Dillingham, Alaska Wind Resource Report
Kanakanak Site

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

Photo © Doug Vaught

Summary Information

Winds measured in Dillingham were consistent with the State wind resource map and are sufficient for wind power development in the community. Because of the proximity of forest to the wind test site, the wind shear and turbulence were higher than seen in other Bristol Bay region communities. Because a successful wind power project has the potential to lower the electrical power generation costs in Dillingham, installation of a 50 meter meteorological tower and selection of a site further from the forest margin may yield better data.

Meteorological Tower Data Synopsis

Wind power class	Class 3 – Fair
Wind speed annual average (30 meters)	5.78 m/s
Maximum wind gust (2 sec. average)	30.9 m/s, April 2005
Mean wind power density (50 meters)	374 W/m^2 (calculated)
Mean wind power density (30 meters)	230 W/m^2 (measured)
Weibull distribution parameters	k = 2.01, c = 6.29 m/s
Roughness Class	3.66 (forest)
Power law exponent	0.286 (high wind shear)
Turbulence Intensity	0.124 (moderate)
Data start date	April 23, 2004
End data date	October 5, 2005

Community Profile

Current Population:	2,370 (2005 State Demographer est.)
Pronunciation/Other Names:	(DILL-eeng-ham); a.k.a. Curyung; Kanakanak
Incorporation Type:	1st Class City
Borough Located In:	Unorganized
School District:	Dillingham City Schools
Regional Native Corporation:	Bristol Bay Native Corporation

Location:

Dillingham is located at the extreme northern end of Nushagak Bay in northern Bristol Bay, at the confluence of the Wood and Nushagak Rivers. It lies 327 miles southwest of Anchorage, and is a 6 hour flight from Seattle. It lies at approximately 59.039720° North Latitude and -158.457500° West Longitude. (Sec. 21, T013S, R055W, Seward Meridian.) Dillingham is located in the Bristol Bay Recording District. The area encompasses 33.6 sq. miles of land and 2.1 sq. miles of water.

History:

The area around Dillingham was inhabited by both Eskimos and Athabascans and became a trade center when Russians erected the Alexandrovski Redoubt (Post) in 1818. Local Native groups and Natives from the Kuskokwim Region, the Alaska Peninsula and Cook Inlet mixed together as they came to visit or live at the post. The community was known as Nushagak by 1837, when a Russian Orthodox mission was established. In 1881 the U.S. Signal Corps established a meteorological station at Nushagak. In 1884 the first salmon cannery in the Bristol Bay region was constructed by Arctic Packing Co., east of the site of modern-day Dillingham. Ten more were established within the next seventeen years. The post office at Snag Point and town were named after U.S. Senator Paul Dillingham in 1904, who had toured Alaska extensively with his Senate subcommittee during 1903. The 1918-19 influenza epidemic struck the region, and left no more than 500 survivors. A hospital and orphanage were established in Kanakanak after the epidemic, 6 miles from the present-day City Center. The Dillingham townsite was first surveyed in 1947. The City was incorporated in 1963.

Culture:

Traditionally a Yup'ik Eskimo area, with Russian influences, Dillingham is now a highly mixed population of non-Natives and Natives. The outstanding commercial fishing opportunities in the Bristol Bay area are the focus of the local culture.

Economy:

Dillingham is the economic, transportation, and public service center for western Bristol Bay. Commercial fishing, fish processing, cold storage and support of the fishing industry are the primary activities. Icicle, Peter Pan, Trident and Unisea operate fish processing plants in Dillingham. Two hundred seventy-seven residents hold commercial fishing permits. During spring and summer, the population doubles. The city's role as the regional center for government and services helps to stabilize seasonal employment. Many residents depend on subsistence activities and trapping of beaver, otter, mink, lynx and fox provide cash income. Salmon, grayling, pike, moose, bear, caribou, and berries are harvested.

Facilities:

Around 90% of homes are fully plumbed. Dillingham's water is derived from three deep wells. Water is treated, stored in tanks (capacity is 1,250,000 gallons) and distributed. Approximately 40% of homes are served by the City's piped water system; 60% use individual wells. The core townsite is served by a piped sewage system; waste is treated in a sewage lagoon. However, the majority of residents (75%) have septic systems. The City has requested funds to extend piped water to the old airstrip and Kenny Wren Road, and expand sewer service to the northeast. Dillingham Refuse Inc., a private firm, collects refuse three times a week. The Senior Center collects aluminum for recycling, and NAPA recycles used batteries. The Chamber of Commerce coordinates recycling of several materials, including fishing web. A new landfill site with a baling facility is currently being planned. Nushagak Electric owns and operates a diesel plant in Dillingham which also supplies power to Aleknagik.

Transportation:

Dillingham can be reached by air and sea. The State-owned airport provides a 6,404' long by 150' wide paved runway and Flight Service Station, and regular jet flights are available from Anchorage. A seaplane base is available 3 miles west at Shannon's Pond; it is owned by the U.S. Bureau of Land Management, Division of Lands. A heliport is available at Kanakanak Hospital. There is a City-operated small boat harbor with 320 slips, a dock, barge landing, boat launch, and boat haul-out facilities. It is a tidal harbor and only for seasonal use. Two barge lines make scheduled trips from Seattle. There is a 23-mile DOT-maintained gravel road to Aleknagik; it was first constructed in 1960.

Climate:

The primary climatic influence is maritime, however, the arctic climate of the Interior also affects the Bristol Bay coast. Average summer temperatures range from 37 to 66 degrees Fahrenheit. Average winter temperatures range from 4 to 30 degrees Fahrenheit. Annual precipitation is 26 inches, and annual snowfall is 65 inches. Heavy fog is common in July and August. Winds of up to 60-70 mph may occur between December and March. The Nushagak River is ice-free from June through November.

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

Site Information and Location

Site number	2259
Site Description	Dillingham
Latitude/longitude	N 59° 00.065’ W 158° 32.756’
Site elevation	32 meters
Datalogger type	NRG Symphonie
Tower type	NRG 30-meter tall tower, 152 mm (6 in) diameter

Tower Sensor Information

Channel	Sensor type	Height	Multiplier	Offset	Orientation
1	NRG #40 anemometer	30 m	0.765	0.35	South (170°T)
2	NRG #40 anemometer	20 m	0.765	0.35	NNE (020°T)
7	NRG #200P wind vane	30 m	0.351	166	NNW
9	NRG #110S Temp C	2 m	0.136	-86.383	N/A

Data Quality Control

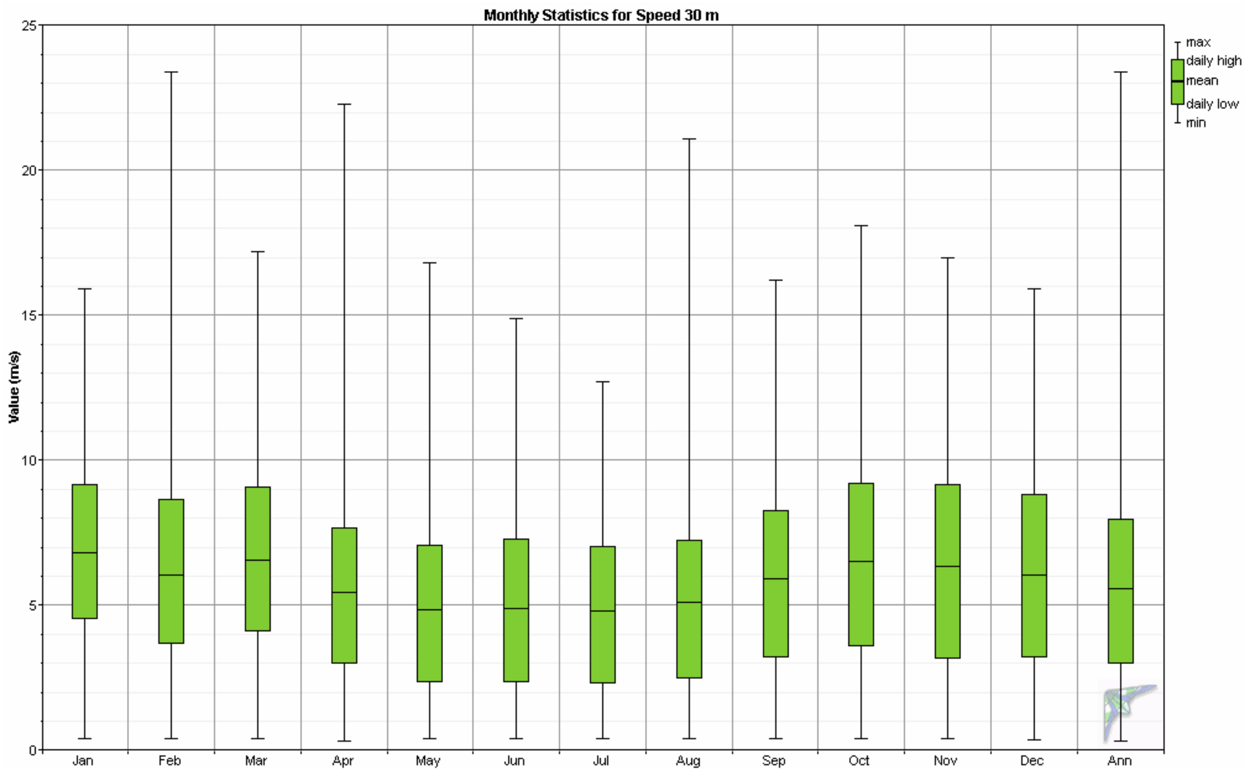
Data was filtered to remove presumed icing events that yield false zero wind speed data. Data that met the following criteria were filtered: wind speed < 1 m/s, wind speed standard deviation = 0, and temperature < 3 °C. Note that data recovery during the months of May through October was 100%, but during the months of November through April some data was filtered, with December being the most ice prone as far as data loss is concerned. Temperature data recovery was 100 percent, indicating full functioning of the temperature sensor. For this file, data was synthesized to replace data lost to icing events.

