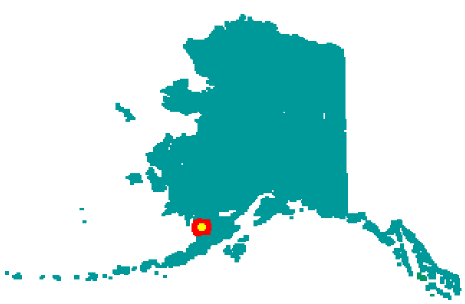
Naknek, Alaska Wind Resource Report

Report written by: Douglas Vaught, P.E., V3 Energy, LLC

Photo © Doug Vaught



Summary Information

The measured wind resource in Naknek showed good potential for wind energy development as a mid-Class 3 wind power class and excellent turbulence behavior. The monitored site, near the borough landfill, does exhibit more wind shear than desirable, necessitating tall turbine towers, and in other respects may not be desirable to develop, but there is plenty of similar terrain nearby suitable for wind power development. In July 2006, the meteorological test tower was moved to a site closer to Naknek Bay which may prove superior to the landfill site because of its closer proximity to onshore winds; early data recovery from the new site suggests this will be the case.

Meteorological Tower Data Synopsis

Wind power class	Class 3 – Fair
Wind speed annual average (30 meters)	6.22 m/s
Maximum wind gust (2 sec. average)	32.9 m/s, April, 2005
Mean wind power density (50 meters)	368 W/m^2 (calculated)
Mean wind power density (50 meters)	301 W/m^2 (measured)
Weibull distribution parameters	k = 1.99, c = 7.02 m/s
Roughness Class	1.86 (few trees)
Power law exponent	0.175 (moderate wind shear)
Turbulence Intensity (30 meters)	0.102 (excellent)
Data start date	July 27, 2004
Data end date	July 19, 2006

Community Profile

Current Population:	577 (2005 State Demographer est.)
Pronunciation/Other Names:	(NACK-neck)
Incorporation Type:	Unincorporated
Borough Located In:	Bristol Bay Borough
School District:	Bristol Bay Borough Schools
Regional Native Corporation:	Bristol Bay Native Corporation

Location:
Naknek is located on the north bank of the Naknek River, at the northeastern end of Bristol Bay. It is 297 miles southwest of Anchorage. It lies at approximately 58.728330° North Latitude and -157.013890° West Longitude. (Sec. 03, T017S, R047W, Seward Meridian.) Naknek is located in the Kvichak Recording District. The area encompasses 84.2 sq. miles of land and 0.7 sq. miles of water.

History:
This region was first settled over 6,000 years ago by Yup'ik Eskimos and Athabascan Indians. In 1821, the original Eskimo village of "Naugeik" was noted by Capt. Lt. Vasiliev. By 1880, the village was called Kinuyak. It was later spelled Naknek by the Russian Navy. The Russians built a fort near the village and fur trappers inhabited the area for some time prior to the U.S. purchase of Alaska. The first salmon cannery opened on the Naknek River in 1890. By 1900, there were approximately 12 canneries in Bristol Bay. The Homestead Act enabled canneries to acquire land for their plants, and also made land available to other institutions and individuals. The parcel owned by the Russian Orthodox Church on the north bank of the River was the first land recorded in Naknek. Squatters built shelters on the church property and were eventually sold lots in what became the center of Naknek. A post office was established in 1907. Naknek has developed over the years as a major fishery center.

Culture:
Naknek is a fishing community, with a mixed population of non-Natives, Yup'ik Eskimos, Alutiiq and Athabascans.

Economy:

The economy is based on government employment, salmon fishing and processing. Naknek has a seasonal economy as a service center for the huge red salmon fishery in Bristol Bay. One hundred fifteen residents hold commercial fishing permits, and several thousand people typically flood the area during the fishing season. Millions of pounds of salmon are trucked over Naknek-King Salmon road each summer, where jets transport the fish to the lower 48. Trident Seafoods, North Pacific Processors, Ocean Beauty and other fish processors operate facilities in Naknek. Naknek is also the seat of the Bristol Bay Borough.

Facilities:

The majority of households, the schools and HUD housing have individual wells. Almost all homes are fully plumbed. A piped sewage collection system operated by the Borough serves most residents; some have individual septic tanks. Funds have been requested to replace septic tanks in the Airplane Lake area with piped sewer. The landfill and bale fill are operated by the Borough, located at mile 5 between Naknek and King Salmon. Refuse collection is provided by a private firm.

Transportation:

Naknek is accessible by air and sea, and connects to King Salmon via a 15.5-mile road. The Tibbetts Airport has a lighted 1,700' long by 60' wide gravel runway. The State-owned Naknek Airport is located one mile north of Naknek. It has a 1,950' long by 50' wide lighted gravel runway and a 2,000' float plane landing area. Jet services are available at King Salmon. The Borough operates the cargo dock at Naknek, which is the Port of Bristol Bay. It has 800' of berthing space, a concrete surface and a couple of cranes. No commercial docking facilities are available at the canneries, although the development of a Fishermen's Dock, Freight dock and Industrial Park are regional priorities. Pickup trucks and cars are common, and taxis are available.

Climate:

The climate is mainly maritime, characterized by cool, humid, and windy weather. Average summer temperatures range from 42 to 63 F; average winter temperatures range from 29 to 44 F. Extremes from -46 F to 88 F have been recorded. Total precipitation is 20 inches annually, including 45 inches of snowfall. Fog is common during summer months.

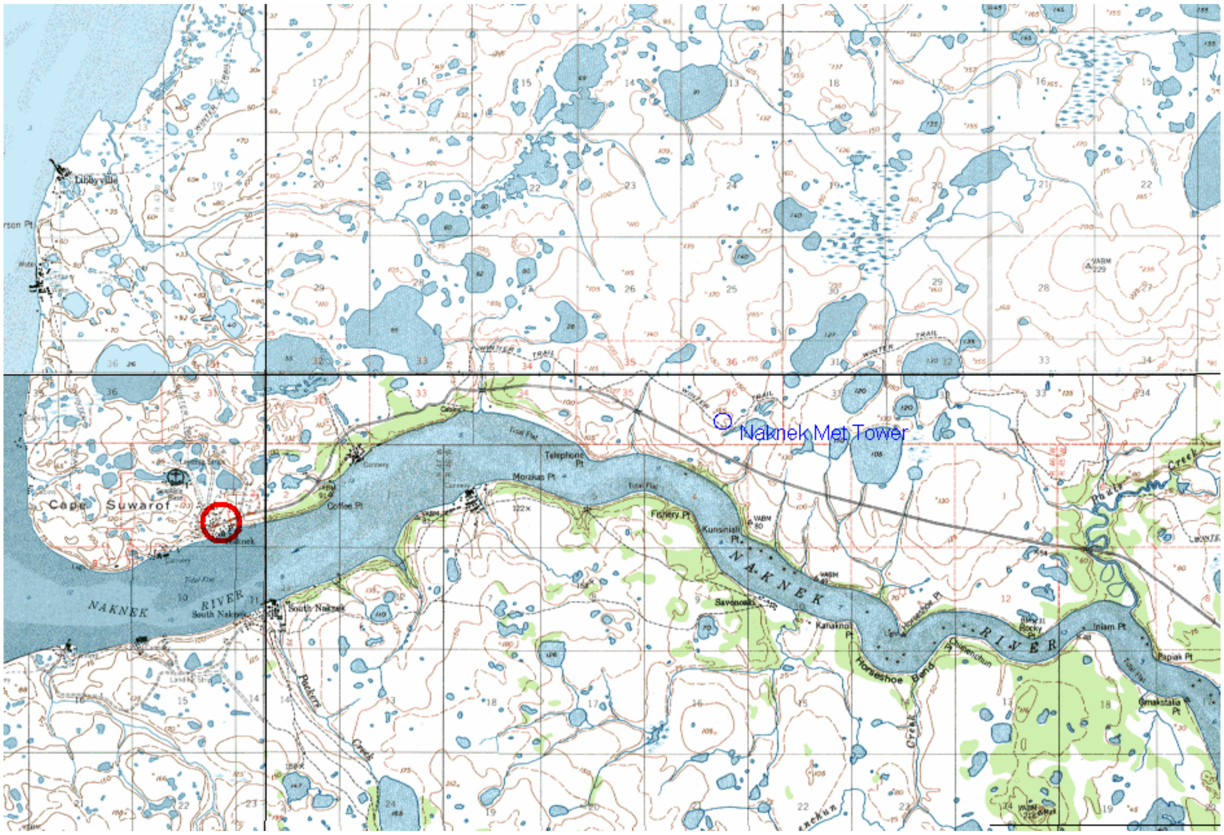
(Above information from State of Alaska Department of Commerce, Community, and Economic Development website, www.dced.state.ak.us)

Tower Sensor Information

Channel	Sensor type	Height	Multiplier	Offset	Orientation
1	NRG #40 anemometer	30 m	0.765	0.35	west
2	NRG #40 anemometer	22 m	0.765	0.35	southeast
7	NRG #200P wind vane	30 m	0.351	262	east
9	NRG #110S Temp C	6 m	0.136	-86.383	N/A

General Site Information

Site number	2398
Site Description	Site is adjacent to the borough landfill between Naknek and King Salmon
Latitude/longitude	N 58° 44.551’ W 156° 52.739’
Site elevation	53 meters
Datalogger type	NRG Symphonie
Tower type	NRG 30-meter tall tower, 152 mm (6 in) diameter


Naknek Met Tower
Cape Suwarof
NAKNEK RIVER
South Naknek
Libbyville
Telephone Pt
Coffee Pt
Fishery Pt
Kunsinish Pt
Savonoski
Horseshoe Bend
Inlam Pt
Paul Creek
WINTER TRAIL

Data Quality Control

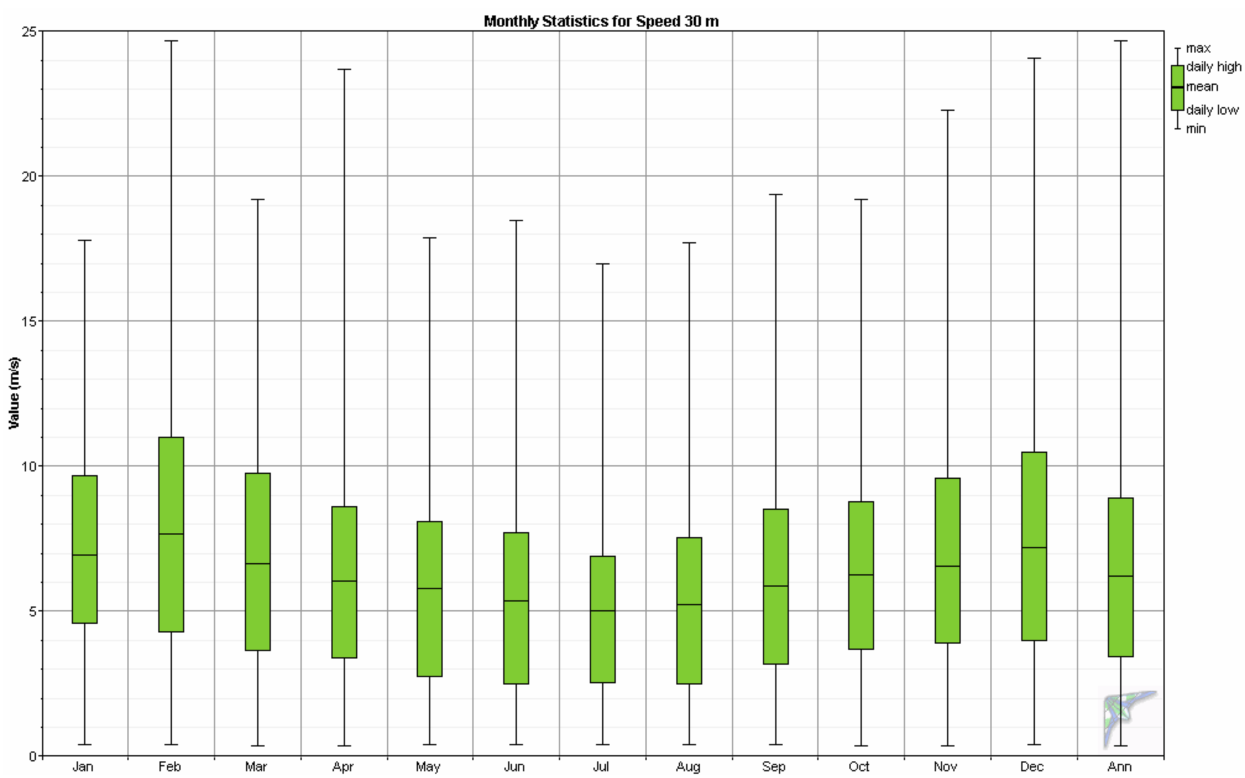
Data was filtered to remove presumed icing events that yield false zero wind speed data. Data that met the following criteria were filtered: wind speed < 1 m/s, wind speed standard deviation = 0, and temperature < 3 °C. Note that data recovery during the months of May through September was nearly 100%, but during the months of October through April some data was filtered, with January being the most ice prone regarding data loss. Temperature data recovery was 100 percent, indicating full functioning of the temperature sensor. Data was synthesized to make up for data lost from icing events; the remainder of this report uses the synthesized data set.

