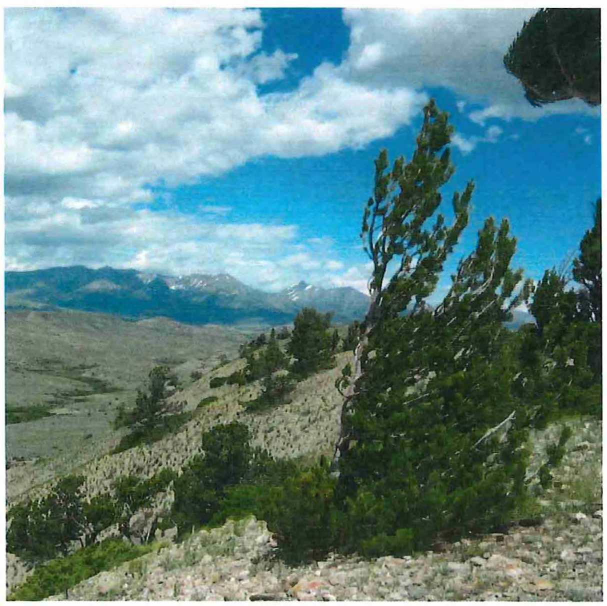
Preliminary Wind Resource Analysis for Camp Ripley, Minnesota



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Document History

Version	Date	Reviewed by	Comments
1.0 DRAFT A	7/7/14	John Bosche	Initial issue
1.1 FINAL	7/18/14	John Bosche	Added 225, 275 kW turbines and glossary

Disclaimer

Report
Camp Ripley PWRA 1.1 FINAL_140717.docx

Classification
CONFIDENTIAL

Report Standard
REVIEW

Status
FINAL

Key to Report Standard

Assessment: Full assessment of the subject of the report, including uncertainty analysis and review from senior-level staff

Review: A review of provided data to give an estimate of the resource, conditions or other information, and does not include detailed analysis, uncertainty evaluations or full review

Key to Classification

Strictly Confidential: For recipients only

Confidential: Can be distributed within clients organization

Internal: Not to be distributed outside Chinook Wind

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Published: No restriction

Contents

List of Figures

List of Tables

1.0 Introduction

The Minnesota National Guard tasked Chinook Wind and Barr Engineering to provide an initial evaluation of the wind resource at Camp Ripley, Minnesota, using data collected from a 6-month SoDAR study on-site. The Atmospheric Systems Corporation (ASC) Model 4000 SoDAR collected data from November 26, 2013 to May 31, 2014, in the southwestern portion of the 53,000 Camp Ripley campus at an elevation of 377 meters above sea level (ASL). The location of the SoDAR with respect to Camp Ripley and the surrounding area is presented in Figure 1.1. Chinook Wind's evaluation of the site includes an analysis of the collected data, correlation to long-term references, and the potential energy production for a single turbine at the site.