		Ch 1 anemometer		Ch 2 anemometer		Ch 7 vane		Ch 9 temperature	
Year	Month	Records	Recovery Rate (%)	Records	Recovery Rate (%)	Records	Recovery Rate (%)	Records	Recovery Rate (%)
2004	Apr	986	84.1	921	78.6	923	78.8	1,057	100
2004	May	4,464	100	4,464	100	4,464	100	4,464	100
2004	Jun	4,320	100	4,320	100	4,320	100	4,320	100
2004	Jul	4,464	100	4,464	100	4,464	100	4,464	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	4,464	100	4,464	100	4,464	100	4,464	100
2004	Nov	4,041	93.5	4,156	96.2	4,013	92.9	4,320	100
2004	Dec	3,895	87.3	4,278	95.8	2,934	65.7	4,464	100
2005	Jan	4,260	95.4	4,365	97.8	4,162	93.2	4,464	100
2005	Feb	4,032	100	3,989	98.9	3,827	94.9	4,032	100
2005	Mar	4,389	98.3	4,464	100	4,389	98.3	4,464	100
2005	Apr	4,320	100	4,258	98.6	4,320	100	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	648	100	648	100	648	100	648	100
All data		75,099	98.3	75,607	98.9	73,744	96.5	76,297	100

Measured Wind Speeds

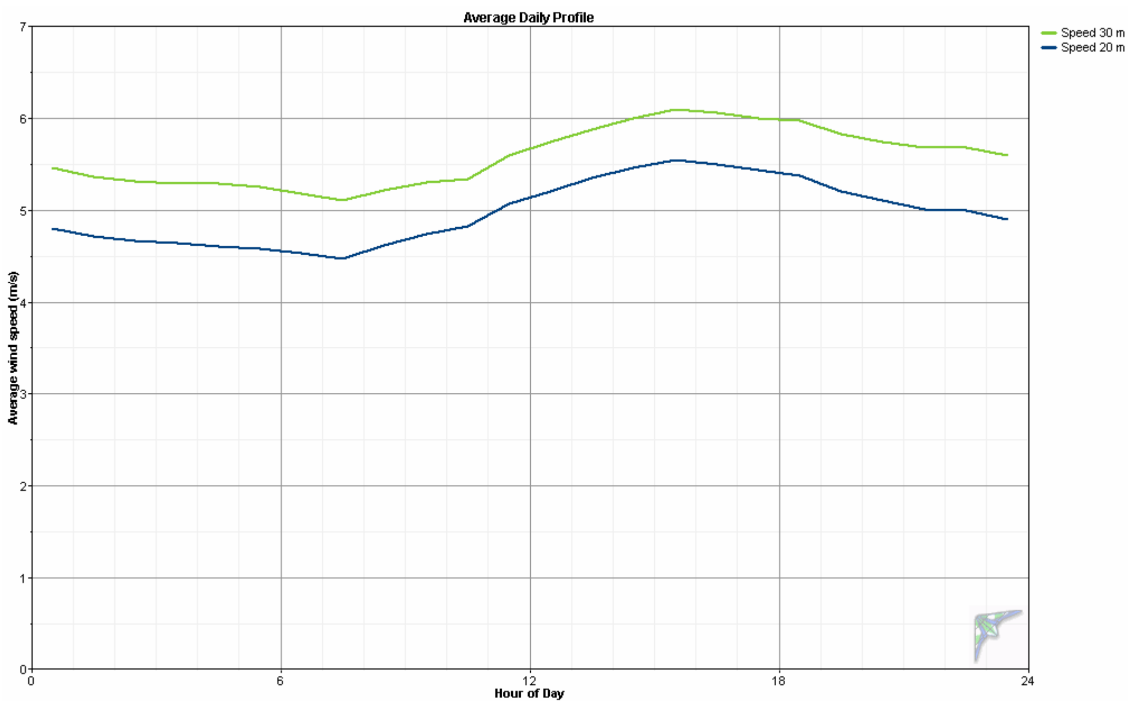
The Channel 1 (30-meter) anemometer average annual wind speed for the reporting period is 5.78 m/s and the Channel 2 (20-meter) anemometer wind speed average is 5.14 m/s. Note that these data are from a data file that includes data synthesized to remove ice event and other unacceptable original data.

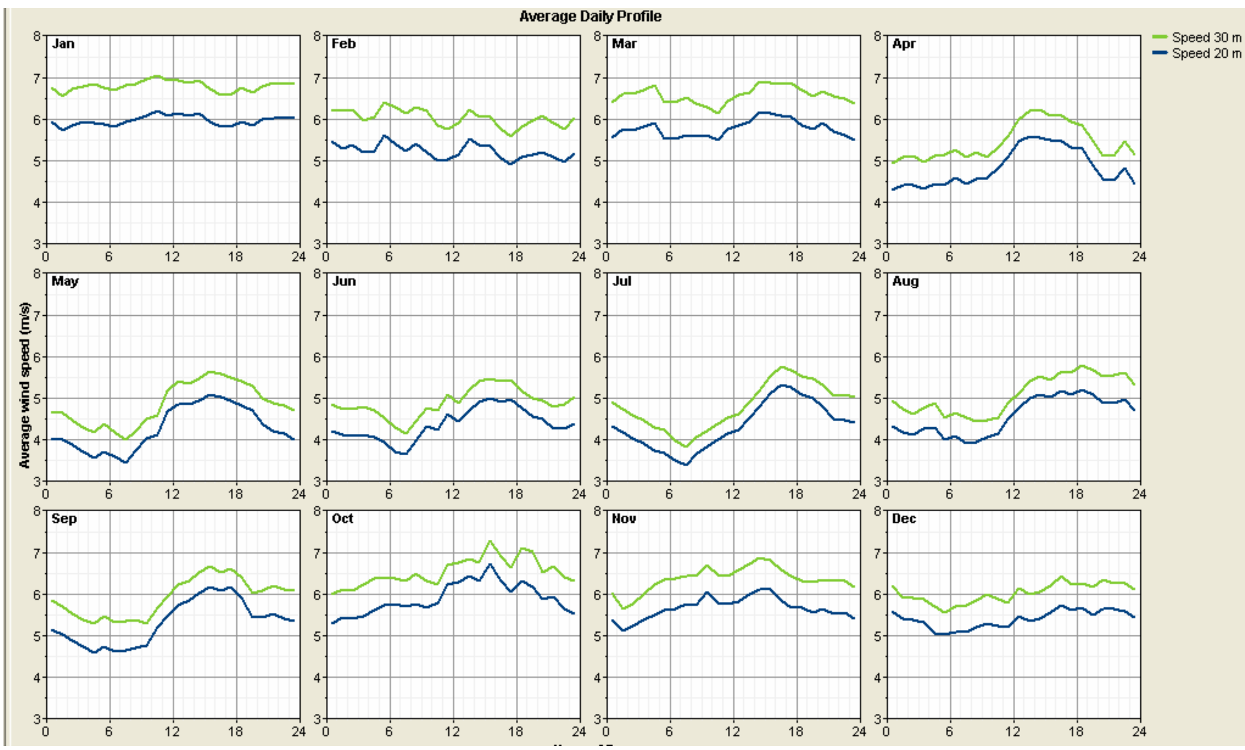
	Ch 1 speed (30 m)					Ch 2 speed (20 m)	
Month	Mean (m/s)	Max (m/s)	Std. Dev. (m/s)	Weibull k	Weibull c (m/s)	Mean (m/s)	Max (m/s)
Jan	6.80	15.9	2.71	2.67	7.60	5.97	14.3
Feb	6.03	23.4	3.11	2.05	6.82	5.23	22.4
Mar	6.58	17.2	3.12	2.19	7.40	5.77	15.1
Apr	5.44	22.3	2.95	1.93	6.14	4.83	19.5
May	4.85	16.8	2.53	1.98	5.46	4.28	14.1
Jun	4.90	14.9	2.58	1.99	5.52	4.37	13.1
Jul	4.81	12.7	2.23	2.26	5.42	4.33	11.8
Aug	5.10	21.1	2.64	2.01	5.75	4.58	18.9
Sep	5.92	16.2	2.82	2.21	6.67	5.32	15.0
Oct	6.53	18.1	3.13	2.17	7.36	5.89	17.1
Nov	6.36	17.0	3.26	1.96	7.12	5.66	14.8
Dec	6.03	15.9	3.10	2.00	6.78	5.40	14.2
Annual	**5.78**	23.4	2.87	2.01	6.29	**5.14**	22.4



Daily Wind Profile

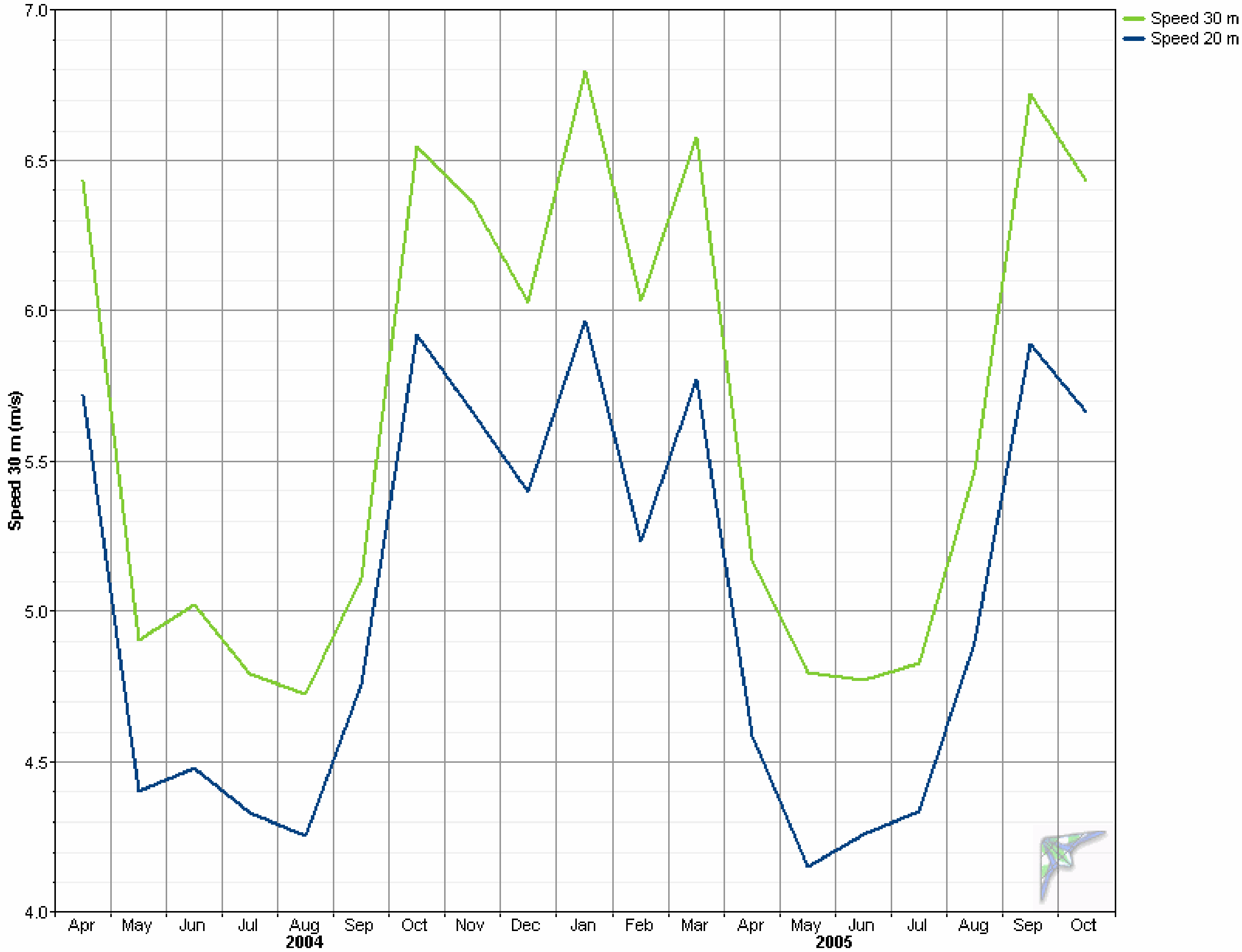
The daily wind profile indicates that the lowest wind speeds of the day occur in the morning hours of 6 to 8 a.m. and the highest wind speeds of the day occur during the afternoon and evening hours of 3 to 5 p.m.