		30 m anemometer		20 m anemometer		wind vane		temperature	
Year	Month	Records	Recovery Rate (%)	Records	Recovery Rate (%)	Records	Recovery Rate (%)	Records	Recovery Rate (%)
2004	Jul	606	100	606	100	606	100	606	100
2004	Aug	4,464	100	4,464	100	4,464	100	4,464	100
2004	Sep	4,320	100	4,320	100	4,320	100	4,320	100
2004	Oct	4,462	100	4,453	99.8	4,453	99.8	4,464	100
2004	Nov	4,116	95.3	4,113	95.2	3,711	85.9	4,320	100
2004	Dec	3,995	89.5	3,995	89.5	2,686	60.2	4,464	100
2005	Jan	3,793	85.0	3,783	84.7	3,752	84.1	4,464	100
2005	Feb	3,977	98.6	3,981	98.7	3,753	93.1	4,032	100
2005	Mar	3,957	88.6	4,231	94.8	4,005	89.7	4,464	100
2005	Apr	4,227	97.8	4,244	98.2	4,224	97.8	4,320	100
2005	May	4,464	100	4,464	100	4,464	100	4,464	100
2005	Jun	4,320	100	4,320	100	4,320	100	4,320	100
2005	Jul	4,464	100	4,464	100	4,464	100	4,464	100
2005	Aug	4,464	100	4,464	100	4,464	100	4,464	100
2005	Sep	4,320	100	4,320	100	4,320	100	4,320	100
2005	Oct	4,436	99.4	4,391	98.4	4,391	98.4	4,464	100
2005	Nov	4,070	94.2	4,006	92.7	3,584	83.0	4,320	100
2005	Dec	4,274	95.7	4,282	95.9	3,297	73.9	4,464	100
2006	Jan	3,953	88.6	3,876	86.8	3,973	89.0	4,464	100
2006	Feb	3,980	98.7	3,992	99.0	3,973	98.5	4,032	100
2006	Mar	4,411	98.8	4,307	96.5	4,096	91.8	4,464	100
2006	Apr	4,316	99.9	4,249	98.4	4,220	97.7	4,320	100
2006	May	4,442	99.5	4,455	99.8	4,440	99.5	4,464	100
2006	Jun	4,320	100	4,320	100	4,320	100	4,320	100
2006	Jul	2,676	100	2,676	100	2,676	100	2,676	100
All data		100,827	97.0	100,776	97.0	96,976	93.3	103,938	100

Monthly Wind Speed Averages

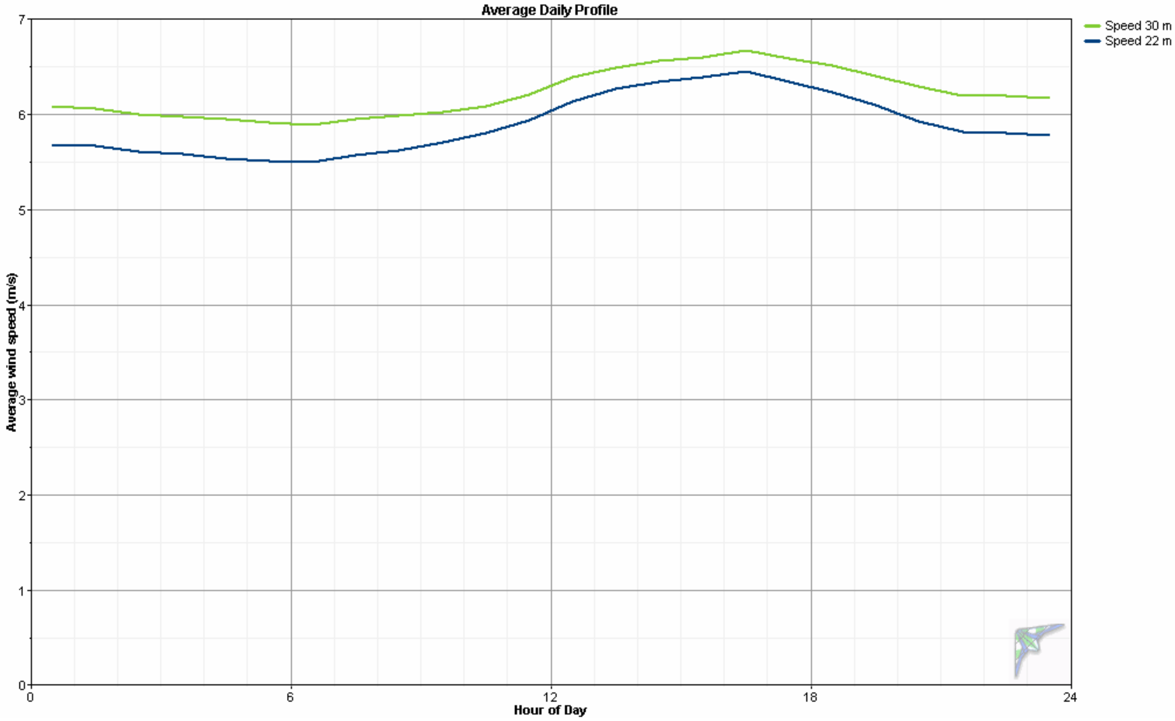
The 30 meter anemometer annual wind speed average for the reporting period is 6.22 m/s and the 20 meter anemometer wind speed average is 5.89 m/s.

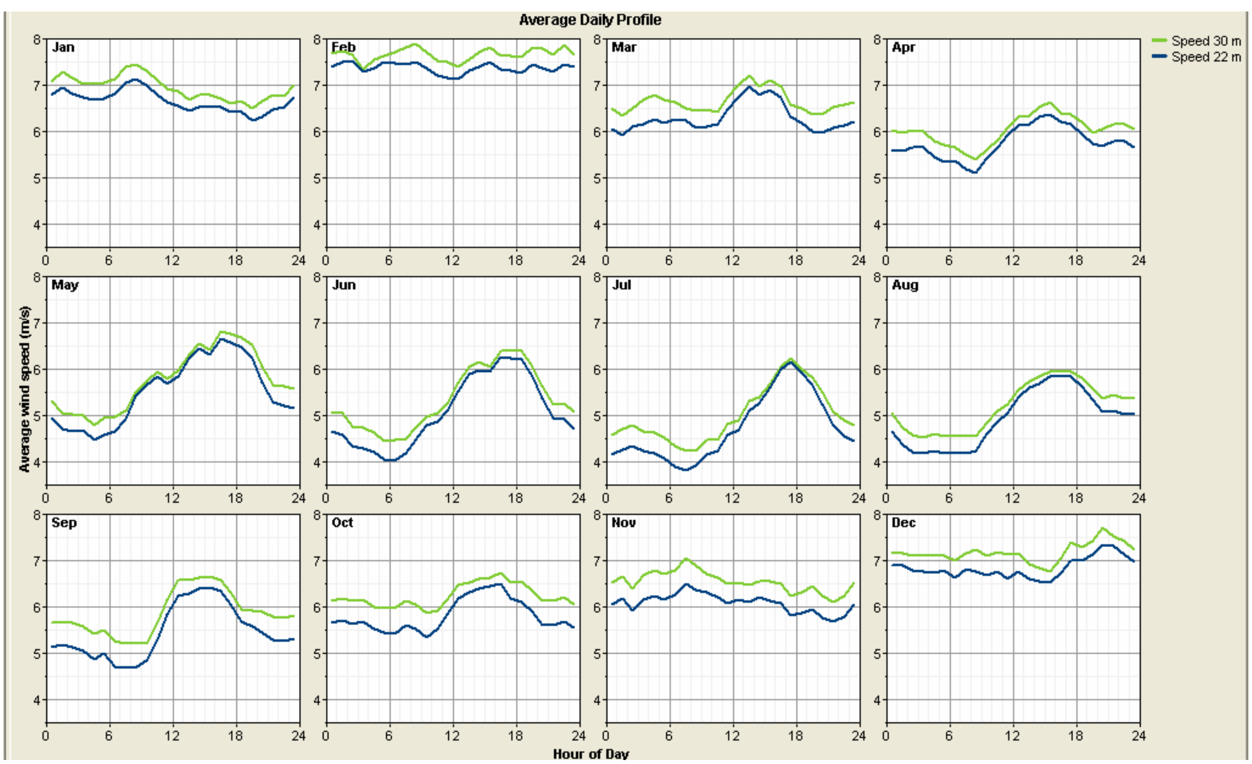
	30 m anemometer					20 m anemometer	
Month	Mean (m/s)	Max (m/s)	Std. Dev. (m/s)	Weibull k	Weibull c (m/s)	Mean (m/s)	Max (m/s)
Jan	6.96	17.8	3.31	2.21	7.85	6.67	16.9
Feb	7.68	24.7	4.06	1.97	8.66	7.39	23.1
Mar	6.66	19.2	3.42	2.05	7.53	6.31	21.7
Apr	6.04	23.7	3.08	2.05	6.82	5.76	21.9
May	5.77	17.9	2.71	2.25	6.51	5.53	17.5
Jun	5.35	18.5	2.73	2.06	6.05	5.07	20.0
Jul	5.02	17.0	2.38	2.20	5.66	4.73	16.4
Aug	5.22	17.7	2.84	1.92	5.88	4.95	17.1
Sep	5.88	19.4	2.96	2.09	6.64	5.46	20.9
Oct	6.25	19.2	3.23	2.02	7.05	5.82	18.9
Nov	6.56	22.3	3.34	2.03	7.38	6.10	21.5
Dec	7.19	24.1	3.69	2.06	8.13	6.86	23.6
All data	**6.22**	24.7	3.27	1.99	7.02	**5.89**	23.6