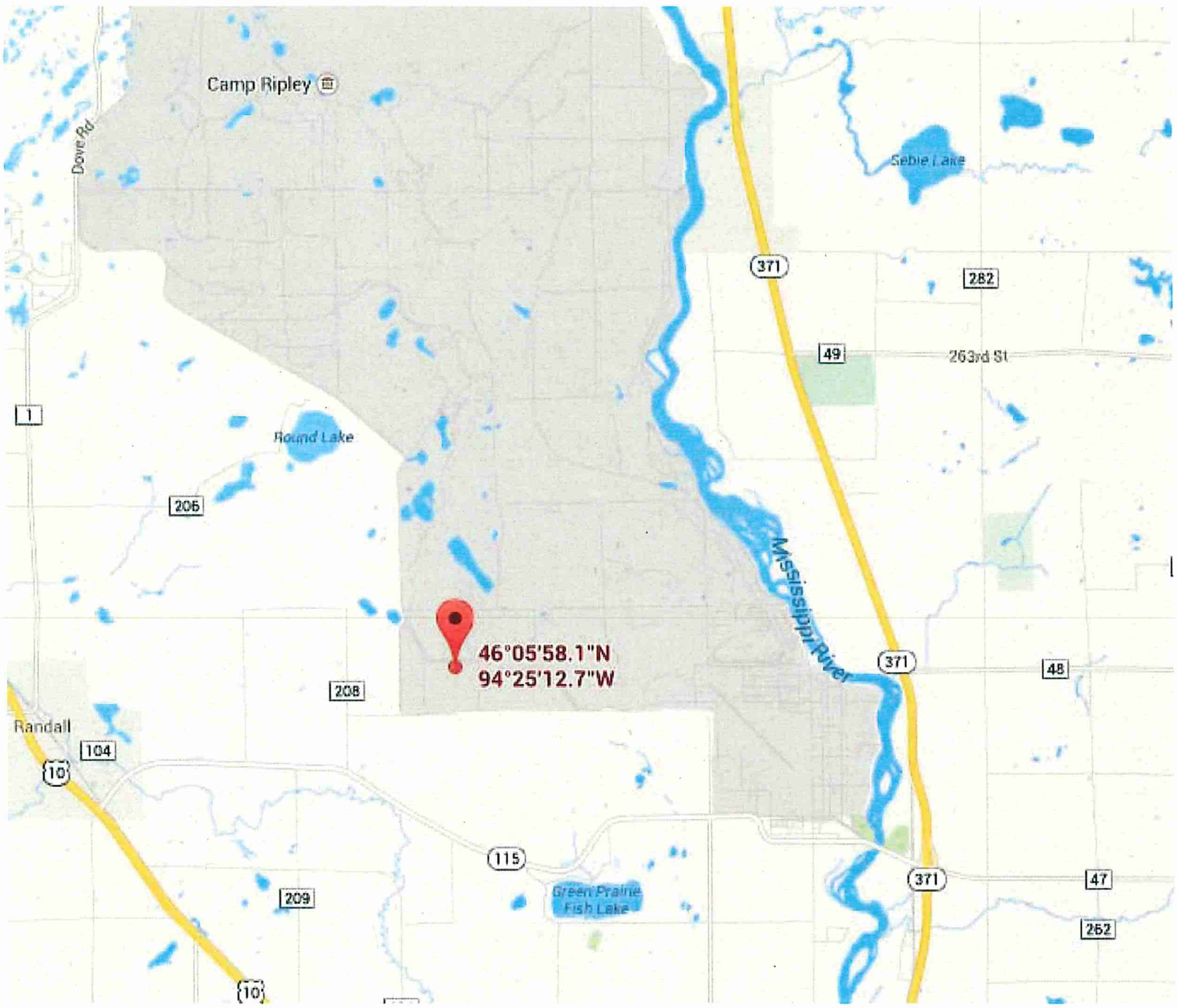

Figure 1.1 SoDAR Location on Project Area

2.0 Site Data

This analysis used wind data collected from the ASC Model 4000 SoDAR, which collected data at 5-meter increments from 30 meters to 150 meters above ground level. Commissioning documentation is included in Appendix C. The SoDAR operates by emitting an audible sound 'chirp' vertically into the air, which reflects off atmospheric turbulence. The SoDAR then measures the Doppler shift of the sound pulse and converts it to horizontal and vertical wind speeds and directions. This enables the analysis of the vertical wind profile from 30- to 150-meters above ground. The SoDAR is essentially a virtual meteorological tower that provides valuable information on how the winds at a site vary with height.

Data collection at the Camp Ripley site began on November 26, 2013, and continued through May 30, 2014. Data recovery has been reasonably good, with some data loss in December due to weather conditions. Chinook Wind reviewed and validated the raw data to remove erroneous values from the dataset. Some data were invalidated during intense snowfall and rainfall events when the SoDAR did not perform well. Mean data recovery during the 6-month period was 92% at 80-meter hub height. Table 2.1 presents the mean wind speeds, in meters per second (m/s) and data recovery for the SoDAR at 30, 60, 80, 100, and 150 meters. Figures 2.1 and 2.2 present the wind frequency rose and energy rose at 80 meters.

Table 2.1 Mean Wind Speeds and Data Recovery

	40 m		60 m		80 m		100 m		150 m	
Month	Mean Wind Speed (m/s)	Data Recovery	Mean Wind Speed (m/s)	Data Recovery	Mean Wind Speed (m/s)	Data Recovery	Mean Wind Speed (m/s)	Data Recovery	Mean Wind Speed (m/s)	Data Recovery
Nov 2013*	2.77	83%	1.69	83%	2.05	83%	2.41	83%	3.94	71%
Dec 2013	4.91	67%	4.97	67%	4.84	67%	4.89	67%	5.48	65%
Jan 2014	5.48	97%	5.56	97%	5.58	96%	6.45	92%	6.89	84%
Feb 2014	5.02	99%	4.85	99%	5.25	99%	6.43	99%	5.88	99%
Mar 2014	2.45	98%	1.62	98%	1.84	98%	2.12	98%	2.45	98%
Apr 2014	2.79	99%	1.44	99%	1.67	99%	1.73	99%	2.01	99%
May 2014**	2.89	98%	1.67	98%	2.00	98%	1.96	98%	2.49	98%
Mean	3.83	93%	3.21	93%	3.40	92%	3.22	92%	4.03	90%

* Period of record begins Nov. 26, 2013; ** Period of record ends May 30, 2014

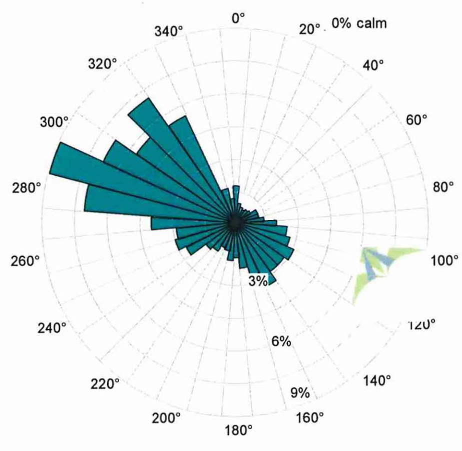

Figure 2.1 80-meter Wind Frequency Rose

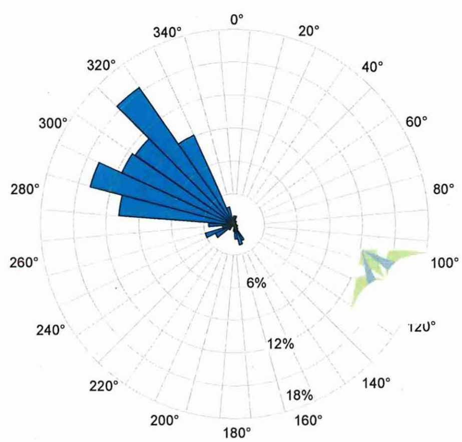

Figure 2.2 80-meter Wind Energy Rose

SoDARs are very useful to analyze shear at a site. Often, the top measurement height of a meteorological tower used to gather wind resource data is not at the same height as the hub of the turbine modeled. Standard practice is to extrapolate measured met tower data to hub height using a power law. While the power law can be used to estimate hub height wind speeds, shear profiles often do not follow the curve of the power law. SoDAR data allows a closer analysis of the shear profile at a site. Figure 2.3 shows the wind shear profile with respect to height for the period of measurement. The measured profile is indicative of a location with poor wind energy potential. The local tree cover appears to be altering the winds at lower levels as indicated by the higher shear around 40 meters, which then drops significantly between 45 and 60 meters. This anomaly in the vertical profile may also be a result of atmospheric stability. In addition, terrain effects that can enhance wind speeds, such as elevated terrain, mountains, canyon or river drainages, do not exist at this location. Table 2.2 shows the mean wind speeds by height for every measurement height.