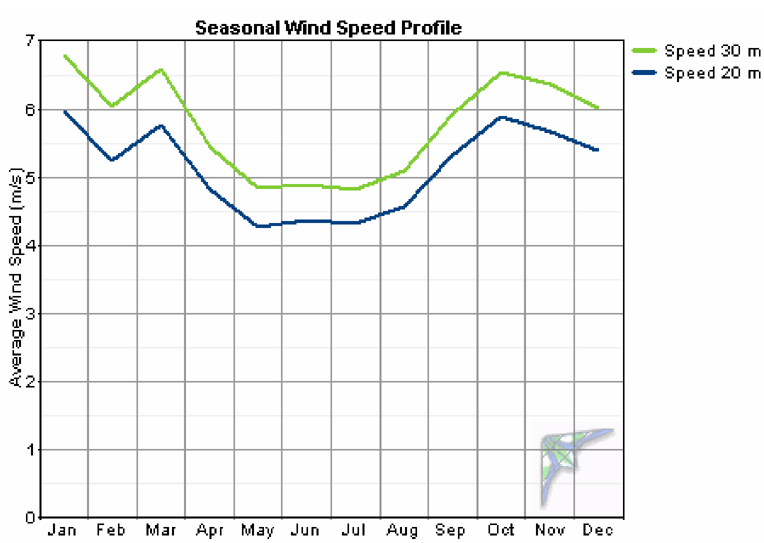




Time Series of Wind Speed Averages

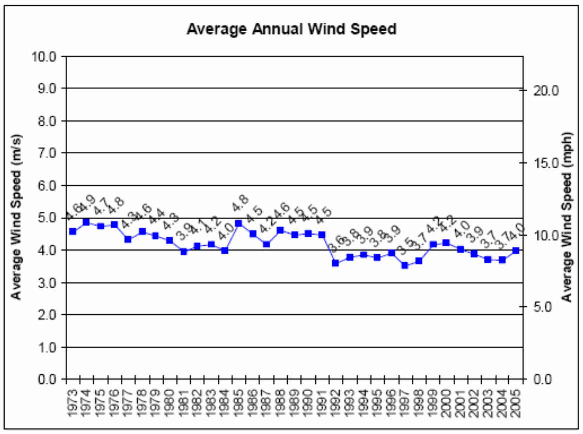
As expected, the highest winds in Dillingham occur during the fall through spring months with relatively light winds during the summer months of May through August.





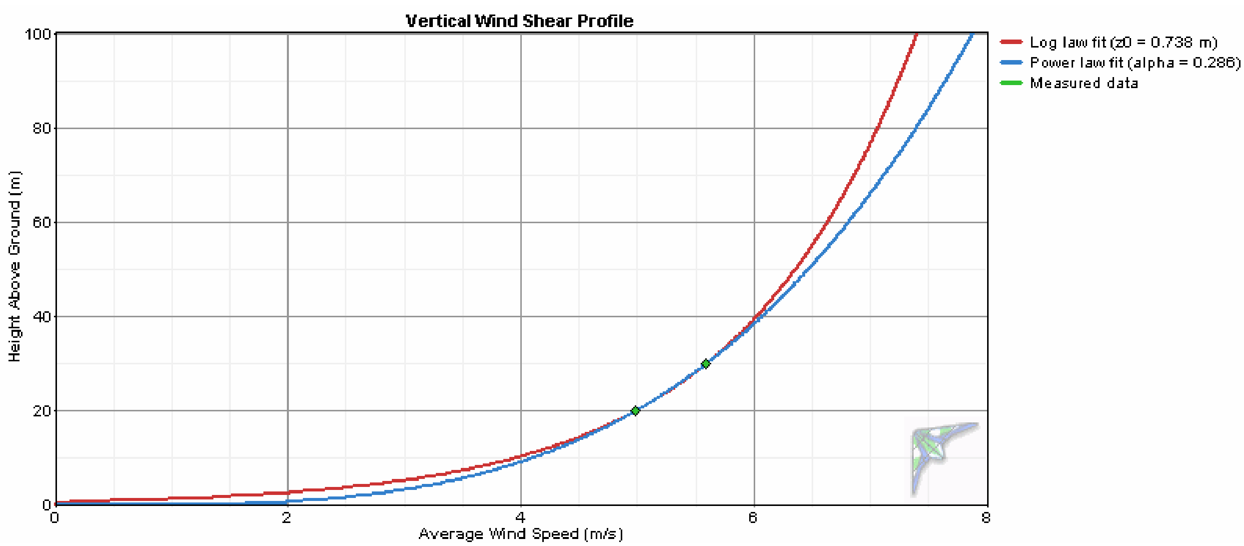
Long-term Data Comparison

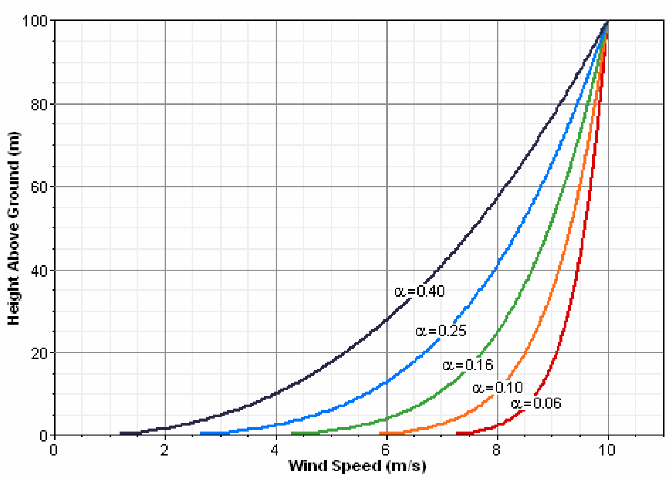
The graph below of average annual wind speed for the nearby Dillingham airport indicates that 2004 and 2005 experienced possibly low average annual wind speeds when compared to data over the past thirty-two years, although in comparison to the past ten years, the 2004/05 wind speeds recorded at the airport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

