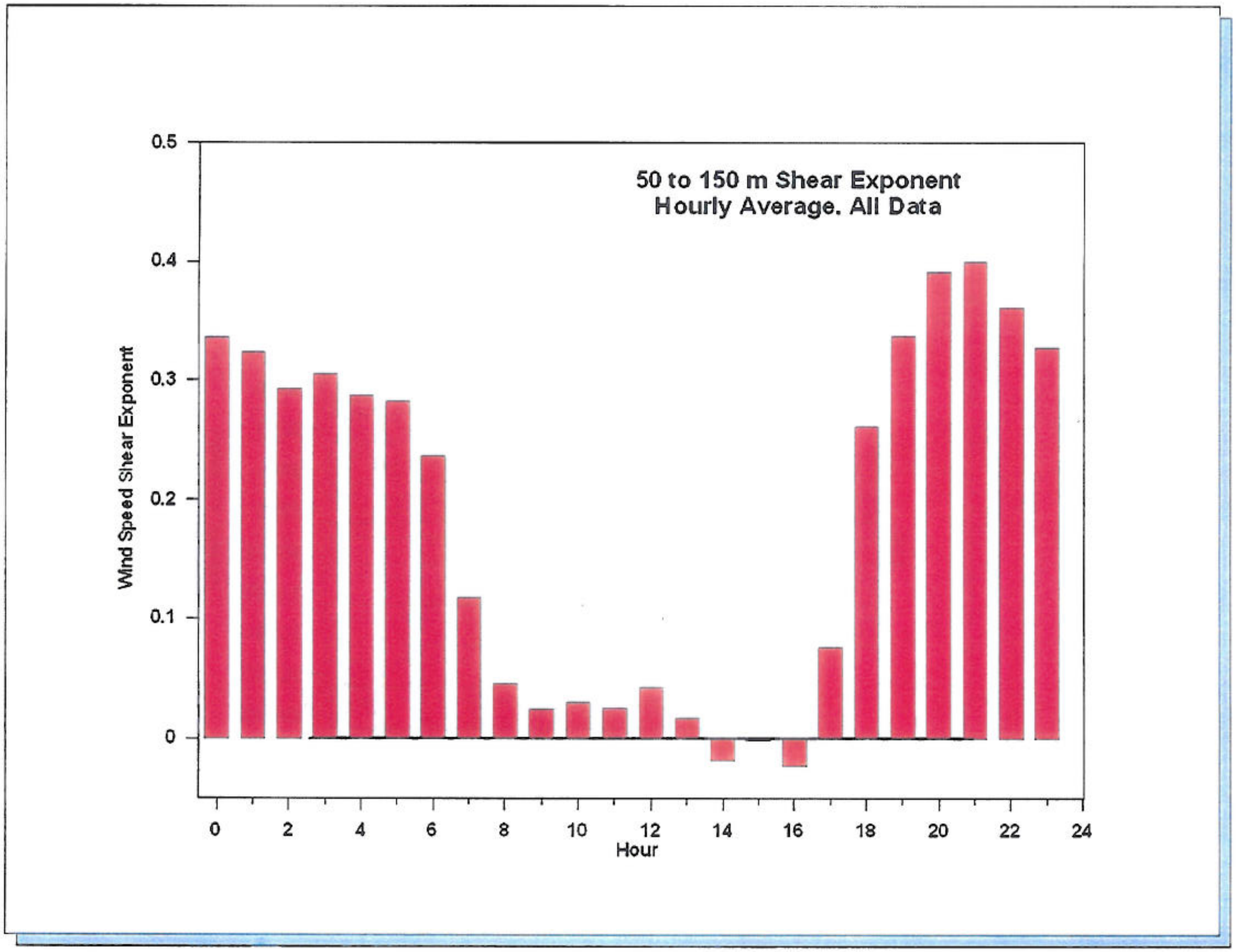


FIGURE 3-10: DISTRIBUTION OF 50 TO 150 m SODAR WIND SPEED SHEAR EXPONENT BY HOUR OF DAY (ALL DATA)