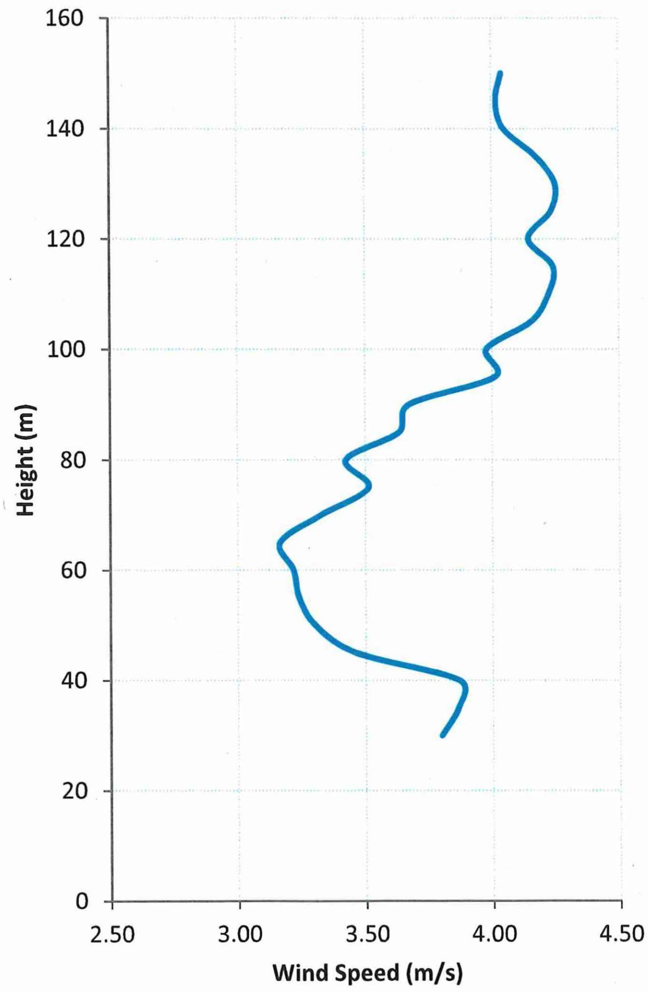

Figure 2.3 Wind Shear Profile

Table 2.2 Mean Wind Speed by Height

Height Above Ground (m)	Mean Wind Speed (m/s)
150	4.04
145	4.02
140	4.05
135	4.18
130	4.25
125	4.24
120	4.15
115	4.24
110	4.22
105	4.16
100	3.98
95	4.01
90	3.67
85	3.63
80	3.42
75	3.51
70	3.33
65	3.17
60	3.22
55	3.24
50	3.30
45	3.46
40	3.87
35	3.86
30	3.80

In order to evaluate the turbulence of the measured winds at Camp Ripley, Chinook Wind also evaluated the vertical wind speed data the SoDAR collected. Figure 2.4 shows the wind rose of the 80-meter measured vertical wind speed versus horizontal wind direction. Negative values are shown in red, which correspond to a downward component of the vertical wind speed or sinking air. The positive values are a result of upward moving vertical winds. This rose shows that positive vertical winds occur when the wind direction is from 10 to 100 degrees. When winds are from the other directions, they tend to have a negative, downward vertical component. This information is useful determining the inflow angle at turbine hub height. The vertical wind speed data shows very little vertical motion, therefore turbulence effects on a wind turbine would be minimal.

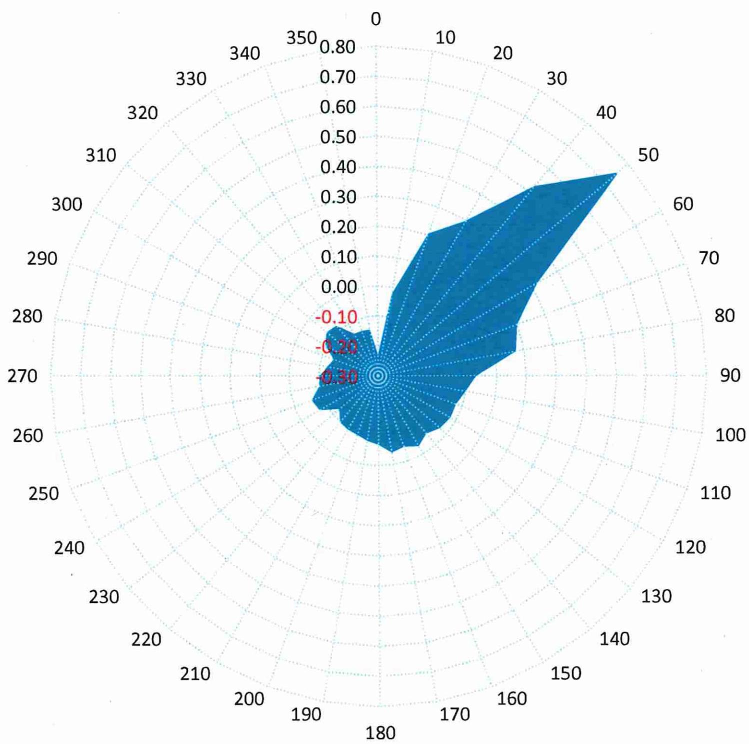

Figure 2.4 80-meter Vertical Wind Speed Rose

3.0 Long Term Wind Regime

3.1 Reference Wind Data

Because the period of record for on-site wind data may not be representative of long-term conditions, it is recommended to correlate on-site measured wind data to a long-term reference data set. In order to obtain a robust and accurate adjustment of on-site data to represent long-term conditions, it is important to select a good reference site. The reference site should be characterized by relatively close proximity (<75 km) to the site, similar exposure and climatology, a long period of record (more than 6 years), good documentation and consistent configuration during the period of record, and a good correlation with on-site wind data (R^2 >~ 0.7 for daily averages).