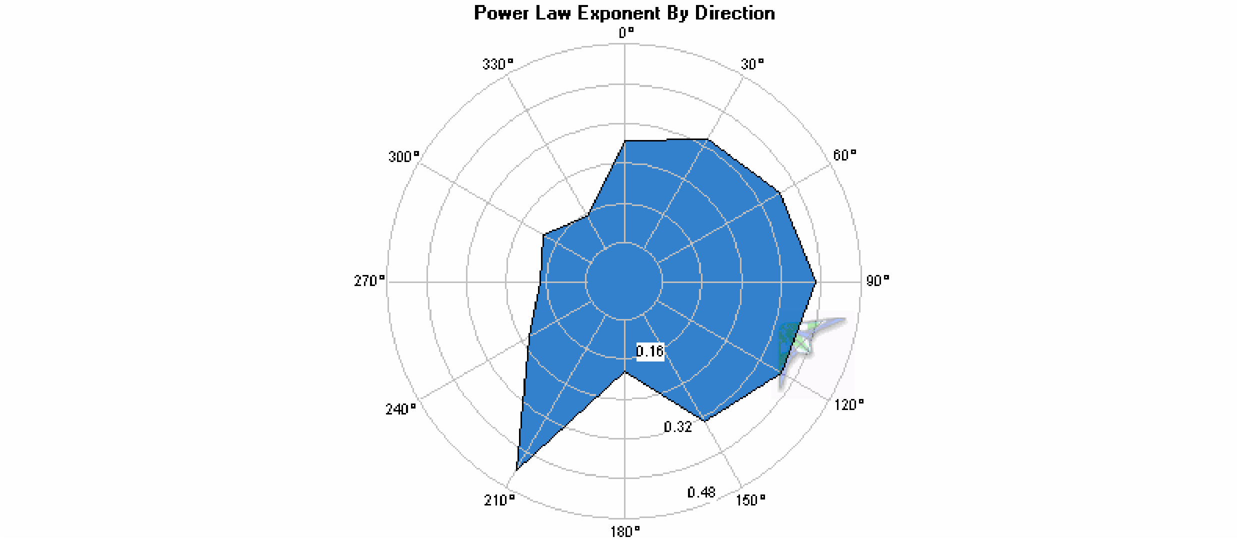


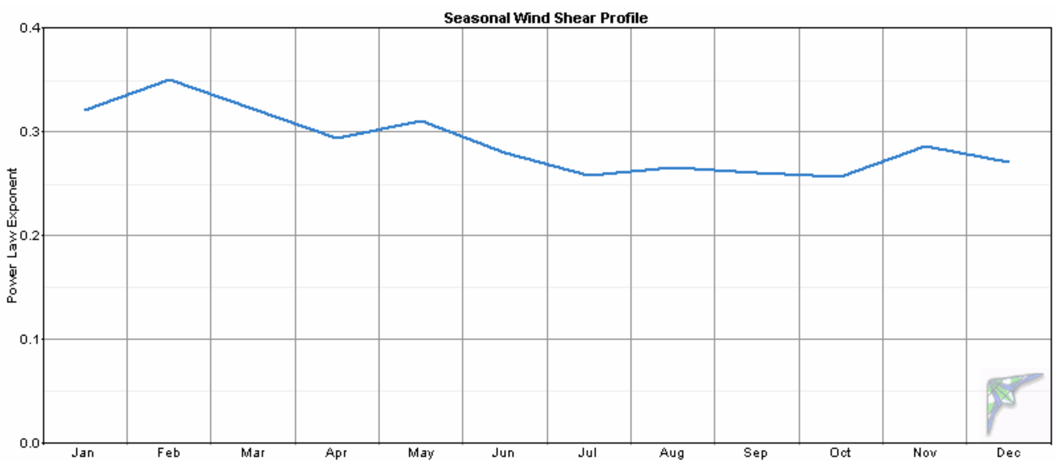
Wind Shear Profile

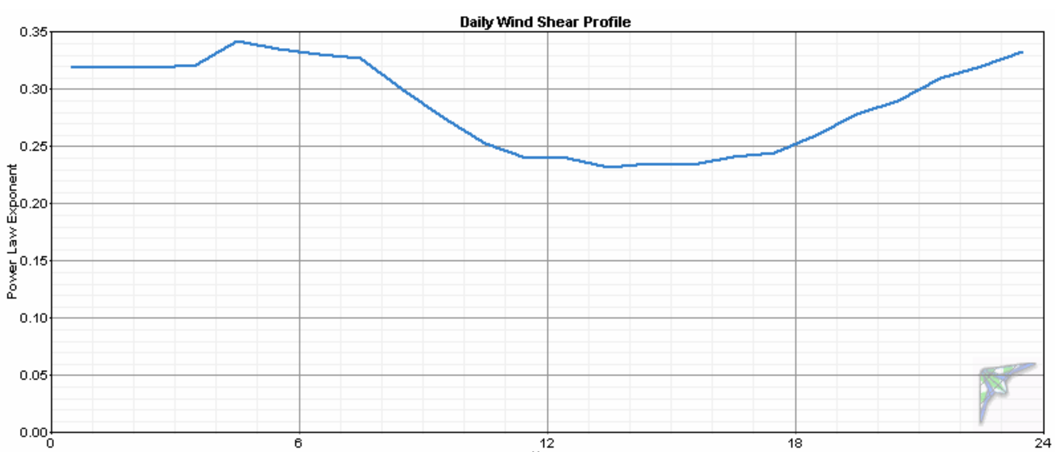
The power law exponent was calculated at 0.286, indicating relatively high wind shear at the Dillingham test site. Wind shear however likely was affected by the near presence of trees to the east and south of the test site and other structures further to the west. A higher met tower with instrumentation at 40 meters or higher would likely indicate less wind shear than indicated by this data. The practical application of relatively high wind shear 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. One caution is that wind speed and performance predictions with this data set may overestimate the wind resource at heights greater than 30 meters.





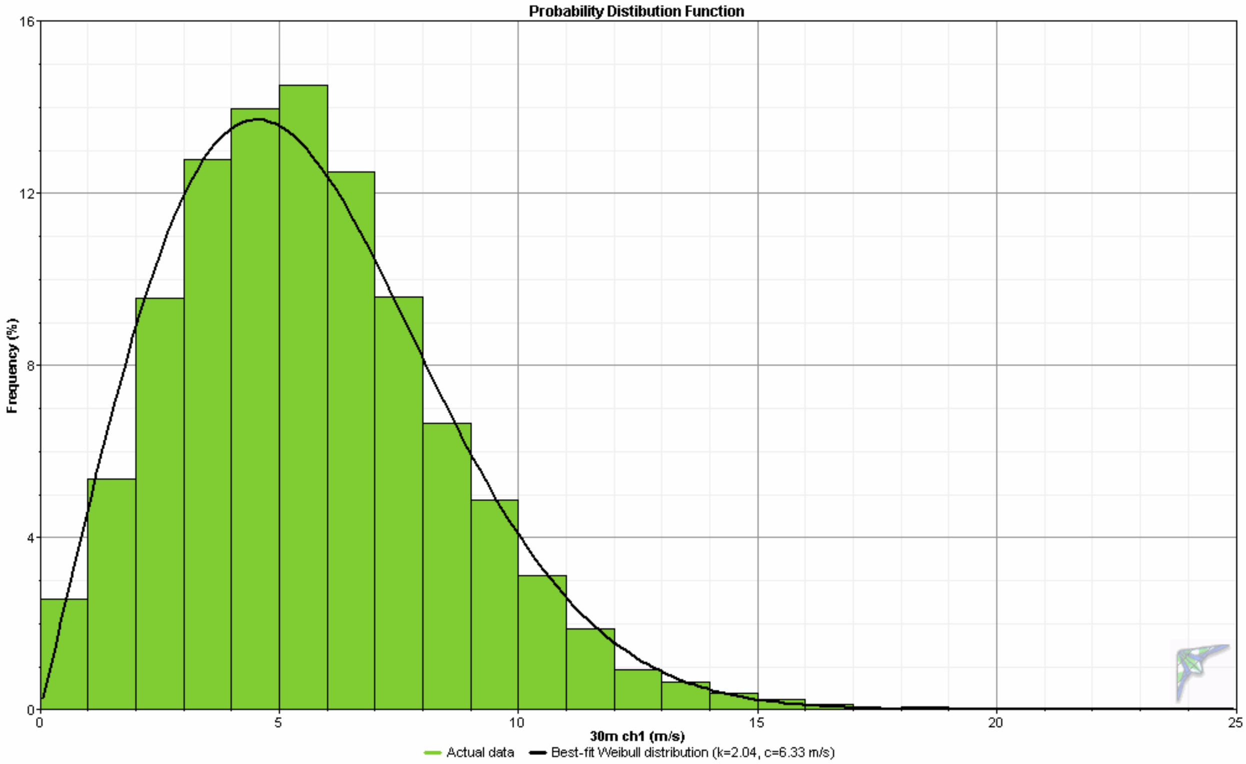

Power Law Exponent By Direction
0°
30°
60°
90°
120°
150°
180°
210°
240°
270°
300°
330°
0.16
0.32
0.48

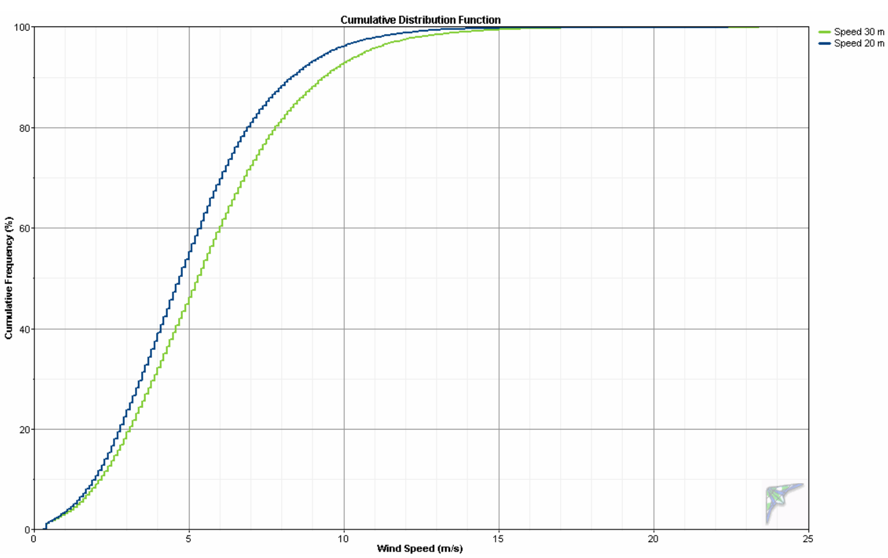

Seasonal Wind Shear Profile
Power Law Exponent
0.0
0.1
0.2
0.3
0.4
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec


Daily Wind Shear Profile
Power Law Exponent
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
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. The black line in the graph is a best fit Weibull distribution. At the 30 meter level, Weibull parameters are k = 2.01 (indicates a relatively low distribution of wind speeds) and c = 6.29 m/s (scale factor for the Weibull distribution) for the eighteen month data collection period. The PDF information is shown visually in another manner in the second graph, the Cumulative Distribution Function.