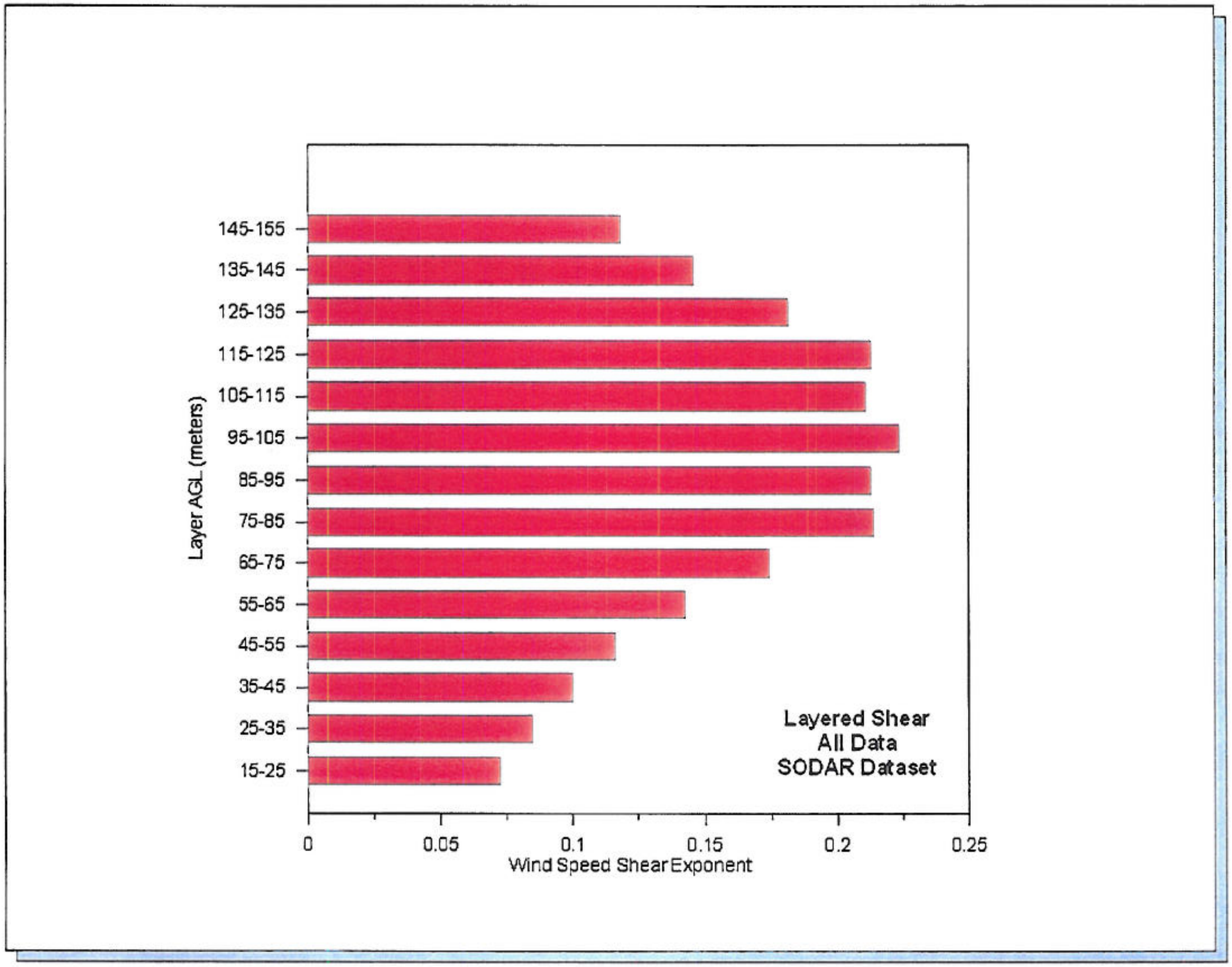


FIGURE 3-11: WIND SPEED SHEAR EXPONENT AVERAGES BY 10 m LAYERED HEIGHT

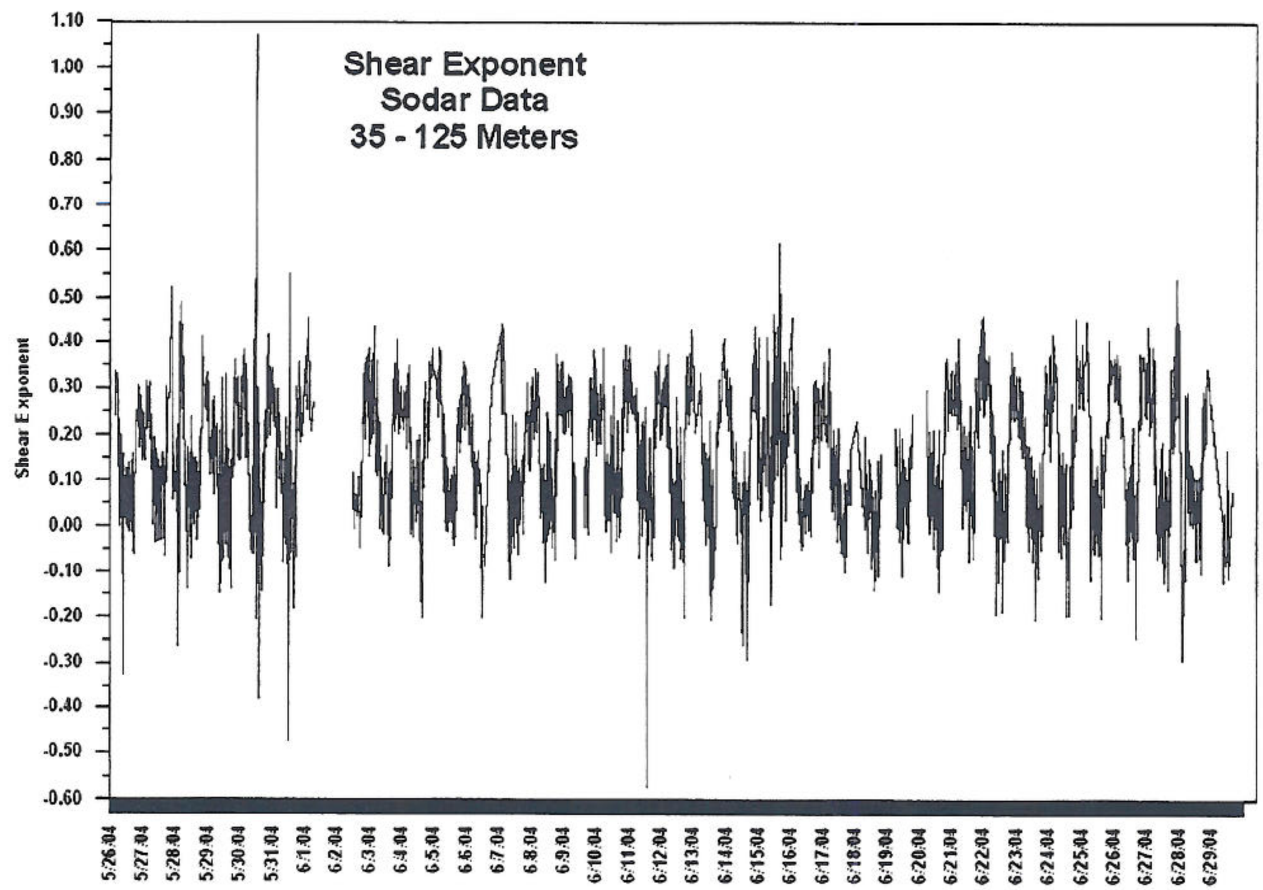


FIGURE 3-12: SHEAR EXPONENT 35 TO 125 m AGL – SODAR DATA (PRACTICAL EXAMPLE)

4.0 REFERENCES

SECOR Project Proposal, February 13, 2004

Doppler MiniSODAR™ System, Operation and Maintenance Manual, April 2001, AeroVironment, Inc.

SodarPRO, SODAR Operator Manual v5, 2003, AeroVironment, Inc.