Chinook Wind obtained data from the three National Weather Service Automated Surface Observing Stations (ASOS). ASOS records data hourly at a height of 10 meters. Data was retrieved for three of the nearest ASOS stations to the site from the National Climatic Data Center (NCDC). Chinook Wind also retrieved data from the National Aeronautics and Space Administration (NASA) Modern Era Retrospective-analysis for Research and Applications (MERRA) dataset. MERRA was produced by assimilating satellite observations with conventional land-based meteorology measurement sources using the Goddard Earth Observing System Data Assimilation System Version 5 (GEOS-5). MERRA is an observation-based product that provides a grid of synthesized 20-year climatic data points across the Northern Hemisphere. The analysis is performed at a spatial resolution of 2/3° longitude by 1/2° latitude. Chinook Wind identified the nearest MERRA grid point to the site to be used in the analysis, and procured hourly time series at 2 meters, 50 meters, and 10 meters for a period of record from 1994 to 2014. Table 3.1 presents the long-term references considered in this analysis. Figure 3.1 shows the SoDAR site and the reference stations considered. Chinook Wind also used the reference station data to calculate a mean air density for the project area, which is used in the energy calculations. The mean project area air density is 1.21 kg/m^3.

Table 3.1 Reference Stations Considered

Reference	Distance to Site (km)
Brainerd ASOS	41
Alexandria ASOS	79
St. Cloud ASOS	68
MERRA, 46, -94.67	22

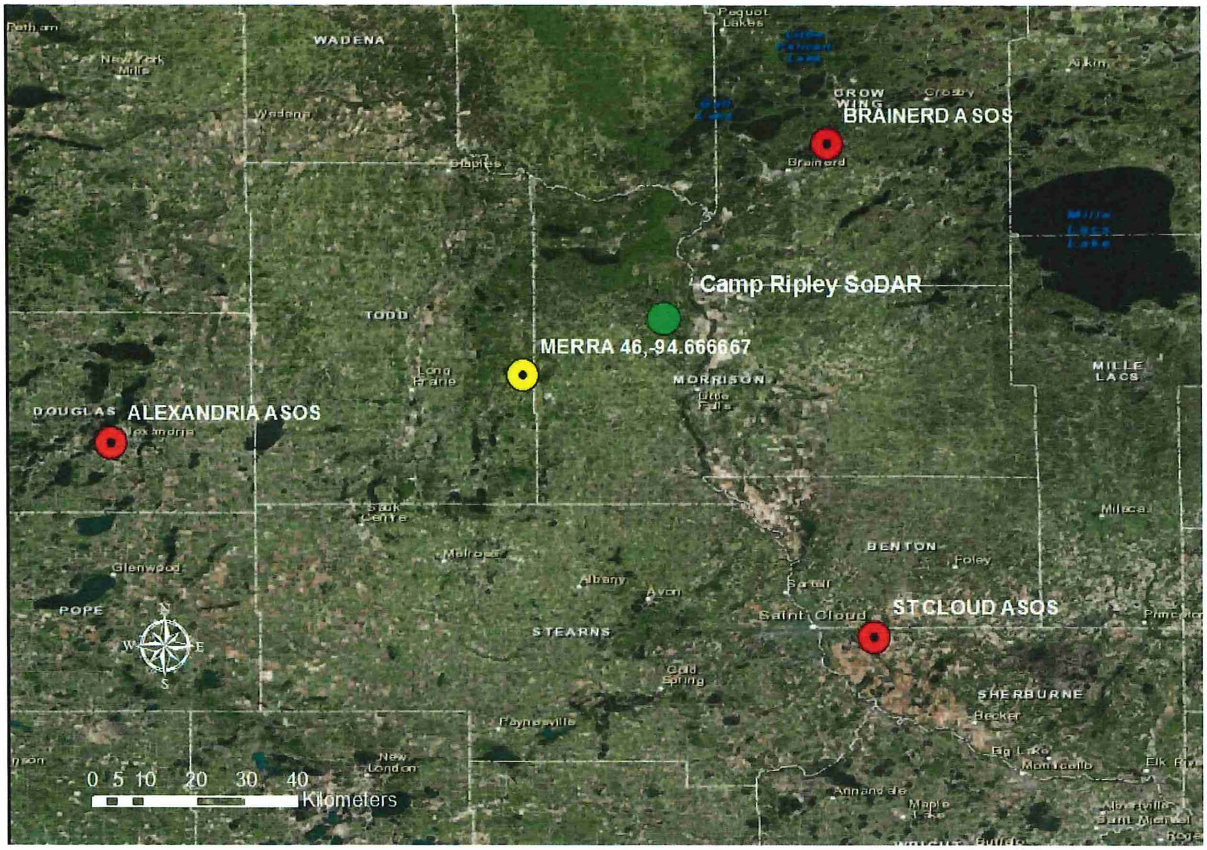

Figure 3.1 Reference Stations Considered

3.2 Long-term Correlations

Chinook Wind conducted daily and monthly-binned correlations from each reference site to the SoDAR data at different heights. Daily correlations were poor, with the highest correlation being from the MERRA grid node to the 80-meter SoDAR data, with an R^2 of 0.14. Monthly-binned correlations also yielded poor results, with R^2s ranging from 0.28 to 0.38.