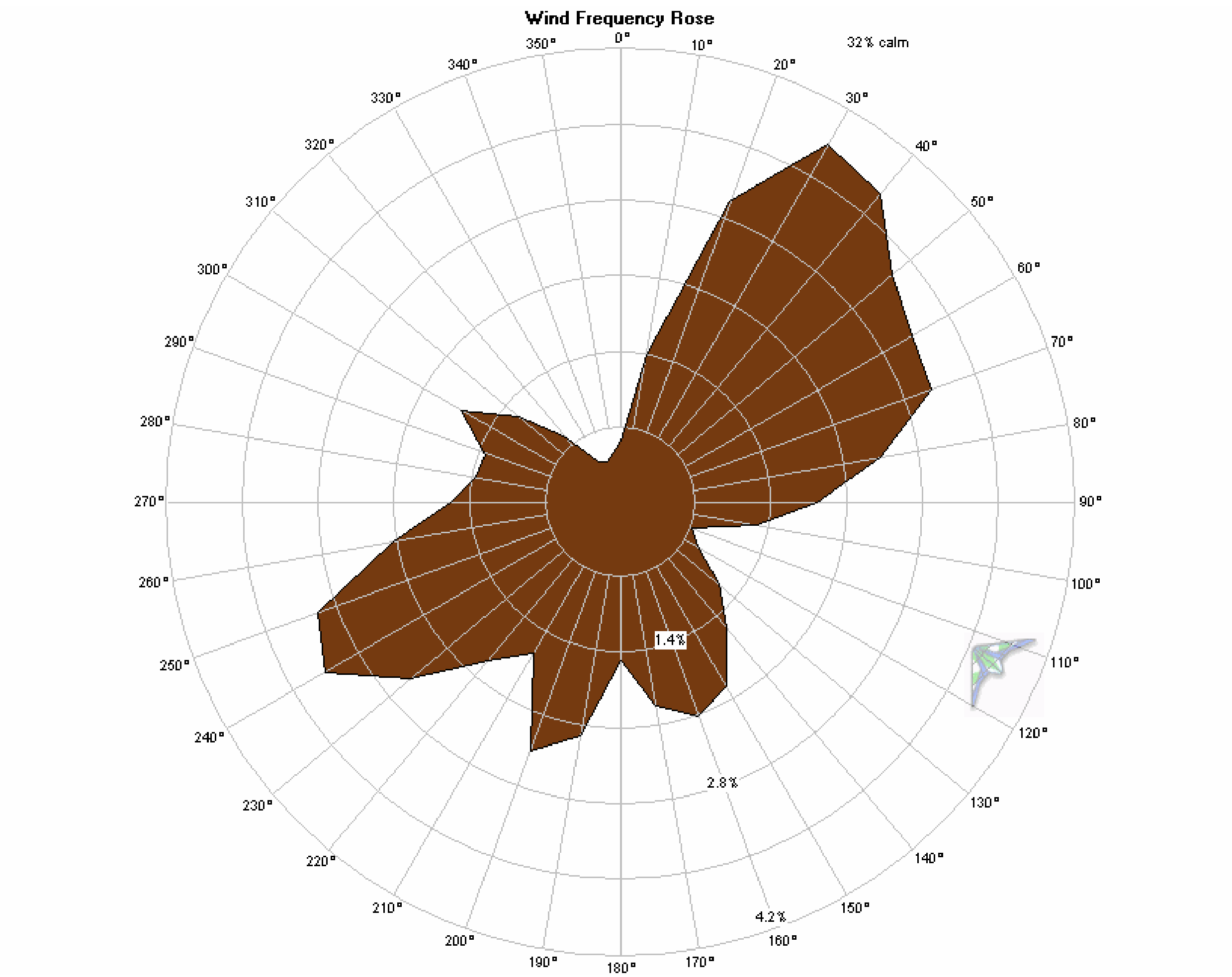




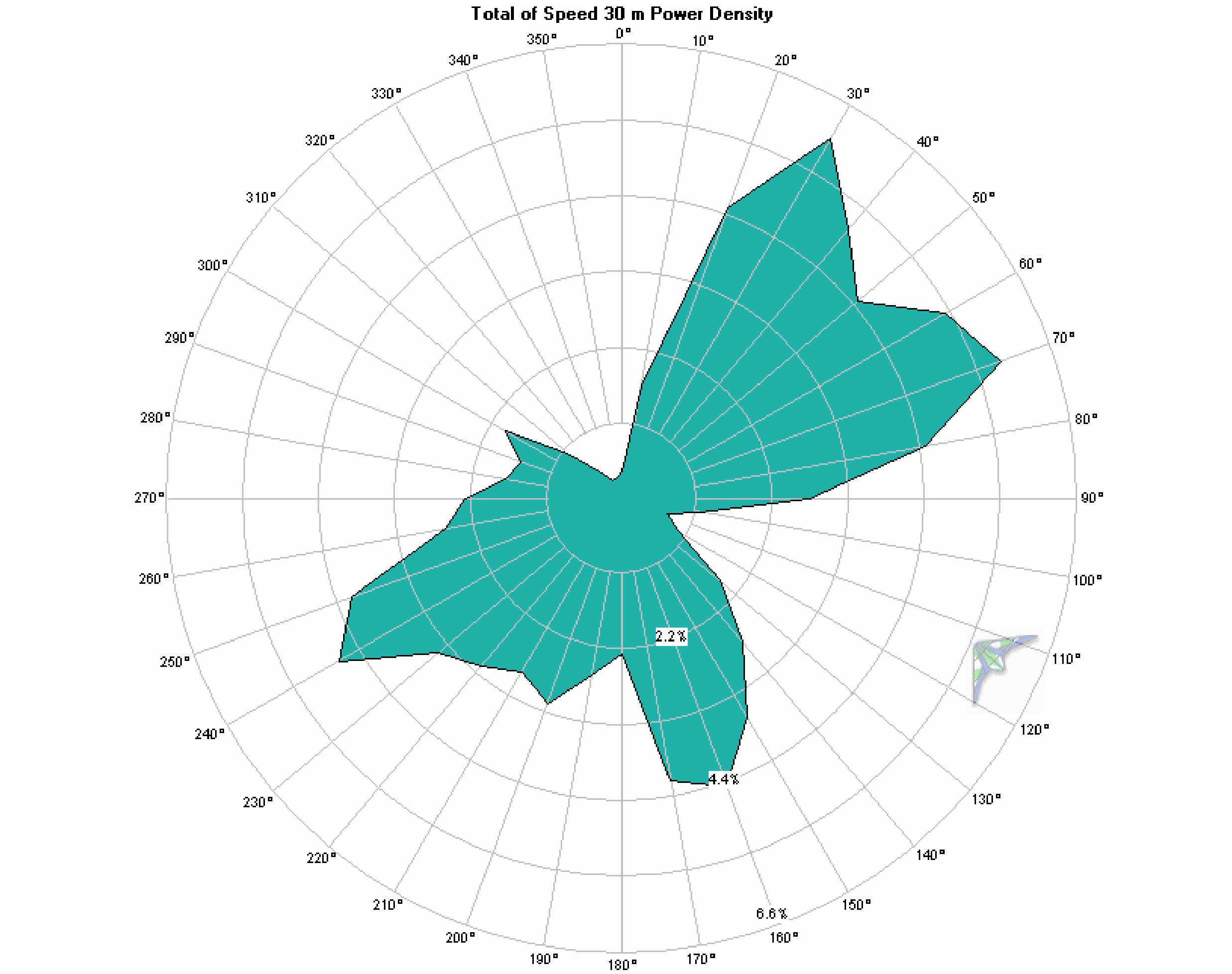
Wind Roses

Dillingham winds are not especially directional; the wind frequency rose indicates northeast, south and southwest components of wind. This observation is reinforced with reference to the power density rose below which indicates power producing winds from the same directions. The practical application of this information is that a site should be selected with adequate freedom from ground interference to the northeast, south and southwest, 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. The indication below of 32 percent calm winds is calculated with a 4 m/s wind speed threshold, the typical cut-in speed of wind turbines.

Wind Frequency Rose (30 meters)

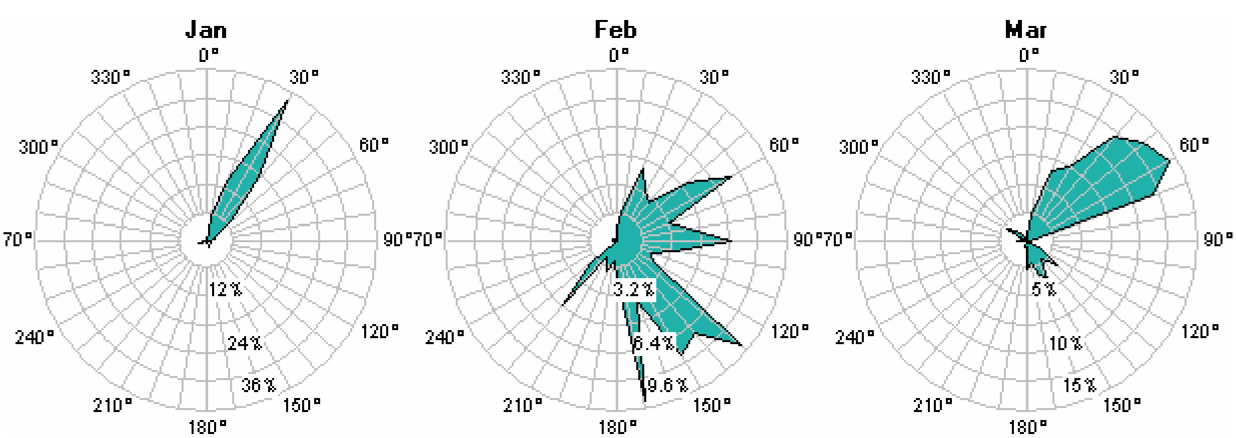


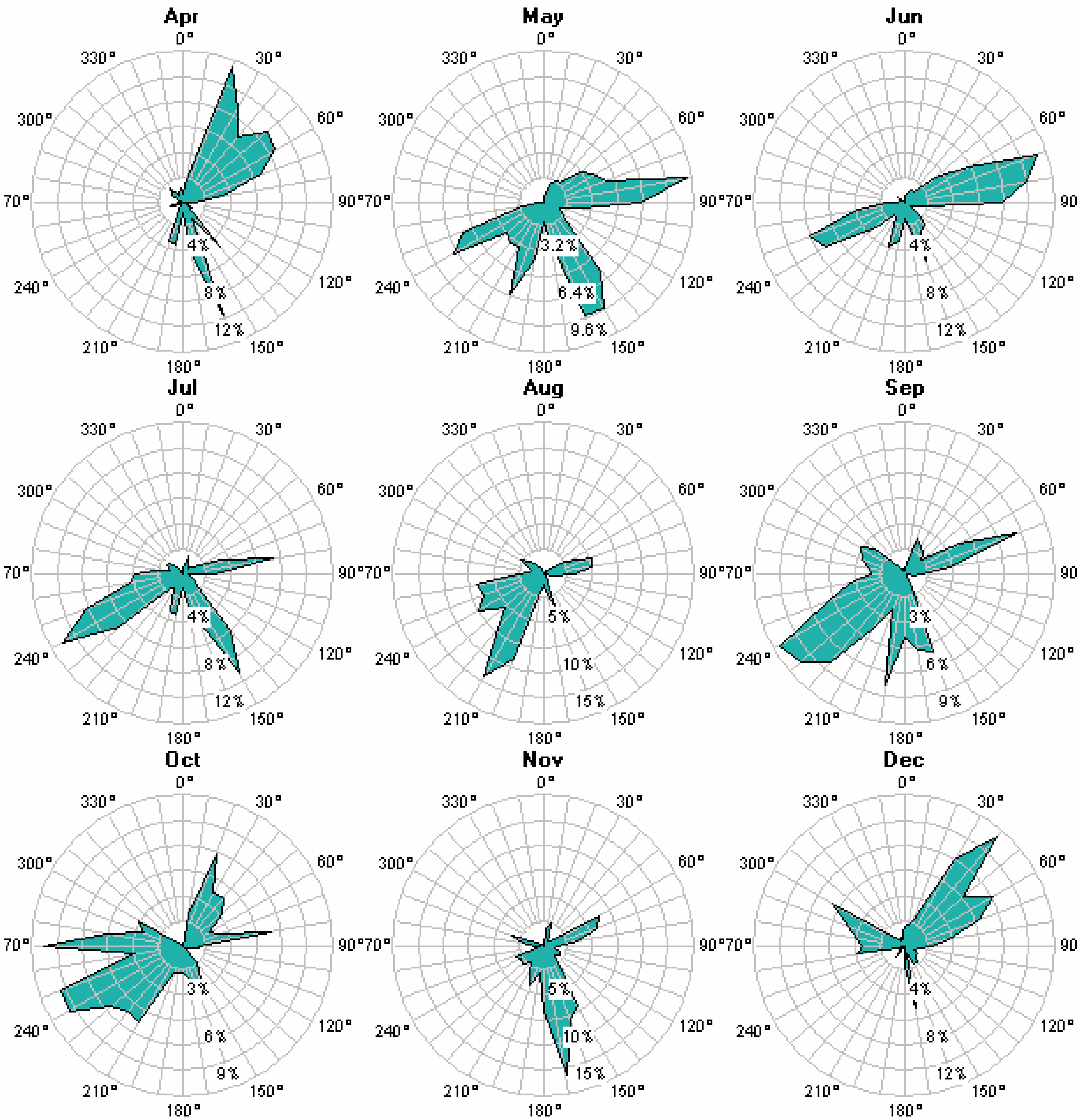
Wind Power Density Rose (30 meters)