"Evaluations of Wind Shear Patterns at Midwest Wind Energy Facilities", NREL/CP-500-32492, May 2002, National Renewable Energy Laboratory, Golden, CO.

An Introduction to Boundary Layer Meteorology, Roland B. Stull, 1988. QC880.4.B65S784 1988. ISBN 90-277-2769-4.

APPENDIX A
DATA PROCESSING SPECIFICATIONS AND STATISTICAL FORMULA

Rio Vista Wind Project Final Report
May 2005
SECOR Project No: 12OT.59000.04

DATA PROCESSING SPECIFICATIONS AND STATISTICAL FORMULA

A.1 Data Recovery Percentage

The data recovery percentage, P_t, for each measured meteorological parameter is determined by:

$$P_t = \frac{h_v}{h_t} \times 100$$

where: h_v = number of hours of valid data for continuous data

h_t = total hours in the period for continuous data

A.2 Wind Speed Conversion Factors

Wind speeds as provided from MET-2 were received in mph. SODAR wind speeds were recorded in meters/sec.

For certain comparisons, SODAR wind speeds (meters/sec) were multiplied by a factor of 2.23694 to convert to mph (statue miles).

When needed, MET-2 wind speeds (mph) were multiplied by a factor of 0.44704 to convert to meters/sec.

A.3 Shear Exponent Calculation

Wind shear is defined as the change in horizontal wind speed with a change in height. Generally a higher shear exponent value means the wind speed increases more rapidly as height increases (as compared to a lower shear exponent value). An assumption is usually made that wind speed increases with height, but that is not necessarily always the case and can result in negative shear values if the wind speed decreases with height. The wind shear exponent (α) is influenced by site-specific characteristics. The $1/7^{th}$ power law value of 0.142 is generally used for the initial site screening, but care should be used in developing a project based solely on this value. Actual shear values may (and usually do) vary considerably from this value. The basic equation is:

$$\frac{V_2}{V_1} = \left[\frac{H_2}{H_1}\right]^{\alpha}$$

Solving the equation above for α provides the following:

$$\alpha = \frac{\ln\left[\frac{V_2}{V_1}\right]}{\ln\left[\frac{H_2}{H_1}\right]}$$

where

V2 = wind speed at height H2
V1 = wind speed at height H1

and

H2 > H1 (NREL 2002)

The wind shear exponent typically ranges from 0.10 to 0.25. A low exponent corresponds to smooth terrain (e.g., sea, sand and snow from 0.10 to 0.13), whereas a high exponent is typical of a terrain with sizeable obstacles. This value is used to calculate the average wind shear at the wind turbine hub height and at 10 m.

APPENDIX B
SPREADSHEET CONTENT AND USE

Rio Vista Wind Project Final Report
May 2005
SECOR Project No: 12OT.59000.04

Spreadsheet name: RVWP-Met2-Sodar-Data.xls
Format: Microsoft Office XP, Microsoft Excel Workbook

The spreadsheet contained on the enclosed CD-ROM is designed to serve several functions:

- First, it contains an archive of the recovered SODAR wind speed and direction data by height for all of the validated 10-minute interval data. These are located in the dated pages (May26 through Jun29) located after the analytical sheets. MET-2 data are located in the Met2-Data page (leftmost tab).

- Second, it is the main analytical tool used to both calculate the shear exponent values and summary statistics.

- Third, it provides a means of experimentation with the lower and upper heights between which the shear exponent is calculated. This allows the user to consider differing tower/hub heights and blade diameter combinations. These (items 2 and 3) are located to the left in the worksheet tab listing at the bottom left of the program. A more comprehensive description follows.

The spreadsheet is large (approx 15Mb), and will take a few moments to load on most computers. It was saved as an Excel 2003 file from Microsoft Office 2003. No encryption or other security methods were used in this spreadsheet. It is being delivered on a CD-ROM which will provide a backup version that cannot be changed. The user should copy the file from the CD-ROM to his/her internal hard drive for faster performance.