The poor correlations to the long-term references could be due to several factors. The SoDAR site may have a different climatology than the reference stations due to terrain effects or other factors. Also, the measured data from the SoDAR is quite low, with mean wind speeds ranging from 3.2 m/s to 4.0 m/s. Low wind speeds at the site are difficult to correlate to, given the uncertainty surrounding the measurements. Figure 3.2 shows the mean monthly wind speeds for the reference stations for the past 10 years and the Camp Ripley SoDAR at 80 meters for its period of record. It is noted the reference stations follow a similar pattern. Figure 3.3 shows the mean annual wind speeds for the reference stations. The reference stations have had relatively lower wind speeds since 2009 compared to the previous years, with the exception of Brainerd. Note that 1996 and 2014 are partial years, and are not shown in this chart.

Due to these factors, Chinook Wind determined that correlating the SoDAR data at Camp Ripley to a long-term reference would not reduce the uncertainty in the analysis. Therefore, the measured site data was used for the energy analysis.

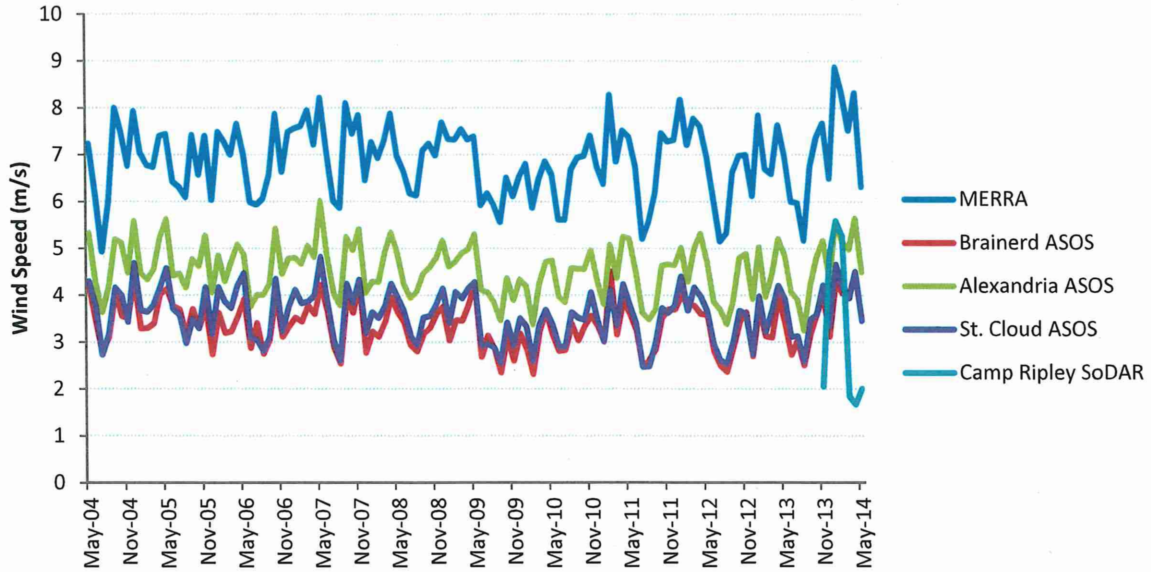

Figure 3.2 Monthly Mean Wind Speeds

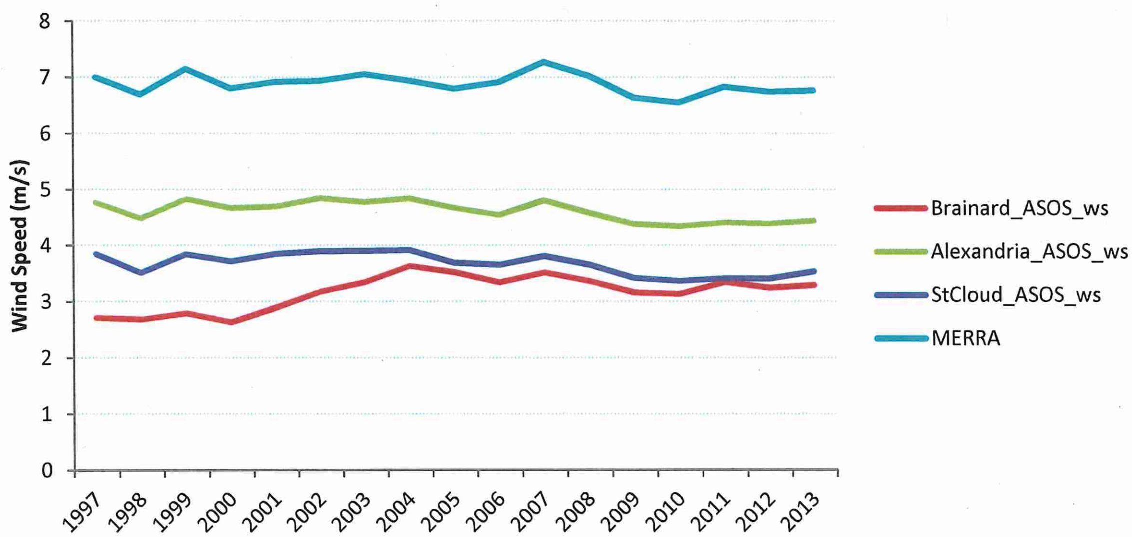

Figure 3.3 Reference Annual Mean Wind Speeds

4.0 Energy Analysis

Chinook Wind performed a preliminary energy estimate for a single turbine modeled at the location of the Camp Ripley SoDAR. No extrapolation across the terrain was made. Due to the relatively flat terrain, it is assumed that the resource will not vary greatly across the project area. However, it should be understood that this estimate is strictly for the SoDAR location and more thorough modeling and optimizations will be required to locate an array of turbines over the project site and calculated associated energy and NCF values for various turbine models. Energy output was estimated using a simple wind speed distribution versus power curve calculation. Since this estimate only represents a single turbine, no wake losses from neighboring turbines were modeled. Since this is an active air base with potential impacts to airspace based on the height of a wind turbine, three different turbines were selected with hub heights ranging from 40 to 80 meters. Chinook Wind estimated gross-to-net energy losses as an initial estimate of total project energy potential for the three turbines: the Vestas V110 2.0 MW at 80 meters, the Vergnet GEC MP C 32-meter rotor 275 kW at 60 meters, and the Endurance X-29 225 kW at 40 meters. It is noted that the Vergnet and Endurance turbines only had power curves available for sea level. Table 1.1 shows the specifications for each turbine.