Daily wind profile

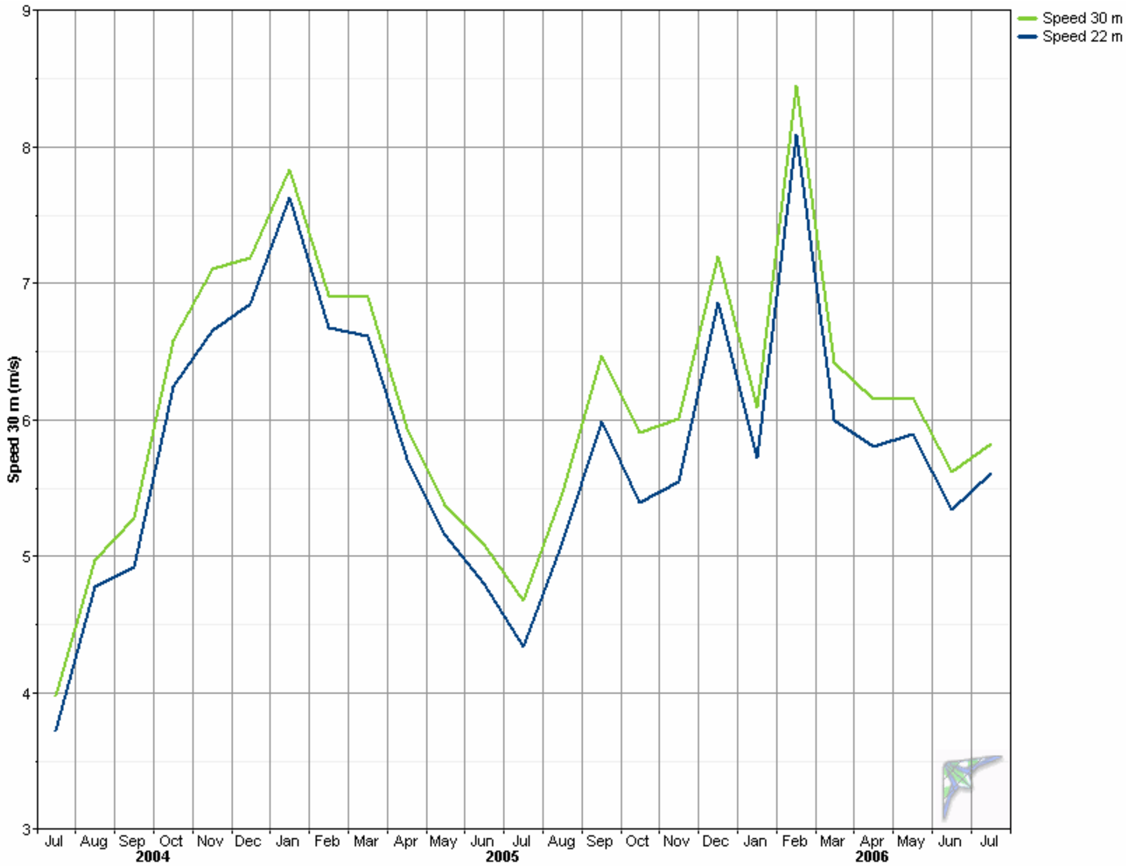
The daily wind profile indicates that the lowest wind speeds of the day occur in the morning hours of 4 to 7 a.m. and the highest wind speeds of the day occur during the afternoon and evening hours of 3 to 6 p.m. The daily variation of wind speed is minimal on an annual basis but more pronounced on a monthly basis.

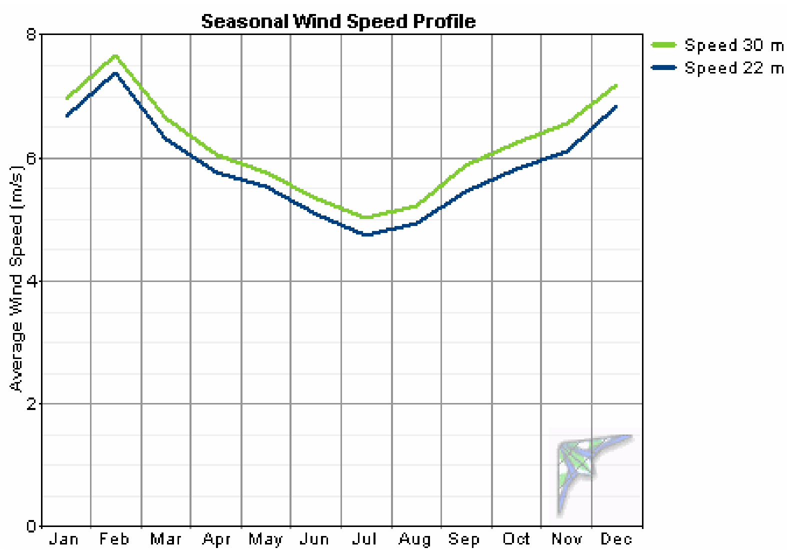




Time Series of Wind Speed Monthly Averages

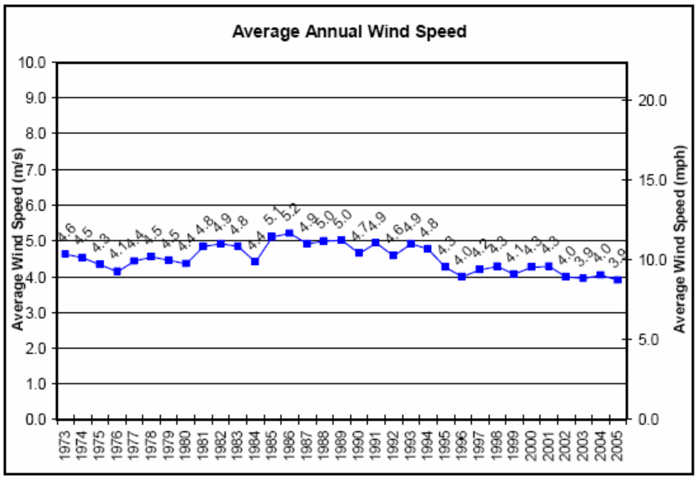
As expected, Naknek's highest winds occur during the winter months of October through March with the lowest winds during the spring-summer-autumn months of April through September. The unusually low winds measured in January 2006 were due to a persistent high pressure system over Alaska that month that yielded calm winds and extremely cold weather Statewide.





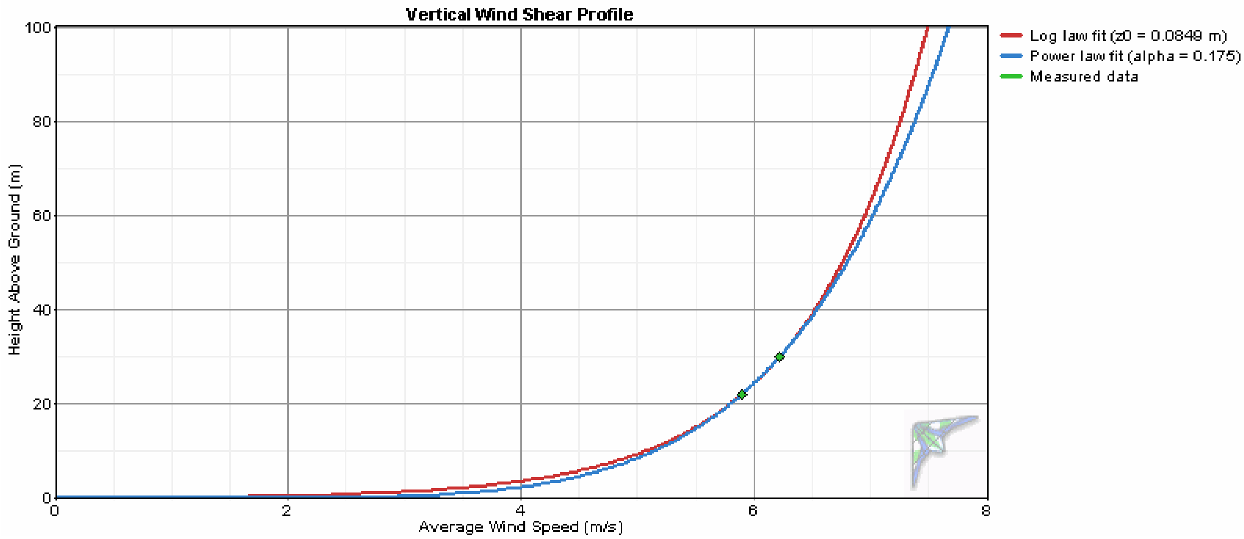
Long-term Comparison

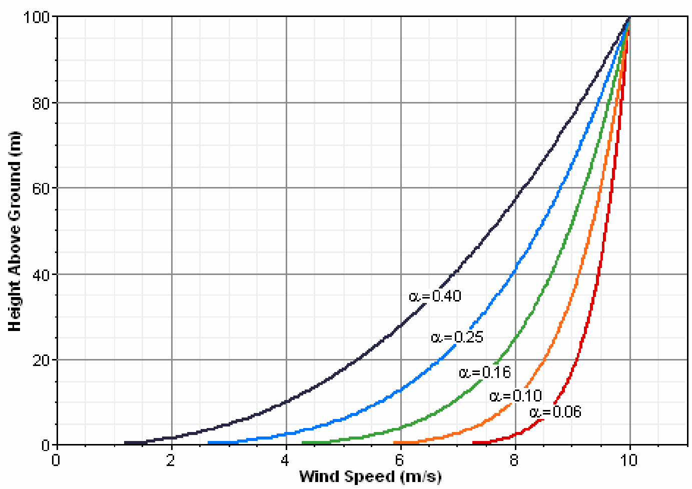
The graph below of average annual wind speed for the nearby King Salmon airport indicates that 2004 and 2005 experienced possibly low average annual wind speeds when compared to data over the past thirty-two years, although in comparison to the past ten years, the 2004/05 wind speeds recorded at the airport were about average. The discrepancy between earlier data and the past ten years can be attributable to an ASOS equipment upgrade approximately ten years ago.