Wind Power Density Rose by Month (30 meters)

Note: for easier visualization of monthly wind direction variation, the scale is <u>not</u> common

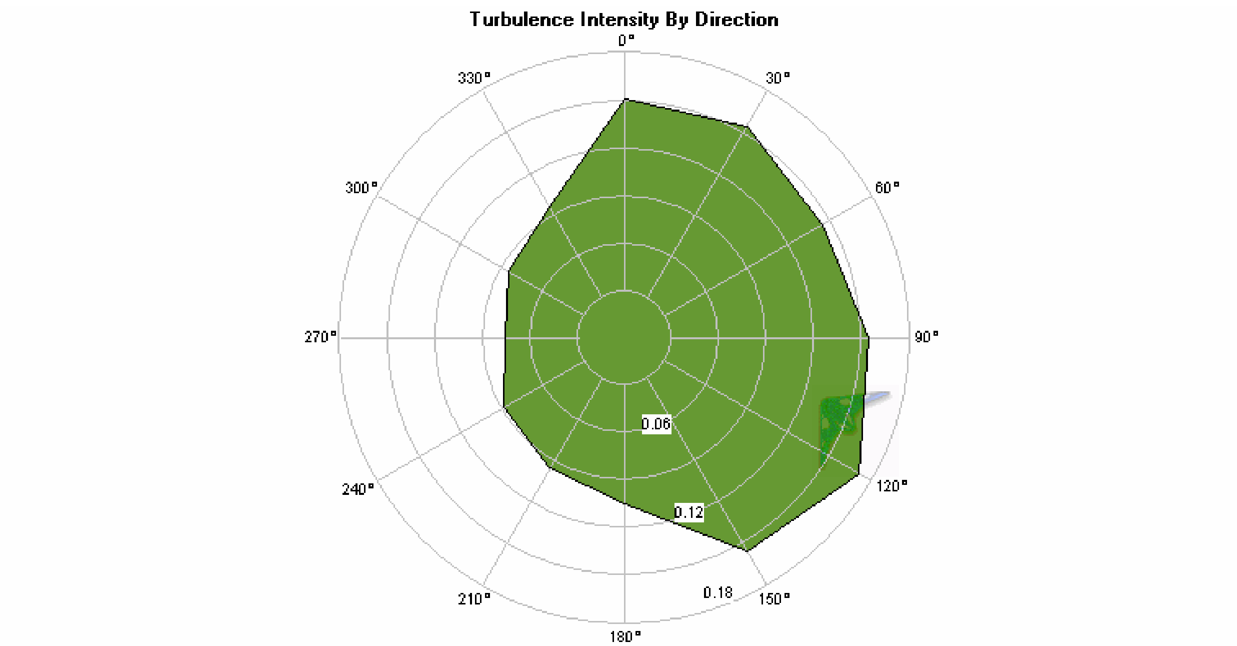



Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
0°
30°
60°
90°
120°
150°
180°
210°
240°
270°
300°
330°
4%
8%
12%
3.2%
6.4%
9.6%
5%
10%
15%
3%
6%
9%

Turbulence Intensity

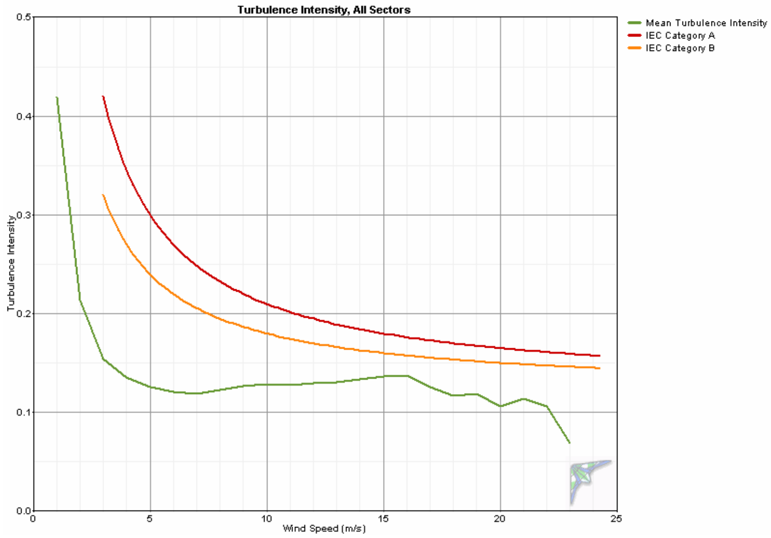
The turbulence intensity (TI) is acceptable for all wind directions, with a mean turbulence intensity of 0.125 (Channel 1) and 0.149 (Channel 2) for the eighteen month data collection period, indicating moderately smooth air. The higher turbulence intensity to the NE to SE directions may be attributable to the presence of nearby forest in this direction. Possibly, turbulence would be less in these directions if measured at a higher elevation above ground level. These TIs are calculated with a threshold wind speed of 4 m/s.

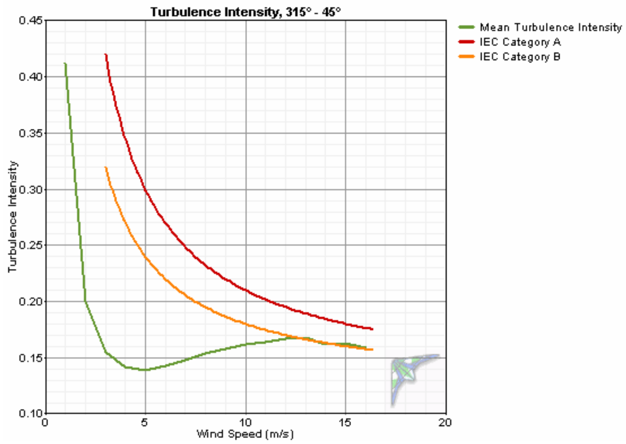
Turbulence Intensity Rose, 30 meters vane, 30 meter anemometer

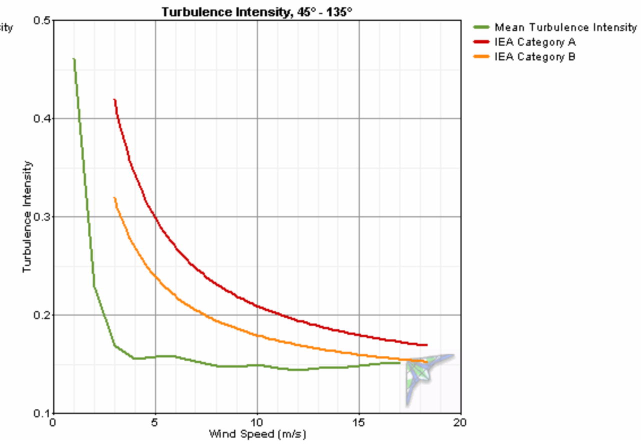


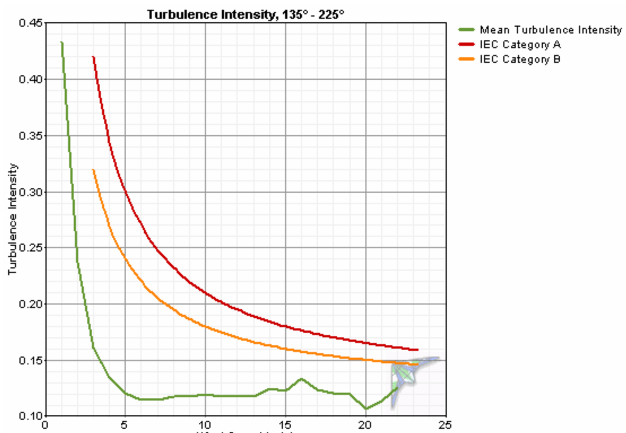
IEC Turbulence Intensity Standards

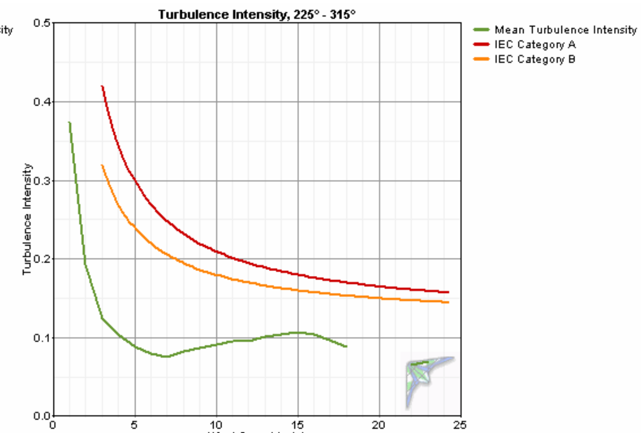
Turbulence at the Dillingham-Kanakanak met tower test site is within International Electrotechnical Commission (IEC) standards at all measured wind speeds and from all four quadrants of the wind rose (except for IEC Category B at higher wind speeds in 315° to 45° sector (this sector experiences infrequent winds, hence this is a minimal concern).