Table 4.1 Turbine Specifications

Manufacturer	Model	Rated Capacity (MW)	Hub Height (m)	Rotor Diameter (m)
Vestas	V110 2.0 VCSS	2.000	80	110
Vergnet	GEC MP C	0.275	60	30
Endurance	X-29	0.225	40	29

Chinook Wind calculated the net capacity factor using the wind speed distribution for the site at each respective hub height if a turbine was placed at the location of the SoDAR. The net capacity factor for each analysis is calculated from a relatively short period of record and is not necessarily representative of the long-term average wind speed at the site. Chinook Wind assumed a gross-to-net capacity factor energy loss of 12%. The industry average gross-to-net ranges from 10% to 16%

Figure 4.1 shows the wind frequency distribution for the site compared to the power curve for the Vestas V110, which is designed for low wind speed sites. The V110 was modeled at an 80-meter hub height. The net capacity factor for a V110 2.0 MW turbine with an 80-meter hub height at the location of the SoDAR is estimated to be 13.3%.

Figure 4.2 shows the wind frequency distribution for the site compared to the power curve for the Vergnet GEC MP C at a 60-meter hub height. Chinook Wind calculated the net capacity factor from this distribution for the site to be 6.6%, if a turbine was placed at the location of the SoDAR.

Figure 4.3 shows the wind frequency distribution for the site compared to the power curve for the Endurance X-29 at a 40-meter hub height. Chinook Wind calculated the net capacity factor from this distribution for the site to be 6.9%, if a turbine was placed at the location of the SoDAR.

Figures 4.1, 4.2, and 4.3 present the Camp Ripley measured wind frequency distributions at 40, 60, and 80 meters, respectively. The distributions peak between 1 m/s and 2 m/s, an indication of a poor wind resource. Most utility-scale wind turbines have a cut-in wind speed of 3 m/s.The Vestas cut-in speed is 3 m/s while the Vergnet and Endurance cut-in at 4 m/s. The turbine power curves are superimposed on the respective distributions. The V110 reaches optimum energy production at 12 m/s, the Vergnet turbine at 13 m/s, and the Endurance at 16 m/s.

Overall, this Summary review shows the site to have little potential for a good wind resource, with wind speeds between averaging 3.2 m/s at 60 meters and 3.4 m/s at an 80-meter hub height. Long-term meteorological data from nearby sites did not correlate well with the site's SoDAR data; therefore, it is not clear whether these data represent a long-term average. However, this preliminary six-month evaluation indicates that additional data collection would likely further substantiate low wind speeds at Camp Ripley.