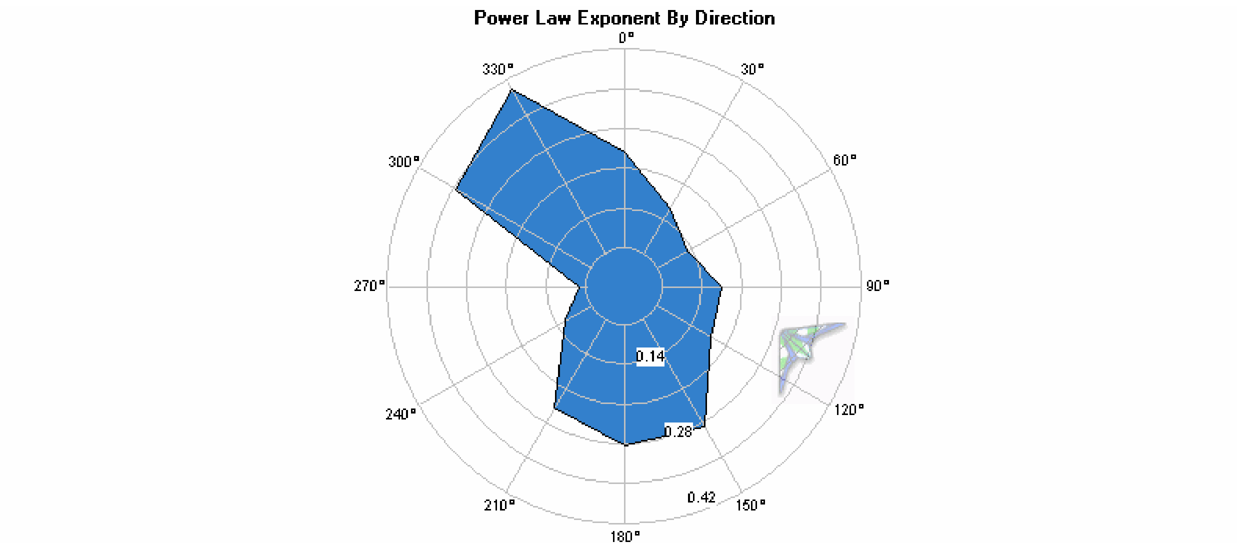


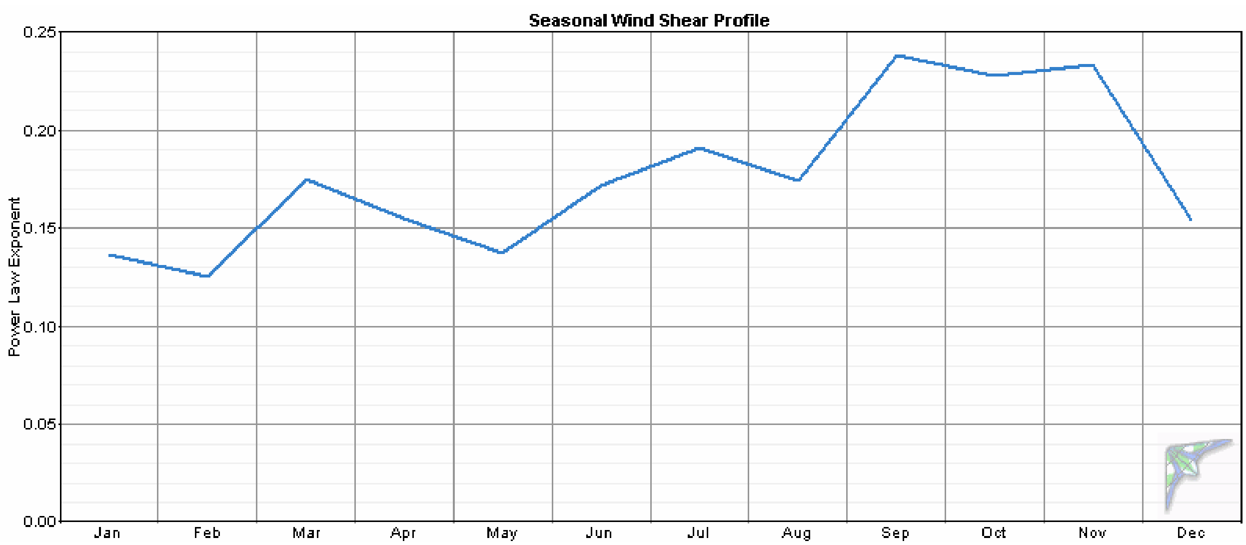
Wind Shear Profile

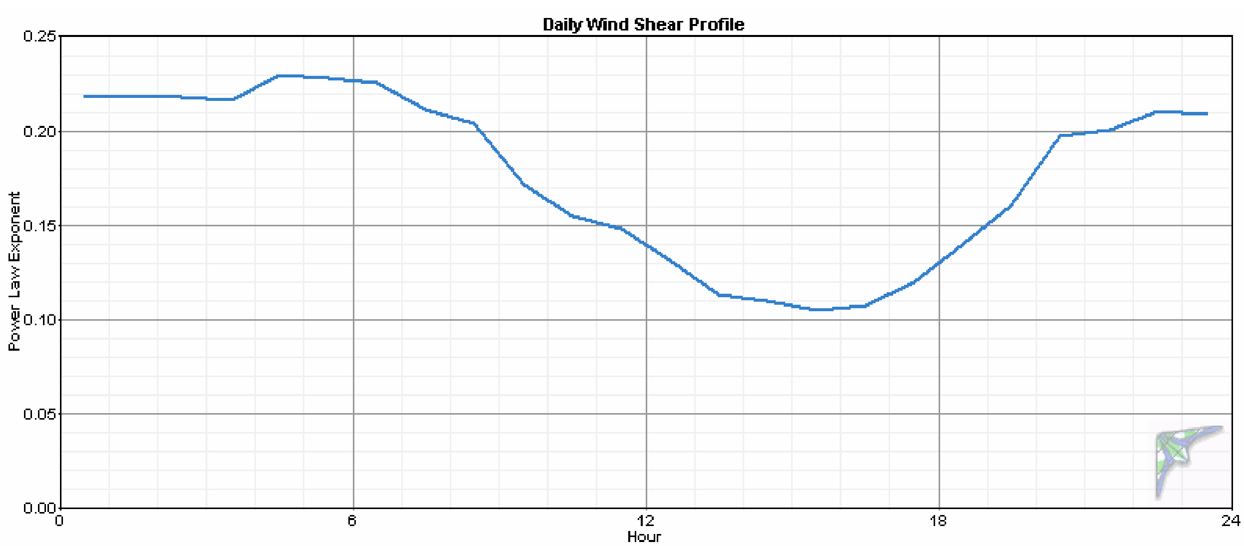
The power law exponent was calculated at 0.181, indicating moderate wind shear at the Naknek test site. The practical application of this data is that a higher turbine tower height is desirable as there will be an appreciable marginal gain in wind speed/power recovery with additional height. A tower height/power recovery/construction cost tradeoff study is advisable.





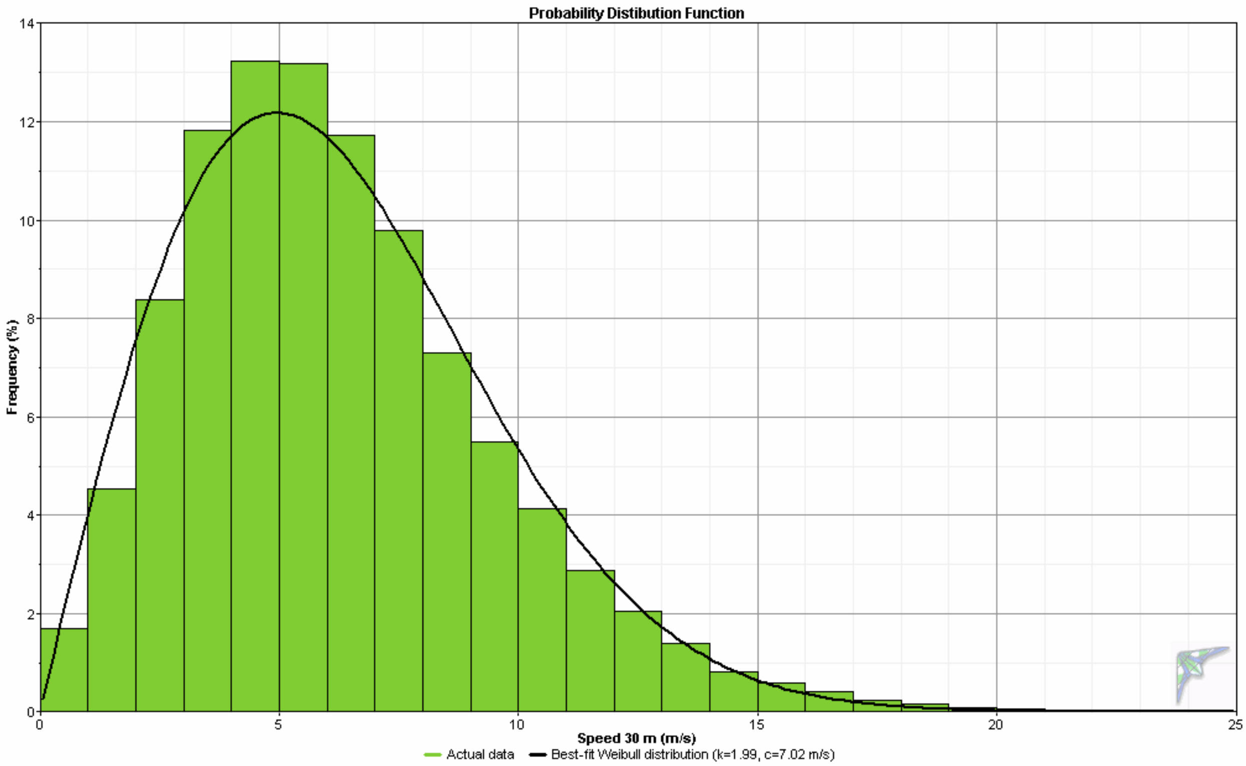

Power Law Exponent By Direction
0°
30°
60°
90°
120°
150°
180°
210°
240°
270°
300°
330°
0.14
0.28
0.42

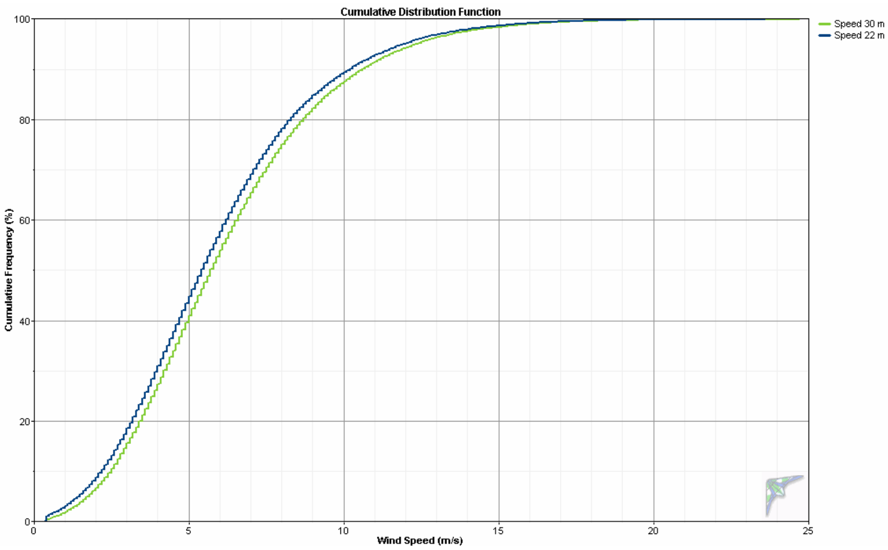

Seasonal Wind Shear Profile
Power Law Exponent
0.25
0.20
0.15
0.10
0.05
0.00
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec


Daily Wind Shear Profile
Power Law Exponent
0.25
0.20
0.15
0.10
0.05
0.00
0
6
12
18
24
Hour

Probability Distribution Function

The probability distribution function provides a visual indication of measured wind speeds in one meter per second "bins". Note that most wind turbines do not begin to generate power until the wind speed at hub height reaches 4 m/s, known as the "cut-in" wind speed. The black line in the graph is a best fit Weibull distribution. At the 30 meter level, Weibull parameters are k = 1.99 and c = 7.02 m/s (scale factor). The PDF information is shown visually in another manner in the second graph, the Cumulative Distribution Function.