Turbulence Intensity, All Sectors
Mean Turbulence Intensity
IEC Category A
IEC Category B
Turbulence Intensity
Wind Speed (m/s)
0.0
0.1
0.2
0.3
0.4
0.5
0
5
10
15
20
25


Turbulence Intensity, 315° - 45°
Mean Turbulence Intensity
IEC Category A
IEC Category B
Turbulence Intensity
Wind Speed (m/s)
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0
5
10
15
20


Turbulence Intensity, 45° - 135°
Mean Turbulence Intensity
IEA Category A
IEA Category B
Turbulence Intensity
Wind Speed (m/s)
0.1
0.2
0.3
0.4
0.5
0
5
10
15
20


Turbulence Intensity, 135° - 225°
Mean Turbulence Intensity
IEC Category A
IEC Category B
Turbulence Intensity
Wind Speed (m/s)
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0
5
10
15
20
25


Turbulence Intensity, 225° - 315°
Mean Turbulence Intensity
IEC Category A
IEC Category B
Turbulence Intensity
Wind Speed (m/s)
0.0
0.1
0.2
0.3
0.4
0.5
0
5
10
15
20
25

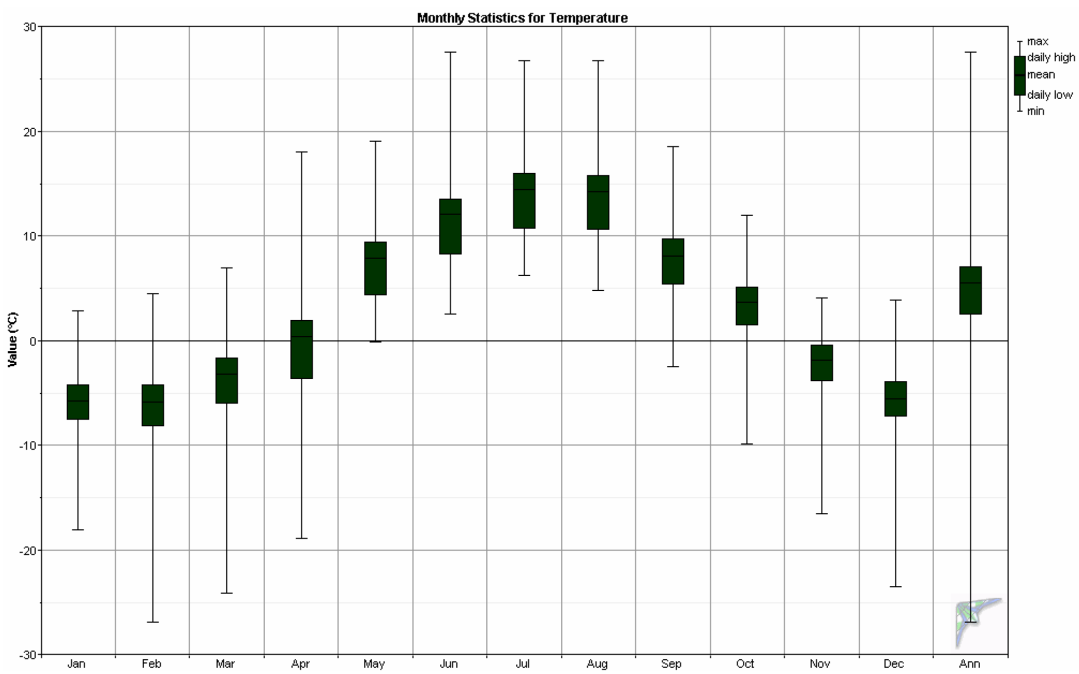
Turbulence Table

Bin Midpoint (m/s)	Bin Endpoints Lower (m/s)	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	2,845	0.406	0.419	0.189	0.608
2	1.5	2.5	5,801	0.417	0.213	0.112	0.326
3	2.5	3.5	9,040	0.458	0.155	0.073	0.228
4	3.5	4.5	10,225	0.537	0.136	0.059	0.195
5	4.5	5.5	10,897	0.623	0.126	0.054	0.180
6	5.5	6.5	10,457	0.716	0.121	0.052	0.172
7	6.5	7.5	8,362	0.824	0.119	0.050	0.168
8	7.5	8.5	6,071	0.977	0.123	0.046	0.169
9	8.5	9.5	4,325	1.129	0.126	0.043	0.170
10	9.5	10.5	2,936	1.279	0.129	0.041	0.170
11	10.5	11.5	1,891	1.395	0.128	0.039	0.167
12	11.5	12.5	1,036	1.537	0.129	0.037	0.166
13	12.5	13.5	574	1.698	0.131	0.037	0.169
14	13.5	14.5	375	1.861	0.134	0.033	0.166
15	14.5	15.5	234	2.029	0.136	0.030	0.166
16	15.5	16.5	120	2.177	0.137	0.028	0.165
17	16.5	17.5	73	2.111	0.125	0.031	0.156
18	17.5	18.5	42	2.100	0.117	0.019	0.136
19	18.5	19.5	31	2.245	0.119	0.024	0.143
20	19.5	20.5	18	2.139	0.107	0.017	0.124
21	20.5	21.5	15	2.360	0.114	0.030	0.144
22	21.5	22.5	3	2.333	0.106	0.041	0.147
23	22.5	23.5	2	1.600	0.069	0.005	0.074
24	23.5	24.5	0	1.600	0.069	0.005	0.074

Air Temperature and Density

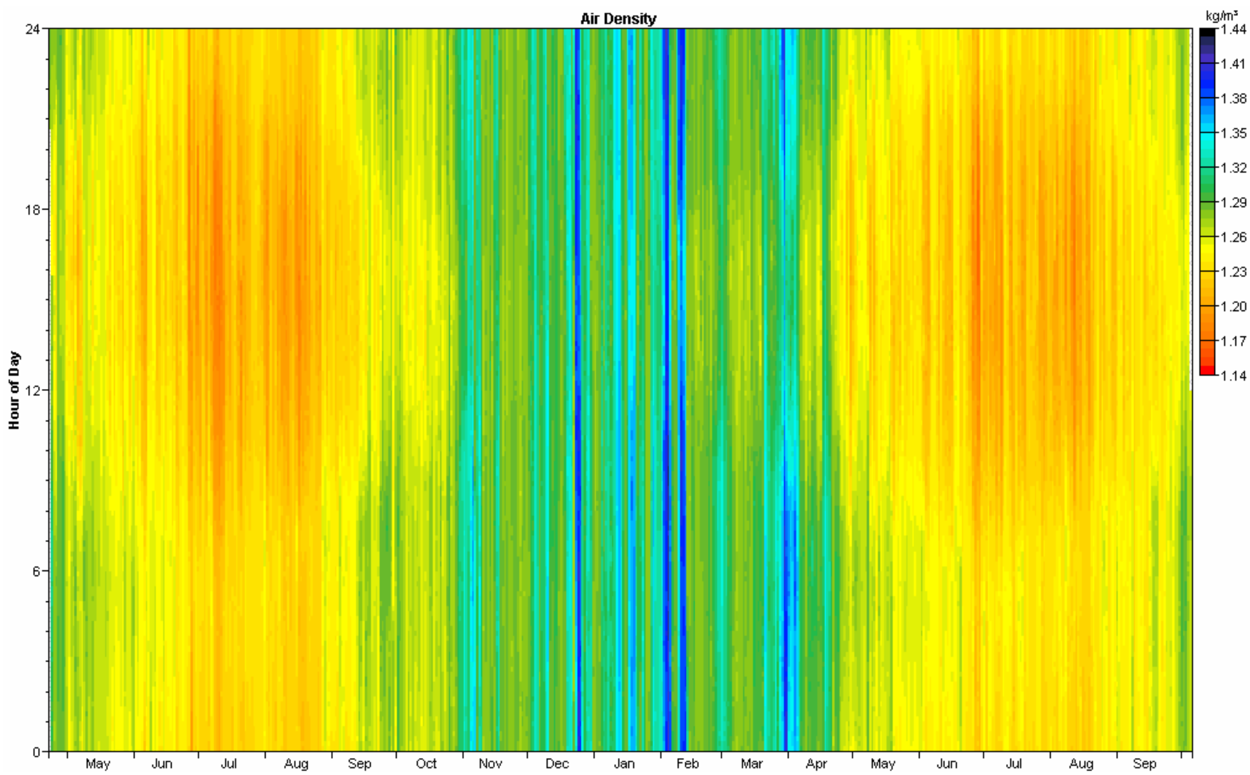
Over the reporting period, Dillingham had an average temperature of 5.6° C. The minimum recorded temperature during the measurement period was -26.9° C and the maximum temperature was 27.6° C, indicating a wide variability of an ambient temperature operating environment important to wind turbine operations. Consequent to Dillingham's cool temperatures, the average air density of 1.272 kg/m^3 is approximately four percent higher than the standard air density of 1.220 kg/m^3 (at 14.7° C temperature and 100.8 kPa pressure at 40 m elevation), indicating that Dillingham, due to its cool annual temperature average and low elevation, has denser air than the standard air density used to calculate turbine power curves. 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/m³)	Min (kg/m³)	Max (kg/m³)
Jan	-5.7	-18.1	2.9	5.03	1.314	1.272	1.377
Feb	-5.8	-26.9	4.5	8.36	1.315	1.265	1.426
Mar	-3.2	-24.1	7.0	5.91	1.302	1.254	1.410
Apr	0.4	-18.9	18.1	6.52	1.285	1.206	1.381
May	7.9	-0.1	19.1	3.31	1.250	1.202	1.286
Jun	12.1	2.6	27.6	4.02	1.232	1.168	1.274
Jul	14.5	6.3	26.8	3.52	1.221	1.171	1.257
Aug	14.3	4.8	26.8	3.54	1.222	1.171	1.264
Sep	8.1	-2.5	18.6	3.46	1.249	1.204	1.298
Oct	3.7	-9.8	12.0	3.46	1.269	1.232	1.334
Nov	-1.8	-16.5	4.1	4.49	1.295	1.267	1.368
Dec	-5.5	-23.5	3.9	5.67	1.313	1.268	1.407
Annual	**3.2**	-26.9	27.6	8.78	**1.272**	1.168	1.426



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 the turbine power curve, while densities lower than standard will yield lower turbine power than predicted. Density variance from standard is accounted for in the turbine performance predictions.



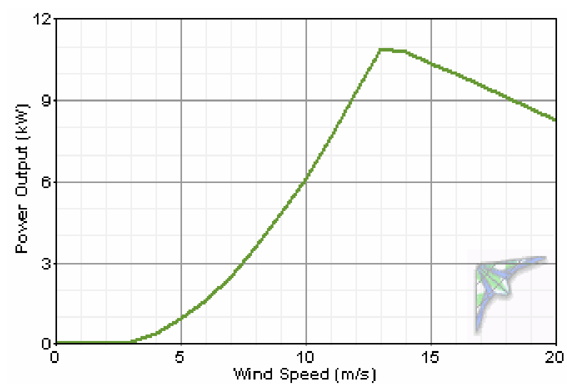
Turbine Performance Predictions

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.