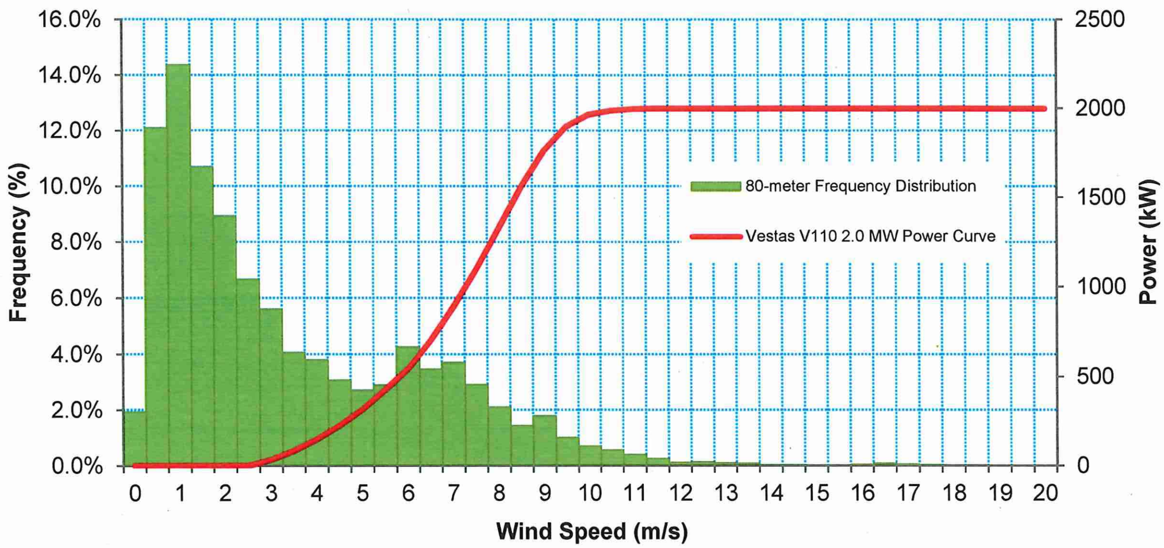

Figure 4.1 80-meter Wind Speed Distribution and Vestas V110 2.0 MW Power Curve

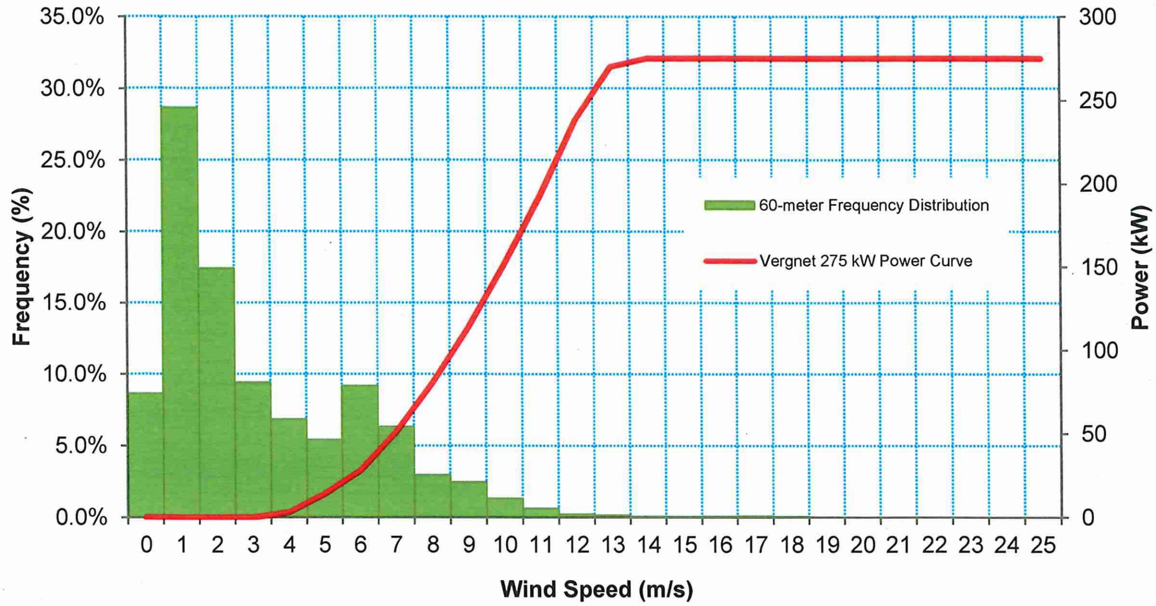

Figure 4.2 60-meter Wind Speed Distribution and Vergnet GEC MP C 32-m 275 kW Power Curve

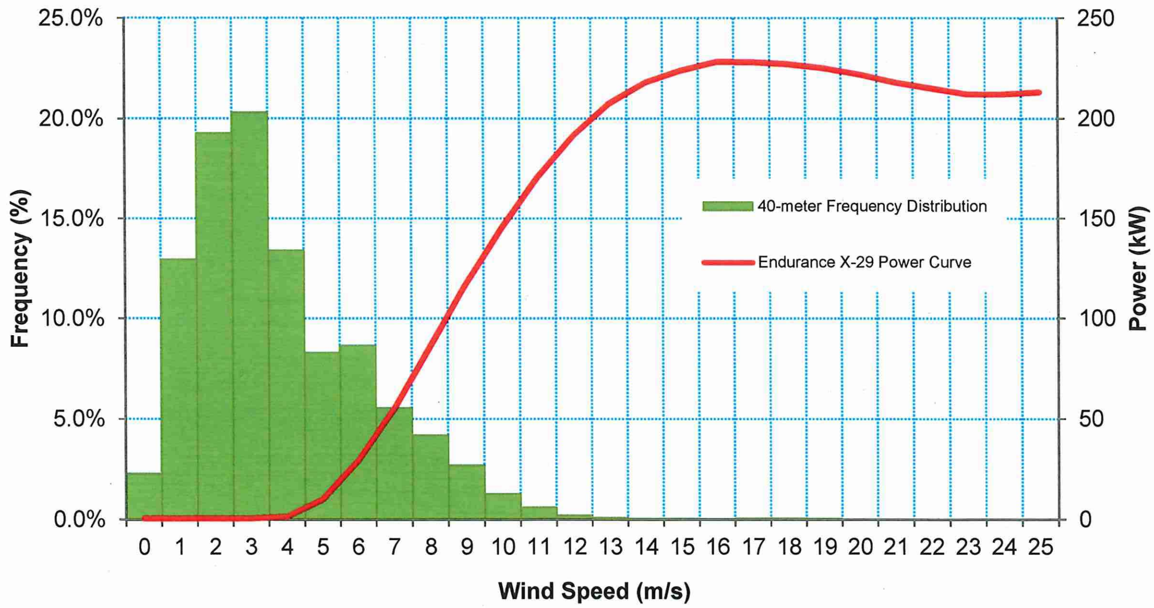

Figure 4.3 40-meter Wind Speed Distribution and Endurance X-29 225 kW Power Curve