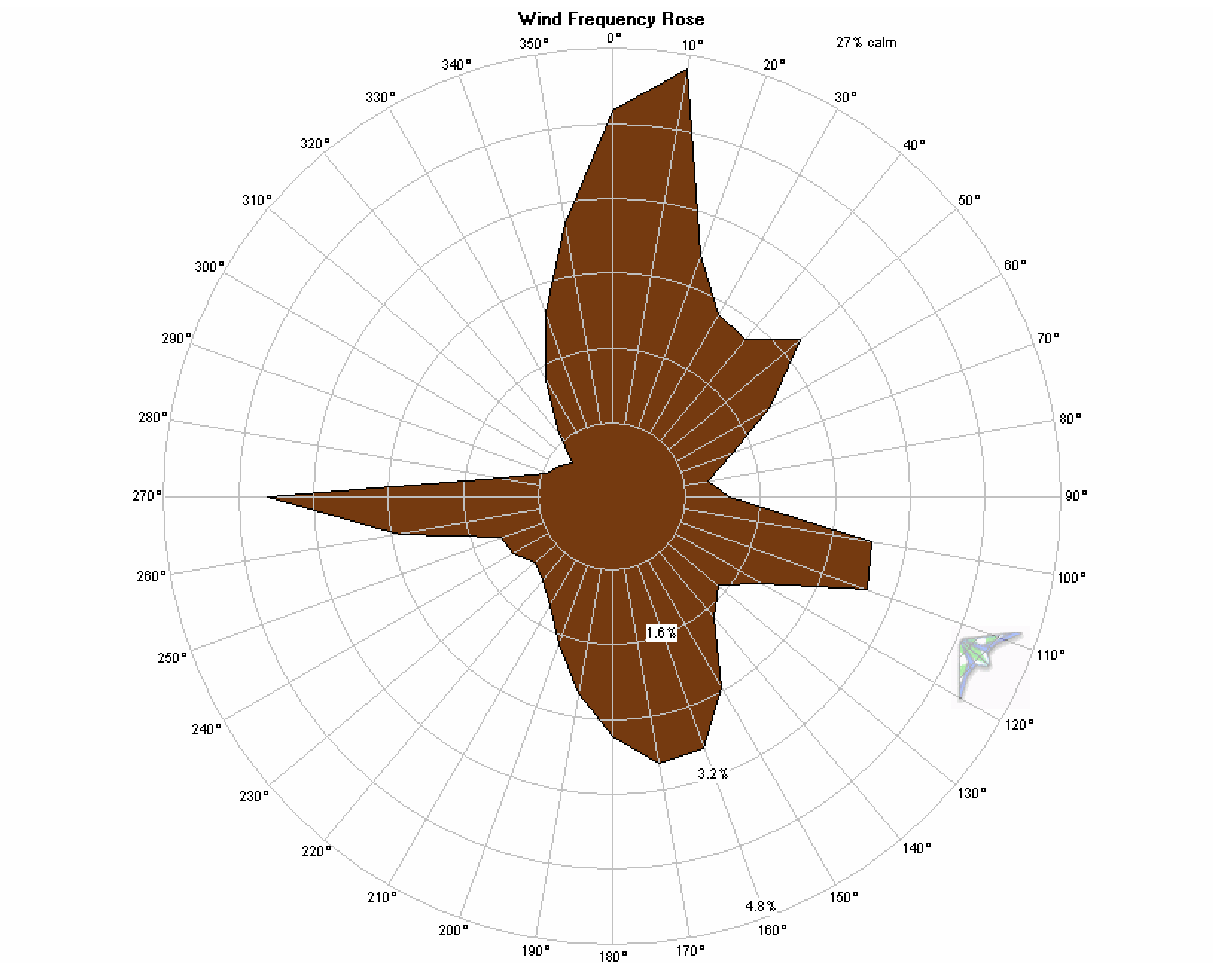


Wind Roses

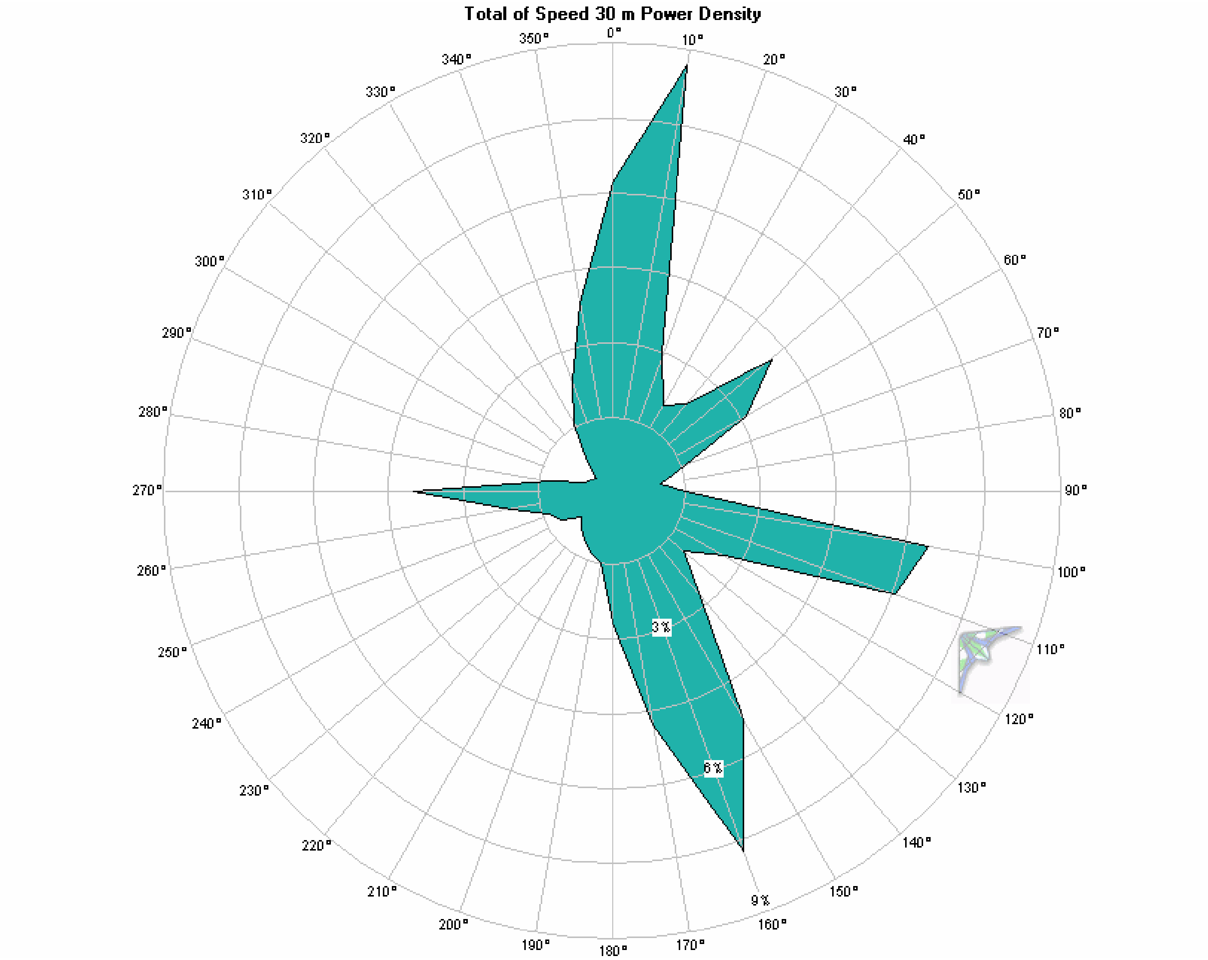
Naknek winds are not especially directional; the wind frequency rose indicates north, west, east and south components of wind. This observation is reinforced with reference to the power density rose below. Power producing winds are chiefly north, south and east with lesser power winds from west and northeast. The practical application of this information is that a site should be selected with adequate freedom from ground interference in all directions and if more than one turbine is installed, the turbines should be adequately spaced apart to prevent downwind (from the power producing winds) interference problems between the turbines.

Note also that a wind threshold of 4 m/s was selected for the definition of calm winds. This wind speed represents the cut-in wind speed of most wind turbines. By this definition, Naknek experienced 27 percent calm conditions during the measurement period (see wind frequency rose below).

Wind Frequency Rose

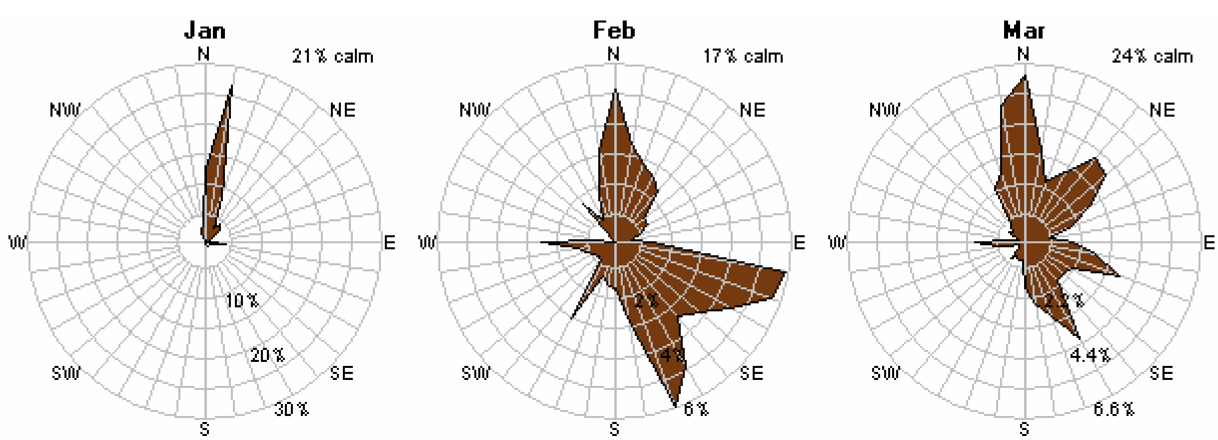


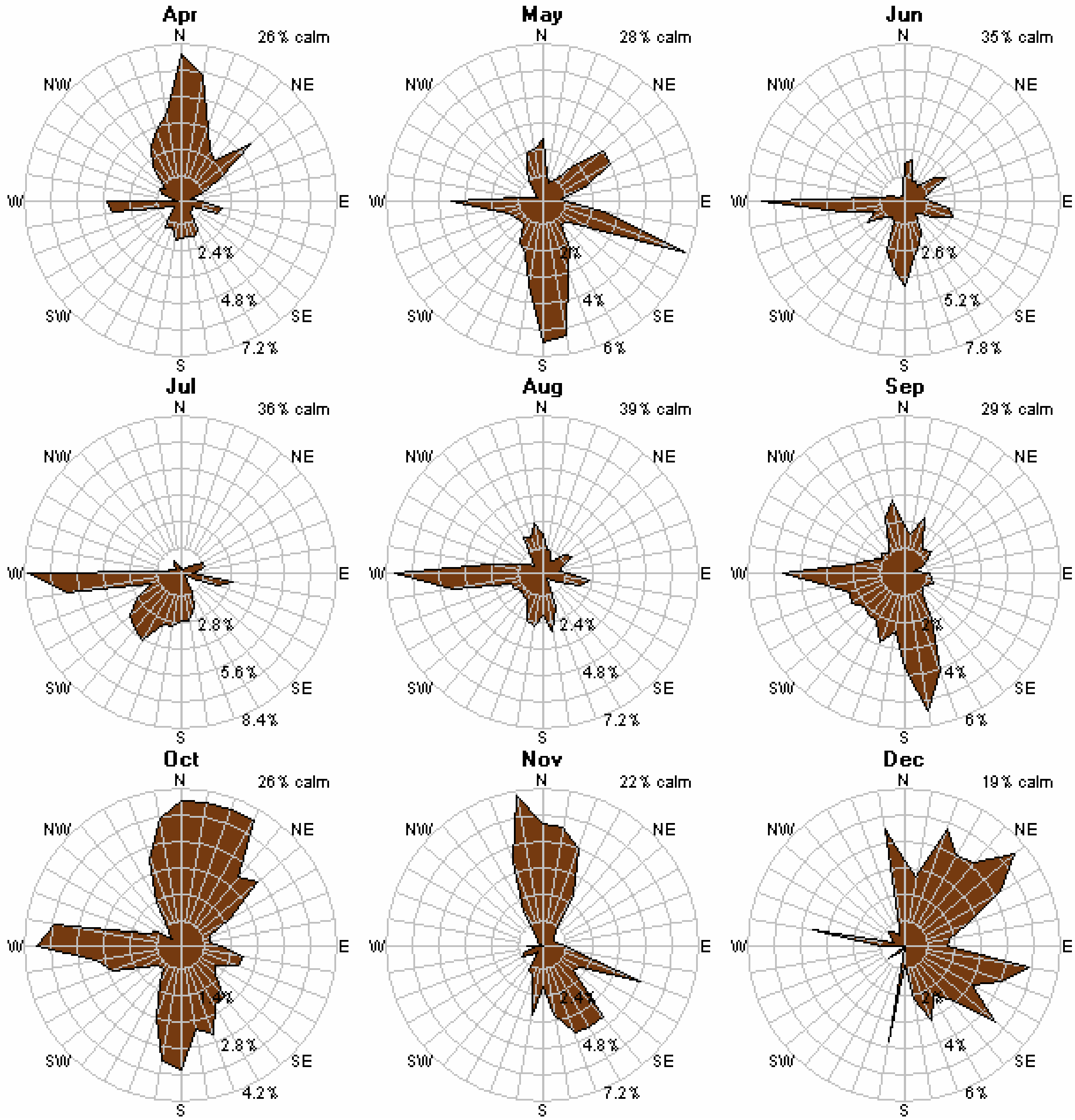
Wind Power Density Rose



Wind Power Density Rose by Month (30 meters)

Note: for ease of visualization, the scale between months is <u>not</u> common.