There are only a few pages that should be used. They are;

- Shear Calc (for SODAR data entry),
- Met2-Shear (for MET-2 data entry),
- Met2-Speeds (to view the wind speeds at various levels).

ShearCalcMet provides a printable view of the shear exponents for the heights specified on the Met2-Shear page together with some statistical information at the bottom of the page.

The SODAR Wind pages can extract a wind speed from a specific level within the daily data pages. This is useful as an upper and lower bound could be used to analyze shear within a range of wind speeds.

The main page to access the SODAR data is the Shear Calc tab. The heights are entered in cells B3 (upper) and B4 (lower). The results appear in the table below, but it is better to view the results on the Shear-Print View page. Better descriptions of the data are at the top of this page, along with the MRHL (Maximum Return Height Lower than upper height specified (i.e., no data)) cells being blank.

The MS-comp-temp pages contain comparisons of the 50 and 20 meter level winds. These levels were chosen because they represent the lowest and highest level of the adjacent Meteorological tower (MET-2) that can be compared with SODAR data. Tables include the MET-2 and SODAR data as well as a difference/summary table for each level.

The MRH page contains the maximum returned data level of the SODAR. This page serves as an input to the shear calculation page by limiting shear calculations to levels which have valid data.

The Sodar-MetShearComp page contains comparisons of MET-2 and SODAR data at several ranges. Tables on the right represent differences of the wind speed at 10 – 50 m AGL (using the lowest SODAR level of 15 m and the lowest MET2 level of 10m), and 20 – 50 m AGL (identical levels for both datasets). Raw data values are on the left (MET-2) and center (SODAR). Some statistical information is shown for the individual datasets at the bottom of the tables to the right. Invalid data have been removed from the datasets to calculate these statistics.

Dated pages beyond these contain the validated 10 minute data by date for the project period.

TABLE B-1 CONTENTS OF VARIOUS SPREADSHEET PAGES

Page Name	Contents	Purpose
Met2-Data	All Met2 data received on L, shear exponent table on R, Time Adjusted data	Calculation of Shear Exponent data from Met2 data
Met-Speeds	Wind speed table from Met2-Data by height	Calculate average vv for Met data by level by day, mph and m/sec
ShearCalcMet	Table of shear exponents, Time Adjusted data (PST), referenced to Met2-Data	Shear exponent table with stats on bottom, printable
Sodar Wind 1	Winds at a specific level can be displayed from the daily data pages in a table by time period and date..	Can be used in determining a range of wind speeds to analyze with upper level on one page, and lower on the other.
Sodar Wind 2		
ShearCalc	Main Shear Calculation Page for Sodar, PST (working page)	Shear Calculations, enter levels in B3 and B4
ShearCalc Temp	Copy of Shear Calc Page	Comparison with ShearCalc and Sodar Wind 1 and 2 pages
Shear-Print-View	Printable Page, Basic Statistics, 2 tables: Sodar calc, 10-50m Met2 fixed, Data in PST	Show results from ShearCalc and reference tables
MS-comp-temp	Old table	Printable tables, stats and differences
MS-comp-temp 50M	3-tables, Raw 50m Met2 data, Sodar 50M DD/VV data and comparison data, Time Adjusted data (MET-2 minus SODAR)	Printable tables, stats and differences
MS-comp-temp 20M	3-tables, Raw 20m Met2 data, Sodar 20M DD/VV data and comparison table, Time Adjusted data (MET-2 minus SODAR)	Printable tables, stats and differences
Sodar Temp	Listing of 50m and 20 m dd/vv Sodar data, PST	Input to Met-Sodar Comparison tables (MS-comp-temp 50 and 20)
MRH	Maximum Return Height of Sodar Data and Stats, PST	QA/QC of Sodar data (statistics), printable table
Sodar-MetShearComp	Tables: Met2 10-50m, Sodar 15-50m and comparison, Met2 20-50m, Sodar 20-50m and comparison, Time Adjusted data	Data comparison, summary statistics, printable tables
GrapherData	Specific datasets for graphing	Input data to grapher 4 program, graphs in this report
Daily Data Files (May26 → June29)	Recovered Sodar wind table data, 26 May to 29 June	Input data to shear calculation pages

As a result of telecommunications and computer difficulties, several time periods of SODAR data were not recorded completely. These tables/periods do have valid data, but did not recover data down to the 15 m minimum level. These time periods are denoted by light blue shading in the spreadsheet daily data pages and listed in Table 2-1 since they produce non-critical anomalies in the shear exponent calculations (####) performed in the spreadsheet.