Appendix A Glossary of Terms

Array Efficiency / Wake	Array efficiency is a measure of the amount of energy an array of wind turbines can produce, accounting for decreases in wind speed from the wakes of upwind turbines, divided by the theoretical energy that could be produced from the free-stream wind if wind speeds were not reduced by wind turbine wakes. Wakes are created by wind turbine rotors as momentum is extracted from the wind passing through the rotor.
ASC	Atmospheric Systems Corporation is the manufacturer of the SoDAR used for this project
ASL	Above Sea Level
ASOS Station	The Automated Surface Observing Systems (ASOS) program is a joint effort of the National Weather Service (NWS), the Federal Aviation Administration (FAA), and the Department of Defense (DOD). ASOS Stations are typically located at airports at a height of 10 meters above ground level and archived at National Climate Data Center (NCDC) in hourly and daily intervals.
Correlation – Daily / Monthly	Correlation through the use of a linear regression, or possibly a non-linear model, of wind speeds measured at two different locations where the correlated wind speeds are daily or monthly averages. For daily correlations, the wind speeds are not separated into wind direction bins because the wind direction can change significantly during the course of a day.
Cut-in Wind Speed	The wind speed at which a wind turbine generator begins to generate power. Typically between 3-4 m/s.
Hub Height	Hub height is defined as the height above ground level to the center of rotation of the rotor of an installed wind turbine.
Hub Height Mean Wind Speed	Hub-height mean wind speed is the estimated average wind speed at hub height. This value is typically derived by extrapolating from the highest measurement height on a met tower to calculate a wind speed at a wind turbine's hub height.
MERRA	Modern Era Retrospective-analysis for Research and Applications – A program of the National Aeronautics and Space Administration (NASA). MERRA was produced by assimilating satellite observations with conventional land-based meteorology measurement sources using the Goddard Earth Observing System Data Assimilation System Version 5 (GEOS-5). MERRA is an observation-based product that provides a grid of synthesized 20-year climatic data points across the Northern Hemisphere.
NCF	Net Capacity Factor - The net capacity factor of a wind farm is the ratio of its actual output to its potential output if it were possible for it to operate at full nameplate capacity. For energy estimates, the net capacity factor is taken from the gross capacity factor, and calculated or assumed losses are applied to reach the net capacity factor.
Power Curve	The power delivered by the turbine as a function of wind speed between the cut-in and cut-out speeds.

Power Law Shear Value / Shear / Wind Shear Coefficient	Wind Shear refers to the relationship of wind speed to height. Relatively close to the Earth's surface, the vertical wind profile of wind speed can be assumed to follow a logarithmic profile. The power law wind shear equation uses known wind speeds at the known measurement heights to estimate hub height wind speed. $U_h = U_r * (Z_h/Z_r)^{Alpha}$ where U_h = Hub height wind speed [m/s], U_r = Top measured wind speed [m/s], Z_h = Hub height [m], Z_r = Top measurement height [m], Alpha = power law wind shear coefficient.
Rated Power	The rated power of a wind turbine is the maximum power the turbine is designed to achieve when the turbine is operating at its peak. A turbine with a rated power of 1 MW will produce 1 MWh of energy per hour of operation under optimal wind conditions. Note that the rated power does not always correspond with a turbine's maximum power output.
Reference Station	Refers to a nearby weather station nearby used to correlate to a site in order to extend the period of record on site and thus better represent long-term conditions.
Roughness	Surface roughness is parameterized within atmospheric boundary layer theory in order to characterize the vertical wind profile as it interacts with the surface. Wind flow models use surface roughness as a boundary condition in order to estimate perturbations at ground level. The roughness length is approximately one-tenth the height of surface roughness elements. Higher surface roughness will tend to slow the wind speeds.
SoDAR	Sonic Detection and Ranging – a meteorological instrument that uses an audible sound 'chirp' emitted vertically into the air, which reflects off atmospheric turbulence. The SoDAR then measures the Doppler shift of the sound pulse and converts it to horizontal and vertical wind speeds and directions.

Appendix B Commissioning Documentation

SODAR COMMISSIONING REPORT

Crew / Staff	Pete Rossmiller/Barr Engineering, Matt Kistner/Barr Engineering		
Site / Location	Camp Ripley - FOB Y2 / Minnesota National Guard Camp Ripley, 15000 Hwy 115, Little Falls, MN 56345		
Date / Time	11/26/13 1300 CST, time synchronized with GPS Sat clock		
Orientation (True North)	285 degrees. Note: ARA -(Antenna Array Angle) was adjusted in SodarView setup, set to 285		
Latitude (NAD83)	46 05.9688° N		
Longitude (NAD83)	94 25.2118° W		
Elevation (m)	377 m		
Sodar / Logger Serial Number	ASC Model 4000		
PICTURES SHOWING ASC (if applicable) IN EACH PHOTO(JPEG NUMBER)			
FACING N: 1a & 1b	**FACING NE:**	**FACING E: 2a & 2b**	**FACING SE:**
FACING S: 3a & 3b	**FACING SW:**	**FACING W: 4a & 4b**	**FACING NW:**
NOTES			
Distance to Trees/Height of Trees--- 38.25m due East of SoDAR/~15m-18m in height			
Distance to Structure/Height of Structure--- (Guard Shack) ~65m SSE of SoDAR/~2.5m-3m in height (Earth mound) ~35m SW of SoDAR/~3m-3.5m in height			
Distance to Tower/Height of Tower	**Nearest Tower is at the Camp Ripley Airport ~4,500 meters to the ESE of the SoDAR site. That tower height is likely 10m in height.**		
Distance to Roads and usage	**31m to gravel road E of SoDAR (almost no traffic Nov to April), 81m to gravel service road N of SoDAR which sees limited traffic Nov to April. 285m to gravel road W of SoDAR no traffic Nov - April**		
Other noise sources	**None observed at time of set-up as FOB-Y2 is presently unoccupied. Anticipate elevated ambient noise in May and June when military training units return to FOB-Y2. Anticipate helicopter traffic in the area during May and June operations.**		

FigureB.1 Facing North to SoDAR

Figure B.2 Facing North from SoDAR

Figure B.3 Facing East to SoDAR

Figure B.4 Facing East from SoDAR

Figure B.5 Facing South to SoDAR

Figure B.6 Facing South from SoDAR

Figure B.7 Facing West to SoDAR

Figure B.8 Facing West from SoDAR