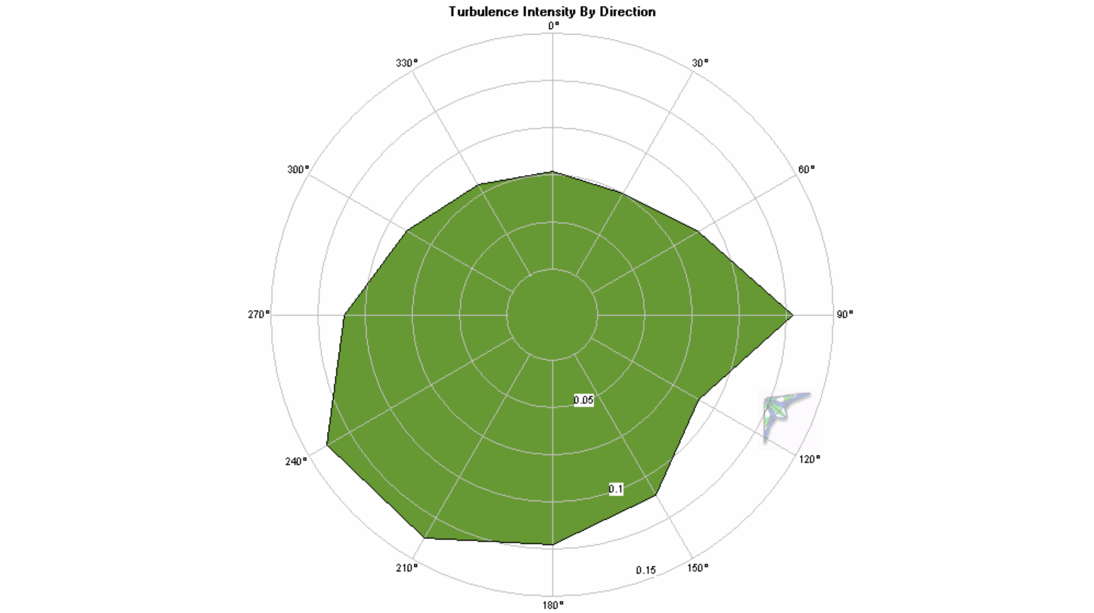



Apr
26% calm
2.4%
4.8%
7.2%
May
28% calm
2%
4%
6%
Jun
35% calm
2.6%
5.2%
7.8%
Jul
36% calm
2.8%
5.6%
8.4%
Aug
39% calm
2.4%
4.8%
7.2%
Sep
29% calm
2%
4%
6%
Oct
26% calm
1.4%
2.8%
4.2%
Nov
22% calm
2.4%
4.8%
7.2%
Dec
19% calm
2%
4%
6%
N
NE
E
SE
S
SW
W
NW

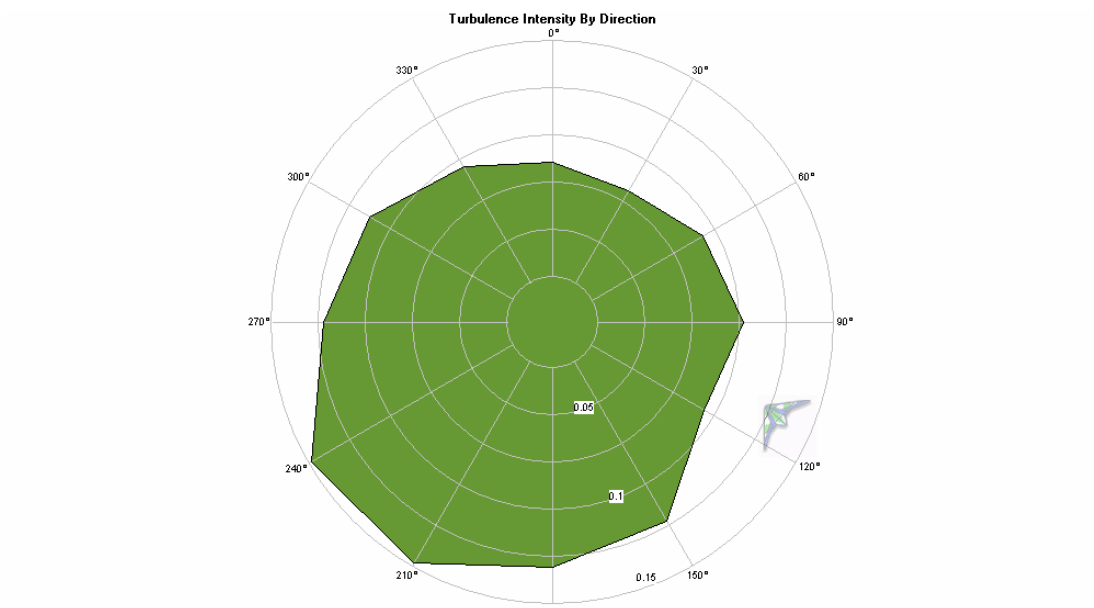
Turbulence Intensity

The turbulence intensity (TI) is quite acceptable for all wind direction, with a mean turbulence intensity of 0.102 (Channel 1) and 0.108 (Channel 2), indicating relatively smooth air. These TIs are calculated with a threshold wind speed of 4 m/s. The spike of relatively high turbulence to the east in the first graph is not observed in the second graph. This is due to placement of the 30 meter level anemometer in relation to the wind vane.

30-meter Turbulence Intensity

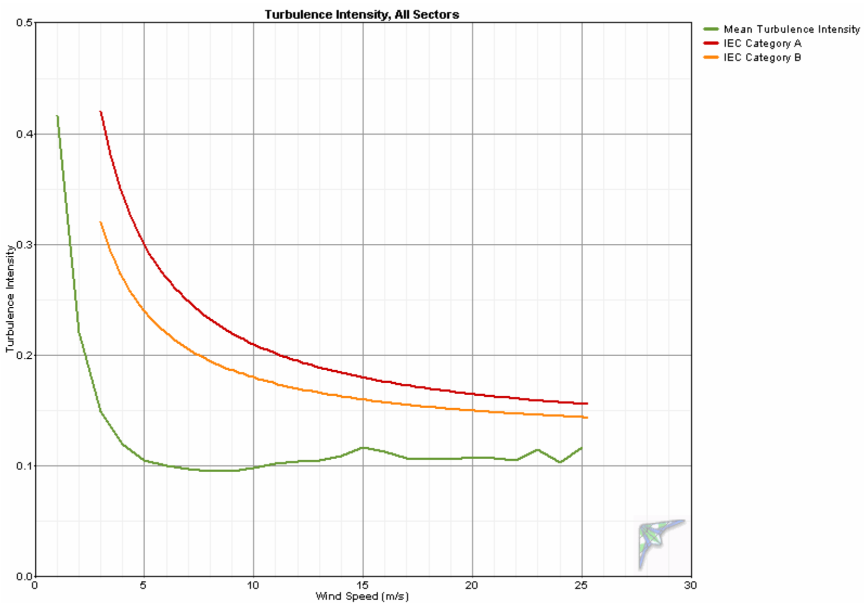


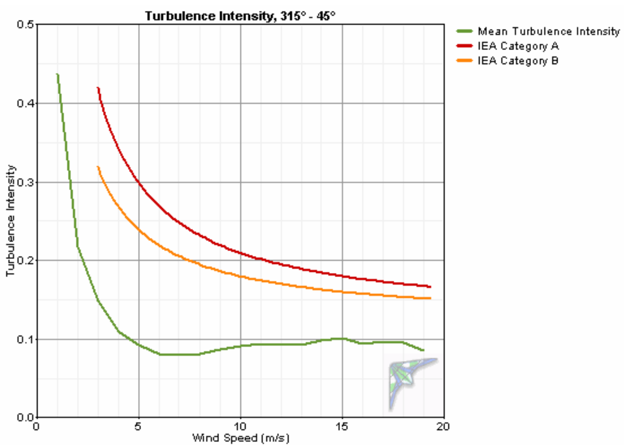
22-meter Turbulence Intensity

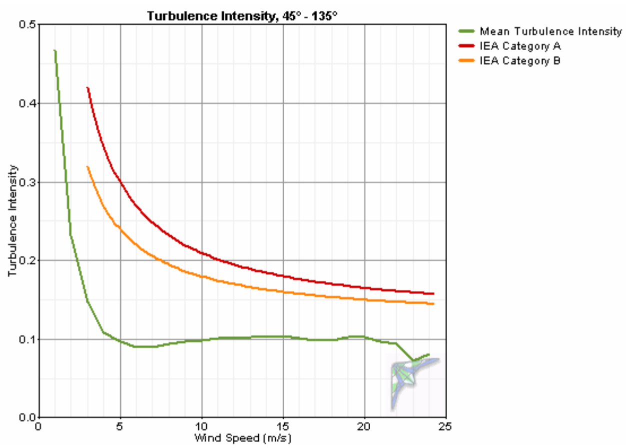


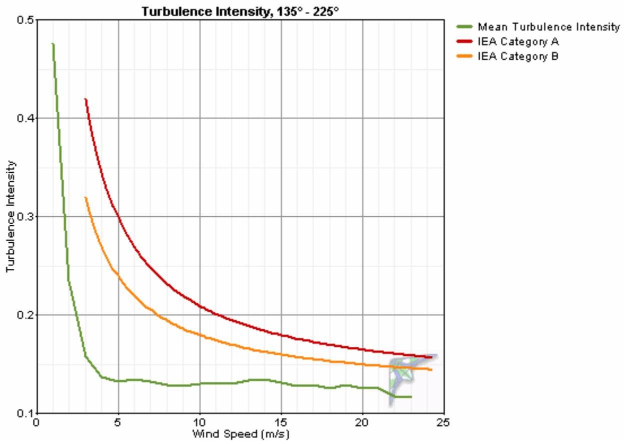
IEC Turbulence Intensity Standards

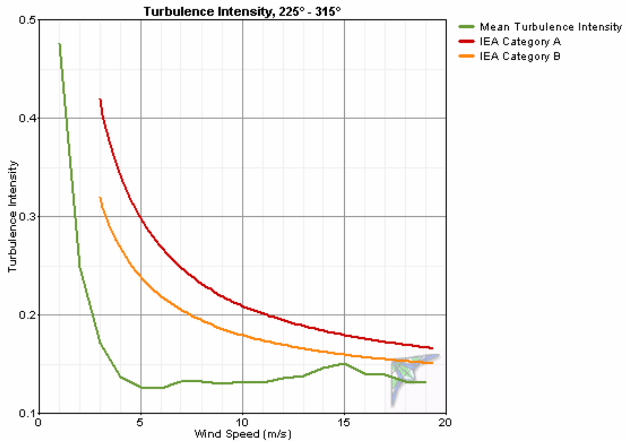
As indicated below, turbulence at the Naknek project test site is well within International Electrotechnical Commission (IEC) standards at all measured wind speeds and from all four quadrants of the wind rose.