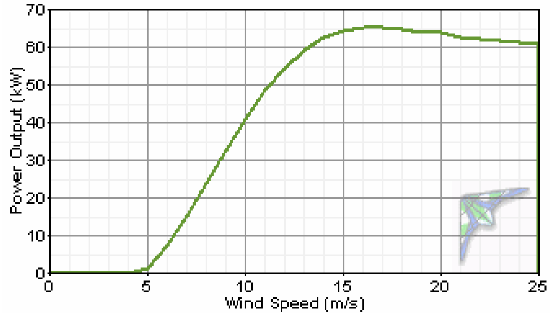
Note that these performance estimates were predicted with use of Windographer® wind analysis software; power curves provided by manufacturers are not independently verified and are assumed to be accurate. The power curves are presented for a standard air density of 1.225 kg/m^3 at sea level and 15° C. 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.

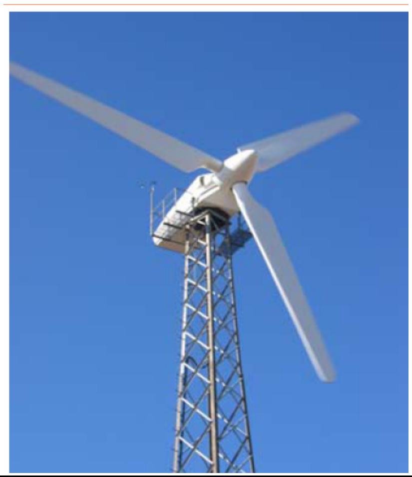
Bergey Excel-S: 10 kW rated power output, 6.7 meter rotor diameter, stall-controlled. Available tower heights: 18, 24, 30, 37 and 43 meters. Additional information is available at www.bergey.com.

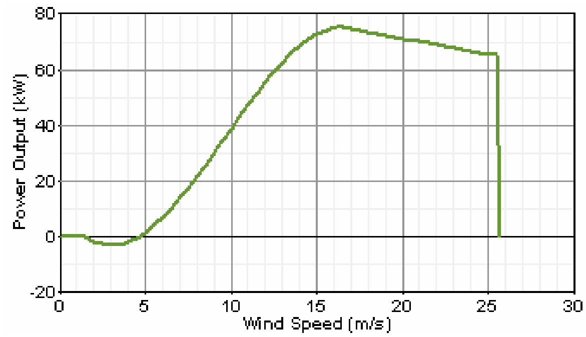


Entegrity eW-15: 65 kW rated power output, 15 meter rotor, stall-controlled (power curve provided by Entegrity Energy Systems). Available tower heights: 25 and 31 meters. Additional information is available at http://www.entegritywind.com/.

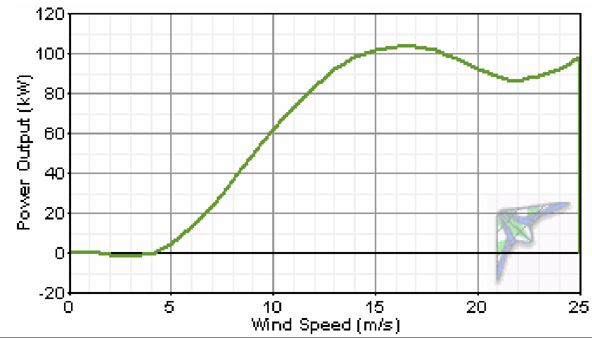


Vestas V15: 75 kW rated power output, 15 meter rotor, stall-controlled (power curve provided by Powercorp Alaska LLC). Available tower heights: 25, 31 and 34 meters. Additional information is available at http://www.pcorpalaska.com/.

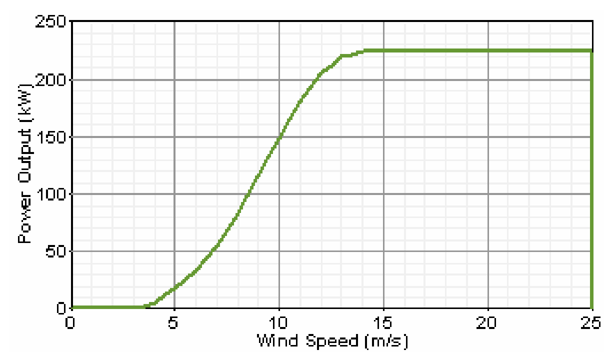




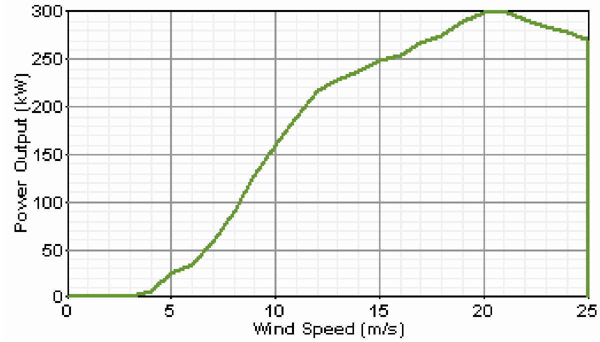
Northwind 100/20: 100 kW rated power output, 20 meter rotor (19 meter rotor blades with 0.6 meter blade root extensions added), stall-controlled (power curve provided by Northern Power Systems). Available tower heights: 25 and 32 meters. Additional information is available at http://www.northernpower.com/.



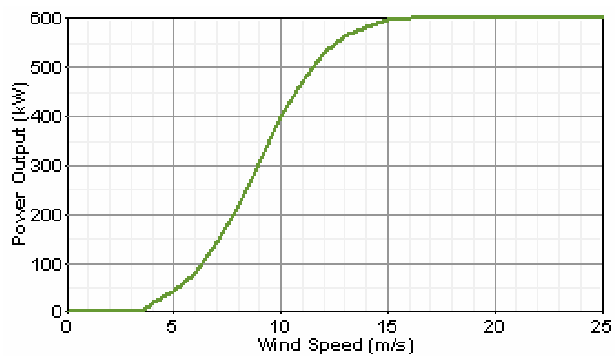
Vestas V27: 225 kW output, 27 meter rotor, pitch-controlled (power curve provided by Alaska Energy Authority).



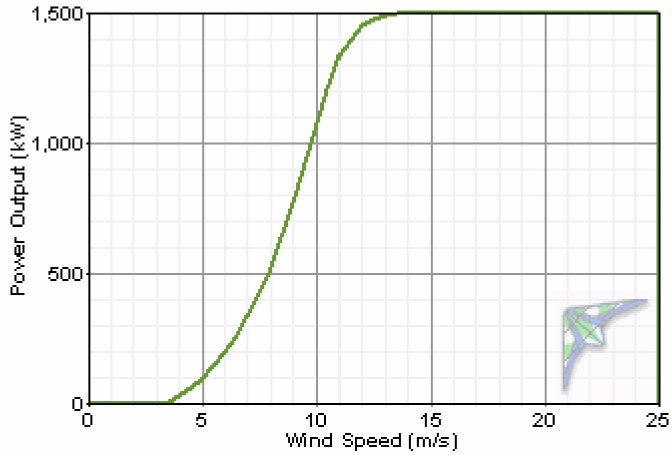
Fuhrländer FL250: 250 kW output, 29.5 meter rotor, stall-controlled (power curve provided by Lorax Energy Systems). Available tower heights: 42 and 50 meters. Additional information is available at www.lorax-energy.com.



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.



General Electric 1.5s: 1,500 kW output, 70.5 meter rotor, pitch controlled (power curve provided by GE). Available tower heights: 54.7 and 64.7 meters. Additional information is available at www.gewindenergy.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	6.44	7.4	3.9	2.8	24,771	28.3
Entegrity eW-15 60 Hz	31	5.83	29.4	1.2	13	116,432	20.5
Vestas V15	34	5.99	35.3	0.8	13	113,656	17.3
Northern Power NW 100/20	32	5.68	29.0	1.2	20	174,691	20.0
Vestas V27	50	6.74	10.2	2.2	70	611,977	31.1
Fuhrländer FL250	50	6.74	7.2	0.3	77	678,313	25.8
Vestas RRB 47/600	50	6.74	18.4	1.5	182	1,596,887	30.4
General Electric 1.5s	65	7.32	16.6	6.8	554	4,853,556	37.0

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	6.21	7.9	3.3	2.4	22,381	25.6
Entegrity eW-15 60 Hz	31	5.63	31.2	0.9	11	105,196	18.5
Vestas V15	34	5.79	37.5	0.6	11	102,688	15.6
Northern Power NW 100/20	32	5.68	30.8	0.9	16	157,833	18.1
Vestas V27	50	6.50	10.9	1.8	58	552,921	28.1
Fuhrländer FL250	50	6.50	7.6	0.2	64	612,856	23.3
Vestas RRB 47/600	50	6.50	19.6	1.2	151	1,442,787	27.5
General Electric 1.5s	65	7.32	16.6	6.8	554	4,385,188	33.4

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

Turbine	Annual Energy Output (kW-hr/yr)	Fuel Quantity Avoided (gallons)	Fuel Price (USD/gallon) $1.75	$2.00	$2.25	$2.50	$2.75	$3.00	$3.25	Turbine Hub Height (m)
Bergey Excel-S	22,381	1,463	$2,560	$2,926	$3,291	$3,657	$4,023	$4,388	$4,754	43
Entegrity eW-15 60 Hz	105,196	6,876	$12,032	$13,751	$15,470	$17,189	$18,908	$20,627	$22,346	31
Vestas V15	102,688	6,712	$11,745	$13,423	$15,101	$16,779	$18,457	$20,135	$21,813	34
Northern Power NW 100/20	157,833	10,316	$18,053	$20,632	$23,211	$25,790	$28,369	$30,948	$33,527	32
Vestas V27	552,921	36,139	$63,243	$72,277	$81,312	$90,347	$99,381	$108,416	$117,451	50
Fuhrländer FL250	612,856	40,056	$70,098	$80,112	$90,126	$100,140	$110,154	$120,168	$130,182	50
Vestas RRB 47/600	1,442,787	94,300	$165,025	$188,600	$212,175	$235,750	$259,325	$282,899	$306,474	50
General Electric 1.5s	4,385,188	286,614	$501,574	$573,227	$644,881	$716,534	$788,187	$859,841	$931,494	65

Notes:
1. Dillingham electrical energy production efficiency is 15.3 kW-hr/gal (source: Nushagak Electric Coop)
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.