TABLE B-2: TIME PERIODS WHERE MINIMUM RETURN HEIGHT IS > 15 m AGL

Date	Time Period	Invalid Data Levels	Minimum Return Height (SODAR)
5-31	1740-1750	15-20	25
5-31	1820-1830	15-20	25
6-9	0840-0850	15-30	35
6-10	1240-1250	15-30	35
6-11	1420-1430	15	20
6-22	1540-1550	15-30	35
6-24	1140-1150	15-30	35
6-26	0640-0650	15-30	35

APPENDIX C
DIGITAL FILE CONTENTS

Rio Vista Wind Project Final Report
May 2005
SECOR Project No: 12OT.59000.04

****
Rio Vista Wind Energy Project
May 3, 2004 through June 29, 2004
3 CD-ROMs enclosed
****

These CD-ROMs contain validated tabular data and invalidated binary data from the AeroVironment, Inc., MiniSODAR 4000 which was operated and maintained by SECOR International Incorporated (SECOR) during May and June of 2004.

Validated data for the period from May 26, 2004 - June 29, 2004, are included on these CD-ROMs. Non-validated data for the period May 3, 2004 to May 26, 2004 are also included on these CD-ROMs.

Datafolders are named utilizing the letter 'A' for ascii data followed by the Julian date, or 'S' for binary data followed by the Julian date. A Julian date to Calendar date conversion table is located on the next page.

Individual datafiles are named in a similar format with the 'A' or 'S' followed by the Julian day followed by the hour the file began. This means the file a1480800 contains tables from May 27th, 2004, from 0800 to 0850 PST. Binary 'S' files follow the same naming convention.

Sodar Data were recovered in PST.
MET-2 Data were collected in PDT.

Validated data are contained on the attached Excel spreadsheet. Raw datafiles consist of tables and binary files. AeroVironment software is required to view the binary files. Binary files are not used for this project and are not contained in the Excel spreadsheet.

CD-ROM 1 contains:

Excel Spreadsheet
Final Report
ASCII Datafiles (Tables) from May 26, 2004 to June 29, 2004
Binary Datafiles from May 26, 2004 to June 8, 2004
NWS METAR data May 1 to June 30, 2004 for KSUU - Travis AFB ASOS
METAR decoding documents

CD-ROM 2 contains:

Binary Data from June 9, 2004 through June 29, 2004

CD-ROM 3 contains:

ASCII Datafiles (Tables) from May 3, 2004 to May 26, 2004
(files A146 and A147 contain partial data)

Binary Datafiles from May 3, 2004 to May 26, 2004
(files S146 and S147 contain partial data)

Calendar Date	Julian Day	Calendar Date	Julian Day
		June 1	153
		June 2	154
May 3	124	June 3	155
May 4	125	June 4	156
May 5	126	June 5	157
May 6	127	June 6	158
May 7	128	June 7	159
May 8	129	June 8	160
May 9	130	June 9	161
May 10	131	June 10	162
May 11	132	June 11	163
May 12	133	June 12	164
May 13	134	June 13	165
May 14	135	June 14	166
May 15	136	June 15	167
May 16	137	June 16	168
May 17	138	June 17	169
May 18	139	June 18	170
May 19	140	June 19	171
May 20	141	June 20	172
May 21	142	June 21	173
May 22	143	June 22	174
May 23	144	June 23	175
May 24	145	June 24	176
May 25	146	June 25	177
May 26	147	June 26	178
May 27	148	June 27	179
May 28	149	June 28	180
May 29	150	June 29	181
May 30	151		
May 31	152	Grey - Primary Data Collection Period	

TABLE C-1: JULIAN DAY TO CALENDAR DAY REFERENCE