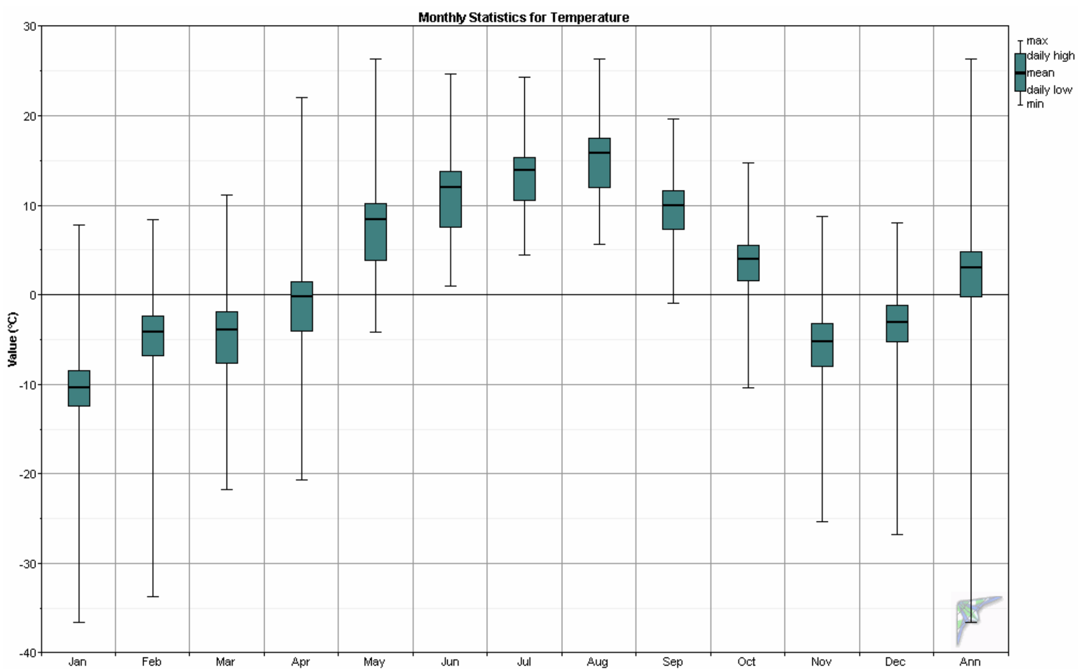
Turbulence Table

Bin Midpoint (m/s)	Bin Endpoints Lower (m/s)	Bin Endpoints Upper (m/s)	Records In Bin	Standard Deviation of Wind Speed (m/s)	Mean Turbulence Intensity	Standard Deviation of Turbulence Intensity	Characteristic Turbulence Intensity
1	0.5	1.5	901	0.401	0.424	0.199	0.624
2	1.5	2.5	1728	0.424	0.216	0.118	0.334
3	2.5	3.5	2757	0.443	0.150	0.088	0.238
4	3.5	4.5	3502	0.440	0.112	0.061	0.173
5	4.5	5.5	4149	0.454	0.092	0.045	0.136
6	5.5	6.5	4432	0.482	0.081	0.040	0.121
7	6.5	7.5	3997	0.552	0.080	0.032	0.112
8	7.5	8.5	3141	0.639	0.080	0.031	0.112
9	8.5	9.5	2260	0.762	0.085	0.030	0.116
10	9.5	10.5	1375	0.885	0.089	0.028	0.117
11	10.5	11.5	867	1.005	0.092	0.024	0.116
12	11.5	12.5	694	1.112	0.093	0.021	0.114
13	12.5	13.5	481	1.201	0.093	0.019	0.112
14	13.5	14.5	156	1.359	0.098	0.019	0.117
15	14.5	15.5	100	1.516	0.102	0.018	0.120
16	15.5	16.5	76	1.500	0.095	0.019	0.114
17	16.5	17.5	14	1.650	0.097	0.024	0.121
18	17.5	18.5	3	1.700	0.096	0.009	0.105
19	18.5	19.5	1	1.600	0.085	0.000	0.085
20	19.5	20.5	0	1.600	0.085	0.000	0.085
21	20.5	21.5	0	1.600	0.085	0.000	0.085
22	21.5	22.5	1	1.800	0.083	0.000	0.083

Air Temperature and Density

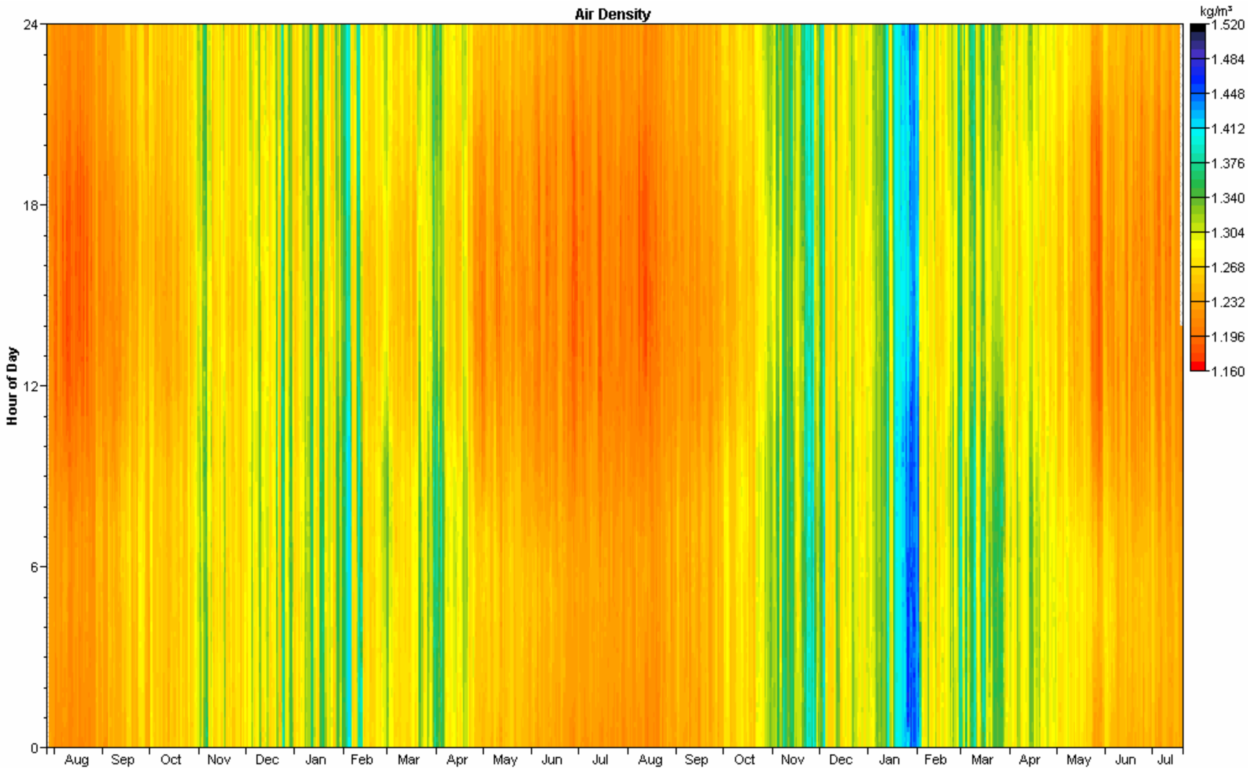
Over the reporting period, Naknek had an average temperature of 3.0° C. The minimum recorded temperature during the measurement period was -36.6° C and the maximum temperature was 26.3° C, indicating a wide variability of an ambient temperature operating environment important to wind turbine operations. Consequent to Naknek's cool temperatures, the average air density of 1.272 kg/m^3 is over four percent higher than the standard air density of 1.218 kg/m^3 (14.6° C and 100.6 kPa standard temperature and pressure at 53 m elevation), indicating that Naknek has denser air than the standard air density used to calculate turbine power curves (power curves are calculate at a sea level standard of 15° C and 101.3 kPa pressure). This density variance from standard *is* accounted for in turbine performance predictions in this report.

	Temperature				Air Density
Month	Mean (°C)	Min (°C)	Max (°C)	Std. Dev. (°C)	Mean (kg/m^3)
Jan	-10.3	-36.6	7.8	10.48	1.336
Feb	-4.1	-33.7	8.4	8.93	1.305
Mar	-3.9	-21.8	11.1	7.16	1.303
Apr	-0.2	-20.7	22.1	6.38	1.285
May	8.5	-4.2	26.3	5.21	1.246
Jun	12.0	1.0	24.7	4.04	1.230
Jul	13.9	4.4	24.3	3.18	1.222
Aug	15.8	5.7	26.3	3.59	1.214
Sep	10.0	-0.9	19.7	3.45	1.239
Oct	4.0	-10.4	14.8	4.74	1.266
Nov	-5.3	-25.3	8.8	8.34	1.310
Dec	-3.0	-26.8	8.0	6.70	1.299
Annual	**3.0**	-36.6	26.3	10.52	**1.272**



Air Density DMap

The DMap below is a visual indication of the daily and seasonal variations of air density (and hence temperature). Air densities higher than standard will yield higher turbine power than predicted by turbine power curves, while densities lower than standard will yield lower turbine power than predicted. Density variance from standard is accounted for in the turbine performance predictions.



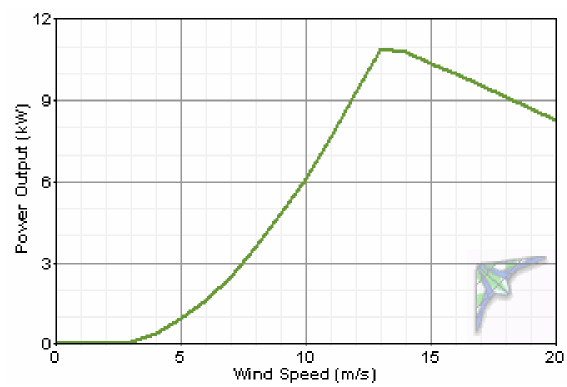
Wind Turbine Performance

The turbine performance predictions noted below are based on 100 percent and 90 percent turbine availabilities. The 100 percent data is for use as a baseline of comparison, but it is realistic to expect ten percent losses or downtime for wind turbines, at least during the first year of operation.

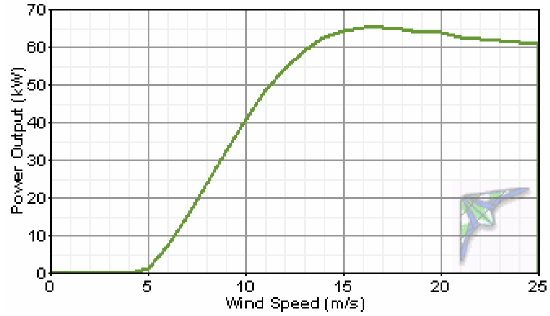
Note that these performance estimates were predicted with use of Windographer® wind analysis software; power curves provided by manufacturers are not independently verified and are assumed to be accurate. The power curves are presented for a standard air density of 1.225 kg/m^3 at sea level and 15° C. However, the predictions of power production are density compensated by multiplying the standard density power output by the ratio of the measured air density to standard air density, accounting for the site elevation.

A number of small to medium turbines are profiled in this report for comparison purposes. These turbines were selected because they have market availability and they are deemed to be within a suitable range for consideration of wind power development in a community the size of Naknek.

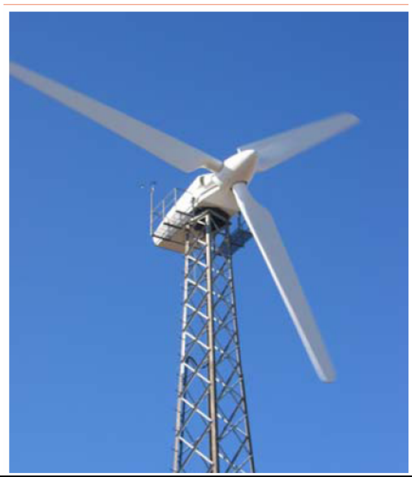
Bergey Excel-S: 10 kW rated power output, 6.7 meter rotor diameter, stall-controlled. Available tower heights: 18, 24, 30, 37 and 43 meters. Additional information is available at www.bergey.com.

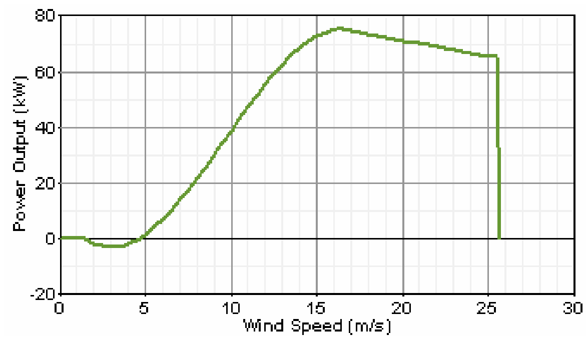


Entegrity eW-15: 65 kW rated power output, 15 meter rotor, stall-controlled (power curve provided by Entegrity Energy Systems). Available tower heights: 25 and 31 meters. Additional information is available at http://www.entegritywind.com/.

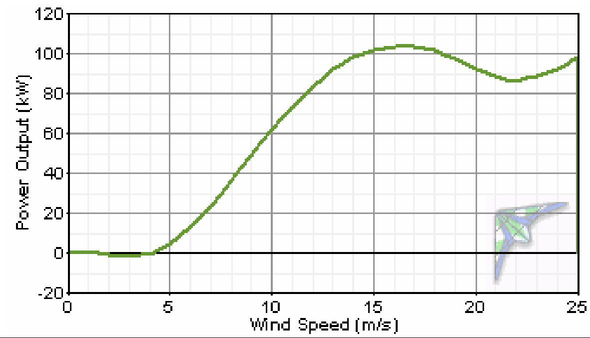


Vestas V15: 75 kW rated power output, 15 meter rotor, stall-controlled (power curve provided by Powercorp Alaska LLC). Available tower heights: 25, 31 and 34 meters. Additional information is available at http://www.pcorpalaska.com/.

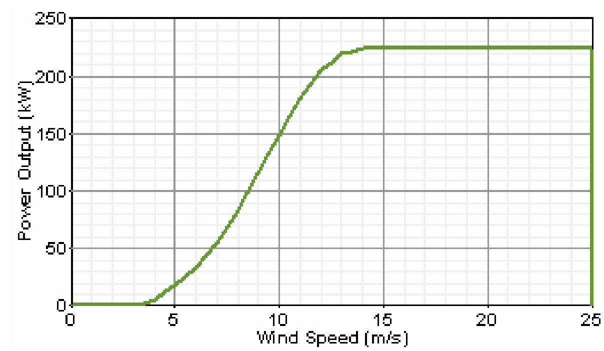




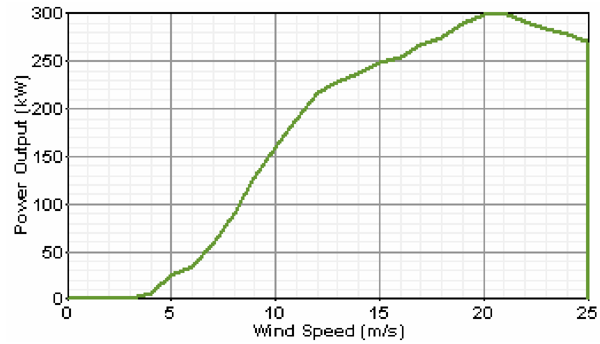
Northwind 100/20: 100 kW rated power output, 20 meter rotor (19 meter rotor blades with 0.6 meter blade root extensions added), stall-controlled (power curve provided by Northern Power Systems). Available tower heights: 25 and 32 meters. Additional information is available at http://www.northernpower.com/.



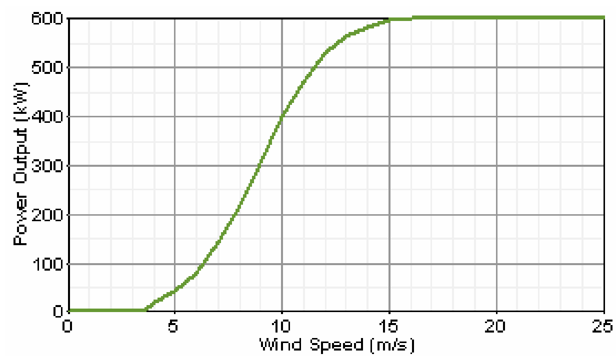
Vestas V27: 225 kW output, 27 meter rotor, pitch-controlled (power curve provided by Alaska Energy Authority).



Fuhrländer FL250: 250 kW output, 29.5 meter rotor, stall-controlled (power curve provided by Lorax Energy Systems). Available tower heights: 42 and 50 meters. Additional information is available at www.lorax-energy.com.



Vestas RRB 47/600: 600 kW output, 47 meter rotor, pitch-controlled (power curve provided by Vestas RRB, India). Available tower heights: 50 and 60 meters. Additional information is available at www.vestasrrb.com.



Turbine Power Output Comparison (100% availability)

Turbine	Hub Height (m)	Hub Height Wind Speed (m/s)	Time At Zero Output (%)	Time At Rated Output (%)	Average Net Power Output (kW)	Annual Net Energy Output (kWh/yr)	Average Net Capacity Factor (%)
Bergey Excel-S	43	6.60	6.5	5.3	2.9	25,631	29.3
Entegrity eW-15 60 Hz	31	6.22	27.0	2.5	15.5	135,670	23.8
Vestas V15	34	6.32	33.4	1.6	15.0	131,051	19.9
Northern Power NW 100/20	32	6.25	26.8	2.3	23.0	201,889	23.0
Vestas V27	50	6.79	9.0	2.8	69.1	605,677	30.7
Fuhrländer FL250	50	6.79	6.3	0.4	77.0	674,789	25.7
Vestas RRB 47/600	50	6.79	16.9	1.8	180.0	1,579,944	30.1

Capacity Factor <20%
Capacity Factor >20%, <30%
Capacity Factor >30%, <40%
Capacity Factor >40%, <50%
Capacity Factor >50%

Assumed turbine losses for predictions of average power output, annual energy output, and average capacity factor:

Downtime (%)	0
Array (%)	0
Icing/soiling (%)	0
Other (%)	0
Total (%)	0

Turbine Power Output Comparison (90% availability)

Turbine	Hub Height (m)	Hub Height Wind Speed (m/s)	Time At Zero Output (%)	Time At Rated Output (%)	Average Net Power Output (kW)	Annual Net Energy Output (kWh/yr)	Average Net Capacity Factor (%)
Bergey Excel-S	43	6.60	6.5	5.3	2.6	23,159	26.4
Entegrity eW-15 60 Hz	31	6.22	27.0	2.5	14.0	122,584	21.5
Vestas V15	34	6.32	33.4	1.6	13.5	118,410	18.0
Northern Power NW 100/20	32	6.25	26.8	2.3	20.8	182,415	20.8
Vestas V27	50	6.79	9.0	2.8	62.5	547,256	27.8
Fuhrländer FL250	50	6.79	6.3	0.4	69.6	609,701	23.2
Vestas RRB 47/600	50	6.79	16.9	1.8	163.0	1,427,549	27.2

Capacity Factor <20%
Capacity Factor >20%, <30%
Capacity Factor >30%, <40%
Capacity Factor >40%, <50%
Capacity Factor >50%

Assumed turbine losses for predictions of average power output, annual energy output, and average capacity factor:

Downtime (%)	4	
Array (%)	2	
Icing/soiling (%)	2	
Other (%)	2	
Total (%)	9.65	(factors are multiplicative)

Fuel Cost Avoided for Electricity Generation by Diesel Generator

				Fuel Price (USD/gallon)							
Turbine	Annual Energy Output (kW-hr/yr)	Fuel Quantity Avoided (liters)	Fuel Quantity Avoided (gallons)	$1.75	$2.00	$2.25	$2.50	$2.75	$3.00	$3.25	Turbine Hub Height (m)
Bergey Excel-S	23,159	6,494	1,715	$3,002	$3,431	$3,860	$4,289	$4,718	$5,146	$5,575	43
Entegrity eW-15 60 Hz	122,584	34,373	9,080	$15,891	$18,161	$20,431	$22,701	$24,971	$27,241	$29,511	31
Vestas V15	118,410	33,202	8,771	$15,349	$17,542	$19,735	$21,928	$24,121	$26,313	$28,506	34
Northern Power NW 100/20	182,415	51,149	13,512	$23,646	$27,024	$30,403	$33,781	$37,159	$40,537	$43,915	32
Vestas V27	547,256	153,451	40,537	$70,941	$81,075	$91,209	$101,344	$111,478	$121,612	$131,747	50
Fuhrländer FL250	609,701	170,960	45,163	$79,035	$90,326	$101,617	$112,908	$124,198	$135,489	$146,780	50
Vestas RRB 47/600	1,427,549	400,285	105,744	$185,053	$211,489	$237,925	$264,361	$290,797	$317,233	$343,669	50

Notes:
1. Naknek electrical energy production efficiency assumed to be 13.5 kW-hr/gal
2. Assumes 90% wind turbine availability with no diversion of power to a thermal or other dump load
3. Assumes linear diesel generator fuel efficiency (i.e., 1:1 tradeoff of wind turbine kW-hr to diesel genset kW-hr)

Temperature Conversion Chart °C to °F

°C	°F	°C	°F	°C	°F
-40	-40	-10	14	20	68
-39	-38.2	-9	15.8	21	69.8
-38	-36.4	-8	17.6	22	71.6
-37	-34.6	-7	19.4	23	73.4
-36	-32.8	-6	21.2	24	75.2
-35	-31	-5	23	25	77
-34	29.2	-4	24.8	26	78.8
-33	-27.4	-3	26.6	27	80.6
-32	-25.6	-2	28.4	28	82.4
-31	-23.8	-1	30.2	29	84.2
-30	-22	0	32	30	86
-29	-20.2	1	33.8	31	87.8
-28	-18.4	2	35.6	32	89.6
-27	-16.6	3	37.4	33	91.4
-26	-14.8	4	39.2	34	93.2
-25	-13	5	41	35	95
-24	-11.2	6	42.8	36	96.8
-23	-9.4	7	44.6	37	98.6
-22	-7.6	8	46.4	38	100.4
-21	-5.8	9	48.2	39	102.2
-20	-4	10	50	40	104
-19	-2.2	11	51.8	41	105.8
-18	-0.4	12	53.6	42	107.6
-17	1.4	13	55.4	43	109.4
-16	3.2	14	57.2	44	111.2
-15	5	15	59	45	113
-14	6.8	16	60.8	46	114.8
-13	8.6	17	62.6	47	116.6
-12	10.4	18	64.4	48	118.4
-11	12.2	19	66.2	49	120.2

Wind Speed Conversion Chart m/s to mph

m/s	mph	m/s	mph	m/s	mph
0.5	1.1	10.5	23.5	20.5	45.9
1.0	2.2	11.0	24.6	21.0	47.0
1.5	3.4	11.5	25.7	21.5	48.1
2.0	4.5	12.0	26.8	22.0	49.2
2.5	5.6	12.5	28.0	22.5	50.3
3.0	6.7	13.0	29.1	23.0	51.4
3.5	7.8	13.5	30.2	23.5	52.6
4.0	8.9	14.0	31.3	24.0	53.7
4.5	10.1	14.5	32.4	24.5	54.8
5.0	11.2	15.0	33.6	25.0	55.9
5.5	12.3	15.5	34.7	25.5	57.0
6.0	13.4	16.0	35.8	26.0	58.2
6.5	14.5	16.5	36.9	26.5	59.3
7.0	15.7	17.0	38.0	27.0	60.4
7.5	16.8	17.5	39.1	27.5	61.5
8.0	17.9	18.0	40.3	28.0	62.6
8.5	19.0	18.5	41.4	28.5	63.8
9.0	20.1	19.0	42.5	29.0	64.9
9.5	21.3	19.5	43.6	29.5	66.0
10.0	22.4	20.0	44.7	30.0	67.1

Distance Conversion m to ft

m	ft	m	ft
5	16	35	115
10	33	40	131
15	49	45	148
20	66	50	164
25	82	55	180
30	98	60	197

Selected definitions (courtesy of Windographer® software by Mistaya Engineering Inc.)

Wind Power Class

The wind power class is a number indicating the average energy content of the wind resource. Wind power classes are based on the average wind power density at 50 meters above ground, according to the following table. Source: Wind Energy Resource Atlas of the United States (http://rredc.nrel.gov/wind/pubs/atlas/tables/A-8T.html)

Wind Power Class	Description	Power Density at 50m (W/m^2)
1	Poor	0-200
2	Marginal	200-300
3	Fair	300-400
4	Good	400-500
5	Excellent	500-600
6	Outstanding	600-800
7	Superb	800-2000

Windographer classifies any wind resource with an average wind power density above 2000 W/m^2 as class 8.

Probability Distribution Function

The probability distribution function f(x) gives the probability that a variable will take on the value x. It is often expressed using a frequency histogram, which gives the frequency with which the variable falls within certain ranges or bins.

Wind Turbine Power Regulation

All wind turbines employ some method of limiting power output at high wind speeds to avoid damage to mechanical or electrical subsystems. Most wind turbines employ either stall control or pitch control to regulate power output.

A stall-controlled turbine typically has blades that are fixed in place, and are designed to experience aerodynamic stall at very high wind speeds. Aerodynamic stall dramatically reduces the torque produced by the blades, and therefore the power produced by the turbine.

On a pitch-controlled turbine, a controller adjusts the angle (pitch) of the blades to best match the wind speed. At very high wind speeds the controller increasingly feathers the blades out of the wind to limit the power output.